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Welcome to Healthy Buildings 2021 - Europe!

Organized every 2 years, during years with no Indoor Air conference, Healthy Buildings conferences bridge the gap between science and profession, making it one of the most influential conferences on best-practice sustainable solutions for the indoor environment.

Healthy Buildings Europe 2021 is organized by OsloMet (Oslo Metropolitan University), SINTEF and NTNU (Norwegian University of Science and Technology), under the auspices of ISIAQ (International Society for Indoor Air Quality), and with technical contributions from a numerous of organizations, including REHVA (Federation of European Heating, Ventilation and Air Conditioning Associations) and NVG (Nordic Ventilation Group).

The conference topics include four important D’s

- **Disease**: We spend more time indoors, with exposure ourselves to multiple pollutant sources and microbes. The COVID-19 pandemic has lead to an astounding increase in research / knowledge on the transmittance of respiratory diseases in the buildings.

- **Decarbonization**: of the European building stock by 2050. Deep energy renovation of buildings and neighbourhoods without compromising indoor health. We need improved LCA-methods to evaluate embodied energy in buildings and fittings.

- **Digitization**: Increasing automation and sensor tech opens up opportunities to optimize the design, operation, and IEQ of new or refurbished nZEB buildings. However, technically advanced sensor-based control (e.g. demand-controlled ventilation) have many practical challenges.

- **Dwellings**: How can we achieve healthy homes with increased urbanization? Community-scale measures, such as outdoor air quality regulation, urban canyon issues, heat island effects & climate adaptation (heat and extreme rainfall) for urban buildings.

In addition to the traditional scientific content, we have many workshops and seminars covering topics that will appeal to professionals and specialists alike.

The conference has two kinds of written publications:

- **Scientific/technical/review papers (Full papers)**: These are published in the Open Access scientific proceedings, after a double-blind 2-stage peer-review.

- **Applications/case-study papers (Short papers)**: We have also welcomed short papers (also called extended abstracts), which will be appended to this Book-of-Abstracts after the conference. This suitable for contributors with who wish to publish short case studies of fresh results from ongoing studies.

Peter G. Schild  
President of HB21 - Europe  
Professor, OsloMet,  
Senior Scientist, SINTEF

Sverre B. Holøs  
Vice-President of Practice for HB21 - Europe  
Senior scientist, SINTEF

Guangyu Cao  
Vice-President of Science for HB21 - Europe  
Professor, NTNU
Conference sponsors

We are very grateful for financial support from our sponsors

**Avidicare AB** is a research-based medical tech company focusing on infection prevention. They develop systems for managing airborne bacteria and virus contamination in hospitals.

Avidicare was initially part of Airsonett AB, which introduced tech from industrial cleanrooms to the healthcare sector. As part of Airsonett, they developed airshowers and TcAF (Temperature controlled Air Flow), new opportunities to prevent harmful bacteria in medical environments. This gave rise to Opragon – a ventilation system for infection-sensitive surgery in ultra-clean air.

The company is based in Lund, south in Sweden, where a state-of-the-art laboratory to study different ventilation solutions in operating rooms was constructed in 2013.

**GK** is Scandinavia’s leading end-to-end technical contractor and service partner with a turnover of over NOK 6 billion. With more than 3,000 employees and over 80 offices in Norway, Sweden and Denmark, they deliver smart and sustainable solutions in ventilation, cooling, building automation, electrical installations and plumbing.

They work with project design, installation, service and maintenance of technical systems in buildings. Their track record comprises large, complex installation projects, such as a new hospitals, museums, theatres, hotels and data centers.

Its mission is to build sustainable societies for generations to come.

**Camfil** is a leading manufacturer of solutions for air filtration and air pollution control, improving worker and equipment productivity, with a life-cycle approach to sustainability, energy use and service life costs.

It is a global operator with 30 manufacturing sites, 6 R&D centres, and the HQ in Stockholm, Sweden.

**Airthings** is a Norwegian tech company that develops and manufactures out-of-the-box solutions for businesses (airthings.com/business), consumers, and radon professionals.

Founded in 2008, Airthings is on a mission to ensure that people around the world recognize the impact of air quality, and make radon and indoor air quality sensors an essential element of every building.
Programme at-a-glance

**Monday June 21**
Theme: Airborne Transmission & Methods

- **09:00**: Opening ceremony with plenary lecture 1
  - Yuguo Li: From SARS to COVID-20 and beyond

- **10:00**: Coffee break with digital mingling

- **11:00**: Airborne transmission of infectious diseases
- **12:00**: Lunch break with digital mingling
- **13:00**: IAQ in dwellings
  - IAQ measurement
  - Workshops: Deposed dust analysis Semin: Portable air cleaners
  - HVAC system solutions
  - Indoor epidemiology

- **14:00**: Coffee break with digital mingling

- **15:00**: Plenary session with keynote lecture 2
  - Jelena Srebric: How to mitigate future respiratory virus pandemics

- **16:00**: Closing ceremony (summaries, prizes, upcoming events)

**Tuesday June 22**
Theme: Ventilation, IAQ, Thermal Comfort

- **09:00**: Plenary session with keynote lecture 3
  - Richard de Dear: Individual digitized thermal comfort prediction

- **10:00**: Coffee break with digital mingling

- **11:00**: Symposium: Zero infections in health inst.
  - Thermal environment in homes
  - Indoor environment

- **12:00**: Lunch break with digital mingling
  - ISIAQ Chapters Luncheon (All are welcome!)

- **13:00**: Seminar: IAQ criteria
  - Seminar: Legionella prevention in buildings
  - Seminar: IAQ and health in schools & kinderg.

- **14:00**: Coffee break with digital mingling

- **15:00**: Plenary session with keynote lecture 4
  - Pawel Wargocki: CO₂ and the infamous 1000 ppmv threshold

- **16:00**: Seminar: Indoor microbiota

**Wednesday June 23**
Theme: Indoor Chemistry, IEQ and Health

- **09:00**: Plenary session with keynote lecture 5
  - Nicola Carslaw: Indoor air chemistry for healthy indoor env.

- **10:00**: Coffee break with digital mingling

- **11:00**: Seminar: Indoor chemistry
  - Seminar: Indoor symptoms
  - Seminar: Legionella

- **12:00**: Lunch break with digital mingling

- **13:00**: Workshop: Low-cost IAQ sensors

- **14:00**: Seminar: Indoor effects of pollutants
  - Seminar: Multi-domain indoor env.
  - Seminar: Smart sustainable healthcare

- **15:00**: Plenary session with keynote lecture 6
  - Martin Täubel: Health-promoting indoor microbiota

- **16:00**: Closing ceremony (summaries, prizes, upcoming events)

- **17:00**: Student party

The programme has three kinds of colour-coded sessions:

- **Red**: Each day starts and ends with plenary sessions (i.e. everyone in one Zoom-room) with invited keynote speakers, at 09:00 and 15:00 CET. These are ZOOM Webinar sessions; attendees can use a handy Q&A function to ask the presenters questions.

- **Yellow**: Technical/scientific sessions, starting 10:30 and 13:00, for oral presentations of submitted papers, followed by interactive Q&A. The detailed programme gives you access to the full papers. These are ZOOM Webinar sessions; attendees can use a handy Q&A function to ask the presenters questions.

- **Blue**: Seminars, workshops and practice-related mini-courses, are planned both during the daytime and on Monday & Tuesday evenings. These are described in detail in the programme. These are highly interactive ZOOM Meeting sessions, where all attendees join with webcam & mic.

In addition, it is possible to mingle in the virtual lounge (WONDER) during breaks/lunch.

During the Zoom Webinar sessions (Red and Yellow), all attendees can ask questions in Zoom Chat. However, we encourage all to rather ask their questions in the blue “discussion boxes” in online programme; see below. All questions will be answered live by the presenters at the end of the session.
How to join the virtual conference

STEP 1: Pay attendance fee

Click on “Register to attend” on the conference website ([https://HB2021-Europe.org/](https://HB2021-Europe.org/)). This will lead to a page where you select “Register as Participant”. The admittance fee gives you full access to join all the events (Zoom sessions/workshops, and Wonder social events), and to read full-text of all the papers.

STEP 2: Attend the conference

Links to all the online events are available on the online programme:

[https://www.conftool.com/hb21-europe/sessions.php](https://www.conftool.com/hb21-europe/sessions.php)

Click on the ZOOM button for any session that you wish to join (or the WONDER button to mingle in the lobby)

If you cannot see any ZOOM-buttons, then you are either not logged in, or have not paid the attendance fee:
Click on “LOGIN” at the top of the page, then repeat STEP2. If you have not paid the attendance fee, then click on “OVERVIEW” at the top of the page to show your main menu (STEP1).
# Programme

## Monday morning, 09:00-13:00 CEST, 21st June 2021

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<th>Workshop 273: Ventilation rates in homes</th>
<th>Seminar 332: Smart Windows</th>
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<td>From SARS to post COVID-20 and beyond — What we have learnt on safeguarding indoor environments</td>
<td>Chair: Yuxia Sun</td>
<td>Chair: Yuwei Du</td>
</tr>
</tbody>
</table>

### Coffee break:
- Location: Mingling lounge (Wonder)

### Session 10: Airborne transmission of infectious diseases
- Transport of Contaminated Agents in Hospital Wards - Exposure Control with a Personalized Healthcare Ventilation System: Numerical Study
- Experimental investigation of the spread of airborne CFU in an research-OR under different airflow regimes using tracer particles
- COVID-19 dent guard and movable room for dentists' practice with design solution for air cleaning in natural ventilation.
- Ventilation strategies to minimise the airborne virus transmission in indoor environments
- A Practical and Efficient Testing Method for Indoor Airborne Pathogens
- Characterization and Dispersion of Human Expiratory Droplets - a Review
- The potential of bio-based insulation products to support indoor air quality and reduce aerosol transmissions of contagious respiratory viruses such as SARS-CoV-2 in the construction industry.

### Session 12: Numerical simulation
- Can we measure buildings' affordance?
- CFD simulation of non-isothermal ventilation flow in a generic enclosure: Impact of inlet velocity boundary conditions
- Numerical simulation and field survey research of indoor thermal comfort for healthy building: A case study of Lingnan residential building
- Numerical Simulation of Double Skin Facade used to produce Energy in Buildings
- Numerical study of the influence of balconies on indoor environment in winter: A case study of college dormitories in Jinan, China
- INCHEM-Py: A new open source model for investigating indoor air chemistry
- Identification of most important factors (Building factors: artificial lights and window materials; External factors: cloud factors, season, latitude) affecting indoor photolysis rates
- Development of an underground space using to produced cold energy in summer conditions in the building thermal conditions performance

### Session 5: Indoor particles, aerosols and VOCs
- Indoor Aerosols - Calculation of Zonal Particle Concentration and Particle Deposition in the Human Respiratory Tract
- Effects of suspended particles, chemicals, and airborne microorganisms in indoor air on building-related symptoms: a longitudinal study in air-conditioned office buildings
- Human personal cloud associated with particles and gases in an office study: Preliminary results
- Experimental & Modelling Studies for the Determination of Pollutant Emissions from Cooking and Cleaning
- Characterization of PM2.5 and its Indoor-Outdoor Ratio in an Office Building Connected to a Chemical Production Plant in Gebeng Industrial Zone, Pahang Malaysia
- Phytoremediation of Airborne Particulate Matter in Indoor Environments
- How Does Indoor Air Chemistry Affect Outdoor Air Pollution?
- Green Plant Walls as an Indoor Air Quality Enhancer in a Recently Built Office Building
- Characterising multi-sensor platforms performance to investigate indoor air quality events, and quantify personal exposure

### Lunch 1: Lunch break with opportunity to mingle
- Location: Mingling lounge (Wonder)
Session 13: IAQ in dwellings
- Healthy Home – Taking health into the design and use of (Dutch) dwellings
- Architectural Design Modification Study for Improvement of Indoor Air Quality for Aversion of Aeroallergen Sensitization in the Standard Naturally-Ventilated Urban Dwelling
- How to transform European housing into healthy and sustainable living spaces using a Belgian case study? – the RenoActive principles tackle climate and renovation challenges
- Perceived indoor environment in social housing with different ventilation principles
- Chemical characterization of ultrafine particles released from 3D printers
- Research on Thermal Comfort of Activity Space under Viaduct in Mountain City – Take Chongqing Epongyn Bridge as an example
- Indoor Thermal Environment of Huizhou Vernacular Dwellings of Guizhou, China in Winter Based on the Impact of Immigration
- Research on industry-spatial relationship of existing industrial zones in Beijiao, Shunde based on comparison of data Point of Interest
- Study of the thermal environment construction technology of the traditional residential of the Bai nationality

Coffee 2: Coffee break
Location: Mingling lounge (Wonder)

Plenary session 2: COVID and ventilation
How can we mitigate future respiratory virus diseases? - Findings from five studies on COVID-19 transmission
Jelena Srebric

Session 14: IAQ measurements
- Reducing infection risk and optimization of airing concepts for indoor air quality by accurate aerosol & CO₂ measurements
- Measurement and simulations of the influence of green wall systems on indoor air quality
- Intrinsic dimension estimation as a tool to sensor selection for an indoor air quality multisensory system
- A method for determining the time-dependent indoor CO₂ concentration to evaluate air hygiene
- Interaction between controlled natural lighting and IEQ. Integrated double skin facades approach applied on an office building
- Big Data in IAQ research, an example of the application in IEA EBC Annex 86
- Optimal sensor positioning for monitoring indoor air quality in a simulated office environment
- A new simplified daylight evaluation tool, description and validation against the standard method of EN 17037

Long break, 16:00-19:00

Session 9: Work environment
- An empirical study of occupants’ evaluation of short-term combined thermal, visual, and acoustic indoor-environmental exposure
- The influence of employees’ workspace satisfaction on mental health while working from home during the COVID-19 pandemic
- Interaction effects of acoustics at and between human and environmental levels: A review on the acoustics in the indoor environment
- The challenge of finding definitions for well-being and health within the built environment
- Impact of the indoor environmental quality on employee well-being in a LEED-certified office building
- Relationships between mental health and indoor environmental quality (IEQ) in the home workplace
- Comparing tangible and graphical interface of occupant voting system: Preliminary results of experimental field study in an office
- Numerical Investigation of Human CO₂ Emission in a Personalized Work Environment
- Properties of Hydrogel-Wood Composite as a New Thermochromic Glazing Material

Workshop 206: Analysis of deposited and airborne dust as part of detailed indoor climate audits
Chairs: Johan Mattsson, Kolbjørn Mohn Jenssen

Workshop 334: Can portable air cleaning substitute ventilation?
Chair: Alireza Alshari
Co-chair: Bjarne W. Olesen

Seminar 330: RENVA-IAQ
Workshop on COVID-19 transmission
Chair: Atze Boerstra
Co-chair: Jarek Kurnitski

Workshop 208: IEQ guidelines worldwide - Open database for research and practice
Chair: Quan Jin
Co-chair: Linda Hägerhed
Co-chair: Ulfa Haveinen-Shaughnessy

Workshop 168: Advanced mini-course on tracer gas analysis methods for ventilation studies
Chair: Peter G. Schild
# Programme

## Tuesday morning, 09:00-13:00 CEST, 22nd June 2021

### Plenary session 3: Thermal Comfort

**A paradigm-shift in accurate individualized & digitized thermal comfort prediction**

Richard de Dear

### Coffee 3: Coffee break

Location: Mingling lounge (Wonder)

### Session 18: Ventilation for IAQ

- **Is the air change efficiency sufficient to assess the removal of airborne contamination in mixing ventilation?**
- **Demand-controlled ventilation in schools: Influence of base ventilation rates on subjective symptoms, perceived indoor environment and young adults’ learning performance**
- **Can human CO₂ emission rates staying awake be used staying asleep?**
- **Local ventilation for general patient rooms**
- **Proposing a new tracer gas for future field applications of passive tracer gas tests for air change rate measurement**

### Session 8: Thermal comfort

- **Provision of thermal comfort via user-centric radiant cooling elements: An experimental investigation**
- **Verification of Thermal Comfort of Combined Convection-Radiation Air Conditioning System using Building Structure**
- **Evaluation of Personalized Thermal Conditioning Chair in Net Zero Energy Building Office**
- **Electroencephalography associated with thermal discomfort induced by temperature upward ramping**
- **Thermal comfort and skin temperature of adolescents compared to young adults**
- **Association between physiological signal from wearable device and alertness of office workers**
- **Thermal Insulation of Clothing Assessment of Cleanroom Clothing Ensembles**

### Session 4: Thermal environment in homes

- **Assessing the indoor air quality of natural-ventilated bedrooms in renovated Norwegian houses using detailed field measurements**
- **Bacterial and fungal aerosols in dwellings with domestic animals: preliminary results**
- **The risk of overheating and energy demand of new and old Finnish apartment buildings in the cooling season**
- **Evaluating the Influence of Ventilation Strategies on Energy Consumption and Indoor Air Quality in Residential Dwellings**
- **Subjective assessments of bedroom environment in the heating season in Denmark**
- **The relation between indoor air quality in a bedroom and sleep quality of ageing adults**
- **The resulting CO₂ levels and the heating/cooling consumption of apartments with balanced ventilation versus window ventilation**

### Symposium 320: Towards Zero Infections in Health Institutions

Chair: Clemens Bulitta
Co-chair: Peter Höjerback

### Seminar 313: REHVA Design Guidebook: Occupant-targeted ventilation

Chair: Arsen Melikov

### Lunch 2: Lunch break with opportunity to mingle

Location: Mingling lounge (Wonder)
### Session 2: HVAC system solutions
- Operation status and improvements of integrated hybrid VRF system
- Evaluation of a novel 3-pipe solution for hydronic heat distribution in passive-house standard apartment buildings
- Prediction of Electricity Consumption of a HVAC System in a Multi-Complex Building Using Back-Propagation and Radial Basis Function Neural Networks
- Investigation of work-practices, skills and everyday challenges of building operators with respect to indoor climate and energy
- Mucociliary clearance is humidity dependent—contrary to common belief: HVAC systems overstress human noses during the heating season—the consequences
- Development and Application of a Ventilation System based on Vertical Descendent Confluent Jets
- Better building operation, maintenance and well-being in apartments with smart indoor climate meters
- Assessment of three experimental methods for determining the emission parameters of VOCs from a solid material
- An overview of transparent and translucent 3D-printed façade prototypes and technologies

### Session 16: Indoor epidemiology
- Pandemic and Office Design: A review of health effects of different office concepts.
- How well are health institutions prepared for pandemics, in terms of ventilation and protective equipment?
- Impacts of the indoor environment in our homes and schools on child health: A novel analysis using the EU-SILC Database
- Indoor Exposure to Fine Particulate Matter and Practical Mitigation Approaches - a U.S. National Academy of Sciences Workshop
- Robust and reliable deep renovation by advanced prefabricated façade elements. Air-tightness performance and assessment of a demo case
- Longitudinal characterization of the human personal cloud effect associated with gaseous and particle pollutants in Switzerland

### Session 6: Ventilation and IEQ in healthcare facilities
- Thermal comfort in hospital isolation room – A laboratory study
- Experimental investigation of the local air exchange behind an obstacle in laminar flow
- Experimental study on the thermal plume from a surgeon in an operating room with mixing ventilation during COVID-19 pandemic
- Performance assessment and clinical validation of Operating Room ventilation systems
- Visualizing bacteria-carrying particles in the operating room: exposing invisible risks
- Thermal comfort level of patients and surgical staff in operating rooms at a Nordic hospital

### Seminar 114: Use of Infection Risk Calculators to Manage Building Occupancy Post-COVID
- Chair: Brad Prezant
- Co-chair: Lidia Morawska
- SPEAKERS: Lidia Morawska, Brad Prezant, Giorgio Busnanno

### Seminar 241: Legionella prevention in buildings - Are we effecting meaningful change or just checking all the boxes?
- Chair: Michael B. Waak
- SPEAKERS: Michael Waak, Karolina Stráby, Hanne Therese Skr, and representatives from Norwegian Institute of Public Health

### Coffee 4: Coffee break
- Location: Mingling lounge (Wonder)

### Plenary session 4: CO₂ and humans
- CO₂ exposure — The truth about the infamous 1000 ppmv threshold.
  - Pawel Wargocki

### Long break, 16:00-19:00

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**Tuesday afternoon & evening, 13:00-16:00 & 19:00-20:30 CEST, 22nd June 2021**

**Session 225: Inspection and commissioning of ventilation systems, including VAV-systems**
- Chair: Lars Elberg
- Co-chair: Peter G. Schild

**Workshop 143: Synergistic Effects of the Exposure to Air Pollutants indoors**
- Chair: Józef Stefan Pastuszka

**Workshop 153: Multi-domain approaches to indoor environmental perception – current status and ways forward**
- Chair: Marcel Schweiker
- Co-chair: Ardesthi Mahdavi
- Co-chair: Christiane Berger
- SPEAKERS: Marcel Schweiker, Christiane Berger, Ardesthi Mahdavi, Julia Day

**Workshop 169: Smart, safe and sustainable healthcare**
- Chair: Yili Liu
- Co-chair: Sverre B. Holes

**Seminar 292: Determinants and sources of indoor bacteria and consequences for respiratory health**
- Chair: Randi Jacobsen Bertelsen
- Co-chair: Maryia Khomich
- SPEAKERS: Randi J. Bertelsen, Vivi Schlünssen, Hesham Amin, Inge Wouters, Malin Alived, Lidia Casas
Wednesday morning, 09:00-13:00 CEST, 23rd June 2021

Plenary session 5: Indoor chemistry
A grand day in? A guided tour through indoor air chemistry.
Nicola Carlaw

Coffee 5: Coffee break
Location: Mingling lounge (Wonder)

Session 15: Indoor exposure and health
- Measurements of indoor air quality in schools
- Inflammatory effects of exposure to different stone types used in Norwegian asphalt
- FireDAVG – Fire related Damages with Attention to Vulnerable Groups. Guidance for vulnerable groups on handling of fire, soot, and smoke related damages in indoor environment.
- Trihalomethanes in indoor swimming pools: estimating exposure and assessing carcinogenic risk among non-competitive attendees
- Oxidative stress in individuals with Building Related Intolerance after exposure to acrolein
- Particle exposure of cooks in commercial kitchens
- Downscaling from material flow analysis to indoor CFD for health risk assessment associated with DEHP exposure
- Thermal Comfort and Occupant Adaptive Behaviours in Naturally Ventilated Hospital Wards in a Hot-Humid Post-epidemic Context
- A method to visualize and quantify “aerosols” of our surround living around the perimeter of barrier masks.
- Analysis of workers’ tendency to answer questionnaires of positive and negative questions, along with understanding the relationship between comfort and self-efficacy
- Improving the indoor thermal environment with ceiling radiant terminals
- The effect of thermal conditions during working hours on thermal perception at home – methodological considerations

Session 1: Indoor chemical pollutants
- Impact of indoor temperature on the possible release of adsorbed Volatile Organic Compounds from sorptive materials
- Characterization of the surface chemistry of Activated Carbons: a tool for sorptive indoor material formulation
- Diffusions of essential oils in a 40m³ experimental room: from emission rates to impact on indoor air quality
- VOCs emissions from the human during sleep under different ozone and air change rate levels
- Modeling physico-chemical processes impacting particles formation and fate indoors
- Effect of ageing conditions on decorative and renovation products containing biocides: Assessment of its impact on indoor air quality
- Indoor Environment and Energy Consumption of an Elementary School in a Subtropical Region

Session 11: Indoor environment and symptoms
- Humans report? – Myths and realities
- Characteristics of non-specific building-related symptoms
- Understanding “Symptoms Associated with Environmental Factors” (SAEF) in buildings, e.g. “sick building syndrome”, “electromagnetic hypersensitivity” and “multiple chemical sensitivity”
- Possible mechanisms underlying non-specific building-related symptoms
- Technical Specification of Human Nose: Bi-directional, cyclically operating combi-device for air-conditioning, heat and moisture recovery, filtration and odor detection but limited capacity
- A field study of indoor air quality and overheating in newly built primary classrooms in low-carbon UK school
- Performance, psychological and physiological effects of office noise

Seminar 331: Ventilation and IAQ criteria in EN 16798-1 revision
Chair: Jarek Kurnitski
Co-chair: Pawel Wargocki
SPEAKERS: Bjarne Olesen, Jarek Kurnitski, Peter G. Schild, Pawel Wargocki

Seminar 217: Ultrafine particles (UFP): could we filterate them with HVAC filters and purifiers?
Chair: Anders Hedström
Co-chair: Lidia Morawska
PANELISTS: Anders Hedström, Lidia Morawska, Magnus Svartengren, Britta Permail, Bertil Forsberg

Lunch 3a: ISIAQ chapters luncheon
Chair: Lada Hensen Centenirová
Co-chair: Mervi Ahola
Everyone is cordially invited to the ISIAQ Chapters luncheon.
● Information to all who are curious about starting new ISIAQ chapter in their country.
● Networking between existing chapter organizers

Lunch 3b: Lunch break with opportunity to mingle
Location: Mingling lounge (Wonder)
### Session 3: IEQ and health in schools and kindergartens
- Reviewing the impact of indoor air quality management and asthma education on asthmatic children's health outcomes – A pilot study
- VOC contributions from building materials, furniture, and user equipment in low-emitting and modular classrooms
- The influence of indoor air quality in classrooms on the short-term academic performance of students in higher education: a field study during a regular academic course
- Analysis of natural ventilation of a large educational building using parallel opening windows
- Ventilation strategies of school classrooms against cross-infection of COVID-19: A review
- Ventilation rate in classrooms of elementary schools and its association with respiratory infections
- "Schools on hold" – how simple measures can help improving the indoor environment in schools
- Analysis of the effect of indoor environment on pupils’ health in one Norwegian school during COVID-19 pandemic

**Coffee 6: Coffee break**
Location: Mingling lounge (Wonder)

### Session 17: Odour and emissions
- Achieving a healthy indoor air by using an emissions barrier
- Odour problems in buildings - the result of 682 cases
- The effect of Relative Humidity on the Emission of Volatile Organic Compounds (VOCs) from Building Materials
- Further Development of Odour Testing of Building Products – Sample Presentation and Evaluation of Perceived Intensity
- Discerning relative humidity trends in vernacular and conventional building typologies for occupant health
- Evaluation of the physiological effect on human subjects of different odourant environments
- Monitoring Mold growth and VOC-emissions from Wood Wool insulation under unfavorable hygrothermal conditions
- Influence of wooden Flooring on Indoor Air Quality
- Indoor air 2-ethylhexanol levels in an office building after floor repair – a follow-up study
- Olavi Vaittinen

### Session 7: Moisture in buildings
- Moisture-dependent insects (Silverfish species and Psocid species [Psocoptera]) in modern buildings – A sign of hidden moisture and mould damage
- The indoor mycobiome in Norwegian daycares revealed by DNA high throughput sequencing
- Fungal growth on newly cast concrete floors and moisture membranes
- Implementation of MALDI-TOF mass spectrometry to identify moulds from the indoor environment as an added value to the classical microscopic identification tool
- Xerophilic fungi in museum repositories challenge our perception of healthy buildings and the preservation of cultural heritage
- Seasonal Distribution of Alternaria, Aspergillus, Cladosporium and Penicillium Genera Isolated from Estonian straw-bale and reed-bale dwellings

### Seminar 340: New understandings of “unclear” building related complaints and experiences
- Chair: Jan Vilis Haanes
- Co-chair: Steven Nordin

**Workshop 338: Value of sensors for end users - indoor air quality; based on experiences from innovation projects**
- Chair: Matthias Vogt
- Co-chair: Alena Bartonova
- SPEAKERS: Hiten Chojer, Juliana Pinheiro de Sá, Maria Justo Alonso, Mila Rödenas, Erlend Bolle
Keynote lectures

**Plenary session 1: From SARS to post COVID-20 and beyond — What we have learnt on safeguarding indoor environments**

**Yuguo Li**

*Bio:* Dr. Yuguo Li is Professor, Associate Dean of Engineering (Research) and former Head of Department of Mechanical Engineering, The University of Hong Kong. He studied at Shanghai Jiaotong University, Tsinghua and KTH in Stockholm, and was a Principal Research Scientist at CSIRO. His main research interests are on built environment engineering (indoor air quality, city climate, and environment studies of infection). He led the development of 2009 WHO guidelines on natural ventilation, and more recently contributed to the ASHRAE Position Documents on Infectious Aerosols (incl. COVID). He currently serves as an Associate Editor of Indoor Air, and President of ISIAQ Academy of Fellows. He received John Rydberg Gold Medal from SCANVAC in 2014, and an Honorary Doctor Degree from Aalborg University, Denmark, 2015 and the Inoue Memorial Award, SHASE, Japan in 2016. He was elected a Fellow of ASHRAE, ISIAQ, HKIE, and IMechE.

**Keywords:** Respiratory viruses, Epidemiology, Airborne transmission, Ventilation

**Abstract:** The lesson to the indoor air community is significant to me - we also learned a lot in the last 12 months thanks to the efforts worldwide. With your extraordinary experience in indoor air quality research during these two pandemics, a topic like ‘From SARS 2003 to COVID 2019, what we have learnt indoors?’ or something similar will be much appreciated. ASHRAE. recently contributed to the ASHRAE Position Documents on Infectious Aerosols.

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**Plenary session 2: How can we mitigate future respiratory virus diseases? - Findings from five studies on COVID-19 transmission**

**Jelena SREBRIC**

*Bio:* Dr. Srebric is a Professor of Mechanical Engineering and a founding Director of the Center for Sustainability in the Built Environment at the University of Maryland (City@UMD). The original focus of Srebric’s research is on measurements and multi-scale modeling of built infrastructure to provide reliable assessments of how these systems affect occupant respiratory health, building energy consumption, and associated CO₂ emissions. Her most recent work focuses on personal protective equipment and personal comfort systems to improve health and comfort outcomes for occupants. She taught and developed new courses at University of Maryland, Penn State, and Harvard. She also presented more than thirty invited lectures at different institutions including Stanford, Princeton, MIT, Columbia University, National Academy of Sciences (NAS), and National Academy of Engineering (NAE). Her work on Covid-19 was featured in News media including The New York Times, NPR, NBC News, Wall Street Journal, The Baltimore Sun, and others. She was elected an international member of the Serbian National Academy of Engineering in 2013. Dr. Srebric became an Elected Fellow of the International Society of Indoor Air Quality and Climate (ISIAQ) in 2018, and an Elected Fellow of the International Building Performance and Simulation Association (IBPSA) in 2019. Her research work was recognized with a 2020 USM Board of Regents’ Faculty Award for Excellence in Innovation.

**Keywords:** Respiratory viruses, Airborne transmission, Ventilation

**Abstract:** Jelena will give a 45 minute keynote lecture
Plenary session 3: A paradigm-shift in accurate individualized & digitized thermal comfort prediction

Richard DE DEAR

**Bio:** Over the last 35 years, Professor Richard de Dear has focused his research career on defining what occupants want and need from their built environments, and assessing the performance of buildings in terms of meeting those requirements. He is currently the most highly cited living researcher in the domain of thermal comfort, with over 250 peer-reviewed papers plus several monographs on the subject. Within that body of research it is his adaptive model of thermal comfort that’s had the greatest impact, not just on the research community but also on the design and operation of actual buildings. De Dear’s adaptive model underpins the American Society of Heating and the Refrigerating and Air Conditioning Engineers’ thermal comfort standard, ASHRAE 55-2004, 2010, 2013, which in turn, informs several national thermal comfort standards around the world.

**Keywords:** Thermal comfort, Thermoregulation, IEQ

**Abstract:** We now have cutaneous thermoreceptor impulses for human subjects undergoing various thermal environmental transients and have trained an artificial intelligence model to recognise and rate thermal pleasure or displeasure experienced by subjects as their thermal environment changes around them. This is new work that brings us significantly closer to the holy grail of being able to diagnose whether an indoor environment (actual or design-stage) will be perceived by its occupants as being pleasant or unpleasant. This far outperforms the conventional PMV/PPD approach to modelling human comfort inside buildings.

Plenary session 4: CO₂ exposure — The truth about the infamous 1000 ppmv threshold

Pawel WARGOCKI

**Bio:** Assoc. Prof. Pawel Wargocki received his PhD from the Technical University of Denmark, where he has been teaching and performing research ever since. He has more than 20 years of experience in research on human requirements in indoor environments. He is best known for his seminal work demonstrating that poor indoor environmental quality affects performance of office work and learning. Other work influenced requirements for ventilation and air cleaning. Recent research includes studies on emissions from humans, on sleep quality and on performance of green buildings. He has collaborated with leading research institutions, universities, and industrial partners around the world such as National University of Singapore, Jiaotong University in Shanghai, Syracuse Center of Excellence, United Technologies and Google. He was President and long-standing board member of the International Society of Indoor Air Quality and Climate (ISIAQ), Vice President of Indoor Air 2008, and Chair of ASHRAE committees. He has received several awards for his work including Rockwool Award for Young Researchers, ASHRAE Ralph Nevins Award, ISIAQ’s Yaglou Award and Best Paper Award in Indoor Air. He is the member of Academy of Indoor Air Sciences.

**Keywords:** Carbon dioxide, Respiration, Metabolism, Performance, Sensors, Controls

**Abstract:** Pawel will speak about the effects of CO₂ on individuals and its relevance in connection with the current pandemic. There are few new studies on CO₂ and the matter is not completely solved. Pawel will also speak about the use of CO₂ in connection with DCV and when air cleaners are used. Finally he will discuss the use of CO₂ for evaluating IAQ and ventilation. We have some new data on CO₂ emission rates from sleeping and awake people. Colleagues have looked also on the CO₂ levels in the vicinity of occupants compared with the levels at the room level. All this makes a very interesting and timely story when CO₂ sensors become prevalent and affordable. Pawel will tough upon how touse sensors properly.
Plenary session 5: A grand day in? A guided tour through indoor air chemistry

Nicola CARSLAW
University of York, United Kingdom

Bio: Nicola Carslaw is a Professor of indoor air chemistry at the University of York. Her work involves numerical modelling of air pollution chemistry in the indoor environment, investigating the chemical processes that cause high concentrations of air pollutants indoors, particularly those that are likely to be harmful to health. Our current research focuses on indoor air pollution that arises following cleaning, emissions from materials (e.g. furnishing) and humans (e.g. from skin and breath) and the impact of indoor photolysis. She has been co-PI on the Chemistry of Indoor Environments (CIE) programme modelling consortium (MOCCIE) funded by the Alfred P. Sloan Foundation since 2017 and Chair of the EU INDAIRPOLLNET COST Action since 2018, leading and coordinating the activities of ~200 (mainly) European scientists in indoor air pollution research. She is also a member of the UK Committee on the Medical Effects of Air Pollution (COMEAP) and an Associate Editor (on indoor air pollution) for Atmospheric Environment.

Keywords: IAQ, VOC, Ventilation

Abstract: Indoor air chemistry is a relatively recent research field, with the first papers dating back to the 1980s. We have moved from simple sets of measurements and models used for early studies, to recent field campaigns that involved a suite of expensive instrumentation, coupled with sophisticated models. We have learnt an immense amount about indoor environments since those early pioneering days, but as recent measurements have shown us, we still have much to learn. This paper aims to reflect on what we have learnt about indoor air chemistry since the early studies and where the key areas for research might be in the future. It will focus mainly on gas-phase chemistry, summarizing what drives the chemistry indoors, what species we might expect to find in a typical residence, how indoor air composition has changed over time, and how it might further evolve in the future as we improve vehicle technology and hence outdoor air quality.

Plenary session 6: Towards health-promoting indoor microbiota – with robotic crawling infants, microbiota transplants, or a walk in the park

Martin TÄUBEL
National Institute for Health & Welfare, Finland

Bio: Martin Täubel has 15 years of research experience on the topic of indoor microbial exposure and the associated adverse and beneficial health effects. He heads a multidisciplinary research team studying indoor (microbial) exposures and associated health effects, at the Environmental Health Unit of Finnish Institute for Health and Welfare in Kuopio, Finland. The Kuopio research group integrates expertise in microbiology, exposure assessment, environmental sciences, bioinformatics, epidemiology and health sciences. Martin’s background is in microbiology and environmental biotechnology, and has earned him an adjunct professorship in Microbiology of the Built Environment at University of Eastern Finland. Martin has worked many years on aspects such as moisture damage, associated microbial exposure and adverse health effects, infant exposure to microbes, and the health-promoting potential of microbial contacts early in life. Martin has been involved in expert work assignments, including work with WHO Europe on a school IAQ survey, and he currently serves on the board of the International Society for Indoor Air Quality and Climate (ISIAQ) and as the chair of ISIAQ’s Scientific Technical Committee on Microbes in Indoor Environments.

Keywords: Human microbiome, Indoors biota

Abstract: Martin will give a 45 minute keynote lecture.
Session 1: Indoor chemical pollutants

Paper 1.1*: Impact of indoor temperature on the possible release of adsorbed Volatile Organic Compounds from sorptive materials

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Keywords: Adsorption, depolluting materials, passive air treatment, Temperature Programmed Desorption, Isothermal Desorption

The removal of indoor Volatile Organic Compounds (VOCs) by sorptive processes on the surfaces of construction materials is a promising alternative to conventional air treatment systems. Implementing Activated Carbons (ACs) in construction materials is a way to improve the global uptake abilities of the products. However, uptake capacities of indoor material are mostly investigated under mild ambient temperature and humidity, while these parameters fluctuate on long-term, questioning the fate of taken up species. Depending on thermal conditions, sorptive air treatment materials may act as secondary sources of taken up VOCs.

This work questions the behavior of Activated Carbon (AC) regarding toluene uptake and release under a wide temperature range. In this work, after toluene uptake, Isothermal Desorption (ID) originally completes the classical Temperature-Programmed Desorption (TPD). TPD consists in linearly increasing the temperature until high values to induce a complete desorption under controlled heating rate. Its interest for indoor conditions is limited because of heating rate and extreme temperature range. ID relies on submitting the system to successive temperature steps. The selection of temperatures of interest along ID experiments is useful to study the behavior of ACs under realistic indoor conditions.

Experiments evidence that, from the temperature threshold of toluene desorption (Tstart) until the maximum temperature (Tpeak), both retrieved by TPD, the quantity of desorbed toluene linearly increases with the temperature set. Consequently, it can be stated that until Tstart, AC does not behave as an indoor secondary source. However, at higher temperatures, the quantity of released toluene can be predicted through linear regression by knowing the temperature of the AC surface. Finally, after Tpeak, the material is exhausted as all the taken up toluene have been desorbed. However, it should be noted that typical Tpeak values are far from any indoor conditions. Thus, a fraction of the toluene taken up is not releasable under indoor conditions.

This study points at the complementarity of both desorption methods, the classical TPD and the innovative ID, for characterizing the taken up toluene on ACs. Moreover, this result is useful to predict the quantity of adsorbed VOCs that are desorbed from sorptive air treatment materials for any given temperature. Therefore, the implementation of these processes in IAQ models allows improving their representativeness. As the study has been performed on ACs only, the conclusion given in this abstract has to be confirmed with desorption tests on the final product, i.e. the AC-doped construction material.

* Extended abstract for Paper 1.1 is available at the end of this book.

Paper 1.2*: Characterization of the surface chemistry of Activated Carbons: a tool for sorptive indoor material formulation

Brunel, Raphael¹,², Avhad, Mangesh Ramesh³, Kaper, Helena³, Chenal, Marion², Soisson, Arnaud², Verriele, Marie¹, Thevenet, Frederic¹

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Keywords: Uptake, Volatile Organic Compounds, depolluting materials, passive air treatment, surface groups

The removal of Volatile Organic Compounds (VOCs) by sorptive processes involving indoor surfaces is an alternative to conventional air treatment systems. Implementing Activated Carbons (ACs) in construction materials is a way to improve the uptake abilities of these products. However, correlations between the physico-chemical properties of selected ACs and their retention capacities towards VOCs remain poorly understood, especially on realistic time scales and conditions. Specific surface area (Sspe) and surface chemistry are recognized as key parameters. But there is large diversity of indoor VOCs, which are not identically affected by these parameters.

This work aims at evaluating the impact of the surface chemistry of various ACs on VOC uptake at ambient temperature. Selected ACs have equivalent Sspe, ranging from 900 to 1200 m².g⁻¹. They differ in their nitrogen (N) and/or oxygen (O) content. The level of heteroatoms is controlled along their syntheses. Toluene and formaldehyde are selected as model pollutants due to their ubiquity in indoor environment and their contrasted natures. VOC uptakes on ACs are characterized by: partitioning coefficient K (µg.m⁻³), total adsorbed quantity qads and uptake reversibility. The surfaces of ACs are characterized using X-ray Photoelectron Spectroscopy XPS and X-ray scattering.

Regarding toluene, qads is maximum for AC without heterogeneous atoms. On the opposite, qads of HCHO is by two orders of magnitudes lower. This behavior is discussed in terms of polar interactions. The presence of N or O atoms negatively
impacts the quantity of toluene taken up. On the contrary, it positively influences the irreversible nature of HCHO uptake, attesting of stronger interactions of HCHO with such modified ACs. To interpret uptake results further, characterization of the ACs are performed. XPS is used to identify the nature of the chemical groups involving the N and O atoms on the surface of ACs. X-Ray Spectroscopy (silver-based source) is considered to determine the distribution of the heteroatoms on the surface of ACs, whether homogeneously organized or clustered.

This work experimentally points at the role of the surface chemistry of ACs for indoor VOCs uptake under realistic experimental conditions. Moreover, the use of multiply surface characterization techniques is promising to better comprehend the AC surface, for identifying the most suitable ACs for VOC removal. As the study has been performed on ACs only, the evidenced contrasted behavior has to be confirmed with tests on final products, i.e. the AC-enriched construction material.

* Extended abstract for Paper 1.2 is available at the end of this book.

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**Paper 1.3**: Diffusions of essential oils in a 40m³ experimental room: from emission rates to impact on indoor air quality

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**Keywords**: Essential oils, Indoor air, Emission, Terpenes, large scale experimental chamber

Essential oils have attracted increasing interest due to their performances as inhibitors of the metabolic functions of microorganisms. They are widely promoted as easy-to-use compounds to improve indoor air quality through passive remediation practices associated with their purifying actions. However, the potential toxicity of essential oils released in indoor air has not been clearly established.

This study aims to assess the emissions of terpene molecules contained in essential oils in confined environments by employing two diffusion mechanisms under real conditions in a real-scale experimental room: one ceramic heat diffuser, and one capillarity diffuser. This study also evaluates the impact of chamber volume on emission dynamics of essential oil constituents.

Evidence is found of contrasted concentration levels and kinetics depending on the diffusion mechanism used. Results show that the impact of indoor essential oil diffusion varies from 6 hours to 51 days, depending on the device used. Concentration levels can exceed recommended exposure levels by more than one order of magnitude. Additionally, the relative contributions of individual terpenes in the gas phase vary throughout the diffusion process.

Finally, several limitations are found regarding the evaluation of TerVOC emissions using test chambers with small volumes, typically in the 1 m³ range. Indeed, the concentration of TerVOCs and their emission kinetics are noticeably dependent on the chamber volume, which evidences the interest of determining emission rates using real scale and well-controlled experimental chambers to provide applicable experimental data for accurate exposure assessment.

* Extended abstract for Paper 1.3 is available at the end of this book.

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**Paper 1.4**: VOCs emissions from the human during sleep under different ozone and air change rate levels

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**Keywords**: VOCs, Emission rate, Sleep, Ozone, Air change rate

INTRODUCTION: Indoor pollutants emitted from occupants, which is bioeffluents, have attracted great attention of researchers. As a major part of bioeffluents, the components and emission rates of VOCs have been investigated. While most of the studies were conducted when occupants were awake. There is very limited knowledge of VOCs emission rates from sleeping people. Therefore, the present study was performed in a climatic chamber to estimate VOCs emission rates from sleeping people to fill in this gap.

METHOD: Eight healthy college-age subjects were recruited to sleep at three different conditions in a specially constructed capsule located in the chamber to create a small confined space. The three conditions consisted of two ozone levels (with a concentration of 0 and 25 ppm) and two air change rates resulting in CO₂ concentrations of about 800 ppm and 1700 ppm respectively. The temperature was 24 °C. Activated carbon was installed at the inlet of the air in the ventilation system to remove ozone in the background. An ozone generator was applied to doze a specific amount of ozone to the capsule. Each subject slept in a balanced order. VOCs in the capsule were sampled before and during sleep at a fixed time with Tenax tubes. The samples were then determined by thermal desorption - gas chromatography-mass spectrometry. Two typical pollutants, acetone and isoprene, were selected to estimate VOCs emission rates using a mass-balance equation.
RESULTS: The emission rates of isoprene and acetone emitted from sleeping people were around 0.08 mg·h⁻¹ and 0.06 - 0.2 mg·h⁻¹ respectively, which were much lower than that emitted from awake people (the emission rates for isoprene and acetone were about 0.16 mg·h⁻¹ and 1.0 mg·h⁻¹ respectively). Meanwhile, the results indicated that dosing ozone into the capsule could increase the concentration and emission rate of acetone, but had little influence on that of isoprene. While increasing the air change rate could decrease the concentrations of both isoprene and acetone significantly. It also increased the emission rate of acetone but decreases the emission rate of isoprene slightly. Further research needs to be performed to explore the mechanism of the influence of ozone and air change rate on VOCs emissions during sleep.

* Extended abstract for Paper 1.4 is available at the end of this book.

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**Paper 1.5**: Modeling physico-chemical processes impacting particles formation and fate indoors

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**Keywords:** Aerosol, Secondary Organic Aerosol, Coagulation, Condensation, Nucleation, Building, Indoor Air Quality, Atmospheric simulation chamber

People spend on average 80% of their time indoors while several monitoring campaigns showed that high levels of organics and particulate matter (PM) could be reached (Blanchard et al., 2014; Morawska et al., 2017). Conventional indoor air quality (IAQ) diagnostics are based on measurements, and thus expensive and time-limited. To overcome this issue, several models simulating aerosols concentration indoors have emerged. However, most of them disregard aerosol formation via condensation of Semi-Volatile Organics (SVOCs), which turns out to be one of the main source. Indeed, this requires a good knowledge of SVOCs concentrations in the gaseous phase.

To overcome this need, this study aims at developing and validating a numerical model for simulating aerosols indoors based on the INCA-Indoor model which has been developed to simulate concentrations of various volatile and semi-volatile organic compounds and oxidants in multi-rooms (Mendez et al., 2015). INCA-Indoor model showed good agreement in reproducing the gas phase (Mendez et al., 2015, 2016, 2017) and is currently used to carry out IAQ studies in support of building design projects (www.octopuslab.fr).

The aerosol module simulates the different physico-chemical processes impacting aerosols concentration both in number and mass: coagulation, nucleation, condensation with the use of the H2O model (Couvidat et al., 2012), indoor-outdoor exchange and deposition.

The robustness of the model is evaluated thanks to a comparison between simulation results and experiments in simulation chambers. Two types of aerosols have been selected to cover several processes: 1- coagulation from Diesel soot in the AIDA chamber (KIT) and 2- Secondary Organic Aerosol (SOA) formation after an ozonolysis reaction in the EUPHORE chamber (CEAM).

Results show good agreement between simulation and measurements: the RMSE between the observed value and the simulated value is less important than the uncertainty on the measurement. The model simulations are therefore in the uncertainty interval on the observation.

To conclude, this model is promising to better account for aerosols formation and fate when designing healthy buildings.

* Extended abstract for Paper 1.5 is available at the end of this book.

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**Paper 1.7**: Effect of ageing conditions on decorative and renovation products containing biocides: Assessment of its impact on indoor air quality

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**Keywords:** Fungi, VOCs and SVOCs emissions, ageing process, building and finishing materials, biocides

Building and finishing materials are among the main sources of indoor air pollution. Depending on the environmental conditions, these materials can be exposed to physico-chemical ageing and prone to microbial growth. The ageing process may affect indoor air quality (IAQ) throughout the emission of Volatile and Semi Volatile Organic compounds (VOCs and SVOCs). In order to prevent the biological growth, nowadays, some manufacturers add biocides to building and decorative materials.

The aim of this study is to develop a methodology to evaluate the impact of the ageing process on the effectiveness of biocides and on the emissions of VOCs and SVOCs. To do so, a renovation plaster (decorative material) was added to a polyester-cellulose (wall covering) before being subjected to accelerated ageing. The latter process consists of adding a detergent and exposing the material to a visible light spectrum, high relative humidity, and moderate temperature. The aged and non-aged
materials were inoculated by fungal spores using a dry aerosolization system prior to incubation. Developed fungi were then quantified using the cultured cell method.

The emission rates of VOCs and SVOCs from the aged, non-aged, inoculated, or non-inoculated materials were determined using the Field and Laboratory Emission Cell (FLEC). Gas samples were collected for each material after three days of emission. The identification and quantification of the emitted compounds were carried out using gas (TD-GC-MS/FID) and liquid (HPLC) chromatography.

The obtained results by the cultured cell method showed a proliferation of inoculated mold on the surface of the non-aged polyester-cellulose, whose concentration of developed spores was 10 times higher than the concentration of deposited spores. Whereas, no visible growth was detected on the polyester-cellulose combined with the renovation plaster, before and after ageing.

Regarding VOCs/SVOCs emissions, 64 compounds were emitted from the non-aged materials, out of which 5 are SVOCs. The emission rates of 29 compounds decreased with ageing, in particular biocides, whereas 17 other compounds have “newly” emerged. Similar results were obtained after the inoculation and incubation processes which led to a decrease in the emission rates of 37 compounds and the appearance of 7 “new” VOCs. However, the behavior of compounds was more variable when comparing emissions from the aged materials to those from the inoculated and incubated materials.

This study can be used to evaluate the lifespan of the applied biocides and to evaluate the potential impact of ageing on IAQ.

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**Paper 1.8: Indoor Environment and Energy Consumption of an Elementary School in a Subtropical Region**

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**Keywords:** Elementary school, Thermal comfort, Air quality, Subtropical zone, Energy consumption

Indoor thermal and air quality environments were measured in a subtropical region to clarify the performance and utilization of air conditioning system. The target school is existing in Okinawa, Japan, of which the latitude is about 26.2N. Annual maximum and minimum temperature is about 35 C 15 C and the RH is always over 75%. All the school buildings are equipped with air conditioning systems (ACs) because of not only hot and humid circumstances but also noise of airplanes. However, ACs without ventilation often make higher concentration of CO2 in the indoor air. It is necessary to operate and manage ACs and natural ventilation correctly to achieve and keep better thermal comfort and air quality and to save energy. The measurement results show the following environmental conditions: (1) The ACs were worked when the daily average air temperature was over 22deg. C. (2) The ACs in the class rooms were controlled by the teachers individually, and sometimes the room air temperatures were overcooled. (3) Direct solar radiation penetrated the class rooms in the early morning, which increased the heat load of ACs. (4) Vertical distribution of air temperature in the class rooms was clear, the higher point the higher temperature under air conditioning. (5) The concentration of CO2 in the class rooms were kept under 1000ppm by heat exchange ventilation systems.
**Session 2: HVAC system solutions**

**Paper 2.1: Operation status and improvements of integrated hybrid VRF system**

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**Keywords:** variable refrigerant flow system, COP, packaged air conditioner

In recent years, the importance of energy saving and the best mix of energy has increased. In particular, the best mix of energy is important in terms of energy supply stability. There is a need for air conditioning with energy options. Therefore, an integrated hybrid variable refrigerant flow system (Hybrid VRF system) was developed in which gas engine driven heat pump (GHP) and electric heat pump (EHP) were connected to the same refrigerant system. The Hybrid VRF system is a type of packaged air conditioner. This system can freely change the ratio of EHP and GHP. By controlling the operating ratio of EHP and GHP, Hybrid VRF system achieve high operating efficiency. It operates EHP when the load factor is low, and operates GHP when the load factor is medium. When the load factor becomes high, both EHP and GHP are operated. Packaged air conditioners are often used in small to medium-sized buildings. However, the actual performance characteristics of Hybrid VRF system have not been investigated. In this report, the authors conducted an actual survey of Hybrid VRF system which was introduced to a commercial facility. As a result of actual survey, it was found that the actual operation was different from the expected operation. It turned out that GHP is often operated when the load factor of the system is low. This operation is not optimal operation Therefore, the authors calculated the energy consumption when the system is operated in optimal operation. From the data obtained from the actual survey, we created the characteristic formulas of the primary COP and the load factor. Next, we created a table that defines the optimum operating ratios of GHP and EHP for each load factor. We calculated the primary energy consumption in optimum operation from the load factor and the amount of heat produced and the characteristic formula obtained in the actual measurement. Compared with the energy consumption of actual driving, the energy consumption of optimal driving is smaller. In optimal operation, primary energy consumption was about 25% less than the actual energy consumption. It was found that Hybrid VRF system which was actually measured this time has points to be improved in the operation method.

**Paper 2.2: Evaluation of a novel 3-pipe solution for hydronic heat distribution in passive-house standard apartment buildings**

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**Keywords:** Waterborne, energy, Legionella, heating, CFD

The energy efficiency of new buildings in Norway has been steadily improved over the last decades, but with less heating, hydronic heating systems have adversely increased in price. Lessening electric power consumption in new buildings is an important part of the government’s plan to de-carbonize, in which hydronic heating is a suitable alternative for electric heating. In this regard, a developer claimed to have found a potential cost-efficient hydronic solution in terms of investment cost. This solution is based on two measures, using the Domestic Hot Water (DHW) circulation loop to cover both DHW demand as well as space heating demand in the building, and significantly reducing the number of heat emitters. In this work, we studied the possible benefits and the issues associated with this solution and performed an analysis based on the following accounts, i) the distribution system, ii) indoor climate, iii) energy demand/consumption, iv) hygienic security. A newly finished apartment complex located in central Oslo is chosen for this purpose. Two apartments and the central heating are examined by inspection, experimental measurements, and Computational Fluid Dynamics (CFD) simulations. The distribution system is examined to confirm the alleged cost efficiency with a simplified cost calculation based on the BIM-model and the documentation provided by the developers. We estimated an additional cost of 67 NOK per square meter in comparison to the electrical heating. The end user could also financially benefit from using less expensive district heating. Using fan-coils as main heat emitter in each apartment was found to produce satisfactory indoor climate, however, in one apartment it was found that poor planning sabotaged its intended function which negatively affected indoor climate. Additionally, we found a lack of measures to protect the DHW from Legionella-growth, which is a violation of Norwegian building code TEK17.

**Paper 2.3: Prediction of Electricity Consumption of a HVAC System in a Multi-Complex Building Using Back-Propagation and Radial Basis Function Neural Networks**

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University, Tianjin, China; 4 Department of Mechatronics and Robotics, Xi’an Jiatong-Liverpool University, Suzhou, China; 5 School of Thermal Engineering Shandong Jianzhu University, Jinan, China

Keywords: Energy prediction, HVAC system, Artificial neural network, Back Propagation, Radial Basis Function

This study examined approaches to predict electricity consumption of a Heating, Ventilation and Air-Conditioning (HVAC) system in a multi-complex building using two neural network models: Back Propagation (BP) and Radial Basis Function (RBF) with input nodes, e.g., temperature, humidity ratio, and wind speed. Predicting HVAC energy consumption of buildings is a crucial part of energy management systems. We used two main neural network models, BP and RBF, to evaluate the prediction performance of electricity consumption of HVAC systems. The BP neural network method exhibited good performance, but it exhibited relatively large fluctuations and slow convergence in the training process. In contrast, RBF exhibited relatively fast learning and reduced computing costs. The HVAC energy consumption rate of working days was higher than that of non-working days. The results indicate that the prediction of HVAC energy consumption using neural networks can effectively control the relationship between the HVAC system and environment conditions.

Paper 2.4: Investigation of work-practices, skills and everyday challenges of building operators with respect to indoor climate and energy

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Keywords: Indoor Environmental Quality, Building Operation, Energy Efficiency

Focus on sustainable construction brings many requirements and standards to ensure energy efficiency and high indoor environmental quality (IEQ). However, these are mainly used in design phase. Commissioning becomes increasingly common to ensure functionality when building is taken into use. However, buildings are expected to stay in use for many years. It is a building operator, who ensures that building delivers healthy and comfortable environment. It is beyond discussion that his/her skills and professional level affect building's actual performance. The present study that had an objective to investigate work skills, experiences and professional challenges of building operators in Danish office buildings with particular focus on IEQ and energy efficiency. Thirty building operation professionals working in 23 companies were interviewed. The results showed that occupant complaints were a driving factor with respect to IEQ related measures. Building operators had a general interest in analysis of the IEQ in their buildings, but their knowledge of related standards and requirements turned up to be rather superficial. In most cases, there was a lack of a well-defined operational strategy regarding IEQ. The results show that there is a need to provide a missing link between technological part of building operation and a strategic part defining a clear goals and practices.

Paper 2.5: Mucociliary clearance is humidity dependent—contrary to common belief: HVAC systems overstress human noses during the heating season—the consequences

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Keywords: biogeographical cline in nasal shape, nasal cycle, desert like heated indoor environments

Unlike all mammals including primates, the species homo sapiens spread throughout all climate zones in the 350'000 years of his evolution. Three features, unique to humans, made this possible: a flexible, multipurpose nose, sweating and clothing. Regarding the nose, anthropologic studies and comparative anatomy have verified a significant biogeographical cline [biological gradient] that evolves from low profile, relatively wide noses, where seasonal absolute humidity is high to protrusive, narrow ones, where the air contains little moisture but high dust concentrations. Together with the “nose cycle” (abstract 1) this substantiates the assumption that the multiple tasks of our nose (protecting lower airways from desiccation, overheating, cooling, infection and pollution) is challenging and needed anatomical and physiological adaptations throughout evolution.

During the last two hundred years however, building industry imposed an unprecedented, ultimate climate challenge to our noses: heated, mechanically ventilated indoor environments, where we spend roughly 90% of lifetime since the industrial revolutions. While extreme outdoor climate conditions result in sparse population, heated and ventilated indoor conditions expose the entire population of the temperate climate zone to desert like conditions, for weeks, not for hours (see abstract 1).

Contrary to the widespread opinion, MCC efficiency, first and foremost nasal MCC, is humidity dependent. Yet the lower humidity limits of building codes are based on the assumption that MCC is resistant to very low ambient humidity. This is only supported by a couple of studies by Anderson and Procter that included exclusively young, healthy Danish students as test persons. Their studies indicate that selected young and healthy persons may support very low humidity for up to 78 hours without impairing MCC. By contrast, when including people of all ages and with common diseases, all studies (they will be presented at the conference) provided ample evidence for humidity dependence of nasal MCC.

Providing suitable indoor climate conditions for everybody is imperative. Increasing the lower relative humidity limit to 40% (building reality in winter is often 20-30%) would protect the health of all occupants and reduce the burden on public health by chronic respiratory diseases and seasonal respiratory infections.
Paper 2.6: Development and Application of a Ventilation System based on Vertical Descendent Confluent Jets

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Keywords: Confluent Jets, Virtual Thermal Manikin, Thermal Comfort, Indoor Air Quality, ADI, Numerical Simulation

This paper presents the development and application of a ventilation system based on vertical confluent jets. The thermal comfort and indoor air quality levels, Air Distribution Index and energy consumption are evaluated and discussed. The numerical study is carried out in a virtual chamber with dimensions of 4.50x2.55x2.50 m³. This chamber is equipped with six tables, twelve chairs, one outlet system and one confluent jets system, and is occupied with twelve virtual occupants. The inlet system has two horizontal 0.15 m diameter ducts, installed at a height of 1.8 m from the floor, which have consecutive holes in order to promote downward jets close to the side walls. The outlet system has six air ducts, located above the head of the occupants, connected to the ceiling area. The study was developed for three different airflow rates, considering winter conditions. As the airflow rate increases, indoor air quality improves, thermal comfort remains within an acceptable level and ADI improves slightly.

Paper 2.7: Better building operation, maintenance and well-being in apartments with smart indoor climate meters

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Keywords: Smart meters, Energy billing, indoor climate in apartments

The justification of energy consumption in dwellings is to maintain comfortable and healthy indoor climate. Air exchange and comfortable temperatures may also protect building structures against decay and mould growth. Expenditures in relation to building maintenance and loss of health normally by far exceed the expenditures in relation to energy consumption. But in blocks of flats with billing for energy use in relation to individually metered consumption it is economically attractive for tenants to keep their indoor temperatures low. Their savings can become very big when temperatures are slightly lower than in surrounding flats because the walls and floors between flats are more important for the heat loss from an individual apartment than building envelope. The introduction of smart indoor climate meters of temperature, humidity and carbon dioxide concentrations is a modern alternative to energy consumption metering. The meters permit calculation of payments according to ability to maintain a healthy indoor climate.

The purpose of this paper is to examine the differences in indoor climate quality and heating expenditures between rental apartments in the same tenement before and after the introduction of smart indoor climate meters.

We analyzed heating accounts from approximately 500 apartments in three tenements. The apartments were equipped with equipment logging temperature, relative humidity and CO₂. Energy use before introduction of indoor climate meters show more than a factor 15 difference between minimum and maximum payments in apartments with similar characteristics. Furthermore, preliminary results indicate that differences in energy consumption does not correlate with the measured differences in indoor temperature, humidity and carbon dioxide. These results could also illustrate a need for revision of the common recommendations regarding the preservation of energy to give a more sustainable set of guidelines, especially in apartment buildings where temperature competition between tenants potentially can damage the whole building.

Paper 2.8*: Assessment of three experimental methods for determining the emission parameters of VOCs from a solid material

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Keywords: ventilation; VOC; partitioning coefficient; diffusion coefficient; initial emittable concentration

Emissions of volatile organic compounds (VOCs) from solid materials directly impact indoor air quality. Their contribution to pollutant dynamics have to be integrated to indoor air simulation models. Therefore, reliable and validated experimental data are
expected by modelers. The VOC emission processes from a solid material can be described by three key parameters: the partition coefficient (K), the initial emittable concentration (C0) and the diffusion coefficient (D). Three experimental methods from literature allow determining simultaneously the three emission parameters: the C-history methods operated under (i) airtight or (ii) ventilated conditions, and (iii) the alternative airtight ventilated emissions (AAVE). However, these methods have never been compared using the same material and addressing simultaneously a variety of VOCs emitted.

This work provides an experimental assessment and comparison of the three methods. Experiments are carried out using a 128 L well-mixed chamber containing a particleboard as VOC source. The chamber is connected to an online gas analyzer (Selected Ion Flow Tube-Mass Spectrometry), allowing the effective characterization of emitted VOCs. Different samples of the same material are used along experiments. Thus, after evaluating the variability of VOC emissions between samples, each method has been assessed three times to address their individual variability and reproducibility and allow proper comparisons between methods.

If the protocols of the C-history methods require shorter and easier experimental tests, they impose advanced data treatments. Moreover, contrasted and unexpected values observed between airtight and ventilated C-history methods question the influence of the aeraulic conditions on the determination of the emission parameters and the subsequent representativeness of their experimental conditions. The AAVE method definitely requires a more advanced control on the experimental conditions. Nevertheless, the protocol interestingly encompasses various ventilation regimes and the possible exhaustion of the sample. The comparison of the emission parameter values obtained from the AAVE method with the C-history methods and the literature data underlines the ability of the AAVE methods to provide more accurate and reliable emission parameters. Therefore, experimental data retrieved by AAVE methods should be privileged for implementation in simulation models.

* Extended abstract for Paper 2.8 is available at the end of this book.

**Paper 2.9: An overview of transparent and translucent 3D-printed façade prototypes and technologies**

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**Keywords:** 3D-print, Façade, Material, Transparent, Energy-saving

3D-printing has transformed traditional manufacturing, by enabling the fabrication of individually designed complex systems in a short amount of time. The building's facade is also one of the most complex and challenging systems because it has positive impacts on controlling the built indoor environment and increasing energy-saving. Thus, the main objective of this research was to distinguish 3D-printing technologies that can improve transparency and translucency in the façade of the buildings in order to decrease artificial lighting consumption, control solar energy, and improve energy saving. A literature study was performed in this article and firstly, different types of 3D-printing techniques, and their methods for producing transparent materials were reviewed from academic databases. Then, transparent 3D-printed facade prototypes based on what was extracted from resources were identified. In order to achieve reliable resources, the Impact Factor of journals was checked. Sources that were written by an authentic author or university were selected. Moreover, about 3D-printed prototypes, the tests which were used to check their features and qualities (e.g. transparency, insulation) were studied and investigated. By analyzing prototypes, it became obvious that most of them used the FDM 3D-printing technique and Polyethylene Terephthalate Glycol (PETG) as a material to enhance natural lighting transmission. These prototypes didn't consider the disadvantages of the FDM technique for the lighting transmission. Several 3D-printed prototypes performed like an adaptive facade and tried to control daylight and reduce discomforts such as overheating and glare. Some 3D-printed prototypes were such as glazed facades, compare to a static facade they were transparent, but compare to an adaptive facade they did not have any control over daylighting discomforts. Additionally, the energy efficiency of prototypes was analyzed and compared based on their solar gain control, natural ventilation, and daylight penetration. These prototypes attempted to improve energy-saving which ranged from applying recyclable materials to controlling solar gain.
Session 3: IEQ and health in schools and kindergartens

Paper 3.2: Reviewing the impact of indoor air quality management and asthma education on asthmatic children's health outcomes – A pilot study

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Keywords: Indoor air quality (IAQ), asthma, children health, air purification, asthma education

Indoor air quality (IAQ) impacts asthmatic children’s health. Previous research suggests that individual interventions such as home-based education and IAQ management positively impact health outcomes for asthma and other respiratory diseases. This study aims to evaluate the impact of the combination of home-based education and IAQ management with an air purifier as a single intervention, rather than individual interventions, to improve health outcomes of asthmatic children.

This study was conducted between June and November 2019 in McAllen, Texas. Foobot devices were used to monitor the temperature, relative humidity, particulate matter 2.5µm (PM2.5), and total Volatile Organic Compounds (TVOC) in the bedroom, kitchen, and living room of 13 homes. The monitoring was carried into phases of equal length of pre- and post-intervention. Families received asthma education together with recommendations on how to manage and improve IAQ. The children’s health outcomes were evaluated at the beginning and end of the study using certified surveys. Comparison of the PM2.5 and TVOC levels and the scores for health outcomes were made between pre-and post-intervention.

The results showed that PM2.5 and TVOC levels reduced significantly after intervention. The health outcomes were improved in asthmatic children. However, only the difference in the health-related quality of life was statistically significant. The results cannot be generalised; however, they provide evidence of the combined intervention's impact, including asthma education and IAQ management, with an air purifier to improve asthmatic children's health outcomes.

Paper 3.3: VOC contributions from building materials, furniture, and user equipment in low-emitting and modular classrooms

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Keywords: TVOC, formaldehyde, school, indoor air quality, ventilation

To prevent the accumulation of pollutants in indoor spaces, such as schools, proper source control, and adequate ventilation are necessary. A common approach is to select low-polluting building materials which in turn would reduce the energy demand for ventilation outside occupied hours. However, furniture and user equipment might also contribute to indoor pollutant levels. Modular classrooms, where there is less emphasis on the selection of building materials, are frequently used as a temporary solution when schools are being renovated. This study aimed to assess whether building materials, furniture, and user equipment are sources of pollution that would influence ventilation needs.

The indoor climate in four regular classrooms in a low-emitting school was compared with the indoor climate in four modular classrooms in a prefabricated school, taken in use in 2016 and 2019, respectively. Passive sampling of volatile organic compounds (VOCs) and aldehydes was carried out in the classrooms under the following conditions: "emptied", "with furniture only", "with furniture and user equipment" and "in normal use". For the first three conditions, the classrooms were measured with either no ventilation or "low" airflow rates. Each measurement period lasted for a week and took place in the period between 2017 and 2020.

The results show that the highest total VOC (TVOC) concentrations were measured in an unventilated modular classroom (3611 µg/m3 furnished; 2626 µg/m3 emptied). Turning on the ventilation to low reduced the TVOC concentrations to below 400 µg/m3 in the modular classrooms under the two aforementioned conditions. This was similar to the average TVOC levels measured in unventilated regular classrooms (397±46 µg/m3 furnished; 441±28 µg/m3 emptied).
With the ventilation off, the measured indoor formaldehyde concentrations in the modular classroom for all three conditions without occupancy greatly exceeded the existing WHO guideline value (100 µg/m³ as a 30 min average). With low airflow rates, the average formaldehyde concentrations were considerably reduced but still higher than the measured concentrations in unventilated regular classrooms.

Our results indicate that a substantial proportion of TVOC in regular classrooms was from the user equipment. The high TVOC and formaldehyde concentrations in the modular classrooms signify the importance of selecting low emitting building materials and proper ventilation. Furthermore, the ventilation should be turned on a few hours before occupancy to ensure low levels of air pollutants and a higher airflow rate might be needed during occupied hours, especially for modular classrooms.

**Paper 3.4: The influence of indoor air quality in classrooms on the short-term academic performance of students in higher education: a field study during a regular academic course**

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**Keywords:** Short-term academic performance, classroom, higher education, indoor air quality, quality of learning, perceived cognitive performance

The indoor air quality (IAQ) in classrooms in higher education can influence in-class activities positively. In this context, the actual IAQ, student’ perceived IAQ (PIAQ), perceived cognitive performance (PCP), and their short-term academic performance (SAP) were examined in two identical classrooms during regular academic courses. During the lecture, key performance indicators (KPI) for the IAQ, i.e. carbon dioxide concentration, particulate matter 2.5, and total volatile organic compounds, were measured. After the lecture, responses of 163 students were collected with a validated self-composed questionnaire and a cognitive test, which covered topics discussed during the lecture. A significant association between the IAQ KPI and the PIAQ was found (p < .000). The PIAQ significantly predicted the PCP (p < .05) and the PCP significantly predicted the SAP score (p < .01). These results indicate that the IAQ in classrooms is associated with the PIAQ and PCP, and therefore is associated with students’ SAP.

**Paper 3.5*: Analysis of natural ventilation of a large educational building using parallel opening windows**

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**Keywords:** natural ventilation, computational fluid dynamics, on-site measurements

Natural ventilation can be used as a sustainable way of controlling the indoor environment. Natural ventilation by means of openable windows is not often applied in medium to high-rise buildings due to the possibly large wind pressures, resulting in too high indoor air velocities and possible nuisance. However, it has a strong potential to provide ventilative cooling. This study focuses on natural ventilation in a large educational building (Atlas) at TU Eindhoven. Natural ventilation is possible through parallel opening windows (POW). However, there is a lack of knowledge on the application of parallel opening windows in high-rise buildings and how to prevent nuisance and optimize ventilative cooling requires more detailed information. Full-scale on-site experiments and computational fluid dynamics (CFD) simulations are conducted. The simulations show that close to the POW very high velocities can occur. However, the incoming jet flows are dissipated within a limited distance, reducing the possible nuisance.

* Extended abstract for Paper 3.5 is available at the end of this book.
Paper 3.6*: Ventilation strategies of school classrooms against cross-infection of COVID-19: A review

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Keywords: ventilation, school, airborne transmission, respiratory droplet, COVID-19

With COVID-19 still rapidly spreading all over the world, so far in the Netherlands over 900,000 people were tested to be infected, where 11% of them are children aged from 4 to 17. Some early stage studies observed milder symptoms among paediatric patients, yet existing evidence is not sufficient to determine whether children are less frequently infected or infectious. Despite of this worrying situation, there are still ongoing debates upon whether schools should be reopened under the growing pandemic.

Considering the long hours children (will) spend in their classrooms every day, it is of urgent need to determine whether schools and classrooms are equipped with sufficient measures to prevent cross-infection. A literature study is therefore conducted to investigate the common ventilation strategies currently in use by schools and assess their efficiency of preventing cross-infection of respiratory-related diseases in the indoor environment, as well as to seek for future solutions. Research articles, standards/guidelines and reports relevant to ventilation in schools/classrooms, airborne transmission of respiratory droplets and advanced air distribution were examined. The results show that in general most schools and classrooms only have natural (opening windows and doors) or hybrid (mechanical assisted) ventilation, where the overall indoor air quality for students is indicated to be not ideal. It is proved that both natural and mechanical ventilation can reduce the airborne transmission of respiratory droplets indoors efficiently when designed, operated, and maintained properly. However, existing standards and guidelines of ventilation in school buildings are mainly based on the control of CO₂ and chemical contaminants, leading to a shortage of informative guidance for schools on preventing respiratory diseases like COVID-19. Personalized ventilation (PV) has a promising potential in protecting occupants from indoor air contaminants and thus can be an alternative solution to improving ventilation performance in schools, while systematic studies are needed before PV can be applied to children in classrooms.

* Extended abstract for Paper 3.6 is available at the end of this book.

Paper 3.7*: Ventilation rate in classrooms of elementary schools and its association with respiratory infections

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Classrooms in elementary schools have high occupancy levels. In China, usually 40 students share one classroom with a size of 50-80 m². Students spend most of their time in schools, secondary to homes. Therefore, school environment must have a very important influence to their health. In this study, we investigated ventilation rates in classrooms and the influence on students’ respiratory infection rates.

We invited 10 schools to join our study. These schools were all located in Northeast China with cold winter climate. The locations of these schools covered urban, suburban and rural areas. Classrooms in these schools were all naturally ventilated.

In a total, 47 classes in 10 schools joined our study. Among them, 27 classrooms were for second grade and 20 rooms were for fifth grade. Students in these 47 classrooms were all involved in our study, and resulted a total number of 2020 students. The school hours for all the students are basically the same, with an average of 9 hours per day, 5 days per week. We performed online continuous monitoring on indoor air temperature, relative humidity and CO₂ concentrations, from 2018-2019. The CO₂ concentrations were used to estimate ventilation rate, either in air change rate per hour or Liter per second per person.

It was found that the indoor daily average CO₂ concentration ranged from 400 ppm to 3914 ppm, with an average of 1800 ppm. 85% of the samples exceed the 1000 ppm. Winter had the highest indoor CO₂ concentrations. The average daily value was 2300 ppm. 97% of samples were above 1000 ppm. The daily air change rate varied from 0.01 h⁻¹ to 11.2 h⁻¹, with a median value of 0.8 h⁻¹. Considering the high occupancy level in classrooms, we only had fresh air of 1 L/s/person in classroom. The absence rate due to respiratory infections among students were reported by teachers. The average daily absence rate is 1% per day. Winter had highest absence rate.

We use zero-inflated negative binominal model (ZINB) to study the associations between school ventilation and respiratory infections. It was found that an increase of 1 h⁻¹ would reduce absence rate by 30%. The same significant influence on absence rate was observed with another ventilation metric, liter per second per person. It indicated that low ventilation rate was significant risk factor for respiratory infections and airborne transmission might be an important route for infections.

* Extended abstract for Paper 3.7 is available at the end of this book.
Paper 3.8: "Schools on hold" – how simple measures can help improving the indoor environment in schools

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Keywords: Schools, indoor environment, simple measures, thermal comfort, health

This work presents the lessons-learned from a Norwegian project called "Skoler på vent" – "Schools on hold" – which is aiming at finding simple and effective measures for improving the indoor climate in schools that have been put on hold. Schools on hold often suffer from dissatisfying indoor thermal comfort which also extents to affecting people’s health, well-being and learning. Measurement data (temperature, CO2-level and relative humidity) have been collected from several rooms in three schools in the municipality of Trondheim, Norway, during two measurement campaigns. Furthermore, interviews with school employees as well as surveys among the students have been carried out during the same periods to gain insights in the perceived indoor environment. Results show that simple measures such as i) removing the lowering of heating set point at the end of a school day, ii) checking the radiator valve position, iii) introducing routines for natural ventilation during breaks and iv) improving the room cleaning routines can improve the perceived indoor environment notably. Furthermore, the applied methodology is discussed and improvements suggested.

Paper 3.9: Analysis of the effect of indoor environment on pupils’ health in one Norwegian school during COVID-19 pandemic

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Keywords: school, IAQ, health, machine learning

The aim of this project is to investigate and predict the quantified effect of indoor environment on pupils’ health in schools in Norway during the COVID-19 pandemic. The results are based on field measurements of the indoor environment in a Norwegian school. In addition, a survey (Mitt Inneklima) from NAAF was given to the pupils, and the result was investigated by using a machine learning model.

From the field measurements it was found that the indoor temperature was generally too high, the relative humidity was too low, and the CO2-concentration was typically below 1000 ppm.

The survey shows that more pupils are experiencing various indoor climate problems every week compared to the reference school for almost all of the parameters. By using machine learning, it is found that Too hot is an important feature for 11 of the 12 health problems, while Dry air is an important feature for nine of them.
Session 4: Thermal environment in homes

Paper 4.1: **Assessing the indoor air quality of natural-ventilated bedrooms in renovated Norwegian houses using detailed field measurements**

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**Keywords:** natural ventilation, bedroom, IAQ, window opening

Small wooden dwellings are responsible for more than half of the total energy use in Norwegian buildings. Renovation usually includes a substantial improvement of the air-tightness, which reduces the air change rate due to infiltration. A recent study found that 60% of the Norwegian detached households made no changes to the ventilation system when performing an energy renovation, while only 9% installed balanced mechanical ventilation. The objective of this study is to investigate indoor air quality (IAQ) in window ventilated bedrooms in renovated houses.

Ten bedrooms in six case houses were investigated by measuring temperature, relative humidity, CO\(_2\), PM, formaldehyde and TVOC. The window opening angle was also logged with an accelerometer. The measurements were conducted over 2-3 weeks, during March and April. In addition, participants answered a questionnaire about motivation and habits on window opening. The dwellings were renovated single-family houses and terraced houses from 1950 – 80, in Trondheim. All the bedrooms had natural ventilation, and the occupants stated they used to open bedroom windows at night.

Results show that windows were open every night in most of the bedrooms. High CO\(_2\) levels were found in only two out of ten bedrooms. In the other bedrooms, the CO\(_2\) concentration was at a satisfying level during the nighttime. For some bedrooms, levels were higher during the day, when windows were closed. Six bedrooms had a time-averaged air temperature during nighttime below 18°C.

The work suggests that it is possible to achieve a high IAQ with manual window ventilation, also in energy renovated houses. This is however not guaranteed: not all bedrooms showed acceptable IAQ indicators. These results indicate that many occupants keep the bedroom windows sufficiently open for a good indoor air quality. However, the number of bedrooms investigated is too limited to generalize the conclusions.

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Paper 4.2*: **Bacterial and fungal aerosols in dwellings with domestic animals: preliminary results**

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The aim of the study was to obtain the preliminary properties of bacterial and fungal aerosols in selected city flats with small domestic animals, compared to reference flats (without animals). The research consisted in the simultaneous determination of bioaerosol concentrations in flats with animals and in reference flats with the same building and hygienic characteristics as flats with animals. The samples of airborne bacteria and fungi were collected using a 6-stage Graseby-Andersen impactor. The species identification of bioaerosols was also carried out. It was found that in homes with pets, the concentration levels of fungal aerosol were only slightly increased, while the concentrations of bacterial aerosol were 2-3 times higher compared to the control (reference) apartments. Moreover, the presence of animals in apartments also influenced the species composition of the bacterial aerosol. In homes with a cat or a dog, a slightly increased proportion (contribution) of Gram-negative bacteria was observed. In turn, in apartments with aquariums with small fishes, there was a significant increase in the concentration of Gram-positive rods (Corynebacteria) and mesophilic actinomycetes (Actinomycetes). It was also observed that in houses with dogs, Staphylococcus intermedius, Propionibacterium avidum and bacteria from the Enterobacteriaceae family are often found, while the strain Plesiomonas shigelloides was found only in the air of dwellings with aquariums.

* Extended abstract for Paper 4.2 is available at the end of this book.
**Paper 4.3:** The risk of overheating and energy demand of new and old Finnish apartment buildings in the cooling season

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**Keywords:** Building energy performance simulation, Indoor temperature conditions, Overheating, Residential building

This study has compared the risk of overheating of a new and old apartment building in Finland and aimed to improve the indoor temperature conditions of the new apartment building by means of the passive strategies (sun shading, window opening, and window properties) and an active cooling system. Seven different cases were defined and simulated. Regarding the results, the risk of overheating in the old building is significantly less than in the new building, and using new well-insulated windows with the same old wall construction in the old building, decreases the heating demand but has no significant effect on indoor air temperature. Hence the windows are more important for energy usage but not for the indoor air temperature in the old Finnish apartment building during the summer period. Using openable windows would be the best passive solution for keeping the indoor air temperature of the spaces of the new building within the comfort limits with less than 10% of the time above the recommended temperature limits based on En 15251 standard without any significant increase in heating demand. While using an active cooling system in the living room of each apartment is the only solution that can provide thermal comfort for 100% of the cooling season in all the spaces including bedrooms.

**Paper 4.4*: Evaluating the Influence of Ventilation Strategies on Energy Consumption and Indoor Air Quality in Residential Dwellings

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**Keywords:** energy efficient building, ventilation, modelling

The International Energy Agency identified that energy efficiency is an important energy resource, highlighting that the "energy use avoided" by IEA member countries was larger than any other single supply-side resource. While there is potential for significant health and well-being benefits associated with improved energy efficiency; it is also documented that if energy efficiency measures are implemented incorrectly, they can have negative impacts on Indoor Air Quality. Regulatory measures need to ensure that multiple objectives are achieved in order to avoid policy failure. A realistic view of the trade-offs (thermal comfort, human health and energy performance) is required, if current policies are to be effective. An integrated approach is required to simultaneously achieve energy efficiency while also maintaining good indoor air quality. With a limited number of exceptions, the vast majority of studies focus on a single outcome at a time (thermal comfort, human health or energy consumption). The current study utilises a modelling framework that comprises of three existing models: CONTAM, EnergyPlus and IAPPEM. Each model has unique attributes that focus on the temporal and spatial distribution of indoor temperature profiles and energy consumption, dynamic airflow and pressure values, and indoor air pollution. This combined approach assesses both the energy performance and ventilation in energy-efficient dwellings. Simulations focus on assessing the energy consumption, risk of overheating and multiple indoor air pollutants (PM2.5, radon, humidity, CO2, CO, TVOCs). Five different archetypes (bungalow, two-storey dwelling, semi-detached, terrace and apartment) were developed. A matrix parametrisation approach incorporates varying room dimensions, meteorological conditions, ventilation and airtightness characteristics, building thermal characteristics, occupant profiles, outdoor air pollution concentrations and geogenic radon potential. The ventilation and energy performance parameterisation is based on recent updates to the Irish Technical Guidance Document. Simulations will assess the impacts on indoor air quality and energy consumption under i) various retrofits scenarios; ii) current and future climate scenarios; iii) current policies and projected future policy. This study will help in better understanding the relationship between energy consumption, ventilation, temperature, and indoor air quality in highly energy-efficient dwellings. The results will help inform future energy policy recommendations to ensure that the potential benefits, including those to health, are not compromised by the drive to towards improving the energy performance of the building stock.

* Extended abstract for Paper 4.4 is available at the end of this book.
**Paper 4.5: Subjective assessments of bedroom environment in the heating season in Denmark**

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**Keywords:** Bedroom environment, Thermal comfort, Air quality, Acoustic comfort, Visual comfort

A satisfied bedroom environment is vital for the sleep quality of human beings. Thermal comfort, air quality, acoustic comfort, and visual comfort are all verified to be indispensable for the overall bedroom comfort. However, few studies reported how occupants rate those environmental aspects in their bedrooms. The present study figured out this question by online morning and evening sleep diaries conducted in the capital region of Denmark in the heating season. A total of 169 sets of responses to the sleep diaries from 82 subjects were received. Compared to those who accepted the bedroom environment, the subjects had the highest levels of the unacceptability of noise, following by stuffy air and a hot bedroom. Acoustic and thermal comfort and air quality can be improved for occupants to have a more satisfactory bedroom environment. The present study gives a sight of which aspects should be improved for people to have a better bedroom environment.

**Paper 4.6: The relation between indoor air quality in a bedroom and sleep quality of ageing adults**

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**Keywords:** ventilation, sleep quality, intervention study, physiological data, subjective data

The present study examined the effect of the indoor air quality, indicated by CO2 levels, on sleep quality of ageing adults. Bedroom indoor air quality was changed by increasing the ventilation rate with a mechanical ventilation system with heat recovery with the intention to decrease the CO2 levels.

Twenty-two volunteers were studied during four consecutive nights in their bedroom at two different settings of the mechanical ventilation system with heat recovery (high and low). During the night indoor air quality was measured continuously (CO2, temperature, and relative humidity), additionally the background noise was measured. Physiological indicators of sleep quality were analyzed using actigraphy (Sensewear). Three different questionnaires (PSQI, GSQS and sleep diary) provided subjective data on sleep quality and the Hope questionnaire provided subjective data on the perception of the indoor climate.

Bedroom CO2 increased rapidly during the night at a low ventilation rate (15 m3/h) to 1409 ±412 ppm, but remained low at the high ventilation rate of 91 m3/h (680 ±106 ppm CO2). At the same time air humidity decreased at the high ventilation rate. The sound pressure level remained low at the low ventilation rate (35 ±2 dB) but increased to 39 (±4) dB at the high ventilation rate. The bedroom air temperature remained stable and did not, as opposed to the other indicators, differ significantly between the conditions.

The sleep quality obtained with the Sensewear was not affected by the change in IAQ. Also no significant difference was analyzed for the PSQI and the GSQS questionnaire. However, the HOPE questionnaire (indoor air quality) had multiple significant correlations with the measured indoor environmental quality. The subjects rated the air fresher but experienced more air draft with the high ventilation rate. The results of the sleep diary (length of sleep and latency) were correlated with the results obtained with the Sensewear.

Characteristics of the subjects appeared to have a significant effect on sleep conditions (age) and on indoor air quality perception (gender). Older people experienced more nightly awakenings, and the depth of sleep was significantly better. Women judged the air quality significantly lower when compared to men.

**Paper 4.7: The resulting CO2 levels and the heating/cooling consumption of apartments with balanced ventilation versus window ventilation**

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**Keywords:** balanced ventilation, window ventilation, indoor air quality, space heating consumption, space cooling consumption

Four apartments have been monitored for an entire year. Two apartments were ventilated with a balanced ventilation system, and two apartments were ventilated by manual opening of windows. CO2 values have been registered as indication of indoor air quality.
in each living room and the available bedrooms. The opening of windows and doors was registered, from which an airing factor was calculated. The heating and cooling consumptions was also registered for each apartment.

The CO\textsubscript{2} levels in all rooms of the apartments with balanced ventilation was lower than the manually ventilated apartments, with less variation between hours and seasons. The percentage of hours exceeding 1000 ppm is below 1\% of the year for the apartments with balanced ventilation and 30-60\% of the year for window ventilated apartments.

Space heating and cooling use are investigated by energy signatures of the four apartments. The balanced ventilation - including recovery - not only brings a higher indoor air quality, but also a lower heating (-24\%) and cooling use (-50\%) as follows from the specific heating slope and specific cooling slope in the energy signatures.
**Session 5: Indoor particles, aerosols and VOCs**

**Paper 5.1: Indoor Aerosols - Calculation of Zonal Particle Concentration and Particle Deposition in the Human Respiratory Tract**

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**Keywords:** Indoor Aerosol Modeling, ICRP, Human Respiratory Tract, Indoor Air Quality, Material Balance Model

This study presents a modeling approach to calculate the particle concentration in mechanically conditioned indoor environments and predict particle deposition in the Human Respiratory Tract (HRT) by combining two aerosol models. The developed Indoor Aerosol Model (IAM) combines the semi-empirical Respiratory Deposition Model (RDM) presented by the International Commission on Radiological Protection (ICRP) in its publication 66/130 with a Material Balance Model (MBM). This enables the determination of total regional deposition fractions in the HRT for different particle diameters, subjects, levels of exertion or respiration types. These total regional deposition fractions are then incorporated into the MBM, which can be used to determine the number and mass of particles deposited in the HRT over a maximum period of 24 hours. Furthermore, the time history of the airborne particle concentration, as well as the surface loading and, in addition, the particle fate can be determined for well-mixed single zones.

**Paper 5.2*: Effects of suspended particles, chemicals, and airborne microorganisms in indoor air on building-related symptoms: a longitudinal study in air-conditioned office buildings**

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**Keywords:** building-related symptoms, chemicals, epidemiology, microbes, particles

We conducted a one-year longitudinal study in Osaka and Tokyo to examine the effects of suspended particles, chemicals, and airborne microorganisms in indoor air on building-related symptoms (BRSs) in air-conditioned office buildings. In total, 648 subjects, in 24 office rooms and eleven office buildings, were recruited for the present study. In order to collect information on BRSs and those indoor air pollutants in the office room, we measured air concentrations of carbon monoxide (CO), suspended particles [particle counts of each cutoff size in diameter (>0.3 μm, >0.5 μm, >0.7 μm, >1.0 μm, >2.0 μm, >5.0 μm)], PM2.5, formaldehyde, acetaldehyde, volatile organic compounds (benzene, toluene, ethylbenzene, xylenes, styrene, p-dichlorobenzene, and tetradecane), total volatile organic compound (TVOC), fungi, bacteria, and endotoxin in the office rooms and provided a health questionnaire once every two months for one year. The sampling interval for these compounds was 30 min in a single day. The surveys were conducted between June 2015 and February 2017. In total, 483 office workers (53.4% male, 46.6% female) participated in the present study. Of the 4520 questionnaires distributed during the survey, 1800 valid responses were obtained (response rate, 39.8%). Weekly BRS was defined as symptoms experienced at least 1 day per week in the last 4 weeks that improved when one was away from the building, suggesting the associations between health symptoms and work environment are strong. Monthly BRS showed symptoms that were experienced at least 1 day in the last 4 weeks that improved when one was away from the building, suggesting the associations between health symptoms and work environment are weak. Multivariable analyses revealed that weekly BRSs, including eye irritation, upper respiratory symptoms, and general symptoms were not significantly correlated with indoor air pollutants. In monthly BRSs, upper respiratory symptoms were significantly correlated with increase of air concentrations of benzene, ethylbenzene, and Acremonium species. On the other hand, upper respiratory symptoms were significantly correlated with decrease of air concentrations of CO, endotoxin, and yeast species. Indoor air concentrations of benzene and ethylbenzene were lower than those specified in Japanese air quality guidelines. Although the indoor air concentration of each pollutant was low, when they collectively exist in an indoor environment, they can lead to a greater combined health risk. Our data suggests that further research on the total health risk due to multiple low-level indoor pollutants is required.

*Extended abstract for Paper 5.2 is available at the end of this book.*
Paper 5.3*: Human personal cloud associated with particles and gases in an office study: Preliminary results

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Keywords: Human exposure, field study, concentration increment, VOCs, microbes

“Personal cloud” is defined as the concentration difference of air pollutants in breathing zone relative to room-average levels. The personal cloud of air pollutants is commonly encountered in indoor environments where the air is not well-mixed. Yet, investigations on the nature and significance of the human personal clouds remain scarce. This study aims to quantify the magnitude of personal air pollutant cloud in an office environment and to probe the relative importance of several personal and environmental factors.

In a three-person naturally ventilated office, we measured the personal clouds of CO$_2$, volatile organic compounds (VOCs), ozone, total particles (10 nm – 10 μm), fluorescent biological aerosol particles (FBAPs) and airborne microbes. The field experiment ran continuously for two weeks: 1) “standard office work without manipulation” and 2) “manipulation week”. The first-week measurement aimed to investigate daily nature of personal cloud and the potential disparities among occupants. We measured 0.3-10 μm particles, VOCs, CO$_2$ and airborne microbes at the breathing ozone of the three occupants, as well as at four stationary locations in the office so as to quantify the personal clouds. Additional measurements were taken in the breathing zone of Occupant #1 and at one stationary site, where we monitored concentration differences of FBAPs, ultrafine particles (10-100 nm) and ozone. The objective of the second (“manipulation”) week was to examine the influence of application of personal care product and hand sanitizer, cooking activities during the lunch break, clothing worn over extended period, office occupancy density and distance from other occupants. Here, personal cloud was characterized for the Occupant #1 only. During the experimental period, outdoor concentrations of the target air pollutants were also recorded. Additionally, occupants’ activities were recorded using daily questionnaire and on-site occupancy sensors.

The preliminary results have shown that the VOC personal cloud magnitude can range within 100-1000 μg/m$^3$, depending on specific compounds and occupants. The ongoing data analyses are expected to reveal the magnitude of human personal clouds of diverse air pollutants in the office environment, and to quantify the relative importance of factors contributing to the personal clouds. The results are valuable for refined characterization and enhanced control of personal exposure to air pollutants.

* Extended abstract for Paper 5.3 is available at the end of this book.

Paper 5.4*: Experimental & Modelling Studies for the Determination of Pollutant Emissions from Cooking and Cleaning

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Keywords: Cooking, Cleaning, Experimental, Modelling, Pollutant, Emissions

In developed countries, we spend approximately 90% of our time indoors, and a significant fraction of this time within our homes. Consequently, exposure to air pollutants typically happens almost exclusively indoors, even for pollutants generated outdoors, which ingress via windows, doors and cracks in buildings. Occupant activities such as cooking and cleaning produce high pollutant concentrations, with concomitant impacts on human health including respiratory and cardiovascular diseases.

The IMPeCCABLE project aims to enhance our knowledge of the impact of cooking and cleaning on indoor air quality through a combination of experimental and modelling studies. Research into pollutant emissions from cooking and cleaning activities indoors, and the subsequent chemistry that occurs following these emissions, will enable the identification of strategies to remediate against high indoor air pollutant concentrations, leading to improved building design and management and enhanced indoor air quality.

Although measurements of cooking and cleaning emissions exist, they tend to focus on a few emission rates, rather than studying a wide range of emitted species and the chemistry that follows from the emissions. The IMPeCCABLE project adopts a holistic approach with combined experiments and modelling studies over a range of spatial scales, to understand the resulting IAQ when we cook and clean indoors at the process level.

We will present findings from multiple experiments, focussed on measuring emission profiles during cooking and cleaning activities of varying complexity. Online measurements of volatile organic compounds (VOCs) and particulate matter (PM) were obtained using selected ion flow tube mass spectrometry (SIFT-MS) and optical particle counter (OPC), respectively, during cooking and cleaning activities performed within kitchen spaces. These measurements were supplemented by offline gas chromatography mass spectrometry (GC-MS) of air samples, as well cleaning product formulation headspace. Cooking experiments included the frying and toasting of spices, frying meat, toasting bread and cooking full meals. Cleaning experiments were focussed on measuring emissions from the use of a range of cleaning products, including those which are marketed as green products.

The pollutant emission profiles obtained from these experiments will feed in to the INCHEM-Py model, which will permit greater insight into the chemistry occurring, particularly around radical chemistry and secondary pollutant formation and estimated
Paper 5.5: Characterization of PM2.5 and its Indoor-Outdoor Ratio in an Office Building Connected to a Chemical Production Plant in Gebeng Industrial Zone, Pahang Malaysia

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Keywords: PM2.5, PAHs, Elemental, Indoor/Outdoor Ratio, Indoor Air

PM2.5 is a dominant pollutant in indoor air, also a carrier for many toxic compounds. This study aims to characterize PM2.5 in terms of mass concentration, polycyclic aromatic hydrocarbons (PAHs) and elementals concentrations bound to PM2.5, and to determine indoor and outdoor (I/O) ratio of PM2.5 in the office which is connected to the chemical production plant. The samples were taken for every 8 hours during working days at five sampling points such as outdoor environment (one location), the production plant (one location), and indoor office (three location) via a hand-held dust detector instrument. The filters attached to the instrument were then analysed by using Inductively Coupled Plasma-Mass Spectrometry and Gas Chromatography-Flame Ionization Detector to determine the elementals and PAHs bound to PM2.5, respectively. The results indicated that the mass concentrations of PM2.5 (4.72±1.89 µg/m³ - 55.1±12.29 µg/m³) and PAHs (acenaphthylene (0.0001-0.0002ppm), phenanthrene (0.0001 - 0.0002pppm), fluoranthene (0.0001ppm), pyrene (0.0001ppm), benzo(a)anthracene (0.0002 - 0.0004ppm), chrysene (0.0001 - 0.0002pppm), benzo(a)fluoranthene (0.0001 - 0.0002ppm) and benzo(a)pyrene (0.0001 - 0.0002ppm)) were below the recommended values of World Health Organisation. The elementals such as Ba (0.804±0.302 ppm – 3.246±0.092 ppm), Al (0.121±0.002 ppm – 3.45±0.102 ppm), Ga (0.029±0.001 ppm – 0.112±0.023 ppm), Se (0.002±0.001 ppm – 0.003±0.017 ppm), Co (0.002±0.001 ppm – 0.0095±0.002 ppm) were complied with the permissible exposure limit (PEL) of The Occupational Safety and Health (Use and Standards of Exposure of Chemicals Hazardous to Health) Regulations 2000 (USECHH Regulations 2000). However, Si (5.362±0.2012 ppm – 25.1±5.012 ppm) was found to be the most abundant element and noncompliant with the PEL. The I/O relationship revealed that the source of PM2.5 and elementals are mainly contributed by the outdoor sources. In contrast, the source of PAHs is solely modulated by sources within the building. In conclusion, high concentration of Si found in the office indicated serious indoor air pollution and may contribute to the potential health risks for the workers.

Paper 5.6: Phytoremediation of Airborne Particulate Matter in Indoor Environments

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Keywords: Air pollution, Indoor plants, Buildings, Particles, Deposition velocity

This research is motivated by the urgent need to protect people from the adverse health effects of PM2.5 (particles smaller than 2.5 µm in size) exposure by using potted plants as air filters in indoor environments. We quantified the ability of three different plant species for removing airborne particles by conducting experiments in an environment-controlled chamber. The plants selected were Christmas plant (Araucaria heterophylla, a needle-leaved plant), Ficus plant (Ficus retusa, a small-leaved plant), and Croton plant (Codiaeum variegatum, a broad-leaved plant). The particle deposition velocities ranged from (32.4±10.6 to 41.0±10.8) cm/h for the Christmas plant, (0.6±1.6 to 2.53±3.27) cm/h for the Ficus plant, and (−0.09±3.8 to 6.07±6.28) cm/h for the Croton plant, depending on the particle size. On extrapolating those results to a small residential room, we found that 35–44 Christmas plants (the most effective species) would be required for reducing the steady-state PM2.5 concentration by 10% at an air exchange rate of 0.5 h⁻¹.

Paper 5.7*: How Does Indoor Air Chemistry Affect Outdoor Air Pollution?

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Keywords: Indoor air modelling, indoor-outdoor air exchange, VOCs, indoor air chemistry

Most air pollutant exposure happens indoors, particularly in our homes. Activities such as cooking and cleaning can be a large source of indoor air pollutants, with some emitted species further reacting to form secondary pollutants. Some indoor air pollutants are potentially harmful to health. Recent evidence also suggests that air pollutants released indoors can significantly
improving outdoor air quality. This paper uses a detailed indoor air chemistry model to estimate the impact of indoor activities such as cooking and cleaning on outdoor air quality. We show that cooking and cleaning can enhance indoor air pollutant concentrations by a factor of 200 and provide a source of air pollutants to outdoors of a few ppb per hour. Our results suggest that as outdoor air quality improves such as through electrification of the vehicle fleet, such indoor activities will need to be considered for their impacts on outdoor as well as indoor air quality.

* Extended abstract for Paper 5.7 is available at the end of this book.

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**Paper 5.8: Green Plant Walls as an Indoor Air Quality Enhancer in a Recently Built Office Building**

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*Keywords:* chemical pollution, physical pollution, living green wall, biofilter

Objectives. Nowadays one of the main focus of public and occupation health is maintain good indoor air quality in office building and public spaces. The aim of this study was to identify indoor air quality, its influencing factors, sources of pollution and air quality enhancers.

Materials and Methods. The data were obtained from recently built and furnished office. The office building was chosen because of worker complains about poor air quality. The quantitative measurements were performed on 2 floors – the control floor (without green plant walls) and test floor. Measured air parameters was temperature, humidity, CO₂ levels, chemical pollutants, the number of dust particles, also office workers filled out health and air quality questioners. The data were collected in in two measurement phases, before and after living green wall adaptation period. Data was analysed using IBM SPSS Statistic 26.0.

Results. The results indicate that indoor air quality does not exceed the permissible levels for office buildings based on found chemical pollutants and CO₂ readings. Identified sources of chemical pollutants were: printers with tonner, personal cosmetic products of workers, hand disinfectant and office cleaning products. Measurements indicated well ventilated rooms. However, the control floor showed lower air humidity levels. Results shows up to 22% air humidity boost from plant green walls on weekends and up to 20% boost on work days.

Conclusion. The green walls with living plants help maintain good humidity levels, but not enough due to high air flow from ventilation systems. To optimize the air quality in offices, it is recommended to make adjustments for the ventilation system to maintain 800 ppm CO₂ instead of 500 – 600 ppm, or instal recuperation system with moisturising module. This ensures both a good CO₂ and higher humidity concentration, as the humidity would not be removed so intensively. Emissions are effectively removed from the potential emission sources of chemical pollution, thus reducing ventilation system capacity would not increase chemical pollution, as it is significantly below the recommended values by WHO issued standards. The low levels of VOC, aldehydes and CO₂ concentrations show good ventilation system’s efficiency, but lack of air humidity regulation without build-in humidifier system of green plant walls installation in the office premises.

Acknowledgments: This study was supported by Rigas Stradiņš University Vertical integrated projects (VIP) and KoTuElpo Ltd (plant green walls producer).

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**Paper 5.9*: Characterising multi-sensor platforms performance to investigate indoor air quality events, and quantify personal exposure**

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*Keywords:* electronic gas sensors, personal exposure, pollution fingerprints

In the area of Indoor Air Quality assessment and personal exposure, the use of gas and particulate multi-sensor systems has become commonplace. Nevertheless, most of the studies focus on particles and CO₂ sensor measurements. Regarding Volatile Organic Compounds, experiments are often limited to a rough evaluation of total VOCs, without even ensuring the ability of the sensors used to exhaustively quantify this parameter. Given their strong impact on health it is however essential to have tools capable to distinguish the diversity of VOCs sources in indoor air. In this study, the metrological performances of 40 replicas of 2 types of VOC sensors: 4 MOX (Figaro, Cambridge CMOS Sensors, SGX Sensortech) and 1 electrochemical (I sense), are evaluated under controlled conditions. They are exposed to 5 VOCs representative of indoor environments (formaldehyde, acetaldehyde, acetone, ethanol, limonene and their mixture) in a 1:1 scale experimental room based on their prevalence and their hazardoustness summarized in guidelines. The correlation curves are established by comparison with the responses of a Selected-Ion Flow-Tube mass spectrometer (SIFT-MS). The results show that the electrochemical sensor, supposed to be dedicated to total VOCs, is acetone-blind and underestimates by a factor of 3 the real quantity of VOCs present, while MOX 1/ require pre-processing of the data to estimate reproducibility, 2/ have differentiated sensitivities by type of VOC, but without homogeneity by family of VOCs, 3/ have non-linear responses depending on the concentration ranges, 4/ can be combined with advanced
statistic tools to establish a specific pollutant footprint of the VOCs considered. These results will help to interpret the data from the Qalipso campaign, during which these sensors were deployed for 4 months in 40 households in Douai city in Northern France. The purpose of the Qalipso project is to evaluate changes in citizens’ behavior towards their exposure to indoor air pollution.

* **Extended abstract** for Paper 5.9 is available at the end of this book.
Session 6: Ventilation and IEQ in healthcare facilities

Paper 6.1: **Thermal comfort in hospital isolation room – A laboratory study**

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**Keywords:** Hospital isolation room, a laboratory study, thermal comfort, air movement, perception

Ventilation and air distribution are important in hospital environments, especially in isolation rooms, where they have an essential role in protecting healthcare workers e.g. from patient-exhaled contaminants. In optimal case the supply air distribution should be able to mix and dilute the air close to the source (patient). However, this is not always the case with traditional mixing ventilation systems.

Previous studies have shown that local downward ventilation above the patient’s bed is effective in reducing the healthcare workers exposure close to the patient. However, it is very challenging to provide thermally comfortable downward ventilation towards patient with low activity level. There is a need to gain more information of the perception regarding thermal environment while lying in patient bed in isolation room having downward ventilation.

The aim of this study is to examine perceived thermal comfort, air movement, symptoms, such as eye-irritation and headache, and measured heart rate-based activity level of persons lying in patient bed in hospital isolation room.

The experiments were done in autumn 2020 in Turku University of Applied Sciences’ (TUAS) HVAC laboratory, where a climate chamber representing a full-scale hospital isolation room was built. 8 volunteers (7 male and 1 female) participated in two different ventilation conditions (1 hour per condition, Troom=23 °C): 1) baseline overhead mixing ventilation and 2) local downward ventilation over the patient bed with background mixing ventilation. All volunteers wore a standard hospital clothing and laid in hospital bed during the whole session. They answered several times in questionnaire regarding thermal comfort, symptoms and perception of air movement. Participants’ heart rate was monitored and activity level was calculated according to standard EN ISO 8996 (2004).

Tentative results show that there were differences in the perceived thermal environment between the test conditions. There were discrepancies in the perceived air movement between the test conditions. Also measured activity levels appeared to vary notably. Detailed analysis will be provided in the conference paper.

This study is part of dECOnhealth (Demand Controlled Ventilation in Healthcare Settings) project. The objective of the project is to develop feasible demand controlled ventilation methods and control strategies for hospital environment without compromising staff, patient and visitor safety and health.

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Paper 6.2*: **Experimental investigation of the local air exchange behind an obstacle in laminar flow**

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**Keywords:** laminar displacement flow, ventilation effectiveness, obstacle, wake area

This study presents two methods to study the wake area of a round plate (Ø=400 mm) in a cleanroom. First, visualizations were conducted, in which the air in the wake area behind the plate was made visible by theatre fog. Second, the local air exchange was studied by comparing the mean aerosol concentration below the plate and the decay time for varying velocities of the air supply.

The particles' decay times below the plate decrease with increasing air flow velocity.

* Extended abstract for Paper 6.2 is available at the end of this book.

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Paper 6.3: **Experimental study on the thermal plume from a surgeon in an operating room with mixing ventilation during COVID-19 pandemic**

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**Keywords:** Negative pressure, Thermal plume, Operating room

In 2003 there were severe cases of SARS (SARS-CoV), after this outbreak, few researched the possibility of negative pressure operating rooms by using CFD simulation. Outside the OR, a reduction in the circulation of the virus is best achieved with a negative pressure environment inside the OR. Following the outbreak of COVID-19 in 2019 studies on how to best prepare for
and perform surgery on infectious patients have been conducted, conclusions were made with good results in protecting the surgical staff from patients infected by COVID-19 in operating rooms with negative pressure. However, it is unclear whether the surgeon’s thermal plume can have an impact on the transport of contaminants up to the breathing zone and thus cause infection. The aim of this study is to quantify the thermal plume in front of the main surgeon in an operating room with mixing ventilation under different pressures. The measurements of the thermal plume will be performed in a full-scale operating room laboratory, which has an area of approximately 61 m², with a mixing ventilation system and for three different cases: positive pressure of 20 and 10 Pa, and negative pressure of -5 Pa. Measurements results will show if the pressure inside the operating room has an impact on the thermal plume and airflow distribution in front of the main surgeon. The knowledge from this study can help to consequently prevent the spread of particles to exposed areas, and also reduce the risk of adverse side effects for the medical team from surgical patients with infectious disease.

**Paper 6.4: Experimental study on the surgical microenvironment in an operating room with mixing ventilation under positive and negative pressure**

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**Keywords:** Negative pressure; Operating room; Airflow distribution; Surgical microenvironment.

Due to the outbreak of Covid-19, negative pressure operating room (NPOR) are strongly recommended to be applied to prevent spreading virus from infected patients to adjacent rooms during surgery procedures. However, there have been few experimental studies on the effect of OR pressure difference on the surgical microenvironment. This study aims to experimentally investigate the airflow distribution in the surgical microenvironment in an OR under different pressure conditions. All measurements were performed in a full-scale laboratory, which has an area of 62 m², and a mixing ventilation. The air velocity and temperature in the surgical microenvironment of a lying patient were measured under positive pressure of 5 Pa, 10 Pa, 15 Pa and negative pressure of -5 Pa, -10 Pa and -15 Pa. The effect of heat generated by operating lamps was also considered. The results show that the airflow distribution around the surgical wound is dominated by thermal plume from the patient under the condition of both positive and negative pressure. In other areas of the surgical microenvironment, regardless the pressure difference conditions, the room airflow distribution by ventilation system is the dominant factor on surgical microenvironment. Variations in differential pressure can affect the temperature distribution around the surgical site, with a smaller differential pressure producing a slightly larger vertical temperature gradient.

**Paper 6.5: Performance assessment and clinical validation of Operating Room ventilation systems**

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**Keywords:** Performance Assessment, OR ventilation systems, microbiological air burden, infection control

**BACKGROUND:** To date there still is substantial discussion in the scientific community which ventilation system provides the most effective and economical respectively efficient control of microbial risk factors during surgery. This is especially important as most standards do not require a performance assessment of the operating room (OR) ventilation, but rather rely on tests “at rest” in empty room. This might be an explanation for the conflicting results regarding infection preventive effects of different OR ventilation systems as well as the ambiguous data for infection rates.

**AIMS:** Thus, we aimed to evaluate how different widely used qualification techniques as well as several operational parameters impact OR ventilation performance assessment. We specifically studied the desired effect of reducing microbiological air burden and infection rates under routine clinical conditions. Therefore, we evaluated the performance of a temperature controlled ventilation system (TcAF) during surgery and its impact on surgical site infections.

**RESULTS:** Clothing, workflow, setup/positioning, staff behaviour and measurement technique (particle versus active and passive cfu measurement) showed to have significant impact on the performance assessment of OR ventilation systems. Nevertheless, most international standards only measure at rest situations during system assessment and thus do not take these critical parameters into account. We could also show that therefore active air sampling is to be preferred. TcAF showed to reliably and robustly provide "ultra-clean" air (<10 CFU / m³) in the entire operating room demonstrating its capability to reduce the risk of airborne microbial transmission during surgery. In a further retrospective analysis of 1000 consecutive patients undergoing total joint replacement (hip, knee) in an operating room with a TcAF system compared to 1000 consecutive cases in an operating room with mixing ventilation showed that TcAF was associated with a decrease in mean postoperative hospital stay, a decrease in percentage of hospital length of stay, and a decrease of infectious complications from 3% to 1%.

**CONCLUSIONS:** Our results show that performance testing is essential for a proper assessment of OR ventilation systems. Moreover, we demonstrated that TcAF systems are able to reliably and robustly ensure "ultra-clean" air (<10 CFU / m³) in the entire operating room demonstrating its capability to reduce the risk of airborne microbial transmission during surgery.
The retrospective analysis of clinical patient data shows positive impact of TcAF on key clinical outcome parameters in line with previous research by Charnley and Lidwell.

**Paper 6.6: Visualizing bacteria-carrying particles in the operating room: exposing invisible risks**

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**Keywords:** Virtual reality, Ventilation systems, Bacteria-carrying particles, Surgical site infections

Surgical site infections occur due to contamination of the wound area by bacteria-carrying particles during the surgery. There are many surgery preparation conditions that might block the path of clean air in the operating room, consequently increasing the contamination level at the surgical zone. The main goal of the current study is to translate this knowledge into a perceivable tool for the medical staff by applying state-of-the-art simulation and visualization techniques. In this work, the results of numerical simulations are used to inform visualization. These results predict the airflow fields in the operating rooms equipped with mixing, laminar airflow and temperature-controlled airflow ventilation systems. In this regard, the visualization uses a virtual reality interface to translate the computational fluid dynamics simulations into usable animations. The results of this study help the surgical and technical staff to update their procedures by using the provided virtual tools.

**Paper 6.7: Thermal comfort level of patients and surgical staff in operating rooms at a Nordic hospital**

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**Keywords:** thermal comfort, hospital, surgical staff, observation, survey, ventilation

In healthcare facilities and hospital environment, it is essential to enable thermal comfort for occupants. Unstable thermal conditions in the operating room (OR) will influence the performance of surgical staff and the infection possibility of patients. In this study, the thermal comfort of patients and surgical staff was measured with two ventilation solutions at St. Olavs hospital ORs in Trondheim, Norway. Research methods include thermal environment measurements during mock (imitation) surgery, a survey among surgical staff, and observation during a real operation. The results show that the mean air velocity near occupants in mixing ventilation (MV) OR was low (max 0.08 m/s) and in laminar airflow (LAF) ventilation OR considerably higher, 0.36 m/s. In conclusion, there was good general thermal comfort of surgical staff in LAF OR, but the surgical staff felt mainly uncomfortable in MV OR.
Session 7: Moisture in buildings

Paper 7.1: Moisture-dependent insects (Silverfish species and Psocid species [Psocoptera]) in modern buildings - A sign of hidden moisture and mould damage

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Keywords: mould, insects, IAQ

Through the last 10 years, it has been an increasing occurrence and activity of moisture sensitive insects in modern buildings. Grey silverfish (Ctenolepsis longicaudata) is the most common species, but it is also an increasing number of cases of silverfish (Lepisma saccharina). Furthermore, aphid species (Psocoptera) such as booklice, which is well-known for feeding on mould fungi is commonly found in modern buildings in frequency and number that is not found in older buildings. The populations of these insects also survive for several years in the modern buildings. This shows both that there are microclimatically humid construction details where they have suitable hot-spots and access to suitable food. The humidity is due to residual building moisture and the moisture levels in such places are so high that there is a basis for growth for several species, such as Aspergillus peniciloides and A. versicolor. It is known that both mould spores and insect excrement can be allergenic. Thus, does the occurrence of these insects represent an obvious risk for a negative indoor climate exposure.

The paper describes the findings from more than 600 examined modern buildings with insects and of those 60 cases of mould samples.

Paper 7.2*: The indoor mycobiome in Norwegian daycares revealed by DNA high throughput sequencing

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Keywords: Mycobiome, fungi, DNA, dust, metabarcoding

Fungi can grow in the indoor environment and act as a source of indoor pollutants leading to poor indoor air quality. This can lead to adverse health effects, such as allergies, asthma and other respiratory symptoms. Studies performed in other parts of the world have analyzed the main determinants and important factors influencing the indoor mycobiome, include building type, geography, ventilation and outdoor air influence. The aim of this study is therefore to improve the knowledge about the indoor mycobiome in Northern Europe by using a high throughput DNA sequencing (HTS) approach. By analyzing dust samples, the indoor mycobiomes were characterized at different spatiotemporal scales; within buildings, across buildings at larger geographical scales, as well as throughout different seasons. A large-scale citizen science sampling of 128 daycares distributed throughout Norway was performed. In addition, two daycares in Oslo were monitored throughout a year by biweekly sampling at four different floors and rooms. The results showed that climate, seasonality, and occupants (number of people present in the kindergardens) are important factors structuring the indoor mycobiome. Thus, temporal variability through the seasons should be accounted for in indoor mycobiome studies and in the evaluation of indoor air quality of buildings.

* Extended abstract for Paper 7.2 is available at the end of this book.

Paper 7.3*: Fungal growth on newly cast concrete floors and moisture membranes

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Keywords: Aspergillus, floor heating, moisture measurement, mould, newly cast concrete

The Danish Technological Institute has during several surveys in new buildings, experienced widespread fungal growth on newly cast concrete floors, with a moisture barrier and floating flooring. Existing recommendations require that the relative humidity (RH) of air in equilibrium with the concrete, measured in the middle of the concrete floor, should not exceed 85-90% prior to mounting the top floors. However, surveys have shown that fungal growth can establish if the RH of the air between the concrete floor and the moisture membrane exceeds 75%. The present case study demonstrates that fungi can grow on newly cast concrete and on the moisture membrane if the RH at the surface is above 75%. The study finds that there is a need to revise existing guidelines for acceptable moisture content in the concrete before mounting the top floor, and maybe even change the way of constructing floors.
Paper 7.4: **Implementation of MALDI-TOF mass spectrometry to identify moulds from the indoor environment as an added value to the classical microscopic identification tool**

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1 Sciensano, Belgium; 2 Brussels Environment, Belgium

**Keywords:** MALDI-TOF MS, Identification, Moulds, Yeasts, Indoor environment

**BACKGROUND:** The quality of indoor air has become a subject of great interest. Biological pollutants such as moulds however can affect this air quality and can cause adverse health effects. The genera Aspergillus, Cladosporium, Penicillium, Alternaria and yeasts are the most common fungi found indoor. Certain species of these genera are able to cause specific allergic or toxic reactions. Therefore it is necessary to seek for fast and accurate tools, enabling an identification to the species level in order to guide general practitioners in their diagnosis and treatment.

**AIMS & KEY PROBLEMS:** Currently, identification of moulds found in the indoor environment is performed by microscopy. This method has, however, some limitations as it needs mycologists with high expertise while identification is often limited to the genus level. In order to increase the specificity and accuracy of the identifications, matrix-assisted laser desorption/ionization time-of-flight mass spectrometry (MALDI-TOF MS) can be an alternative, offering the advantage of being fast and cost-effective. The added-value of MALDI-TOF MS will be compared with the currently used technique of microscopy. In addition, MALDI-TOF MS will also validate the accuracy of microscopic identifications.

**METHODS:** In collaboration with Brussels Environment RCIB/CRPI (Regional Intervention Cell for Indoor Pollution), Sciensano’s (Brussels, Belgium) Indoor Mycology unit performs measurements of fungal contaminations in Brussels dwellings in order to assess a link between a potential indoor air pollution and people’s health problems.

A total of 112 isolates were collected on specific culture medium. After incubation, microscopic identifications were performed. Results obtained with MALDI-TOF MS were compared with data available in an in-house created reference database containing over 1700 strains of the BCCM/IHEM fungal collection (https://msi.happy-dev.fr/login/).

**MAIN RESULTS:** Microscopic analysis only allowed identification to the genus level for more than half of the isolates analysed (68/112) while only 38 isolates could be identified to the species (complex) level. In contrast, MALDI-TOF MS resulted in a more precise identification in comparison to microscopic analysis for 106 isolates (95%), allowing identification to the species level for 101 isolates (with a log score > 2.0). In addition, analysis by MALDI-TOF MS indicated 6 wrong microscopic identifications to the species complex level and 5 to the genus level.

**CONCLUSION:** MALDI-TOF MS can be a highly added value to the standard microscopic analysis in routine practice aiming to identify moulds from dwellings.

Paper 7.5: **Xerophilic fungi in museum repositories challenge our perception of healthy buildings and the preservation of cultural heritage**

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**Keywords:** Xerophilic fungi, indoor environment, cultural heritage, museum, climate changes

**BACKGROUND:** In the last decade, fungal infestations have become an increasing problem in heritage collections in museums, galleries and archives even if RH is controlled according to the environmental guidelines for the preservation of cultural heritage. The infestations have been reported in parallel to climate change.

Fungal infestations have devastating consequences. Fungal growth deteriorates materials and threatens the preservation of heritage artefacts as well as the health of staff and visitors. Therefore, controlling the environmental conditions to avoid fungal growth is of high importance.

The increasing awareness of the human contribution to CO₂ emissions has led to a revision of the environmental guidelines for heritage collections. The recommendations have changed from strictly controlled setpoint value's RH 50±5% to an acceptance of fluctuations from RH 40–60%. Since the borderline of fungal growth is defined to 70%, it should not pose a risk. The revised guidelines allow more sustainable storage of heritage collections by reducing energy consumption; however, the indoor environment's consequences are not well researched.

**AIM:** This study examined surface and airborne fungal species in five Danish museum repositories. The aim is to enlighten why unexpected fungal infestations occur in climate-controlled museums repositories, complying with the environmental guidelines of heritage buildings.

**MATERIALS & METHODS:** The indoor fungal composition was examined with air sampling by MAS-100-ECO on V8, DG18, and MY50G agar and surface sampling from museum artefacts cultivated on V8, DG18 and MY50G agar. Isolates from the museum artefacts were identified to species level by DNA sequencing after amplification with PCR and Calmodulin primers

* Extended abstract for Paper 7.3 is available at the end of this book.
(cdm5/cdm6) to obtain good phylogenetic separation of the species. A single isolate gave no PCR product with cdm5/cdm6, and ITS was used.

RESULTS: The morphological ID of air samples showed the presence of fungal species corresponding to classical indoor fungi. DNA sequencing from growth on museum artefacts showed 100 % identity with A. halophilicus, A. domesticus, A. vitricola and A. magnivesiculatus, species from Aspergillus section Restricti comprising xerophilic fungi able to grow on substrates with low aw. Monitoring of the indoor environment showed RH within the standards for buildings storing heritage collections.

PERSPECTIVES: The growth of xerophilic fungi in climate-controlled heritage buildings challenge the preservation of heritage collections, occupational health, and perception of healthy buildings, and may be associated with the revised environmental guidelines, the global climate changes, or both.

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**Paper 7.6**: Seasonal Distribution of Alternaria, Aspergillus, Cladosporium and Penicillium Genera Isolated from Estonian straw-bale and reed-bale dwellings

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**Keywords**: indoor air, mould, propagules, straw-bale, reed-bale

People spend most of their time in indoor environments and are exposed to indoor pollutants. Most people’s indoor time is spent asleep and indoor air pollutants, such as moulds are affecting health and sleep quality as well. Mould species are more frequently cultured in damp indoor environments and they can potentially release mycotoxin, allergens, and unpleasant smells to air.

Different sustainable standards promote the use of bio-based products like straw and reed, but these materials are extra sensitive to mould growth - they can easily be degraded by fungi. The aim of this study was to evaluate the presence of moulds in indoor air in the bedrooms of reed-bale and straw-bale residential dwellings in Estonia.

Samples were taken from 8 different dwellings. Occupants were asked not to ventilate the bedrooms prior to measurements. Sampling was performed with two Microbio MB2 samplers working at the same time. Malt Extract Agar (MEA) was used as sampling media. Four parallel samples were collected from each bedroom. The corresponding outdoor air samples were collected as reference. Samples were incubated, stained, and identified.

Four major genera (Alternaria, Aspergillus, Cladosporium, and Penicillium) were identified. The dependence of the results on the season was found, colony-forming unit dynamics in the bedrooms were similar. Differences occurred in the number of colony-forming units. The mould community was least abundant in winter and most abundant in summer. Similar levels occurred in spring and autumn.

*Extended abstract* for Paper 7.6 is available at the end of this book.
Session 8: Thermal comfort

Paper 8.1: Provision of thermal comfort via user-centric radiant cooling elements: An experimental investigation

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Keywords: Radiant cooling, laboratory study, thermal comfort, condensation risk

This contribution explores the performance of a user-centric radiant cooling approach. In comparison to conventional radiant cooling solutions, this approach i) positions radiant panels in close proximity to occupants, and ii) allows for panel surfaces temperatures below dew point and thus for potential surface condensation, which is dealt with via integrated water collection devices. The user-centric radiant panels were tested in a laboratory setting. Prototypical panels were installed in two mock-up office rooms. Twenty-eight participants evaluated thermal comfort (including radiant asymmetry and local thermal discomfort) for eight scenarios, including multiple panel surface temperatures as well as different ambient air temperatures. The results provide insights into the potential and limits of the proposed approach. Specifically, the findings pertain to panel surface temperatures, which are necessary to provide thermally comfortable conditions, as well as to surface condensation and radiant asymmetry.

Paper 8.2: Verification of Thermal Comfort of Combined Convection-Radiation Air Conditioning System using Building Structure

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Keywords: Thermal mass storage, Subject experiment, Radiation, Thermal comfort

Air conditioning systems have been required to achieve both energy-saving performance and occupants' comfort. To satisfy this requirement, we have developed an air conditioning system that uses both TABS (Thermal Activated Building System) and airflow to promote heat transfer. The system is called 'Combined Convection-Radiation Air Conditioning System'. Experiments were carried out for the purpose of verifying the thermal comfort of this system, and are reported in the following.

This air conditioning system is being introduced in buildings whose structure is formed by concrete slabs and beams. The ceiling surface is a concrete slab, and water pipes and radiation fins are in contact with the ceiling surface. Additionally, fans which generate airflow on the ceiling surface are installed beneath the slabs. The jet from the fans blows toward the ceiling. Then the air flows along the fins and the bottom surface of the slabs, reaches the sides of the beams, and subsequently descends to the living area. The system aims to create a thermal environment suitable for human metabolism by using the air-flow in the living area. By not burying the piping, the system reduces building frame weight and improves response to heat load fluctuation.

The purpose of the experiments is to verify whether comfort can be maintained in a 27°C temperature environment with a view to energy-saving. Subjects were exposed to thermal environments with different fan operating conditions while imposing tasks with different metabolic rates. The subjects were then asked to give their votes as regards thermal comfort and thermal sensation, and were also measured of their physiological data. Thermal comfort was evaluated from these votes, and the relation of physiological data.

Despite the hot conditions indicated by the comfort index such as PMV, more than 60% reported "comfort" that includes three stages (large to slight) of comfort, and less than 5% reported "discomfort" side. On the thermal sensation vote, there were many replies on the cool side. It was conjectured that the airflow and radiant environment generated in the living area caused cool feeling.

It was thus confirmed that this air conditioning system can form a good thermal environment by combining a TABS with a low velocity air-flow generated in the living area, and that comfort can also be maintained. It is considered that this paper can provide useful data for a control method adjusted to change of metabolic rate.

Paper 8.3: Evaluation of Personalized Thermal Conditioning Chair in Net Zero Energy Building Office

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Keywords: Personalized air-conditioning, ZEB, VRF

The net Zero Energy Building (ZEB) aims at promoting productive activities with highly occupant’s satisfaction and minimum energy input. Personal air-conditioning is the technology that contributes to ZEB.
In this paper, we show the effects of improving occupant’s satisfaction by personalized thermal conditioning chair (TCC). We describe as follows.

(i) We show some features of the TCC. It has 2-modes which are blowing mode and heating mode. Users can control their own thermal environment according to themselves senses. Users can carry it everywhere in their office because its power source is Li battery. It can send the data by Bluetooth. Thermal environment of whole of room and air-conditioning power can be optimized by feedbacking the TCC’s data.

(ii) The TCC is able to change equivalent temperature \(-0.7 \sim 1.2 \, ^\circ \text{C}\). It is examined by thermal manikin’s test. This effect was measured only sensible heat transfer. Adding latent heat transfer, the cooling effect would be 2 \sim 3 times (-1.4 \sim -2.1 \, ^\circ \text{C}). Because the TCC can promote evaporating user’s sweat due to improving convection around user’s body.

(iii) Users controlled the TCC according to their thermal senses. It has been installed at the office which is achieved net Zero Energy Building in design phase and operational phase. Users chose the blowing mode mainly in summer and heating mode in winter according to seasons. Exceptionally, the TCC was used under blowing mode in winter according to increasing metabolic rate of users. This shows that users control the TCC autonomously.

(iv) The TCC was controlled to keep user’s preference thermal environment. Each user’s around temperature under operating the TCC is different from each other. Because their preference thermal environment is different from each other. Users are able to keep their own thermal environment comfortable by operating the TCC.

(v) The thermal sensation votes of users converged to “neutral”. It shows that the user has felt comfortable due to their ability of controlling own thermal environment has improved.

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**Paper 8.4: Electroencephalography associated with thermal discomfort induced by temperature upward ramping**

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**Keywords:** Thermal comfort, EEG, temperature ramping, relative power

This experiment examines the EEG patterns according to the thermal discomfort of the occupants with gradual temperature increasing from comfortable to uncomfortable thermal environment by identifying the moment of participants perceiving “hot” or “uncomfortable” and measuring the changes in EEG at that moment.

Total 72 men and women in their 20s and 30s participated in a chamber experiment. For comparing the EEG in a comfortable environment with that of the moment of changing to an uncomfortable environment, the indoor environment was maintained at the air temperature of 25°C and the relative humidity of 50% for 10 minutes after the start of the experiment. After that, the temperature and humidity were gradually changed so that participants could experience from a comfortable environment to a very uncomfortable environment. At the end of the experiment, the set value of the air temperature was 32°C and the relative humidity was 65%.

We asked subject’s thermal sensation and thermal comfort to measure participants’ psychological response with regard to the gradual upward ramping. Participants, while staying in the climate chamber, pressed the voting button when they perceived hot or cold, and responded to the questionnaire about thermal comfort at that time. And then, they should respond to the questionnaire at any time when the thermal sensation or thermal comfort changed, so the gradual change in psychological responses was examined.

As a result of the temperature increasing, the participants felt uncomfortable and the relative power value of all frequency bands gradually increased. As a result of correlation analysis of individual thermal comfort change and relative power change, the alpha power at Cz, C3, the beta power at Fz, Cz, and C4 and the gamma power at C4 increased. This indicates that unlike the clear change in the specific points and frequency of EEG in case of thermal displeasure experience (Son 2019), EEG increased at all frequency bands.

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**Paper 8.5: Thermal comfort and skin temperature of adolescents compared to young adults**

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**Keywords:** Thermal comfort, skin temperature, adolescent

This study examined thermal comfort and skin temperature of adolescents and young adults to analyze the individual difference in their thermal responses. In a climate chamber with increasing temperature, skin temperature was measured at seven body parts with survey responses. As a result, the indoor environment, thermal comfort, and skin temperature have significant correlations, and there were differences between adolescents and adults in their responses. The neutral temperature of adolescents was slightly lower than that of adults. Generally, adolescents have a higher mean skin temperature than adults, and the hand skin temperature of the adult male group changed much sensitively than others. The difference in thermal comfort and related skin temperature implies the need for investigating adolescents as a separate group from adults for accurate thermal comfort prediction. The results are expected to be used for optimal environmental setting for adolescents.
Paper 8.6: **Association between physiological signal from wearable device and alertness of office workers**

**LEE, Yoonhee**, CHUN, Chungyoon

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Through physiological signals, detecting the changes of occupants’ physical and psychological aspects is possible, and wearable devices have enabled measurement in daily life. In this study, to see whether the wearable device could be used for interpreting the state of the office workers, a field experiment was conducted. A wearable device was applied for monitoring the occupant, and productivity responses were collected inside a real office. As a result, when the productivity and alertness decreased, the room temperature was high, and the skin temperature and electrodermal activity were increased. A comparison between the group of alert and drowsy states was also made. The average and the gradient of skin temperature had a significant difference between the states. The result of skin temperature could be interpreted as suppressing the sympathetic nervous systems in the drowsy state, increasing blood flow, and increasing temperature at the terminal skin. Significant relation with the electrodermal activity can be explained through sweat secretion. The results showed the insight of understanding the occupants’ alert state through wearable device measured data.

Paper 8.7: **Thermal Insulation of Clothing: Assessment of Cleanroom Clothing Ensembles**

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**Keywords:** cleanroom clothing, thermal insulation, thermal manikin, thermal comfort

Besides the known environmental conditions and the level of activity, the occupants’ clothing and its properties are important for the assessment of thermal comfort and determination of optimal temperatures of the analysed environment. The thermal properties of clothing significantly affect the heat balance of the organism, thus also the level of thermal satisfaction of occupants. Without the known and correctly determined values of thermal insulation, the effect of the clothing on the heat balance is skewed.

In the case of the cleanroom clothing, unfortunately, the values of the thermal insulation for these specific ensembles can not be found in the international standards ISO 7730 and ISO 9920. Only, the values can be estimated based on the selected casual ensembles or as a combination of individual garments available in the standards which clearly make the thermal comfort assessment unreliable.

This study is focused on the assessment of cleanroom clothing to determine the thermal insulation properties. For the purpose of this study, four frequently used cleanroom clothing ensembles were selected. These sets represent the most prescribed ensembles in cleanrooms operated as the ISO Class 7 cleanroom known as the most common classes of cleanliness. The measurement of the thermal insulation was carried out following the standard ISO 15831 for the testing by means of a thermal manikin. In this study, the stationary Newton thermal manikin with 36 zones placed inside the climatic chamber was used. The manikin was operated in the temperature mode ensuring the uniform surface temperature in all zones. The testing of each ensemble was repeated two times as the tolerances of the results were below the requirements (2.3 %, 1.8 %, 0.2 % and 1.2 %). The thermal insulation was calculated using the parallel method (ISO 15831) suitable for this type of measurement.

The results showed the variations in the thermal insulations of ensembles that reflect the layers of garments and their materials. The importance of finding the thermal insulation of cleanroom clothing is not only in the more accurate calculation of PMV and PPD indexes but also in the setting of more suitable indoor temperatures in relation to the used ensembles. The casual ensembles available in standards can not represent the specific cleanroom clothing. Thus, the more precise method of determining the thermal insulation with the use of a thermal manikin is needed. Despite the high accuracy, the high investment and operating costs are responsible for the limited applicability of this method.
Session 9: Work environment

Paper 9.1: An empirical study of occupants' evaluation of short-term combined thermal, visual, and acoustic indoor-environmental exposure

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Keywords: human comfort, indoor environment, multi-domain exposure, thermal, visual, auditory

Recently, more attention is being paid to human sensation and perception processes under multi-domain indoor-environmental exposure situations. Despite the existing body of research in this area, many more studies must be conducted to elevate the level of our understanding of such processes. In this paper, we present such a study. Thereby, two identical small office units are assembled within a larger laboratory space. Thermal and visual conditions can be separately controlled in these two units. Furthermore, different acoustical conditions can be emulated in the larger laboratory space that houses the two small office units. During the experiments, participants occupy these offices and are exposed to a number of different combinations of indoor-environmental (thermal, visual, and auditory) factors. A key query thereby is as follows: Are identical thermal conditions evaluated differently given interference attributable to other exposure variables (e.g., glare, noise). The paper presents the research design and the results.

Paper 9.2: The influence of employees’ workspace satisfaction on mental health while working from home during the COVID-19 pandemic

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Keywords: office workplace, home workplace, mental health, stress, burnout

Previous research has, to some extent, investigated the influence of satisfaction with the workplace on employees’ mental health (i.e. mood, sleep quality, fatigue, and stress). However, insights in these relationships while working from home have been lacking. The purpose of this study is therefore to gain understanding in which personal and workspace characteristics are related to employees’ mental health. This study used a cross-sectional data collection approach and a seemingly unrelated regression analysis (SUR) to analyse the relationships. Results indicated that sleep quality, mood, stress, and fatigue are influenced by employees’ satisfaction with the workspace temperature, artificial light, and support of informal interactions while working from home. Personal characteristics (i.e. neuroticism, conscientiousness, and age) are also related to mental health. These findings could be used by workplace managers or employers to optimize their home workplace strategy.

Paper 9.3*: Interaction effects of acoustics at and between human and environmental levels: A review on the acoustics in the indoor environment

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Keywords: Indoor environmental quality, Acoustical quality, Interaction effects, Human level, Environmental level

People spend around 90% of their time indoors, where they are exposed to various physical stressors, such as unpleasant sounds, odours, temperature, and lighting, which may cause annoyance and discomfort. This literature review is focused on substantial studies that emphasize noise as a physical stressor in the indoor environment. Previous studies showed that background noise has a significant impact on human health. Adding to that, several other studies showed significant cross-modal effects between noise and other environmental stressors. However, various previous studies focused on quantifying the indicators of the indoor environmental quality (IEQ) factors rather than studying the differences of each occupant on their preferences and needs. Hence, this literature review highlights studies that take into account the interaction effects of acoustics at and between human and environmental levels. This review study aimed at identifying the key indicators to be taken into account for evaluating acoustical quality.

* Extended abstract for Paper 9.3 is available at the end of this book.
Paper 9.4*: The challenge of finding definitions for well-being and health within the built environment

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Keywords: Health, well-being, definitions, literature review, interdisciplinary

While research on health and well-being is further increasing in numbers, a plethora of definitions for the terms health and well-being exists in scientific literature. These definitions are influenced by individual preferences and objectives, hence to some extent demonstrating the individuals' view on both concepts. As such the analysis of definitions deployed is beneficial for the understanding of the key concepts influencing them.

The objective of this study is the identification and analysis of definitions of well-being and health within and beyond the field of built environment. This short paper summarizes two approaches for such analysis. Firstly, by means of a Rapid Evidence Assessment definitions used in scientific research are summarized and categorized. Secondly, through a qualitative survey among laymen, the expert definitions are contrasted with the subjective definitions of laymen.

* Extended abstract for Paper 9.4 is available at the end of this book.

Paper 9.5: Impact of the indoor environmental quality on employee well-being in a LEED-certified office building

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Keywords: Indoor environmental quality, office building, physical factors, chemical factors, questionnaires

This paper deals with the assessment of the indoor environmental quality (IEQ) in two selected offices of the newly built green administrative building, which has achieved the second highest level of evaluation within the international LEED certification. The assessment of the IEQ was performed through real measurements of IEQ factors and a questionnaire survey. In each office, the total measurement time was set at 24 hours. The data recorded during the 8-hour working time were evaluated separately. During working hours, five employees were present in the first office (larger in area) and two in the second. Measurements were performed under natural conditions. For comparison, 24-hour measurements were repeated in the second office but without the presence of occupants. The results of IEQ monitoring showed that the legislative and LEED limits were not exceeded in any of the offices (either within 24 hours or during working hours). Exceeding the recommended LEED limit for TVOC concentrations in the second office by 34% during 8-hour working hours was related to the presence of people in this office. The measured daylight intensities in both offices met the minimum legislative requirement. The subjective evaluation shows that the occupants of the building themselves perceive IEQ positively. Although more than 50% of respondents said they feel fatigue, lethargy and have a headache while working in the office, given previous IEQ perception results, these symptoms may be related to the type of work performed rather than IEQ. Based on the results obtained from real measurements and a questionnaire survey, it can be stated that the monitored office spaces of the selected green certified building provide a quality, healthy and comfortable indoor environment that does not significantly interfere with their work performance.

Paper 9.6*: Relationships between mental health and indoor environmental quality (IEQ) in the home workplace

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Keywords: home workplace, IEQ sensors, mental wellbeing, productivity

The understanding of mental health in the context of the physical workplace's indoor conditions has not yet received much attention, even less related to employees that are teleworking. Therefore, this study aimed to identify potential relationships between indoor environmental quality (IEQ) conditions and workplace mental health while working from home.

Data was collected through a cross-sectional survey; repeated momentary surveys; and IEQ sensors. Participants worked full-time from home during the measuring period. Datasets were analyzed using bivariate and path analyses.

The findings indicate that both subjective experience and objective IEQ conditions, as well as workplace suitability and distraction are related to workplace mental health.

This study is one of the first to explore workplace mental health in relation to simultaneously assessed (perceived and measured) multiple IEQ parameters in the home workplace. Working from home is expected to be more common in the post-Covid world. Therefore, additional research is required.
Paper 9.7: Comparing tangible and graphical interface of occupant voting system: Preliminary results of experimental field study in an office

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Keywords: Occupant feedback, occupant voting system, thermal comfort, information and communication technology

Occupant voting systems (OVS) are typically applied as a tool for collecting real-time votes on how occupants perceive their thermal indoor environment. Various research studies have demonstrated how the collected occupant votes can be applied to improve control strategies of heating, ventilation and air-conditioning (HVAC) in buildings as to achieve lower energy consumption and improve occupant satisfaction. One essential part of achieving these outcomes is that occupants use the OVS frequently. Some of the research studies on OVS have demonstrated prompting to be an efficient way to remind occupants to vote frequently. However, other studies have reported cases of “survey fatigue” due to too frequent prompting. Therefore, more subtle approaches such as providing occupants with dashboards or distribution of information flyers have also been used to remind or motivate occupants to vote. But very few research studies have investigated whether the interface of OVS, specifically graphical versus tangible, have an influence on voting frequency and occupants’ motivation to vote.

The objective of the study presented in this paper was to demonstrate whether occupants cast more votes with a tangible user interface (TUI) based OVS, designed as a panel of five buttons, compared to a graphical user interface (GUI) based version of the OVS, designed as a smartphone app. The study was designed as a within-group in-field experiment conducted in an open plan office space with fourteen participants over four weeks. The research study revealed that when the participants could only vote with one of the interfaces of the OVS, they did not vote more with the TUI compared to the GUI. However, when the participants could freely choose which interface to vote with, they preferred the TUI over the GUI. Most of the participants agreed that they used the TUI because it was accessible, quicker and easier to use.

Paper 9.8*: Numerical Investigation of Human CO₂ Emission in a Personalized Work Environment

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Keywords: Carbon dioxide, Ventilation rate, Human carbon dioxide emission

INTRODUCTION: Carbon dioxide (CO₂) concentration indoors is often used as an indicator of ventilation efficiency and indoor air quality in occupied buildings. The concentration is a result of outdoor CO₂ level, ventilation rate with outdoor air, CO₂ emission rate from occupants, and mixing of air within a space. To determine ventilation efficiency, it is important to accurately estimate the CO₂ emission rate from occupants. There are mainly two experimental methods for obtaining CO₂ emission rates from humans. One is monitoring CO₂ concentration in an airtight or ventilated chamber where volunteers perform different physical activities; the mass balance equation is subsequently used assuming complete mixing. In the other one, the indirect calorimetry devices such as Douglas bag are used by detecting exhaled CO₂. There is difference in the estimated CO₂ emission rate between these two methods mainly because of the heterogeneous CO₂ concentration distribution in the chamber, especially in the breathing zone.

METHOD: In this study, we developed a numerical gas exchange model between carbon dioxide and oxygen in lungs. This model was then integrated with computational fluid dynamics (CFD) model and computational simulated person (CSP) to reproduce human metabolic heat generation, CO₂ emission under transient breathing cycle (inhalation and exhalation of CO₂) in a small work environment (1.7 m³).

RESULTS: Modelling results show heterogeneous CO₂ concentration distribution even when mixing fans were installed. The differences in CO₂ concentration were seen when comparing averaged volume of a space, exhaled air and inhaled air. The CO₂ emission rate estimated using CO₂ concentration in exhausted air as a representative CO₂ level in the space is higher than the CO₂ emission rate estimated from inhaled and exhaled CO₂ in each breathing. Both of these estimated CO₂ emission rate decreased as inhaled CO₂ concentration increased confirming experimental studies on this topic. The numerical model could improve physical measurements leading to the estimation of CO₂ emission rates.

* Extended abstract for Paper 9.8 is available at the end of this book.
Paper 9.9: **Properties of Hydrogel-Wood Composite as a New Thermochromic Glazing Material**

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**Keywords:** Smart windows, Transparent woods, Thermochromism, Energy-efficient buildings

Recently, thermal-response hydrogel smart window is widely studied because of its high luminous transmittance ($\tau_{\text{lum}}$) and high solar modulation ability ($\Delta \tau_{\text{sol}}$). However, its liquid state is undesirable for window applications. Wood has strong mechanical strength and low thermal conductivity. Due to the unique features of the thermal-response hydrogel and wood, a thermochromic hydrogel wood composite (HWC) that can smartly regulate solar irradiation is proposed by impregnating a thermal-response hydrogel into delignified wood. The novel HWC demonstrates advanced optical properties (i.e. $\tau_{\text{lum}} = 83\%$ and $40\%$ at the cold transparent and hot opaque states & $\Delta \tau_{\text{sol}} = 38\%$) and low transition temperature (i.e. $T_c = 23$ oC). Moreover, the HWC is highly flexible and easily fitted into existing windows frames. Overall, the HWC with its impressive features shows great promise for energy-efficient material for smart windows in buildings.
Session 10: Airborne transmission of infectious diseases

Paper 10.2: Transport of Contaminated Agents in Hospital Wards - Exposure Control with a Personalized Healthcare Ventilation System: Numerical Study

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Keywords: Hospital ward, cross-infection, contaminated agents, ventilation system, Computational Fluid Dynamics

Contaminated agents in hospital wards are the source of nosocomial infections known as hospital-acquired infection (HAI) or healthcare-associated infections (HAIs). The spread of infection is closely associated with indoor airflow patterns created by room ventilation. Ventilation plays an essential role in minimizing the transport of airborne infectious diseases such as Covid-19 and SARS in the hospital ward. The goal of this study is to find efficient elimination technology for better control of contaminated agents. This work aims to study the influence of using local air supply and exhaust on the distribution and removal of airborne particles. Previous studies are compared to determine the factors that influence the environment and contaminants concentration in hospitals, along with infection control information. Numerical analyses of ventilation performance were conducted in a typical hospital ward. This study demonstrates factors that critically affect indoor bacteria-carrying particles conditions in the air. This research also provides a valuable reference to minimize indoor contamination levels with a personalized healthcare ventilation system in the future. Computational Fluid Dynamics technique was used to model the airflow field and contamination distribution in the ward environment. Simulated results of the transmission and removal of airborne infectious particles using local air supply and exhaust showed that the bacteria spread from a patient confined to his bed was limited and for certain conditions significantly eliminated. Consequently, the higher efficiency of particle removal and moderating the transmission of contaminated agents was obtained by using locally implemented air supply diffusers and exhaust grills. Thus, this strategy can shorten the contaminated agent's exposure time for both patient and healthcare staff, as a result, reduction in cross-infection at the hospital.

Paper 10.3: Experimental investigation of the spread of airborne CFU in an research-OR under different air flow regimes using tracer particles

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Keywords: Laminar air flow, operating room, aerosols, surgical site infections, displacement flow

Regarding the risk of surgical site infections (SSI), surgical operations take place in protected environments. SSI can be caused by endogenous germs, smear infections or by airborne colony forming units (CFU) that sediment in the wound or on surgical instruments.

Aim of this experimental study is to design an aerosol generator that produces airborne particles with the aerodynamic properties of airborne colony-forming units (CFUs) occurring in operating rooms (ORs). Those tracer particles are produced by dispersing a suspension of tracer particles with a size range of 2 to 20 µm using a collision nebulizer. The essential properties were investigated by a literature research. Furthermore, the classified source strength and corresponding measurement uncertainty of the aerosol generator were measured using a test stand with an optical particle counter in a cleanroom environment.

It could be shown that the aerosol generators designed produce particles in the relevant size classes of the airborne germs emitted by OR personnel.

The aerosol generators disperse particles with the size of the airborne CFU occurring in real OR, usually between 2 and 12 µm, into the indoor air, in order to be able to make representative statements on the removal of germs considering the aerodynamic properties of particles.

Paper 10.4: COVID-19 dent guard and movable room for dentists' practice with design solution for air cleaning in natural ventilation.

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Keywords: COVID-19, CFD, dent guard, air cleaning, virus, naturally ventilated buildings

Virus could dependently spread in the air rising human infection. The global awareness issue by COVID-19 of virus movement is average size about 0.125 µm smaller than dust leaded to lung disorder. Thus, the new normal lifestyle with social distancing
between human is recommended for minimum 2 meters to lessen droplets infection. Therefore, dentist job is a most risk of unavoidable to contact in respiration area with their patient. A risk of infection for both patient and dentist is high at position of mouth. Thus, a dent guard is prompt designed for reduce water spreading with clear non-reflected plastic shield. Furthermore, a plastic covered-moveable room has been distributed over hospital and healthcare. The outright dent guard is created for temporary solution required to be analyzed its effectiveness for human health protection. A monitoring particle spreading are two solutions for dent guard and moveable room with computational fluid dynamics (CFD) simulation on virus dilution and accumulation in room. The demonstration of air cleaning distribution is a dental guard size 0.50 m. × 0.60 m. with two openings of 0.25 m. diameters for dentist operation. Dental services sensitively prohibit for tooth scaling due to risk of virus diffusion in air. The device of tooth scaling is a source to model air diffusion at general frequency 30 KHz. The virus is performed as a particle flow in building by CFD calculation and monitored in shape of dent guard. The results found summaries on capable dent guard and moveable room for virus dilution in air. This can be a design solution for this crisis.

Paper 10.5: Ventilation strategies to minimise the airborne virus transmission in indoor environments

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Keywords: SARS-CoV-2, ventilation strategies, CO₂, indoor air quality, healthy building

SARS-CoV-2 pandemic highlighted the importance of healthy buildings and proper ventilation in indoor environments. As recently highlighted by the scientific community, the airborne transmission route of the virus suggests that adopting containment measures just relying upon a safe distance (i.e. 1 m as “droplet distance”) cannot reduce the transmission by air in indoor environments whereas a key role in lowering the probability of infection indoors (and, then, limiting the spread of the pandemic) is given to ventilation.

In light of this, indoor environments with high occupancy can be hotspots for pandemic diffusion; indeed, the school environments turned in the spotlight as the governments worldwide were in the uncomfortable role of prioritising the right to education or health.

The present paper aims at determining the probability of infection of people exposed to SARS-CoV-2 and Seasonal Influenza Viruses due to the airborne transmission route in schools under different ventilation, emission, and mitigation scenarios and discussing how to operate the ventilation systems in view of a minimisation of the transmission.

A recently developed approach, able to quantify the probability of infection due to exposure in an environment in the presence of an infected subject, was adopted. The approach is articulated in four steps: (i) evaluation of the virus emission (based on a model recently proposed by the authors); (ii) assessment of the exposure to quanta concentration in the microenvironment (through a box-model method); (iii) evaluation of the dose of quanta received by an exposed susceptible subject; and (iv) estimation of the probability of infection based on a proper dose-response model.

In the presented study, different emission modes (e.g. teacher emitting while taking lesson, students breathing or talking while attending the lesson), ventilation methods (e.g. manual airing, mechanical ventilation) and mitigation solutions (e.g. wearing a facemask, using purifiers, using microphones) were taken into account. Furthermore, the probability of infection and the maximum classroom occupancy to guarantee a reproduction number lower than one were evaluated. Moreover, the adoption of students’ exhaled CO₂ as a proxy of the virus infection risk was demonstrated and discussed. The findings of the study provide a viable method to reopen schools safely and mitigate the spread of the pandemic, even considering the virus airborne transmission route.

Paper 10.6*: A Practical and Efficient Testing Method for Indoor Airborne Pathogens

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Keywords: Virus, Bacteria, Aerosol Sampling, Bioaerosols, COVID

The COVID-19 pandemic has been a global scourge, killing over 2M people in its first year. As devastating as this pandemic has been, it will not be the last; other novel pathogens will undoubtedly emerge. Like SARS-CoV-2, some will be highly transmissible as aerosols. Even the less-feared seasonal influenza kills hundreds of thousands of people every year, and tuberculosis kills about the same number of people as COVID-19 – about 1.5-2M each year. All of these diseases are transmitted primarily via infectious
airborne viruses and bacteria. Instruments capable of rapidly detecting these airborne pathogens will help limit human exposure and mitigate disease transmission.

Here we describe a new approach to sampling bioaerosols using condensation growth tube (CGT) capture. The CGT’s cold-hot temperature zones create water vapor supersaturation forcing condensation onto particles to form droplets. These droplets are gently collected keeping viruses, bacteria and fungal spores intact. The unique advantages of the CGT are: (1) high collection efficiency (>95% of particles from <10 nm to 10 µm), (2) instant genomic preservation of DNA/RNA upon capture, and (3) concentrated sample collection compatible with standard genomic analyses such as RT-qPCR and DNA/RNA sequencing. The work flow for sample analysis is identical to that used in diagnostic testing of nasal swabs.

In response to the need for broader access to effective bioaerosol samplers, we have developed the new BioSpot-GEM™ sampler, which is affordable, compact and quiet. These features as well as automated sample timing and simple operation make it well-suited for bio-surveillance in hospitals, dental offices, nursing homes, schools, and transportation centers by indoor air quality professionals as well as bioaerosol researchers. We used finite element analysis to model flow, heat/mass transfer and condensation-driven droplet growth to optimize the design of the sampler. Our model determines where condensation of supersaturated vapor begins along a particle’s trajectory and then calculates the subsequent droplet growth, accounting for the Kelvin effect on the equilibrium vapor pressure over a curved surface and non-continuum regime transport of both vapor and latent heat from the droplet. We experimentally validated the collection efficiency predicted by our model and demonstrated recovery of viral RNA from samples collected using the GEM sampler compared to a multiple orifice uniform deposit impactor (MOUDI).

* Extended abstract for Paper 10.6 is available at the end of this book.

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**Paper 10.7: Characterization and Dispersion of Human Expiratory Droplets – a Review**

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**Keywords:** Expiratory droplets, droplet size, spread, droplet velocity

The paper reviews studies conducted on human expiratory droplets for the purpose of defining the characteristics of expiratory droplets, their maximum dispersion and the forces influencing that in an unventilated environment. The review shows coughing, sneezing and speaking droplets to have comparable size ranges, while breathing droplets have the narrowest size range. Sneezing droplets have the largest average size and highest velocity among expiratory droplets. Compiled data reveal droplet Froude number offers a plausible quantitative measure of the droplet maximum spread. The fate of the airborne droplets is seen to be dictated by an interplay between their inertial force and gravitational force. The higher the Froude number, the greater is the droplet spread. Small droplets with high flow inertia, such as dry sputum droplets, are capable of reaching longer horizontal distances in comparison to large droplets. The review shows the maximum horizontal distance coughing droplets can reach exceeds 2 m, while sneezing droplets can reach distances above 6 m, greater than the 2 m physical distancing currently adopted to avoid virus contamination.

**Paper 10.8*: The potential of bio-based insulation products to support indoor air quality and reduce aerosol transmissions of contagious respiratory viruses such as SARS CoV-2 in the construction industry.**

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**Keywords:** Biobased, Air Quality, COVID-19, Viral Diseases, Aerosols

Almost half of absenteeism is caused by flu and catching colds. Previous studies have shown that aerosols can contain contagious respiratory viruses such as COVID-19. They have a lighter weight than water vapor and that they can also be absorbed by it. When compared to insulation materials such as mineral wool, biobased materials can absorb and accumulate moisture. This property can help reduce the concentrations of vapor and aerosols in the building climate. With improved air quality and the reduction of aerosols containing respiratory viruses such as COVID-19 their spread can be limited and absenteeism due to flu and colds reduced.

* Extended abstract for Paper 10.8 is available at the end of this book.
Session 11: Indoor environment and symptoms

Paper 11.1: Can we trust what humans report? – Myths and realities

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Keywords: Buildings, symptom perception, predictive coding, brain functions, paradigm shift

Human information is crucial for efforts in the field of buildings, health and experiences. Despite this, there is strikingly little focus on how it is created and may be understood. Division between e.g. “subjective”/“feelings” vs. “objective”/“facts” and thinking that e.g. questionnaires produce “facts” are examples of popular ideas more based on cultural myths than science. Traditionally, the brain is thought to register what happens in- and outside the body. Emerging knowledge indicates that the brain instead should be seen as creating all conscious experiences. In principle, the creation is an “integration” of (a) our previous experiences (i.e. acting as a model to generate predictions on future events) and (b) what actually happens (i.e. the inputs the brain gets, e.g. from our senses); (a) and (b) themselves not being consciously experienced. In this “integration”, factors (a) vs. (b) may have any distribution. If (b) dominates, the traditional model may fit, i.e. experience is rather equivalent to what actually happens. If (a) dominates, the traditional model fails, experience has limited relevance to what actually happens and may be understood as a “copy” based on previous experiences; e.g. still getting symptoms in a building long time after proper renovation of a water-damage. The new knowledge has several important implications, like: (1) Talking, questionnaires etc. “only” give the experience of each person, in principle no “objective” data on causal mechanisms, buildings etc.; (2) As all experiences are “subjective”, no persons report “wrong” data; (3) Cultural misconstructions like “psyche”/“feelings” vs. “soma”/“real” are invalid, misleading and may be destructive. Taking the emerging knowledge into account may be of substantial help for all professions working in the field of buildings, health and experiences.

Paper 11.2: Technical Specification of Human Nose: Bi-directional, cyclically operating combi-device for air-conditioning, heat and moisture recovery, filtration and odor detection but limited capacity

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Keywords: Technical specification of human nose, mucociliary clearance, heat and moisture supply and recovery, isothermal saturation boundary, limitations

We will explain the physiological limitations of our nose for heat and water exchange and explain the potential stress burden by indoor and outdoor temperate climate in winter. Our nose – a small organ (8-10 cm long, surface area 150-200 cm²) bears the burden for heating and moistening roughly 15'000 liters of breathing air per day to 100% humidity and 37°C, Fig. 1, 2. Simultaneously the nose serves as self-cleaning and efficient particle filter. The first task is vital for gas exchange, the second prevents infections and disease by infectious aerosols and air pollution.

The switch from inhalation to exhalation in tidal breathing requires a cycle time of roughly two seconds and a bi-directional workflow process. In intervals of two seconds the nose switches from heat and moisture supply to heat and moisture recovery and is capable to regain roughly 60% of the transferred water and heat. This impressive performance over time is enabled by alternating flow reduction in left and right nose compartment by mucosal swelling, triggered by adjusted blood supply. This allows intermittent work-recovery periods by changing priority from conditioning to filtration and clearance, the key reason for the “nasal cycle”, Fig. 4.

Our nose has a high short-term capacity and may manage increased respiratory minute volumes by physical work or sports activities. But heavy workload by very dry or cold ambient air that persists for several days or weeks, overburdens all noses with a suboptimal performance. This is the case for all elderly people, smokers and all persons with reduce nose breathing capacity for geometric, allergic, vasomotor or infectious reasons, hence more than half of the population. Overburdened noses desiccate and epithelial cell death may result (Fig. 3). The isothermal saturation boundary, normally just above the tracheal bifurcation, moves distally. This exposes a larger portion of conductive airway mucosa to not fully conditioned inhaled air. Conductive airways below the trachea, which are not prepared to resist stress by dry and cold air, become damaged, Fig. 3. Prolonged exposure to dry air (<40% RH) leads to mucosa desiccation, decreased clearance and increased vulnerability for infections and exposure to air pollution.
Paper 11.3*: Possible mechanisms underlying non-specific building-related symptoms

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Keywords: Neural sensitization; neurogenic inflammation; Classical conditioning; symptom misattribution; nocebo

Non-specific building-related symptoms (NBRS) can be referred to health symptoms from the indoor air that are not caused by toxins, showing no organ pathology. The consequences of NBRS for the afflicted individual and society calls for preventive and therapeutic measures, which should be based on mechanisms underlying NBRS. The objective of this paper is to provide a brief overview of theoretical and empirical support for protective psychobiological mechanisms that may underlie NBRS. These mechanisms are neural sensitization, neurogenic inflammation, classical conditioning, symptom misattribution and somatosensory amplification, and nocebo.

* Extended abstract for Paper 11.3 is available at the end of this book.

Paper 11.4: A field study of indoor air quality and overheating in newly built primary classrooms in low-carbon UK schools

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Keywords: air quality, overheating in schools, Climate change indoor, Low energy buildings, new build school

School buildings confront complex design and layout problems due to needing to respond to a wide range of environmental factors while accommodating intermittent high-density occupancy. Despite current policy-driven emphases on improving building energy efficiency, focusing exclusively on energy issues fails to capture the full effect buildings have on their occupants and the environment. This paper investigates recently constructed low-carbon schools in the UK, examining the indoor environmental quality and assessing overheating assessment against established standards. The findings reveal that carbon dioxide concentrations exceeded the maximum threshold (1,000 ppm) for more than 60% of school hours during both heating and non-heating seasons and that particulate matter levels exceeded 20 g/m³ during the heating season and 10 g/m³ during the non-heating season, indicating annual individual exposure above recommended health guidelines. Furthermore, the classrooms monitored experienced overheating for more than 40% of the school day.

Paper 11.5*: Characteristics of non-specific building-related symptoms

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Keywords: Symptoms; quality of life: comorbidity

Non-specific building-related symptoms (NBRS) are common in the general population, calling for better understanding regarding characteristics for prevention and treatment. The present objective was to review the characteristics of NBRS with respect to basic aspects, symptoms and quality of life, and comorbidity. Among the findings, the review suggests that unmarried women with low education constitute a particular risk group for NBRS, and that it is common to have had NBRS for a long period. Symptoms considered to be typical for NBRS (general, mucosal and skin) are reported by 3-4% of the general population, and the impact on quality of life includes daily activities, harassing attitudes and consequences for working life. Comorbidity with NBRS includes other environmental intolerances, inflammatory diseases, functional somatic syndromes and psychiatric conditions. These characteristics imply that assessment for prevention and treatment should include the individual’s life situation and comorbid conditions in a broad sense.

* Extended abstract for Paper 11.5 is available at the end of this book.
Paper 11.6: Understanding “Symptoms Associated with Environmental Factors” (SAEF) in buildings; e.g. “sick building syndrome”, “electromagnetic hypersensitivity” and “multiple chemical sensitivity”  

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Keywords: Symptoms, “sick building syndrome”, “multiple chemical sensitivities”, “symptoms associated with environmental factors”, paradigm shift  

The field of buildings, health and human experiences may be divided between conditions (a) with scientific support for causal relations between exposure and health effects, e.g. dampness in buildings and asthma exacerbation; (b) lacking such scientific support, e.g. “sick building syndrome” (SBS). b) conditions are often disregarded as imaginations, psychogenic etc. Traditional ideas are (1) the brain registers what happens in- and outside the body, thus reports of symptoms and experiences “objectively” reflect the underlying biological processes; (2) all symptoms and experiences result from biological processes in the body, often due to external causes. Emerging knowledge indicates that the brain instead creates all consciously experiences. In principle, experiences are “integrations” of (I) previous experiences (i.e. acting as models to generate predictions on future events) and (II) what actually happens (i.e. inputs to the brain, e.g. from senses); (I) and (II) themselves not being consciously experienced. In this “integration”, factors (I) vs. (II) may have any distribution. If (II) dominates, the traditional model may fit, i.e. experience is rather equivalent to what actually happens. If (I) dominates, the traditional model fails, experience has limited relevance to what actually happens and may be understood as a “copy” based on previous experiences; e.g. still getting asthma(like) symptoms in a building long time after proper renovation of water-damages. This new knowledge offers plausible explanations for learned phenomena like SBS, “multiple chemical sensitivities”, “electromagnetic hypersensitivity” and other conditions with limited scientific documentation for causality between associated environmental factors, e.g. “building”, “electromagnetic” and “chemical”, and experiences like symptoms. Important implications are (A) the symptoms and experiences in e.g. “SBS” are just as real as in any other medical condition; (B) as the symptoms and experiences in such conditions are not caused by the associated factor (e.g. “building”), nor through mechanisms like “syndrome”, “(hyper)sensitivity” etc.; such misleading terms should be abandoned. The new concept and phenomenon description “Symptoms Associated with Environmental Factors” (SAEF) offers a paradigm shift. SAEF opens for a better understanding of such phenomena, including prevention, treatment and the need for interdisciplinary approaches.

Paper 11.7: Performance, psychological and physiological effects of office noise  

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Keywords: Irrelevant speech, Stress reaction, Office noise, Work performance, Laboratory experiment  

BACKGROUND: Background speech is a common disturbance in open-plan offices. Irrelevant speech influences performance and subjective estimations. However, not many studies have examined simultaneously physiological, performance and psychological consequences background speech has on humans.  

AIM: To examine the influence of background speech on subjective experience, performance, and physiological measures.  

METHODS: The influence of background speech compared to silence was examined in a between-group laboratory experiment. Forty subjects participated (22 females, 18 males, mean age 25 years). Twenty-one subjects participated in the speech group and 19 subjects in the silence group (sound level of ventilation 35 dB LAeq). Background speech was a radio dialogue played at 65 dBA level, which people were supposed to ignore while making cognitive tasks and answering questionnaires. Background speech condition lasted for 50 minutes. Participants’ performance, subjective experience and various physiological stress reactions (e.g. stress hormone level, heart rate variability) were measured.  

RESULTS: Compared to the silence group, the speech group had lower performance and higher physiological stress level. Speech was subjectively estimated more annoying and loading, but less tiring than silence.  

PRACTICAL IMPLICATIONS: This study shows that background speech influences experience, performance, and physiological stress level while performing cognitively demanding tasks. Therefore, its influence should be minimized in offices, where work requiring concentration is needed.
**Session 12: Numerical simulation**

**Paper 12.1: Can we measure buildings' affordance?**

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**Keywords:** Buildings, indoor environment, control devices and interfaces, affordance

The term affordance is used in this paper to denote the capacity of buildings to provide occupants the possibility to control the indoor-environmental conditions so as to meet their needs and requirements. This is typically facilitated via buildings’ various control devices and systems meant to control ambient conditions. In this paper, we discuss recent progress in developing a building affordance evaluation method. The idea is to evaluate buildings’ control devices and elements based on their availability as well as their effectiveness. We critically examine the strengths and weaknesses of the proposed affordance measurement method and discuss its future potential to be used as a performance assessment tool by professionals and stakeholders in building design and operation.

**Paper 12.2*: CFD simulation of non-isothermal ventilation flow in a generic enclosure: Impact of inlet velocity boundary conditions**

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**Keywords:** Indoor ventilation; computational fluid dynamics (CFD); inlet boundary condition; non-isothermal

Computational fluid dynamics (CFD) simulations are widely used in the prediction of indoor airflow in enclosed spaces. In most past studies, due to the absence of experimental data at air supply openings or for the sake of simplification, uniform hypotheses of inlet boundary conditions for velocity, temperature, and turbulence parameters were commonly applied. However, when aiming for an accurate simulation of indoor ventilation flows with buoyancy effects and complex geometry of the air supply system, the uniform settings at the inlet boundaries can be insufficient, even with a highly accurate simulation approach such as large eddy simulation (LES).

In this study, CFD simulations of non-isothermal ventilation flow in a generic closure are performed. To find the proper settings of inlet boundary conditions, a high-quality indoor ventilation experiment with detailed information of all relevant parameters near the air supply openings is used. Three different methods of generating inlet boundary quantities from the experimental data are tested, which are the methods of (1) uniform quantities, (2) fitting profiles, and (3) prescribing values. Simulation results demonstrate that for the definition of the velocity at the inlet only the last method, i.e. using available experimental data to prescribe detailed values at the inlet, can provide a good agreement between numerical results and experimental results throughout the studied enclosure. In addition, the current work shows that the inlet boundary conditions of turbulence quantities can also have significant effects on the simulation results of room airflow.

It is recommended that for future CFD validation studies the measured data near the air supply opening, if available, is directly applied as the inlet boundary conditions, especially when the geometry of air supply system is complex. In addition, special care should be taken when imposing the inlet turbulent parameters since these can strongly affect the comparison with experimental data. Finally, if possible, experimental data sets generated for CFD validation should include detailed measurements of all relevant quantities near the inlet to avoid a biased conclusion on the performance of turbulence models and other computational settings.

* *Extended abstract* for Paper 12.2 is available at the end of this book.

**Paper 12.3: Numerical simulation and field survey research of indoor thermal comfort for healthy building: A case study of Lingnan residential building**

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**Keywords:** indoor thermal comfort, healthy building, numerical simulation, field survey, residential building

Due to COVID-19, people spend more and more time indoors. Healthy buildings, therefore, become more attractive to people than ever before. By summarizing specific requirements on relevant standards for healthy indoor thermal condition, this paper adopts numerical simulation and field survey to study indoor thermal comfort with a Lingnan residential building as a study case. After optimizing by building design strategy, the research results show that (1) The numerical simulation method could be used for evaluating indoor thermal comfort based on Ladybug and Honeybee plugins. The results have the same trend as the field survey. (2) Yuedao Courtyard did not meet healthy indoor thermal environment requirements under natural ventilation. It is hot indoors, whatever during the whole year simulation or on the measurement day. (3) The optimization measures could be considered by adding sunshades on the windows under the passive building context. It can be universally used for the standard building which entrance faced west. (4) Numerical simulation is almost not restricted by working conditions, especially for buildings under design, which can evaluate whether the indoor thermal comfort condition is healthy or not. It is useful for designers to solve practical problems for better design.

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**Paper 12.4: Numerical Simulation of Double Skin Facade used to produce Energy in Buildings**

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**Keywords:** Energy production, Numerical model, Double Skin Façade, Energy and mass integral equations

This article introduces a numerical model to project and construct a Double Skin Facade (DSF) in windows facing south, in order to be used on thermal energy generation in winter conditions. The DSF system is applied to a virtual chamber similar to a real experimental chamber and it is connected to a mixing ventilation system. The thermal energy generated by this DSF system is used to further indoor air quality and thermal comfort for occupants. The numerical simulation is done by a software that simulates the virtual chamber and the DSF thermal response. This software uses energy and mass balance integral equations for the opaque surfaces, transparent surfaces and internal air. It also considers the solar radiation simulator, the glass radiative properties and the assessment of radiative and convective coefficients. The results show that the proposed DSF system, using solar radiation, contributes to having acceptable conditions of thermal comfort, during most of the occupation cycle, and indoor air quality.

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**Paper 12.5: Numerical study of the influence of balconies on indoor environment in winter: A case study of college dormitories in Jinan, China**

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**Keywords:** balcony, ventilation rate, indoor environment, coupled method, CONTAM

The ventilation rate of dormitory in winter affects the living quality and learning state of students, while the balcony will affect the indoor ventilation of dormitory. In order to explore the influence of different locations, floor heights and building types on the ventilation rate and indoor environment of the dormitory in winter, this paper used the computational fluid dynamics software PHOENICS and the multi-area network model software CONTAM coupling calculation method to simulate the indoor ventilation conditions of the dormitory in a university with or without balconies under three building types. The results show that the average ventilation volume with balcony is 44.04 m³/h lower than that without balcony. When there are balconies, the room ventilation rate of the first floor of ordinary rectangular building, the second floor of L-type building and the first floor of rectangular-ambulatory-plane building are the largest. The room ventilation rate of different positions on the same floor of ordinary rectangular building is the lowest. Considering comprehensively, it is better to choose rectangular-ambulatory-plane dormitory buildings when there is a balcony.
**Paper 12.6**: **INCHEM-Py: A new open source model for investigating indoor air chemistry**

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**Keywords**: modelling, open-source, kinetics, indoor air

The new INdoor CHEMical model (INCHEM-Py) is a python refactor and development of the internationally recognised INdoor Detailed Chemical Model (INDCM). It is an open source and accessible 1D box model that examines the complex air chemistry of indoor environments. The unique element in this model is the incorporation of an explicit chemical mechanism that considers the step by step degradation of around 150 common volatile organic compounds. The model also considers indoor photolysis (combination of attenuated outdoor plus artificial lighting), exchange with outdoor air, and emissions from/deposition to surfaces. The chemical detail allows the user to understand key reaction pathways and identify the species that accumulate to high concentrations for a range of conditions that are commonly encountered indoors.

The methods used and assumptions made within INCHEM-Py will be described alongside a walkthrough of the solution process. Benchmarking results will be examined and compared to published work. Additional features that were not implemented in the INDCM will also be discussed and linked to the comprehensive documentation designed to aid users and enable efficient scientific progress. Preset scenarios (e.g. cooking and cleaning events) will be demonstrated with outputs compared to available experimental data.

Due to the nature of open source models, INCHEM-Py provides a solid base for future work in the indoor air community, for users of all abilities. Confident users can edit the model to run their own tailored scenarios, but there is also the option to use pre-set scenarios for which only slight modifications are required. We also hope that users will make or suggest future improvements, so INCHEM-Py continues to be relevant. We look forward to continuing our collaboration with a growing community of indoor air scientists, nurturing a collaborative model development environment.

* Extended abstract for Paper 12.6 is available at the end of this book.

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**Paper 12.7**: **Identification of most important factors (Building factors: artificial lights and window materials; External factors: cloud factors, season, latitude) affecting indoor photolysis rates**

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The importance of photolysis for outdoor air chemistry is well established, but the role of indoor photolysis is less well studied and hence quantified. Although photolysis is diminished indoors (e.g. by glass in windows and coverings on light sources), it still occurs, particularly for reactions that occur at longer wavelengths. Indoor lights include artificial lights and attenuated sunlight that can move into indoor environments through windows and skylights. The amount of light that can penetrate indoors is influenced by many factors, including the type of window, meteorological conditions and the building alignment and location.

The aim of this paper is to investigate the impacts of cloud, latitude, season, window material and artificial light on indoor air chemistry. The model used in this work is the INDCM (INdoor Detailed Chemical Model), a near explicit box model which uses a comprehensive chemical mechanism. This mechanism has approximately 20,000 reactions and 5,000 species and represents the degradation of ~143 volatile organic compounds in the gas-phase. The degradation of each VOC is initiated by the reaction with radicals, including NO$_3$, OH and O$_3$, and photolysis where relevant. The process continues until H$_2$O and CO$_2$ are formed as the final oxidation products. The INDCM also includes terms that consider exchange with outdoors, internal emissions, photolysis and deposition to surfaces.

This paper compares the impacts of two building factors (different artificial lights indoors and window materials) and three external factors (cloudiness, time of year and latitude) on indoor photolysis rates, in order to find out the most important controls for the resulting indoor air chemistry. The results show that latitude and time of year are the most important factors affecting indoor radical concentrations, followed by cloudiness and window material. Different artificial lights typically have a smaller impact, although fluorescent lighting can impact radical concentrations under some conditions. Our results show that depending on where a building is situated and the time of year, indoor air chemistry may be quite different.

* Extended abstract for Paper 12.7 is available at the end of this book.
Paper 12.8*: Development of an underground space using to produced cold energy in summer conditions in the building thermal conditions performance

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Keywords: Underground space, cold energy, Building Dynamic Software, air quality, thermal comfort

The aim of this numerical work is the application of underground spaces and Dual Skin Facades (DSF) to improve comfort conditions in a virtual chamber. This virtual chamber, similar to a real experimental chamber, is equipped with an underground space and three DSF installed in front of windows located in the southern surroundings. A numerical model that simulates the Building Dynamic Response is used. This model considers an energy and mass balance integral equations system used to estimate the air temperature and the mass of contaminants inside the virtual chamber and DSF and the temperature in the different elements of the virtual chamber and DSF. The evolution of the air temperature of the virtual chamber, DSF and spaces are obtained and indoor air quality and thermal comfort level are evaluated. The indoor air quality level is acceptable and the thermal comfort level is acceptable according to the international standards recommendations.

* Extended abstract for Paper 12.8 is available at the end of this book.
Session 13: IAQ in dwellings

Paper 13.1: Healthy Home – Taking health into the design and use of (Dutch) dwellings

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Keywords: Health, well-being, dwelling, indoor/outdoor environment, design

Currently, the Dutch building construction sector generally does not yet consciously deal with the theme of health in homes. The government, the construction sector and residents appear more focused on reducing energy. As a result, in practice, there is a lack of awareness. Health in homes, apart from the building decree requirements, is not yet part of the design process and usage.

Some innovative Dutch construction companies do acknowledge the importance of health when building houses and try to develop concepts for that. They, however, are not always aware how to translate ‘health’ best into design solutions for dwellings, and their performance is not always considered consciously.

In this research, the so-called ‘Healthy Homes’ concept was investigated in more detail. The objective was to identify the potential for optimization of the concept, by providing advice for building physical and architectural interventions, and by providing guidelines, also in the use phase.

A literature study has been performed to explore definitions and guidelines concerning health in homes which accumulated in a trend report. The results of this part of the research are divided into four themes: outdoor environment, indoor environment, design and communication. In the second phase of the research a survey, analysis of available measurement data and interviews with experts in the field of building physics and architecture have been performed.

The outcomes identify that residents can influence a healthy indoor climate to a certain degree. This may be further supported by creating awareness among residents through a positive and activating promotion pamphlet. Construction companies then are challenged to implement design considerations to support healthy living conditions in dwellings. In this research, optimization options are elaborated in design guidelines. Apart from known physical indoor environment parameters such as temperature, air quality, ventilation, acoustics and sun/daylight, they include topics such as: view, privacy, orientation, possibilities for social interaction, spatial experience, contact with nature, materials and the possibility of minimalism. Three different variants have developed for the ‘Healthy Homes’ concept. These have been assessed against the design guidelines and compared based on radar charts. The optimized variant shows promising outcomes.

Finally, the research has also identified that the Dutch building decree currently scores very poorly concerning health. Concepts such as ‘Healthy Homes’ may provide a significant improvement in that case.

Paper 13.2*: Architectural Design Modification Study for Improvement of Indoor Air Quality for Alleviation of Aeroallergen Sensitization in the Standard Naturally-Ventilated Urban Dwelling

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Keywords: allergies, dust, environment modification, PM, IAQ

An increase in prevalence of chronic allergic disorders allergic asthma, allergic rhinitis, and itching skin allergic disorder atopic dermatitis is observed in the urbanized regions of Asia due to the rapid changes in the region’s ambient air quality and environment. 25%-34.5% of Asian individuals are affected by one or more allergic disorders. This Asia-specific statistic is consistent with prevalence rates in the Philippines, where allergic rhinitis and asthma affect between 20-27.4% of Filipinos, while atopic dermatitis continues to steadily gain new cases every year at an average growth of 3.7% in the city of Manila alone. Low to middle-income countries in the Asian region such as the Philippines are significantly affected by air pollution due to large concentrations of traffic emissions, and a lack in more renewable sources of energy as traditional solid and fossil fuels widely used in the domestic unit and industrial hubs expel hazardous gases. 69% of the Philippines’ ambient air pollution in 2016 is attributed to vehicle emissions according to the Department of Environmental and Natural Resources (DENR), where 90% of which is concentrated in the country’s urban capital Metro Manila. Management of allergic disorders can negatively affect the patient’s life because of the urban environmental pollutants the patient is exposed to daily. Existing clinically advised environment modification studies have shown direct correlations in the suppression of air pollutants, using mechanical air filtering and home behavioral and sanitation practices, with the alleviation of allergic symptoms — but there is a lack of research on whether similar results can be achieved in a naturally ventilated indoor environment, which is more sustainable and economically accessible compared to the installation and maintenance of mechanical ventilation systems. This study aims to provide a means for allergic symptom alleviation through the design of spatial elements that can naturally suppress air pollutants from entering the indoor environment, namely an air filtering building façade and a cross-ventilated space plan, as guided by architectural design practices and indoor air quality methods. The design will then be tested in a standard-sized dwelling unit using Computational Fluid Dynamic Simulations.
Paper 13.3: How to transform European housing into healthy and sustainable living spaces using a Belgian case study? – the RenovActive principles tackle climate and renovation challenges

APPLICATION OF THE RENOVACTIVE CONCEPT: The RenovActive concept seeks to offer affordable, easy to reproduce, scalable solutions – these were the main criteria set up for the RenovActive project in Anderlecht, Belgium [1]. The aim of the renovation project was to test the Active House principles in social housing and single-family homes where cost, comfort and energy efficiency have to go hand in hand. A key aspect of RenovActive is to prove the financial viability of Active House renovation in social housing schemes across Europe. The affordability is based on the proven quality of each element as well as the different solutions’ ability to be reproduced, allowing economies of scale to take effect. To investigate the concept, the house has been tested by the first family to move in and monitored post occupancy to evaluate how the elements function in practice.

RESULTS: From an occupant perspective [2], the results show that the family is very satisfied with the level of indoor comfort. In both the questionnaire, the time diary as well as during the interviews, the family stated that they were very happy with the indoor temperature, the indoor air quality and the natural light. From a monitoring perspective [3], the results show that the indoor air quality is very good. For more than 95% of the time, the CO₂-concentration in the house, in general, is below 900 ppm. Slightly higher values were measured in the sleeping rooms. The temperatures stay for more than 95% between 21°C and 26°C, while the have slightly higher values, but stays under 28°C. Energy consumption for heating is higher than the estimated value, mainly due to higher indoor temperature than the setpoint used in the calculation.

CONCLUSIONS: In general, home satisfaction is therefore very high. The family indicated that they are very happy with the indoor climate, such as the indoor temperature, air quality and natural light. During the daily life, not many adjustments are needed to the automatic system. The family does indicate that they were sometimes dependent on others to solve technical problems. The health and sleep quality of the family have improved considerably since they moved in the RenovActive house. They also report that their family life as well as social contacts outside the family have greatly improved.

Keywords: Active House Renovation, Hybrid Ventilation System, Indoor Environment Monitoring

Paper 13.4: Perceived indoor environment in social housing with different ventilation principles

The need for renovation and energy retrofitting of Danish social housing from the 1960s and 1970s is substantial. Such energy retrofits often include the installation of mechanical ventilation systems with heat recovery to fulfil the current standards for energy efficiency. These systems typically ensure a more constant and higher ventilation rate than previous systems. Therefore, there is potential for residents to perceive a higher air quality and a reduction in problems due to condensation on cold surfaces and mould growth after retrofits. The purpose of the present study was to evaluate if this potential is realised for residents in social housing complexes. A questionnaire survey was performed among residents in dwellings with ventilation categorised within one of the five ventilation principles: natural ventilation, bathroom fan, exhaust fans in the kitchen and bath, decentralized balanced mechanical ventilation and centralized balanced mechanical ventilation. Compared with residents without balanced mechanical ventilation, residents having such systems perceived less often problems with unpleasant odour from their own apartment and less visible mould, but more often perceived the air as dry. Residents with decentralized mechanical ventilation tended to experience more often problems with noise from their ventilation system. However, results show that nuisance are avoidable with correctly designed decentralized ventilation.

Keywords: Indoor environment, perceived indoor environment, perceived problems, social housing, ventilation principles

* Extended abstract for Paper 13.2 is available at the end of this book.
**Paper 13.5**: Chemical characterization of ultrafine particles released from 3D printers

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**Keywords**: 3D printer, UFP, Emission test chamber, Chemical characterization

Previous studies have shown that desktop 3D printers (Fused Filament Fabrication) emit high numbers of particulate matter, mainly as ultrafine particles (UFP, particle diameter less than 100 nm). However, the chemical composition of emitted particles has been less extensively investigated. In this study, we therefore focused on the chemical composition of particles emitted from 3D printing. The measurements were conducted in a 1 m³ emission test chamber. Emitted particles were sampled by a 13-stage low-pressure cascade impactor onto aluminum foils and then analyzed by TD-GC/MS to identify their organic compounds. Nine commercial filaments made from basic polymers such as Acrylonitrile Butadiene Styrene (ABS), Acrylonitrile Styrene Acrylate (ASA), Polycarbonate (PC), Poly(methyl methacrylate) (PMMA), Nylon, High Performance Polystyrene (HIPS) and a copper-filled Polylactide (PLA) were investigated. The results show that the organic components of the particles are primarily plastic additives such as plasticizer, antioxidant agents, lubricants, UV- absorbers and UV-stabilizers from the filaments.

* Extended abstract for Paper 13.5 is available at the end of this book.

**Paper 13.6**: Research on Thermal Comfort of Activity Space under Viaduct in Mountain City — Take Chongqing Egongyan Bridge as an example

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**Keywords**: viaduct, space, thermal comfort

Rapid development of cities has led to the shortage of land for residents' activities, while rational use of the space under urban viaducts can effectively alleviate this problem. The thermal environment of the space under the viaduct is a key factor that affects human comfort during activities. In this paper, the thermal comfort under the Egongyan Bridge in Chongqing was evaluated by winter thermal environment test, thermal sensational voting (TSV) and universal thermal climate index (UTCI). It was found that the sky view factor (SVF) had a stronger linear correlation with UTCI than the spatial height width ratio (H/B). Furthermore, pedestrians pay attention to environmental thermal parameters mainly in the aspect of sunshine. This study provides a reference for the thermal environment optimization of the space under viaducts in the future, and provides a basis for the sustainable development of the city.

**Paper 13.7**: Indoor Thermal Environment of Huizhou Vernacular Dwellings of Guizhou, China in Winter Based on the Impact of Immigration

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**Keywords**: Immigrants; Huizhou vernacular dwellings; architectural space; indoor thermal environment

During the Ming and Qing dynasties, for the Huizhou people who immigrated to Guizhou, China, the form of their vernacular dwellings has also changed. The paper conducted a field-measured of a typical representative Huizhou vernacular dwellings in Guizhou, and monitored the indoor thermal environment parameters in winter. The Adaptive Predicted Mean Vote (APMV) index is used to evaluate the indoor thermal environment. And the simulation software Design Builder is used to simulate the influence of changes in the architectural space on the indoor thermal environment. We can learn the climate responsive building design strategies of the architectural space of Huizhou vernacular dwellings in Guizhou, and that provides a design basis for the sustainable construction of modern Huizhou vernacular dwellings in Guizhou.
Paper 13.8: **Research on industry-spatial relationship of existing industrial zones in Beijiao, Shunde based on comparison of data Point of Interest**

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**Keywords:** Existing industrial zone in Tanzhou Shuidao west area, Beijiao, Shunde; Point of interest; Spatial distribution characteristics; Industry-spatial relationship; Optimization and strategies

Spatial distribution characteristics of existing industrial zones in cities are important to research on their functional upgrading, optimization and transformation. So is the correlation with surrounding functional facilities which providing business supporting and life safeguard. The methods of Kernel Density Estimation, Standard Deviation Ellipse and Spatial Autocorrelation were used in this study, based on comparison of data Point of Interest (POI) of existing industrial zones in Beijiao. The study discussed the changing of characteristics and influence factors of industrial enterprises and surrounding facilities. It made a comparative analysis of the space correlation among the enterprises and facilities, and determined configuration status of facilities. And it provided the optimization strategy which should follow principles of utilization and proper demolition, and a regional centre should be planned. The building density in the area should adjusted in order to restore the ecological environment. A low-carbon and energy-saving urban form could to be constructed by optimizing the facility allocation. Tracking industrial-spatial dynamics by establishing a transformation database.

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Paper 13.9: **Study of the thermal environment construction technology of the traditional residential of the Bai nationality**

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**Keywords:** Traditional Bai nationality’s residence, Thermal environment, Climate adaptability

The Bai nationality is concentrated in Dali Autonomous Prefecture, Yunnan Province, China. Its special geographical location and terrain—low-latitude plateau, formed the unique architectural form of the Bai nationality. Through the test and evaluation of indoor thermal environment in traditional Bai buildings, the paper analyzes the correlation between indoor thermal environment and spatial form of the traditional Bai nationality’s residence, and analyzes the formation mechanism of indoor thermal environment by numerical simulation method. The study found that the traditional Bai residence has a good thermal comfort, and it responds to the local climate characteristics through the enclosed courtyard and the courtyard technology formed in the building, so as to realize the climate adaptability of the building.
Session 14: IAQ measurement

Paper 14.1: Reducing infection risk and optimization of airing concepts for indoor air quality by accurate aerosol & CO₂ measurements

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**Keywords:** aerosols, aerosol spectrometer, infection risk, indoor air quality

Since the outbreak of the SARS-CoV-2 pandemic and the findings about the virus transmission route through aerosols, indoor air quality is a major topic when it comes to efforts to contain the spread of SARS-CoV-2 in the population.

Most calculations of infection risk, however, still rely on CO₂ as a proxy for exhaled aerosols. This assumption is no longer valid when air filtration devices are used, arising the need to include actual measured aerosol concentration into the calculation of indoor infection risk. To close this gap, a version of Wells-Riley equation, extended to include the effect of air filtration into determination of reproductive number, is introduced and applied to measurement data from indoor air quality during school lessons. The results show, that taking only CO₂ into account will overestimate the real infection risk from aerosols by 20% in the cases without air filtration and by 60% in the cases with air filtration.

Furthermore, measurement results varied strongly between different classrooms. This indicates that general airing recommendation, as applied during these tests, are not enough to assure a healthy environment and more individual measurements are necessary.

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Paper 14.2*: Measurement and simulations of the influence of green wall systems on indoor air quality

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**Keywords:** indoor air quality, green walls, simulation, field experiments, botanical air handling

**BACKGROUND:** Heating, ventilation and air conditioning (HVAC) systems are decisive for the resource consumption of buildings and the indoor air quality (IAQ). A new approach in research and industry is to embed plants into these systems. Research regarding plant-based systems developed from the investigation of the effects of individual potted plants to the evaluation of complex plant-based systems.

**AIMS:** This paper continues this line of research by investigating the performance of plant walls within a real-life office environment. The aim is to quantify the potential contribution of plant-based systems to resource savings and IAQ improvements in comparison and in combination with conventional HVACs.

**KEY PROBLEMS:** To ensure health, well-being and low resource demand, the influence of novel and alternative air conditioning systems need to be tested and optimised.

These new systems must also meet the technical requirements of building automation system to enable the integration into these systems. Criteria and tools are needed for the comparison between different system configurations and to evaluate the efficiency of plant-based systems.

**METHODS:** The testing procedure involves both experimental testing and simulations. The experimental setup consisted of an office room with mechanical ventilation, a plant wall and a source of pollution. A test person or a printer are used as typical pollutant sources of an office environment. The plant wall tested, includes an automated watering and fan system.

**KEY OUTCOMES:** IAQ was evaluated based on concentration of CO₂, volatile organic compounds (VOC), particulate matter (PM) and relative humidity. For consumption analysis, the electrical and heat demand as well as water consumption are considered. Based on this set of parameters, we compared the temporal behavior of the four possible ventilation combinations of plant wall and ventilation system.

The simulation model represents all components of the experimental setting and the resource consumption. It was calibrated according to the measurement results.

**MAIN RESULTS:** The experiment and the simulation show that the plant wall has a supporting effect on humidification and reduction of VOC. The effect of CO₂ reduction is negligibly small. Thus, the plant wall tested cannot serve as standalone air purifier but as support for conventional ventilation systems.

A plant wall model for Modelica was developed and will be available in the Modelica AixLib library. This model enables the comparison of the resource efficiency for water and energy of the plant wall with other building systems, to estimate its effects on the overall building resource demand.

* Extended abstract for Paper 14.2 is available at the end of this book.
Paper 14.3*: **Intrinsic dimension estimation as a tool to sensor selection for an indoor air quality multisensory system**

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**Keywords:** Indoor air quality, multisensory systems, intrinsic dimension, optimization of the number of sensors

Indoor air quality (IAQ) is a growing and multidisciplinary research field domain involving professionals with various expertise, from Materials Sciences, Instrumentation, Electronics, Physics, Chemistry and many more. One of the current hot topics of this field is to equip private accommodation with air quality monitors. For that, it is crucial to develop and choose the more suitable sensors capable of detecting and discriminate different types of gases and volatile organic compounds. The number of needed sensors is related to which substances are going to be monitored. However, this choice is not obvious as the intrinsic information of sensors is not always well understood.

The main objective of this work is to understand and provide a framework on how this choice can be made. Several different types of signals are generated when using multisensory systems, but not all the signals are useful for detecting the aimed substances. By analyzing these signals, it is possible to select the sensors presenting the best match with a given substance detection task.

To analyze the collected data, a technique of intrinsic dimension estimation was used. This technique allows the estimation of how many dimensions (independent variables) are necessary to synthesize equivalent signals. In the case of multisensory systems, the dimensions can be interpreted as the number of sensors present in it. However, the intrinsic dimension estimation of a dataset collected via multisensory systems may reveal a smaller effective dimension, thus possibly allowing the estimation of the minimum number of sensors needed for a given task.

The dataset analyzed in this work is composed by the responses of 40 RUBIX-PODs with 19 sensors each, during 6 experiments where specific gas injections are done to represent different indoor activities (cleaning, cooking, etc.). The intrinsic dimension (ID) of this dataset is estimated. The data was arranged accordingly to an injection discrimination task, i.e., detecting what experiment (here called injection) generated each data point. Preliminary results showed an ID of 3 for the given dataset and indeed when only three specific sensors were used, all the injections could visibly be separated. Although this result shows that ID estimation is a good indication of the number of sensors needed, this experiment is very simple compared to what the multisensory systems face during day-to-day use, more experiments using real world data collected by those systems should provide a better understanding on what they are detecting and what sensors are really needed.

* **Extended abstract** for Paper 14.3 is available at the end of this book.

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Paper 14.4: **A method for determining the time-dependent indoor CO₂ concentration to evaluate air hygiene**

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**Keywords:** CO₂-concentration, indoor air quality, IAQ, concentrativeness

Max von Pettenkofer, one of the first hygiene engineers, evaluated the indoor air quality by means of the carbon dioxide content. As long as humans are the main source of air pollution through their continuous release of metabolic products such as CO₂, carbon dioxide can still be used as a good indicator for evaluating the indoor air quality. However, rooms with a high rate of occupancy, such as classrooms or lecture halls, often do not have sufficient indoor air quality and therefore an increased demand for fresh air is necessary. The trend towards open-plan offices also highlights this problem. The German workplace guidelines (ASR) as well as the Association of German Engineers deal with ventilation requirements as well as the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE). They define indoor limit values for CO₂ concentrations.

Unfortunately, the verification of compliance with the limit values during the use of buildings is often only carried out randomly or not at all. Although independent requirements of necessary minimum air change rates exist, they refer for example to the avoidance of mold growth. The requirements to indoor air quality in terms of low CO₂-concentrations, often remain unconsidered. A sufficient air quality is indispensable for a high concentrativeness and corresponding work efficiency of the users. Therefore, it is of great importance especially in classrooms, lecture halls and offices. Yet, there is no quantity that represents the indoor air quality over a given period of time to evaluate the air-hygienic comfort of rooms, for example, over an entire year. This paper presents a method for the determination of a time-dependent variable for the assessment of indoor air quality with regard to the comfort of the users.

Using measurements or dynamic building simulations over longer periods of time, CO₂ concentrations can be determined as a function of occupancy and air exchange rate. In order to be able to evaluate indoor air hygiene with the newly developed method, the concentration values are integrated as a time-dependent variable in CO₂ hours using a calculation tool. This results in an easy understandable and applicable new parameter for the assessment of indoor air hygiene on the basis of CO₂ concentrations. Using dynamic building simulations, the new method can be applied in the planning phase to gain a parameter which indicates to what extent a ventilation system or a ventilation concept offers sufficient indoor air comfort.

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An important factor for a good indoor climate in homes is adequate air change rate of the premises. It is not possible to feel how good the ventilation is and strikingly often there is significantly poorer air exchange than is desirable. The consequence of this is that there is no desired removal of, among other things, odors, water vapor and airborne dust that are naturally produced by the people staying in the home. In addition, inadequate ventilation can lead to undesirably high radon values in parts of the homes.

The actual symptom of inadequate ventilation can be clarified by measuring relative humidity and radon as well as CO₂. In addition, air sample analyzes with regard to quantities and types of airborne dust will provide a clarification of whether there are abnormally high values in the home.

The ventilation requirements in Norwegian homes have both previously and are still an air change rate of at least 0.5 turnover / hour. It is not possible to feel how good the air exchange is, so it has to be a standardized method to measure and document the relevant air change rate. We have tested a practical method for how air change measurements can be carried out in an objective and accurate way.

The method is technically easy to perform, inexpensive and relatively quick to implement since it provides sufficient clarification during measurement during a day. A representative number of CO₂ loggers is placed in different areas in the home before the rooms is filled with a sufficient amount of CO₂ gas. Logging how fast the CO₂ values decrease down to the natural background levels due to the existing ventilation provides an accurate basis for calculating the actual air change rate.

This article describes with specific cases how the method is used in practice and how the results are interpreted and evaluated.

* Extended abstract for Paper 14.5 is available at the end of this book.

Paper 14.6: Interaction between controlled natural lighting and IEQ; Integrated double skin façade approach applied on an office building

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Keywords: Building Envelopes, Double Skin Façade, Energy Performance, Indoor environmental quality, Thermal Performance, Visual Comfort.

Double skin facades can be used as a balanced solution to facilitate natural lighting into buildings and control the amount of admitted solar radiation. This study aims to identify an optimal solution for daylight and energy performance within an office building by optimizing the façade’s opening size and panel rotation. The goal is to generate a flexible model that contributes to the overall performance and thermal comfort.

The paper provides a methodology using parametric tools of Grasshopper via Energy-plus/ladybug to analyze and evaluate the thermal performance of different iterations of a double skin façade. Although various IEQ aspects affect comfort levels, few studies have investigated the interaction between IEQ and thermal performance levels regulated by double-skin façade.

The results concluded that the proposed skin façade could reduce 30% of the total radiation of the original office building. While, the rotation of the façade panels proved to be a significant factor as it resulted in the highest reduction in radiation, up to 32%.

Paper 14.7*: Big Data in IAQ research, an example of the application in IEA EBC Annex 86

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Keywords: Sensors, Big Data, IoT

In the IEA EBC annex 86 project, we are developing a classification/reporting guideline on IoT-data for energy efficient IAQ management strategies.

We are exploring the potential of the new generation of IoT connected devices (both standalone and embedded in eg. AHU’s) for smart IAQ management. What can we learn from big data? Can we benchmark system energy and IAQ performance based on this data? How can we make sure that the data is available and can be accessed? Can we update what we think we know...
about what happens in dwellings based on what we see in big data rollouts? What are the best protocols and ontologies? How to create viable services out of the data/business plans? How can we integrate data with smart grids?

These issues will be addressed by reporting experiences from a series of implementation case studies and overview of available (types of) datasets.

We address these questions by exploring real life case studies and deriving 'lessons learned' and good practices. In this paper, we use a case study where we analyse CO₂, Humidity and TVOC concentrations measured through the onboard sensors of an IoT connected residential air handling unit as an example of this methodology.

In this particular case study, we were able to check common assumptions on occupancy and pollution loads at a cross-sectional level with highly time resolved data for a full year, based on the data of over 5000 units.

* Extended abstract for Paper 14.7 is available at the end of this book.

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**Paper 14.8**: Optimal sensor positioning for monitoring indoor air quality in a simulated office environment

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**Keywords**: Optimal sensor placement, Indoor air quality, Multi logistic regression model, Human exposure, Spatio-temporal variation

In an office environment, ventilation system and indoor and quality (IAQ) strongly influence occupants' productivity and satisfaction. Among prominent sources on indoor air pollution, humans and their activities have been the most dominant. Spatio-temporal variation of human-associated air pollutants could strongly influence the ventilation performance. Despite recent technological advancements in low-cost IAQ monitoring, the current monitoring practices are limited and typically exclude conditions that are relevant to, and experienced by, building occupants. Dynamic variations of occupants' number and activities influence spatio-temporal variations of indoor air pollutants. Capturing those variations and identifying an optimal sensor placement can be important for improved ventilation performance.

In this study, we aim to investigate optimal sensor placement for IAQ monitoring in a simulated office environment. We conducted a total of 32 experiments in a controlled climate chamber with different number of human participants (2, 4, 6 and 8) performing typical office activities and four space types (two types of shared offices, meeting room and cafeteria). Two different mechanical ventilation strategies (mixing and displacement) and air change rates (2.4 – 2.6 and 3.5 – 3.6 h⁻¹) were studied to evaluate their impact on spatio-temporal variation of indoor air pollutants. The IAQ parameters (CO₂, TVOC and size-resolved PM) were measured at seven locations (wall, center of workstation, near a source, on each participant's desk, side of the desk near an abdomen of seated participant, breathing zone). Preliminary results show that airborne concentration of CO₂/PM recorded in the breathing zone is considerably higher than ambient (background) concentrations from the other sensor locations. For example, approximate exposure concentration to CO₂ (1500 ppm) was over 2 times higher than background concentrations (600-800 ppm), and to PM₂.₅ was 1.5 – 3 times higher than the background levels. For further analysis, multi-logistic regression model will be introduced to identify optimal sensor placement in the office that can approximate human exposure to CO₂/PM. The final results are expected to advance knowledge of spatio-temporal variability of indoor environment combined with identifying optimal sensing location. This is important not only for improving understanding of indoor environments and energy saving potential, but also for developing of control algorithms that can ultimately be incorporated into ventilation control logic on a wider scale.

* Extended abstract for Paper 14.8 is available at the end of this book.

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**Paper 14.9**: A new simplified daylight evaluation tool, description and validation against the standard method of EN 17037

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**Keywords**: Daylight, EN 17037, Building Passport, Residential buildings

The Daylight Evaluation tool uses a simplified assessment method to determine the daylight quantity provided to a room. Its calculation method is based on formulas integrating the main factors characterizing the space and its context. As it is meant to be used by persons with no specific knowledge in daylight calculations methods its results are expressed in a more abstract “Daylight score” rather than a physical value. The Daylight Evaluation tool uses a corrected Glazing-to-Floor ratio (GFR) as a proxy for the daylight provision in a space according to the recommendation in EN 17037 Daylight in Buildings. In principle, the results of the assessment methods are not directly comparable, but the relative classification of different configurations should be equivalent. The verification of daylight provision is assessed for a set of 124 cases which are considered representative for residential buildings in Belgium and Luxemburg. The main purpose of this study is to verify the simplified evaluation method using the Daylight Evaluation tool and to check results against those obtained through a detailed evaluation with Daylight Factors, according to EN 17037.
A sensitivity analysis is carried out to identify the effect of several parameters on daylight provision in an indoor space. One of the main findings is that some parameters have significantly more impact than others. The total area of daylight openings, the light transmittance of glazing and the room depth are obviously important factors. But external obstruction due to site conditions are certainly as essential and frequently overlooked. Masking elements, on the other hand, are relatively less impacting, except for unusual situations, such as extreme protruding elements in relation to the size of the daylight openings.

The main finding of this study is that the simplified method for assessing daylight provision as proposed in the 'Daylight Evaluation' tool is an easy and reliable estimation for daylight provision. A comparison of the simplified tool with daylight simulations show a high correlation and the tool is applicable for any case which has conditions matching closely to the models and situations defined.
Session 15: Indoor exposure and health

**Paper 15.1: **Measurements of indoor air quality in schools

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**Keywords:** School, CO₂, formaldehyde, TVOC, PM

Children spend a minimum of six hours per day in Norwegian schools. Their exposure to different indoor air quality is known to affect their performance. It is very common to use demand-controlled ventilation (DCV) in schools as is estimated to save about 50% of the conventionally used energy for ventilation. CO₂ and temperature are the preferred control parameters. Usually, it was expected that these human-centric controls resulted in high indoor air quality as occupants are the largest source of contaminants. This study presents measurements for two months to up to one year in the supply and room air in the four classrooms whose ventilation is CO₂-based DCV. Using low-cost sensors formaldehyde, PM1, PM2.5, relative humidity CO₂ and temperature were monitored.

Even when the CO₂ concentration lied below 1000 ppm 1) the concentration of formaldehyde surpassed the recommended WHO thresholds in 30% of the time and 2) RH is below 20% during 56% of the time.

**Paper 15.2: **Inflammatory effects of exposure to different stone types used in Norwegian asphalt

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**Keywords:** Human exposure chamber, non-exhaust emissions, inflammation, urban air pollution, source control

During the winter in Scandinavian countries, up to 90% of traffic-related particulate matter (PM) is from non-exhaust emissions sources such as asphalt wear. Measures to reduce urban PM have focused mainly on exhaust emissions, while the contribution from asphalt has received less attention. In vitro studies suggest that the composition of asphalt can affect the inflammatory potential of road dust. Using a whole-body human exposure chamber, we have explored whether different stone materials used in Norwegian asphalt impose different inflammatory reactions in plasma of healthy volunteers. Our results show no acute increases in the inflammatory markers SP-D, P-selectin, or CC16. However, quartz diorite induced an apparent increase in ICAM-1, not seen for rhomb porphyry or placebo dust (lactose). Although this did not reach statistical significance, it resembles previously observed fibrinogen-effects, and may suggest that different types of stone minerals provoke different inflammatory reactions in humans compared to placebo dust.

**Paper 15.3*: **FireDAVG – Fire related Damages with Attention to Vulnerable Groups. Guidance for vulnerable groups on handling of fire, soot, and smoke related damages in indoor environment.

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The Norwegian Asthma and Allergy Association, Norway

**Keywords:** Fire, soot, dwellings, IAQ, counseling

The Norwegian Asthma and Allergy Association (NAAF) has received numerous counseling requests to assist people in vulnerable groups in relation to fire damaged homes. Some were in the process of having their homes repaired, and others reached out for help when their ailments or disease worsened after repairs had been made. Damages from fire, flue gases and soot deposits affect the indoor environment, and proper measures must be taken to repair such complex damages to ensure a healthy outcome when the home is restored.

These requests inspired the development of an online resource catalog (FireDAVG) offering neutral public advice to better prepare homeowners to take actions before, when and after a fire incidence has occurred. FireDAVG is publicly available
and compiled by sourcing information and advice necessary to offer guidance to the reader. Emphasis have been made on documenting assets, construction methods, measures, and maintaining constructive dialogues between the parties.

* Extended abstract for Paper 15.3 is available at the end of this book.

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**Paper 15.4*: Trihalomethanes in indoor swimming pools: estimating exposure and assessing carcinogenic risk among non-competitive attendees**

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**Keywords:** Indoor swimming pools, Multiple exposure pathways, Carcinogenic risk

Health risk estimation for exposure to trihalomethanes (THM) in indoor swimming pools would represent a useful tool for public health management. The aim of this study was to estimate the carcinogenic health risks from exposure to THM through multiple pathways among non-competitive swimming pool attendees.

According to the results of this study, chronic daily exposure for total THM considering all pathways (ingestion, dermal absorption and inhalation) for male and female participants was $5.19 \times 10^{-3}$ and $3.15 \times 10^{-3}$ mg/kg/day, respectively ($p=0.073$). Inhalation was found to be the most relevant pathway and chloroform was the compound contributing the most to total THM chronic daily exposure. The mean values of lifetime cancer risk (LCR) for total THM and through ingestion, inhalation and dermal contact was found to be higher than U.S. EPA acceptable value ($1 \times 10^{-6}$) for both genders.

* Extended abstract for Paper 15.4 is available at the end of this book.

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**Paper 15.5*: Oxidative stress in individuals with Building Related Intolerance after exposure to acrolein**

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**Keywords:** Oxidative stress, acrolein, controlled exposure chamber, Heart rate variability, Glutathione

This paper addresses a possible association between exposure to the reactive indoor air pollutant, acrolein and markers of oxidative stress in individuals with building related intolerance (BRI).

Individuals with self-reported BRI ($n=21$) and controls without BRI ($n=16$) were exposed in an exposure chamber. Participants were exposed twice (80 min) to heptane and a mixture of heptane and acrolein at a dose below previously reported sensory irritation thresholds.

Data from previous studies points towards the importance of acrolein in relation to indoor air health. Preliminary analysis of data from an on-going study show that individuals with BRI have a significantly lower HRV and lower GSH/GSSG ratio during/after exposure to acrolein. The results indicate increased oxidative stress in individuals with BRI due to exposure to acrolein. Whether measures of oxidative stress can be used as a predictor of BRI needs to be further studied.

* Extended abstract for Paper 15.5 is available at the end of this book.

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**Paper 15.6*: Particle exposure of cooks in commercial kitchens**

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bba binnenmilieu, The Netherlands

**Keywords:** Kitchen ventilation, Air quality, Particulate Matter, Health, Cooking, Laboratory study

Cooking is a major source for particulate matter exposure indoors. Especially smaller particles (<2.5 micron, PM2.5) are known to negatively affect health. Therefore a good exhaust system in a kitchen is important to reduce the exposure to fine particles. Particularly in commercial kitchens of restaurants, where cooking is a continuous activity, adequate ventilation is important to prevent the chefs and other personnel from being exposed to high particle concentrations during their workday. For this reason, we studied the influence of different exhaust systems and the influence of the preparation of different meals on the chef’s exposure to PM2.5.

The study was carried out in the laboratory of Halton (Béthune, France). During the experiments PM2.5 was measured continuously in the breathing zone of the chef, using a personal device provided with the inlet at the collar of the chef, and at two
locations in the room. The influence of the type of meal (Hamburgers, Pancakes, Chinese wok) that was being prepared was tested using a canopy hood at two different settings (“high” and “low”). The influence of the type of hood (Canopy and Backshelf) was tested at a “high” and “low” setting when using hamburgers on a grill. The measured concentrations were compared with the WHO limit for general public health (25 µg/m3) and the WELL building standard limit for commercial kitchens (35 µg/m3).

For the “high settings”, the results revealed that the concentration in the room remained low (below 25 µg/m3 for >99% of the time) for all meals prepared. On the other hand, in the breathing zone of the chef, the WHO limit of 25 µg/m3 was exceeded 23% of the time. Peak values reached 528 µg/m³ in the breathing zone when baking pancakes, but were considerably lower when baking hamburgers (30 µg/m³) and stir frying (149 µg/m³). The highest PM concentrations were measured in the breathing zone when using the Backshelf hood without the capture jet (“low setting”), median value of 384 µg/m³.

It was concluded that both hoods were very effective in reducing the PM-concentration when used in the high setting. Still the chef was exposed to increased PM2.5 concentrations (>25µg/m³) during cooking, mainly caused by movements of the head of the chef above the stove or grill. The lower setting of both hoods reduced the efficiency significantly, thereby demonstrating the need sufficient exhaust ventilation in commercial kitchens.

* Extended abstract for Paper 15.6 is available at the end of this book.

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**Paper 15.7**: Downscaling from material flow analysis to indoor CFD for health risk assessment associated with DEHP exposure

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Keywords: Material flow analysis, Computational fluid dynamics, Inhalation exposure, DEHP

INTRODUCTION: Personal exposure to indoor air pollution and consequent health impacts must be assessed for creating a healthy indoor environment; field measurement for a specific space is considered a reasonable method for determining the current situation of indoor pollution. Furthermore, the long-term and extensive health impact of indoor air pollution is also important in terms of facility management of buildings. To reveal and visualize the potential hazards of indoor pollution by chemical compounds, an integrated and continuous framework is needed for assessing the extent of pollution, from macroscopic chemical contamination to microscopic individual exposure.

METHOD: In this study, we propose a numerical method for health risk assessment that integrates inhalation exposure analysis using a computer-simulated person and computational fluid dynamics (CFD) with material flow analysis (MFA). We targeted di(2-ethylhexyl) phthalate (DEHP), for which indoor concentration guideline values (100 µg/m3) have been established in Japan. Eleven types of DEHP-containing products, for example, plasticizer, were selected and dynamic MFA in the life cycle of production, manufacturing, use, disposal, and recycling was conducted using the DEHP production data in Japan and the life function considering the product lifetime data. Based on the MFA results and statistical data in Japan, we conducted an integrated analysis of CFD and computer-simulated person for DEHP inhalation exposure using the estimation result of the total accumulation per house in Japan. In this integrated analysis, the target room was assumed to be covered with wallpaper containing DEHP. The DEHP emission rates from building materials were measured via micro-chamber method ISO 16000-25.

RESULTS: We estimated the amount of long-term domestic accumulation of DEHP by MFA. The amount of DEHP accumulated in Japan increased after the 1950s but reached a maximum value of approximately 2.7 million tons in 1997. After this peak, it decreased monotonically to approximately 1.8 million tons in 2019. This can be converted from a mass-term domestic accumulation to an area-based value, and the results indicated values of 2.3 × 109 m2 (25% of the total) for the general film sheet, 4.8 × 109 m2 (53%) for wallpaper, and 7.7 × 108 m2 (5.3%) for the floor material. As a result of the integrated analysis of CFD and computer-simulated person for a general residential house, the room averaged concentration of DEHP was estimated to be 43.3 µg/m³ under the worst-case scenarios.

* Extended abstract for Paper 15.7 is available at the end of this book.

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**Paper 15.8**: Thermal Comfort and Occupant Adaptive Behaviours in Naturally Ventilated Hospital Wards in a Hot-humid Post-epidemic Context

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Keywords: thermal comfort, occupant adaptive behaviour, hospital ward

Naturally conditioned hospital buildings comprise a significant part of the healthcare infrastructures in countries with the weakest public health systems. In these hospitals, unmet space-cooling demand being driven not only by the accelerating climate crisis but also by higher medical care expectations as the COVID-19 pandemic escalates could cause severe indoor overheating. To date, we lack a comprehensive understanding of human thermal adaptability in naturally ventilated inpatients facilities. Building on the complex links between thermal comfort and occupant adaptive behaviours as these unfolded in real-time in eight naturally
ventilated multi-patient wards, this paper aims to explore how occupant behaviours can mitigate critical differentiation in overheating and airborne infection exposures among hospital occupants. A mixed-methods longitudinal survey, which was co-designed with health workers, was conducted with 771 hospital occupants during the rainy and dry seasons over fieldwork of nine weeks at the main tertiary hospital in a post-epidemic context. The collected dataset, which consisted of physical (7,933 hours) and subjective measurements (45,000 data) and window-opening behaviours (1,914 photos), was analysed using predictive correlations, probit regression, CFD and narrative analysis. The findings revealed that nurses directed the operation of the building-controls. Comparisons between reported and observed, individual adaptive behaviours showed that nurses drank water, visitors moved to cooler places and patients asked for help. Occupant-controlled window operation was irresponsible to outdoor and indoor environmental fluctuations with median changes between shifts standing at 0.00% (SD=2.69). Nurses were exposed to higher air velocities (t-test effect size: 0.42, 95%C.I.=0.27-0.57, p-value<0.001). Whereas severe, frequent, and prolonged nighttime overheating (>4K over more than 50% of the monitoring period) was modelled according to adaptive thermal comfort indexes (ANSI/ASHRAE Standard 55:2017), daytime thermal discomfort was overestimated. Reported thermal comfort was defined by lower tolerance levels to elevated temperatures during the warm season (Top: 28.20–29.38°C) and higher relative humidity levels during the rainy season (R.H.:66.25%–67.50%) with older patients expressing higher sensitivity. Occupants' preferences for higher indoor airflows (0.90 m/s) displayed minor seasonal variation. Thermal comfort restoration among patients and visitors was strongly linked with water and food consumption (Cramer's V coefficient: 0.50-0.66, p-value<0.001). In the strictly regulated hospital environment, where physiological and behavioural adaptive capacity among patients, staff and visitors differs, and the effectiveness of natural ventilation in the dilution of airborne pollutants remains highly unstable the integration of occupant adaptive behaviours in established safe practices of healthcare can alleviate unequal vulnerabilities while strengthening climate-resilient and zero-carbon hospital operations.

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**Paper 15.9**: A method to visualize and quantify "aerosols" of outwards leakage around the perimeter of barrier masks.

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**Keywords**: masks, COVID-19, leak visualization, fluorescence

Wearing a barrier mask has become obligatory in most countries due to the surge of SARS-CoV-2. Barrier masks are designed as a preventive measure to protect people surrounding the wearer, in case the wearer is a carrier of the virus. This type of mask has been encouraged to be worn by the public over medical masks, and companies have capitalized on the public’s need to wear them to put on the market a wide range of masks.

Official guidelines exist in certain countries specifying different types of tests to be performed on masks, such as visual inspections (tears, looseness, fit, etc.), filtration, resistance material for daily wear, and filter breathing resistance. However, tests specific to the performance and leakage through the face seal perimeter of the mask or fit tests have not been specified in guidelines yet.

The aim of this study is to design a method to visualize and quantify ‘mist’ exhaled by a mask wearer, to assess the outward leakage of barrier masks.

A setup was designed by using a Styrofoam head that was carved to mimic an adult head’s respiratory cavities, and was connected to a breathing apparatus that imitates the human exhalation rate. A container with a solution of 9 parts of water to 1 of fluorescent tracing liquid acted as a chamber where the fluorescent mist was built up with the use of an ultrasonic mist maker. Ultrasonic mist makers are devices generally used to create fog for indoor humidifiers. Six UV lights were set pointing at different areas surrounding the head, and a GoPro Hero 8 camera was used to record the exhaled fluorescent mist.

Fourteen different masks were used having footage from the front and the side. The footage was recorded during 2 minute runs of exhalations, in which one picture was taken every two seconds. For the analysis, a two-step process took place: 1-background subtraction was performed with FFmpeg, in order to highlight the moving mist and eliminate the static background, and 2-the resulting images were statistically analysed, by clustering the colours (mist vs background) and producing a percentage of mist on the frame.

T-tests were performed to compare the means of the runs in order to validate the reproducibility and reliability of the method. The results show that the method is promising in quantifying and visualizing leakage, however, the surrounding conditions of the setup need to be well controlled.

* Extended abstract for Paper 15.9 is available at the end of this book.
Paper 15.10*: Analysis of workers’ tendency to answer questionnaires of positive and negative questions, along with understanding the relationship between comfort and self-efficacy

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Keywords: questionnaire survey, airborne radiant air conditioning, self-efficacy, multiple regression analysis

In recent years, in Japan, the view that environmental, social, and corporate governance considerations are necessary for corporate management and growth (e.g., ESG) has become an important element in architecture, and the need to reduce environmental impact while ensuring user comfort, health, and resilience has become a necessity.

Current indices for measuring comfort include thermal environment assessment such as the predicted temperature and cold declaration PMV and standard effective temperature SET*. However, these indices are used in the steady state, and it should be noted that there are many points to be considered when these indices are used directly as an evaluation index in the non-steady state, such as the actual office space, where the spatial components are constantly changing. Therefore, it is effective to ask the workers directly to measure the comfort of the office in a realistic way.

In order to improve the comfort of the office, it is necessary to extract workers' complaints about the office environment from these backgrounds, and it is important to conduct questionnaires focusing on the psychological elements of workers, their living and working patterns, etc. in addition to measuring the physical environment elements. However, human beings sometimes unconsciously understand the intentions of others and act in response to them. Even in response to questionnaires, they are unable to collect accurate opinions, for example, they try to predict the purpose of the research and respond in the better direction. This is called a demand characteristic. It is important to take measures against the demand characteristics and to collect accurate opinions from the administrators. Therefore, this study reports the results of understanding and evaluating the physical and psychological characteristics of office workers by using several questionnaire methods, focusing on the changes in the psychological quantity of individual workers. In addition, actual measurements of the physical environment are conducted for two consecutive years and the results of the actual measurements are compared. The purpose of this study is to understand the characteristics of the change in the psychological quantity of the workers and to consider the relationship between the change and the thermal environment.

* Extended abstract for Paper 15.10 is available at the end of this book.

Paper 15.11: Improving the indoor thermal environment with ceiling radiant terminals

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Keywords: radiant air-conditioning, thermal environment, air temperature, PPD index

A CFD (computational Fluid Dynamics) simulation model of the porous ceiling radiant air-conditioning system was established to study the influence of the ceiling temperature and envelope temperature (including the temperature of the walls and the floor of a room) on the thermal environment in the room equipped with such a system. The results showed that, for the summer condition, higher ceiling temperatures would result in higher indoor air temperature and higher Predicted Percentage Dissatisfied (PPD), which meant potential discomfort of occupants in the room. For the winter condition, however, a higher ceiling temperature within 28°C would result in a lower PPD, thus improved the thermal comfort. Considering the energy-conservation, the thermal comfort could be assured if the ceiling temperature was not more than 28°C. As for the effect of envelope temperature, the result showed that the increase in the envelope temperature during summer could result in a higher indoor air temperature, but the thermal comfort of occupants could still be ensured under such condition. Considering both the thermal comfort and the energy-conservation, a ceiling temperature of 18°C (underside surface temperature of the ceiling) and an envelope temperature between 26°C and 32°C were proved appropriate for the summer. Similarly, based on the simulation results, a ceiling temperature of 26°C, and an envelope temperature between 8°C and 11°C were found appropriate for the winter. The results indicated that for the porous ceiling radiant air-conditioning system, ceiling temperature should be controlled to increase the ratio of radiant heat transfer in the summer, and the envelope temperature should be lowered to improve the energy-conservation of the system. In the winter, the heat transfer by radiation of the porous ceiling would account for a larger ratio, therefore the system showed good heating capacity and energy-conservation performance in winter.
Paper 15.12*: The effect of thermal conditions during working hours on thermal perception at home – methodological considerations

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Keywords: thermal comfort, thermal perception, sleep quality, air-conditioning, naturally-ventilated

People working in public and commercial spaces are often exposed to thermal conditions that differ greatly from naturally occurring outdoor temperatures. For example, in Central and Western European summers, when outdoor temperatures rise above 30°C, the gap between thermal conditions during daytime working hours indoors (often ~21°C, according to ASHRAE 55 recommendations), and thermal conditions outdoors or in residential buildings, can easily be greater than 10K. Large temperature differences likely affect thermal perception when people return home after work, as most dwellings in this part of the world are naturally-ventilated (NV). Consequently, thermal conditions outside air-conditioned (AC) spaces are likely to be perceived as less comfortable and warmer in the evening after exposure to cool conditions during the daytime. In contrast, people working in NV spaces (or even outdoors) will benefit from natural acclimatization effects, and be less affected by large differences in thermal conditions during and after work. The discrepancy in thermal exposure during daytime may also have an effect on sleep quality in people working in AC vs. NV buildings.

While long-term (seasonal) and acute, short-term effects have been studied in the past, information regarding the above-mentioned medium-term effects is lacking. The present study seeks to close this gap by evaluating the effect of cool versus warm conditions in a simulated office environment, representing a workday in an AC vs. NV building, on thermal perception and sleep quality at home.

In the process of setting up the study protocol, a series of methodological questions have arisen. To achieve statistical power, a group of 40 healthy participants between the age of 18-45 will have to be recruited for the experiment. The study will consist of two parts: a simulated workday at the Aachen Work Place Simulation Laboratory, and subsequent field observations at the participant’s private homes. All participants will undergo one cool (21°C) vs. one warm (28°C) condition, representing an AC and an NV office day. To perform laboratory and field measurements with a group this large, within a time frame of three months (summer season), 6-7 participant measurements have to be conducted per week. Hence, aspects concerning monitoring intensity, availability of measurement tools, finances, time management, and potential confounding variables have to be balanced against each other.

Within the scope of this conference presentation, methodological considerations, and decision-making for the present study set-up will be elaborated on and discussed.

* Extended abstract for Paper 15.12 is available at the end of this book.
Session 16: Indoor epidemiology


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**Keywords**: Covid-19, sick leave, disability retirement, design research, literature review.

**BACKGROUND**: The Covid-19 pandemic has led to changes in how office work is carried out. Flexible and open office concepts that have seen rising popularity in past years are now called into question regarding risk of infection. This has merged with the pre-pandemic discussion regarding office concepts’ risk for sick leave and disability retirement, creating an increased focus on how office concepts influence the health of employees.

**AIMS**: Our paper summarizes international empirical research on the connections between working in flexible or open office concepts, and the risk of sick leave and/or disability retirement.

**METHODS**: Relevant studies were identified from existing literature overviews on the topic, database searches using PubMed and Google Scholar, contact with experts in the field, and reference lists. The quality of the evidence has been assessed according to GRADE (very low, low, moderate, and high levels of evidence quality).

**RESULTS**: We have identified seven relevant empirical studies. As compared to cell offices, we found:

1. Very low evidence for increased risk of sick leave among employees working in flexible office concepts. This risk is possibly higher for men than for women.
2. Low evidence for an increased risk of sick leave for employees working in open office solutions, with a potential higher risk for women than for men.
3. No basis to conclude regarding risk of disability retirement for employees in flexible office concepts.
4. Low evidence for increased risk of disability retirement for employees working in open office solutions.

Additionally, there was no basis to conclude regarding differences in sick leave or disability retirement risk between open-plan offices of different sizes.

**DISCUSSION**: The evidence on these topics range from absent to being of low quality. There is need for more research on these issues, and on the specific factors that could influence the health of the large global population of office workers.

The Covid-19 pandemic has led to an increased awareness of work-related infections, and virtual meetings and the number of office workers working from home have increased significantly. In future assessments of office concepts, we believe that the opportunities and challenges of flexible use of workspaces in offices and at home, including virtual meeting places and new ways of organizing work, must be considered.

*Extended abstract* for Paper 16.1 is available at the end of this book.

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**Paper 16.2**: How well are health institutions prepared for pandemics, in terms of ventilation and protective equipment?

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**Keywords**: Pandemic, ventilation, respirator protective equipment

To deal with a pandemic, health institutions require, among other things, good ventilation and the necessary protective equipment. But how good is the ventilation in health care institutions today? Many institutions have existing rooms for isolation of patients with a high risk of infection. But how is the focus on ventilation if premises need to be reallocated to handle high-risk infection?

It seems that there has been little discussion on this topic regarding covid-19. I will discuss recommended air exchange versus actual air exchange in examples from some health institutions.

A pandemic causes abnormally high consumption of respiratory protection and protective equipment. This can lead to a shortage of personal protective equipment. To ensure good access to respiratory protection in a situation of shortage, health institutions should facilitate the use of reusable respiratory protection (masks). I will discuss disposable mask versus reusable mask during a pandemic.

Reusable masks require locations that enable their maintenance, cleaning and disinfection. These localities most likely do not exist, and this requires plans for alterations / developments. I will discuss whether it will be possible to facilitate such developments.

This presentation will focus on these issues as well as look at what solutions can be found.
Paper 16.3: Impacts of the indoor environment in our homes and schools on child health: A novel analysis using the EU-SILC Database

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1 RAND Europe; 2 VELUX A/S

Keywords: Unhealthy Homes, Children, Schools and Sick days, Economic Benefits, DALY

Today, more than 26 million European children are living in unhealthy homes putting them at higher risk of experiencing health problems. Good air quality, sufficient access to daylight and adequate ventilation are important for creating a healthy indoor environment in any home, with the effects reaching far beyond childhood. Our research is based on analysis of the Eurostat microdata from the EU-wide survey “Income and Living Conditions in Europe” (EU-SILC). The results show that mould and dampness, as well as poor ventilation, can take a child from good health to poor health with links to higher levels of asthma, allergies, eczema, and lower and upper respiratory conditions. A growing number of children are burdened with ailments that challenge their ability to be present and fully engaged at school. Across Europe, the prevalence of children affected by asthma has become an increasing problem in the last few decades. It is not just childhood health that is affected by poor indoor climate. Unhealthy home environments can result in higher absence from school and work, putting a greater strain on both children, parents and the economy. Tackling the unhealthy homes in which a third of European children live and the many unhealthy schools and day-care centres they attend, is an opportunity to improve the health and quality of life of the most vulnerable Europeans. Furthermore, it is also an opportunity to improve societies, deliver on our energy and climate commitments and address inequalities, while saving money and valuable resources at the same time.

Our study has found that a significant proportion of children in the EU-28 are exposed to one or several indoor climate hazards. In summary, if in all dwellings reporting damp, noise, excess cold and/or lack of daylight those respective deficiencies were removed, the health of more than 1 million children (aged 0–15) in the EU could be improved. The burden of disease from indoor damp and mould exposure of children in relation to asthma, atopic dermatitis, as well as respiratory infections is 37,500 disability adjusted life years (DALYs) for the EU as a whole. The total number of school days missed by children across the EU that is attributable to the prevalence of damp and mould in their homes is 1.7 million.

Paper 16.4*: Indoor Exposure to Fine Particulate Matter and Practical Mitigation Approaches - a U.S. National Academy of Sciences Workshop

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Keywords: PM2.5, exposure, health, mitigation

Particulate matter (PM) dominates the known health impacts of air pollution. Most exposure to PM from both indoor and outdoor sources takes place in indoor environments, a circumstance exacerbated by the COVID-19 pandemic. Exposure to fine particulate matter (PM2.5) is especially concerning because a large and growing body of scientific literature indicates that it is associated with adverse health outcomes, including cognitive effects.

In response to a request from the U.S. Environmental Protection Agency, the National Academy of Engineering of the National Academies of Sciences, Engineering, and Medicine is convening scientific experts in a workshop that will address the state-of-the-science on exposure to fine particulate matter indoors, its health impacts, and engineering approaches and interventions to reduce exposure risks, including practical mitigation solutions in residential settings. The workshop will feature invited presentations and panel discussions on these topics. It will include consideration of:

1. the key implications of scientific research and engineering practice for public health, including potential near-term opportunities for incorporating what is known into practice; and
2. where additional research will be most critical to understanding indoor exposure to PM2.5 and the effectiveness of interventions.

Opportunities for advancing research by addressing methodological and technological barriers and enhancing coordination and collaboration between the science, medical, and engineering communities will also be given attention. The workshop will take place in Spring 2021 and will be broadcast live over the internet to facilitate international participation. Videos of the sessions and copies of the presentations will be posted to the ‘net for later reference. A proceedings summarizing the workshop will be released in Summer 2021.

The paper and conference talk will summarize the results of the workshop, reviewing the issues regarding indoor PM exposure and health, identifying the major unknowns, the research needed to resolve them, and the measures that can be taken to mitigate adverse effects. Information on a second National Academies study regarding the emerging science on indoor chemistry will also be presented. As the workshop has not yet been held and the indoor chemistry study has yet to begin, it is not yet possible to provide further detail regarding the content.

* Extended abstract for Paper 16.2 is available at the end of this book.
Paper 16.5: **Robust and reliable deep renovation by advanced prefabricated façade elements. Air-tightness performance and assessment of a demo case**

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**Keywords:** Deep renovation, prefabrication, air-tightness

Deep renovation of the existing building mass is an important task to reach the target of energy efficient buildings and neighbourhood.

However, the current renovation rate is only 1% of the European building stock each year, and barrier for increased rate must be addressed. Attaching prefabricated elements with integrated technologies such as photovoltaic panels or ventilation equipment to the façades and roofs can improve energy performance and indoor climate as well as provide local renewable energy supply. The construction period can be short, with limited disturbance to building usage.

The project 4RinEU has developed and demonstrated solutions suitable for several climates. Building airtightness of the renovated buildings is an important design goal of the refurbishment, and is determined by blower-door tests before and after renovation.

This paper presents air-tightness results from a demo case study in Norway. In the demo case the airtightness as determined by blower-door tests quite unexpectedly deteriorated, while the design goal for the projects was a major improvement. Probable causes for the discrepancy are discussed, and include leakage from the ground, in element joints and in unplanned openings.

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Paper 16.6*: **Longitudinal characterization of the human personal cloud effect associated with gaseous and particle pollutants in Switzerland**

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**Keywords:** personal exposure assessment, continuous monitoring, particulate matter, carbon dioxide, volatile organic compounds, source apportionment

Exposure to elevated levels of air pollutants such as particulate matter (PM) and gases is associated to detrimental health effects and decrease in work performance. Increasing research efforts are dedicated to assessing personal exposure by using ambient stations as proxies, however, this method often poorly resembles the air we breathe indoors since it cannot account for the effect of personal activities and the proximity to indoor sources. Studies in the past identified the personal cloud effect which suggests an increase of air pollutants' concentration inhaled compared to those detected by stationary monitors. Hence, it is essential to understand exposure at the individual level in order to assess and mitigate air pollutant exposures.

In this study, ten participants were monitored during five consecutive days by concurrent measurements in the breathing zone and stationary level in their homes and offices. Real-time data were obtained for particulate matter (size range 0.3-10 µm) and carbon dioxide, while integrated samples were collected for particulate matter of size smaller than 10 µm (PM10), volatile organic compounds (VOCs) and aldehydes for chemical analysis. In addition, a time-activity diary phone-app was used by the participants to record their location and activities. The results show that personal exposures to PM10 mass were consistently higher than indoor ambient concentrations for all participants in the home and the office. The personal PM10 cloud magnitude varied between 5-25 µg/m³. Correlations between personal and ambient stations were sensitive to the stationary monitor location in the home environment; the ambient station displayed a stronger correlation with the personal station when it was located in the bedroom than in the living room. Additionally, a source apportionment analysis was done for personal and ambient PM10 samples and six types of sources were identified. An overall of 33 compounds were detected from the VOCs and aldehydes in the sampling locations. The personal cloud magnitude was less pronounced or absent for gaseous pollutants relative to particulate matter. Through spatially and temporally resolved measurements of individual level exposures this study examines the diversity and variation of multiple air pollutants and presents insights that can be useful for enhancing the exposure prediction to indoor air pollutants.

* Extended abstract for Paper 16.6 is available at the end of this book.
Session 17: Odour and emissions

Paper 17.1*: Achieving a healthy indoor air by using an emissions barrier

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**Keywords:** Emissions, barrier, air quality, remediation

Spread of chemical and biological emissions from construction materials of a building into the indoor air may result in symptoms such as asthma, skin and eye irritation, fatigue etc. Here we report the use of an emissions barrier developed at Lund University Sweden for stopping and binding such emissions without affecting the building structure (Markowicz P, Larsson L, Atmospheric Environment 106 (2015) 376-381). We describe three premises with complaints on the indoor air quality where installing the barrier resulted in decrease or disappearance of measured as well as perceived emissions.

1. A townhouse where the tenants suffered from symptoms (itchiness) when staying at home was studied. A PVC flooring had been glued onto a concrete slab which had become moist through diffusion of water from the ground. The air concentration of 2-ethylhexanol, a compound formed from hydrolysis of glue and/or phthalates of PVC floorings, was 63 µg/m³ (directional measurement). The barrier was attached onto the existing flooring, and the symptoms disappeared. 3 months after barrier had been installed the air concentration was 1.5 µg/m³, a value which persisted in a follow-up study 6 years after installation - and the residents still reported no symptoms.

2. There was a disturbing smell in a wooden summer house built in 1964 which had been treated with chlorophenol-containing preservatives. At moist conditions chlorophenols may be bioreacted to form chloroanisoles having an intense mouldy odour. The ceiling, walls and floor in the bedroom, but not in the living-room, were covered with the barrier. Tetrachlorophenol, trichloroanisole, and pentachloroanisole were detected in the air of the living-room, but only tetrachlorophenol was found in the bedroom, at an air concentration 93% lower than in the living room. Also, the mouldy odour in the bedroom disappeared.

3. A building where a creosote-based tar layer had been attached onto the concrete slab as a moisture barrier was studied. The air concentration of polycyclic aromatic hydrocarbons (PAH) indoors was 1726 ng/m³ air. A disturbing PAH smell inside the building persisted even after the tar had been removed. After the barrier had been installed, on about 75 percent of the wall surface, the smell disappeared and the PAH air concentration decreased to 139 ng/m³ thus corresponding to a reduction of 92%.

In summary, use of an emissions barrier may provide an efficient, economic, quick, and environment-friendly way of ensuring a healthy indoor air.

* Extended abstract for Paper 17.1 is available at the end of this book.

Paper 17.2: Odour problems in buildings - the result of 682 cases

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**Keywords:** odour, sources, survey

Various odours can cause a negative perception of the indoor air quality. The intensity of the odour fluctuates for example due to weather conditions, ventilation, and use. In addition, the degree of odour perception among inhabitants is highly variable. Absence of an adequate measuring method make it difficult to get a systematic and uniform description of the odour and where in the building the odour is most noticeable. This leads to challenges in clarifying the causes and relevant measures are often difficult to submit.

Examination of 420 cases with odour in dwellings and commercial buildings have shown that causes and remedial actions can be revealed by a systematic procedure. Those who complain are asked to characterize the smell in few, standardised words and describe where and when they experience the odour. This process normally takes from a few days to several weeks. The preliminary information is often crucial for the surveyor when performing the following building examination. In cases where the cause of the odour is detected, relevant actions is performed to eliminate the odour-source and thus the problem. Our surveys have shown that odour problems can be divided into seven main groups depending on the cause of the odour. These are in declining extent: mould and actinobacteria, sewage system, dead rodents, moist building materials, smoke, urine, and heating oil. In addition, there is a residual group of odour problems of unknown origin. Some odour problems were caused by a combination of several sources.

Intensity of odours reduces through time by natural decomposition. In cases where this process is time-consuming, active measures are needed. Which measures depend on the source of the odour, material properties and building physics. The optimal solution is removal of the odour source. Where this is not possible, a thorough cleaning can have a satisfactory effect. Use of ozone or products with odours to mask the problem usually have limited lasting effect.

Measuring odour is difficult and complicated for various reasons: the human olfactory organ is extremely sensitive and even small particles or molecules can be detected by the human nose. The results of for instance chemical measures such as VOC (volatile organic compounds), normally give a low result despite a distinct smell at the location. Chemical measures on a molecular level can be carried out, but the result is in most cases hard to interpret and rarely lead to the actual cause of the odour.
Paper 17.3*: The effect of Relative Humidity on the Emission of Volatile Organic Compounds (VOCs) from Building Materials

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Keywords: Building materials, CLIMPAQ, relative humidity, VOCs

The presence of Volatile Organic Compounds (VOCs) in indoor environments affects greatly indoor air Quality (IAQ) and can cause severe human health effects. Building and consumer materials are considered a major source of VOC emissions. The internal structure of walls in France is mainly composed of vapor barrier for damp proofing, thermal and acoustic insulating material, and plasterboard for fire protection and insulation which are potential sources of indoor VOCs. Moreover, the emission of VOCs from these materials is many-factor dependent among which relative humidity (RH) has a significant effect. Recently, bio-based insulations have been replacing conventional ones for their lower energy consumption during production; however, studies on their emissivity at different RH values are still not well developed.

The effect of RH on the emission of VOCs from commercially bought vapor barrier, glass and wood wools, and plasterboards has been characterized in this study. This was done by placing each material in the CLIMPAQ at 50% RH for 28 days and then increasing RH to 85% for another 28 days. VOCs and aldehydes measurements took place based on the ISO 16000 series.

A total of about 90 compounds was identified and quantified from the different materials including aldehydes, ketones, carboxylic acids, terpenes, and microbial VOCs. Among the studied materials, wood wool, which is the only bio-sourced material, is the most emissive where the emission rate (ER) of Total VOCs (TVOCs) is 69.8 µg/m².h at 85% RH, followed by the vapor barrier (64.6 µg/m².h), plasterboard (47.8 µg/m².h), and glass wool (2.3 µg/m².h). Moreover, the emission of VOCs and aldehydes from these materials was greatly affected by the change in RH. ERs of TVOCs and carbonyls emitted from the four materials were multiplied by about 2 to 10 times upon increasing RH from 50 to 85%.

Building products constitute a major source of indoor pollutants, especially at high humidity levels. Moreover, even if bio-sourced insulating materials might be energetically a good substitute for mineral-based materials, their impact on IAQ must be taken into consideration.

* Extended abstract for Paper 17.3 is available at the end of this book.

Paper 17.4*: Further Development of Odour Testing of Building Products – Sample Presentation and Evaluation of Perceived Intensity

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Keywords: odour, ISO 16000-28, perceived intensity, sampling containers

The indoor air quality is affected among other by the emission of volatile organic compounds (VOC) or the odour from building products. Odours can be measured by applying the standard DIN ISO 16000-28 (2020) "Indoor air - Part 28: Determination of odour emissions from building products using test chamber".

In the study presented here proposals for further technical development of the ISO 16000-28 (2020) method should be prepared. Especially the sampling procedure (1) and the evaluation method (2) of the perceived intensity are examined because they have a major influence on reproducibility of measurement results.

(1) Sampling procedure: Since the ISO was revised end of last year, the standard procedure for odour assessment by using containers is established. Direct assessment is with most common test chambers with volumes up to 1 m³ not possible because they are typically operated with an air outlet of less than 0.14 L/s. Due to the fact that 0.6 to 0.9 L/s is necessary for odour measurements this is not enough. An adapter for air sample collection and presentation to the panel will be developed, built and tested. The aim is to shorten time between sampling and presentation and to avoid transport of sensitive air samples, what can reduce measurement errors.

(2) Evaluation method: In Germany the AgBB demand a pi value of 7 pi for products to be suited for the indoor use. A method to simplify the evaluation of perceived intensity on a comparative scale is examined to test its suitability. The results shall help to increase acceptance of the evaluation with perceived intensity and to be able to determine odours from building products more and more precise by following objective evaluation criteria. The research topic and first results will be presented at the conference.
**Paper 17.5**: Discerning relative humidity trends in vernacular and conventional building typologies for occupant health

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**Keywords**: Moisture, Occupant health, Vernacular Dwellings, Earthen Construction, Quality of Built environment

The indoor built environment has a significant impact on the occupant's physiological, psychological, and behavioral health. Moisture is an important parameter that has a direct bearing on the quality of a built environment. Commonly referred to as water, moisture impacts nearly all dimensions of a building's functional performance, i.e., structural, durability, thermal, acoustics, indoor air quality, ventilation/freshness/odor, aesthetics, and also influences the health of occupants. Very high humidity can cause physical and chemical deterioration of materials, increased action of biological contaminants, and accelerate the spread of infections. However, low humidity can result in breathing difficulties, cough, irritation in the eye, wheeze, skin chapping, etc.

Building materials have an impact on indoor air quality. Vernacular building materials are often effective in regulating the thermal performance of a building, ensuring energy efficiency. Also, people residing in such dwellings have been found to have high resilience to withstand the adverse external conditions. This exploratory study aims to understand the performance of building materials for the regulation of indoor moisture and air quality for promoting the health and well-being of the building and the occupants. The study involves monitoring a conventional (brick, concrete) dwelling and vernacular dwellings (adobe construction, brick/lime construction) situated in India's Composite Climatic zone. The result suggests that dwelling constructed with earth (adobe) maintains the narrowest range of variation in indoor relative humidity. The indoor relative humidity variation range is widest in cement concrete construction.

The paper examines factors that regulate relative humidity in the indoor environment. Understanding the moisture buffering capacity of the building materials in indoor RH regulation for occupant health has also been discussed.

**Paper 17.6**: Evaluation of the physiological effect on human subjects of different odorant environments

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**Keywords**: odorants, physiological measurements, sensory analysis, chemical analysis

Different molecules or combinations of molecules can be used to formulate odorant products. Even if the commonly used methodology involving expert panelists is designed to reduce interindividual differences, the odorant sensitivity differs from one person to another. In this study, the physiological effect of different odorants was investigated by using sensory and physiological measurements. Chemical measurements of the exposure environment were also made simultaneously. The objective was to investigate the benefits of the addition of physiological data to discriminate the effects of the different odorants and to link them to the declared perception of intensity and well-being, and to the chemical composition of the exposure environment.

Eight subjects, aged from 24 to 56, with a normal BMI, non-smokers, and having a high declared and measured sensitivity to odorant stimuli were selected among a larger representative sample.

Two odorant products were evaluated using self-assessment questionnaires and physiological measurements, as well as a neutral environment without odorant emission (E0). The first odorant (E1) was a deodorant with a verbena and lemon scent, the second one (E2) was a deodorant with a lavender scent.

The perceived intensity and its associated well-being were evaluated using two 11-points scales, at several times after starting the odorant emission in the test chamber.

The physiological responses which were measured were heart rate, skin blood flow, electrodermal response (EDR) and respiration rate.

The experiments took place into a specific test emission chamber of 30 m3, with controlled temperature and humidity. The subjects were exposed individually to the three different environments, in the test emission chamber for 15 minutes. The air in the chamber was sampled during the exposure in order to be chemically analyzed with GC techniques.

Results obtained from the sensory questionnaires show that there are significant differences between the three odorant environments. E0 was perceived significantly less intense and less pleasant than E1 and E2. E1 was perceived as the most pleasant. Tuckey's multiple comparisons post-hoc test show that E0 and E2 were not significantly perceived as different in intensity but that E1 was perceived significantly higher in intensity.

Results also indicate significant differences between the odorants for all the physiological responses. Electrodermal response, heart rate, and skin blood flow were lower for E1 than for E0 and E2, and, on the contrary, breathing rate was significantly higher for E1 than for E0, E2 was intermediate on this indicator.
Paper 17.7: Monitoring Mold growth and VOC--emissions from Wood Wool insulation under unfavorable hygrothermal conditions

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Keywords: Mold growth, wood wool, humidity, fungal inoculation, VOCs emission

Mold growth in damp environments has been recently cited as the cause of a wide range of human diseases, mainly allergic and respiratory problems. The growth of indoor-surface molds depends on a group of physical and chemical conditions. The presence of nutritive bio-based support, such as wood wool, at a high humidity level, is considered the most satisfactory medium for surface-mold development. The detection of Microbial Volatile Organic Compounds (mVOCs) in indoor environments is considered an important marker of mold formation. These compounds are formed in the metabolism of fungi and bacteria and were recently analyzed in indoor-air environments.

In order to characterize the development of micro-organisms in indoor environments, a wall of a similar building structure to those of the town-hall of Moncheaux in France was reproduced at scale 1 for testing in the laboratory. It was placed under hygrothermal conditions (T=22°C and RH=70±5%) favoring the development of micro-organisms. After one month, a part of the wood wool insulator was inoculated for another month after spraying about 700 CFU/cm² of fungi to evaluate the proliferation of micro-organisms under these conditions. Two Field and Laboratory Emission Cells (FLEC) were used to monitor the surface emissions of not only mVOCs but also Total VOCs (TVOCs) and aldehydes from the inoculated and non-inoculated surfaces.

Only three mVOCs were detected from both surfaces with low and approximately equal emission rates (ER) of less than 0.5 µg/m².h. Moreover, no mold development was observed neither on the inoculated nor on the non-inoculated surfaces of the wood wool after one month of experimentation. This is confirmed by the constant CFU number obtained upon extraction of micro-organisms. Therefore, the detected mVOCs cannot be considered a reliable indicator of mold development. In addition to mVOCs, about 70 VOCs and aldehydes were quantified from both surfaces. The ERs of TVOCs and aldehydes were 90.3 and 8.6 µg/m²h, respectively from the non-inoculated surface and 71.2 and 8.5 µg/m²h from the inoculated one. The difference in emissions is about 20% indicating no significant effect of inoculation on the emission of these compounds; however, the slight decrease in the emission of TVOCs might be due to their depletion from the material with time.

The obtained results emphasize that relative humidity levels up to 75% are not sufficient for mold development on wood insulators. More unfavorable conditions should be tested to check the resistance of bio-based materials against mold growth.

Paper 17.8: Influence of wooden Flooring on Indoor Air Quality

PAUL, Swaraj

PP Polymer AB, Sweden

Keywords: wooden flooring, parquette flooring, formaldehyde, VOC, UF adhesives

Due to new environmental trends and restrictions and due to more interest in using renewable materials with circularity, wood has become an important group of building materials for such as flooring.

Since flooring materials uses relatively high amounts of adhesives mostly belonging to urea-formaldehyde (UF) and contain terpenes, it is of utmost interest to investigate how such materials influence the indoor air climate and thereby may cause health problems.

For this reason, we investigated several commercial flooring materials and found some very unexpected results. According to international Occupational Exposure Limit levels (OEL), aldehydes are very hazardous for health at incredibly low concentrations. They are also classified as human carcinogens according to EPA.

In this presentation emission results and the ways to reduce or eliminate emissions will be discussed.
Paper 17.9*: Indoor air 2-ethylhexanol levels in an office building after floor repair – a follow-up study

VAITTINEN, Olavi  
Raksystems Suomi, Finland

Keywords: 2-ethylhexanol, VOC, floor repair, follow-up study

2-Ethylhexanol (2-EH) is a pollutant often found in indoor air. It can be emitted for example due to degradation of phthalate plasticizers used in polyvinyl chloride (PVC) floorings. Another significant source of 2-EH is ethyl-hexyl acrylate-containing adhesives. A prominent characteristic of 2-EH is the seasonal fluctuation of its indoor air concentration. The compound is detected at higher concentrations in high-temperature and humid seasons and at markedly lower concentrations during winter.

2-EH may affect human health even at relatively low concentrations. It may provoke irritation of the respiratory tract and cause asthma-type symptoms at levels of exceeding 175 µg/m³. In any case, the detection of 2-EH is a strong indicator of PVC flooring degradation and indirect proof of occupant exposure to possibly dangerous DEHP levels. 2-EH is also a potential marker for microbial growth.

Abnormally high levels (up to 25 µg/m³) of 2-EH were observed in indoor air of an office building one year after flooring renovation. In subsequent investigations, the adhesive was found to be the likely and dominant source of 2-EH. Material samples proved that 2-EH was penetrated only into the very top screed layer.

The flooring materials of the premises were reinstalled. The textile carpets were completely removed and the screed was grinded for at least 3 mm. The correct grinding depth was secured using material samples of the screed. After reinstallation, the emission of the new flooring materials is studied with air samples.

In this study, indoor air concentrations of VOCs in an office building are measured during one year. The air sampling is carried out in four stages: 1) one month after floor repair; 2) three months after repair; 3) six months after repair; 4) one year after repair. Samples are collected from across the premises at least in 10 different locations. One room without renovations was earmarked as a reference space. Measurements are performed with standard ventilation settings at a constant indoor air temperature. Altogether about 70 air samples will be collected. First results show that the indoor air 2-EH levels have decreased by about a half or more during the first three months after repair. More results will be presented at the conference.

* Extended abstract for Paper 17.9 is available at the end of this book.
Session 18: Ventilation for IAQ

Paper 18.1: Is the air change efficiency sufficient to assess the removal of airborne contamination in mixing ventilation?

BROCKMANN, Gerrid 1, HARTMANN, Anne, KRIEGEL, Martin
Technische Universität Berlin, Germany

Keywords: age of air, air change efficiency, residual lifetime, indoor air quality (IAQ), CFD

There are two common methods to assess the ventilation effectiveness: the air change efficiency (ACE) and the contamination removal effectiveness (CRE). For known contamination sources in a room, it is easy to determine the CRE. Often this is not given. Especially, when the contamination is exhaled from a random position and get mixed up in the environment. Then the ACE, the ability of the ventilation to exchange the air in the room, will be chosen for IAQ assessment.

By determining the residual lifetime, the averaged time for air transport from a specific point in the room to the exhaust, it is possible to examine the resulting CRE if the point is the source position and the contamination is airborne. This data can be averaged for the whole room or a potential source zone. The present numerical investigation will focus on a simple mixing ventilation scenario with different conditions: air change rate, specific heat flux, supply air diffuser and exhaust position. It will analyze the correlation between an averaged CRE value based on the residual lifetime and the ACE to better understand their relationship and give a recommendation for the IAQ-assessment of ventilation designs.

Paper 18.2: Demand-controlled ventilation in schools: Influence of base ventilation rates on subjective symptoms, perceived indoor environment and young adults' learning performance

HOLØS, Sverre B. 1, 2, YANG, Aileen X. 1, 2, THUNSHELLE, Kari 1, MYSEN, Mads 1, 2
1 SINTEF, Oslo, Norway; 2 OsloMet - Oslo Metropolitan University, Oslo, Norway

Keywords: Demand-controlled ventilation, Performance, School, Ventilation rate

Demand controlled ventilation may significantly reduce energy consumption by lowering the ventilation rate when spaces are unoccupied (base ventilation). Air quality in a room will be affected by the base ventilation rate for some time after occupancy, as even the higher ventilation rates used during occupancy will not be able to immediately reduce pollutant levels to new steady-state levels. Also, commonly used control-systems, like CO2-based control of the ventilation rate, will require some time to adjust to the number of people present.

Classrooms typically have relatively short but intense hours of occupancy, and a low base ventilation rate can result in high energy savings. Thus, it is of interest to examine how different base ventilation rates affect subjective symptoms, perceived indoor environment, and performance, to make recommendations for base ventilation rates in different situations.

In this study, we compared the effect of exposing 10-12 young adults to base ventilation rates of 1.1 vs. 2.01/s per m² in two small classrooms built from presumably low-emitting materials. Upon entry, the ventilation rates were increased to 5.7 1/s per m². The air temperature during the different tests varied in the range of 22.6 °C to 25.4 °C due to temperature rise during tests and room differences.

Symptom intensity and perceived environmental quality were recorded on a visual scale, and performance was examined by identifying three different letters in a nonsense text. Tests were done immediately after entering the classroom and after 75 minutes. A test of the operational memory span was performed at 75 minutes.

We observed no significant or consistent effects of increasing the base ventilation rate on the measured outcomes. These results indicate that decreasing the base ventilation from 2.0 to 1.1/s per m² does not influence the performance, symptoms, or the perceived indoor environmental quality.

Paper 18.3*: Can human CO2 emission rates staying awake be used staying asleep?

FAN, Xiaojun 1, 2, SAKAMOTO, Mitsuharu 2, SHAO, Huiqi 3, KUGA, Kazuki 2, LAN, Li 4, ITO, Kazuhide 2, WARGOCKI, Pawel 1
1 International Centre for Indoor Environment and Energy, Technical University of Denmark; 2 Interdisciplinary Graduate School of Engineering Sciences, Kyushu University; 3 School of Chemistry and Biological Engineering, University of Science and Technology Beijing; 4 Department of Architecture, School of Design, Shanghai Jiao Tong University, China

Keywords: Carbon dioxide, Human CO2 emission rate, Sleeping condition, Ventilation rate, Air temperature

Carbon dioxide (CO2) as a product of human metabolism is the dominant pollutant from occupants. Its concentration indoors has been widely used as a surrogate of ventilation efficiency, hence indoor air quality (IAQ). When estimating ventilation rate
(VR), the CO₂ emission rate (CER) needs to be known. While CER till now is mainly obtained from people staying awake. There are few studies showing if it can be used for sleeping people, so the VR estimation in bedrooms. This study experimentally determined human CER during sleep and compared it with that of people staying awake. Recruited 11 participants slept in a specially designed capsule for four nights at three conditions combined by two temperatures (24 and 28 °C) and two levels of IAQ indicated by two CO₂ concentrations (800 and 1700 ppm), the order of sleep was balanced, and the first night was for adaption. The CER was estimated using measured CO₂ concentration with a mass-balance equation after the CO₂ level reached steady-state during sleep. The measured CER was on average 11.04±1.43 L/h per person. This was similar to what predicted using the models provided by the standard and previous study. Measured CER from sleeping people is significantly lower compared with that of people staying awake. No significant differences in CER were observed across conditions. Present results suggest that CER from awake people can not be used for sleeping people. Otherwise, it will increase energy consumption due to overestimated VR in bedrooms.

* Extended abstract for Paper 18.3 is available at the end of this book.

Paper 18.4: Local ventilation for general patient rooms

XIE, Zichan ☁️, BIVOLAROVA, Mariya Petrova ☁️, MELIKOV, Arsen Krikor ☁️

International Centre for Indoor Environment and Energy, Technical university of Denmark, Denmark

Keywords: combined ventilation system, hospital ventilation, ventilation efficiency, thermal comfort

Numerous studies on ventilation of general patient rooms have been performed, while most of the studies have focused on total volume air distribution (mixing or displacement). This study presents results of local ventilation (LV) aimed to efficiently protect a lying person from cross-infection due to airborne respiratory viruses. Experiments performed in a climate chamber (4.7 m × 4.7 m × 2.6 m) included LV when used alone and when coupled with background mixing ventilation (MV). A thermal manikin and a heated standing dummy were used to simulate respectively a patient lying in bed and an infected doctor or nurse standing beside the bed. The LV was able to reduce substantially the exposure of the patient to the infected air exhaled by the doctor. The results show that the efficiency of the LV depended mostly on its supply air flow rate. An increase of the background ventilation's supply flow rate, i.e. increase of the air change rate in the room, was less important. At 15 L/s supplied by LV the concentration of a contaminant at the patient's mouth decreased by 76%. The findings of the paper give insights for researchers and designers in developing a novel ventilation system to be used during a pandemic in general patient rooms.

Paper 18.5: Proposing a new tracer gas for future field applications of passive tracer gas tests for air change rate measurement

✈️ PARALOVO, Sarah Lima (1,2) ☁️, STRANGER, Marianne (2), LAZAROV, Borislav (2), SPRUYT, Maarten (2), LAVERGE, Jelle (1)

1 Ghent University, Belgium; 2 VITO, Belgium

Keywords: Ventilation, air change rate, indoor air quality, tracer gas test, passive sampling

Ventilation is critical in interpreting indoor air quality (IAQ), yet most IAQ assessments do not report ventilation adequately. The ultimate aim of this research is to encourage researchers, contractors and building owners to include ventilation measurements in their IAQ assessments, thus making them more comprehensive and representative. Most ventilation assessments use tracer gas tests (TGTs) to measure total air change rates (ACH), but currently applied TGTs present at least one of three major shortcomings: (1) limited comparability between ACH and IAQ data due to differing timescales, (2) inadequate substances employed as tracer gases, either from a health or environmental perspective, and (3) tendency to bias due to imperfect air mixing. Therefore, this paper proposes a new TGT approach, intended for use in large-scale IAQ assessments and based on constant tracer injection. The new proposed TGT employs an alternative and more adequate tracer gas that is captured and analyzed together with commonly assessed IAQ pollutants (VOCs) by means of commercially available passive IAQ samplers, thus simultaneously addressing (1) and (2). To address (3), the new TGT also proposes the inclusion of a careful simulation-based planning phase to help finding the optimal positioning of sources and samplers. The present paper is focused specifically in the developments aimed at addressing (1) and (2); developments regarding (3) will be dealt with in future publications. Via literature study and lab experiments, decane-D22 was found to be a suitable tracer substance. A passive source of decane-D22 was developed and optimized in lab, providing stable and repeatable emission rates under standard temperature, while unaffected by varying RH and ACH. The effect of the liquid solvent level over the source emission rate was only barely noticeable, but a range of adequate solvent level is suggested nevertheless. The selected tracer was also shown not to adhere/absorb significantly to surfaces. Additionally, a consistent exponential curve was derived for determining the source emission rate from the room temperature. Field applications of this new TGT method are ongoing and will be published elsewhere shortly.
Workshops & seminars

Here are listed only the short abstracts for each workshop/seminar. Detailed descriptions are 5 pages ahead.

**Workshop 109: Workshop of smart, safe and sustainable healthcare**

LIU, Yiliu (1) ☑, HOLØS, Sverre B. (2), CAO, Guanyu (1), KISS, Gabriel (1)

1 Norwegian University of Science and Technology, Norway; 2 SINTEF Community

**Keywords:** S3Care, Gemini, Operating room of the future

The workshop will include presentations state-of-art researches and round-table discussions in the fields of smart, safe and sustainable healthcare.

New practices in such multi-disciplinary domains involve researchers and practitioners from medicine, energy engineering, information technology and safety engineering. The topics in this workshop will be around environment management of operating rooms, ventilation and energy saving technologies in hospitals, augmented reality technologies for visualizing dynamic volumetric data such as airborne contaminants, and data analytics to minimize energy consumption. Brainstorming on the following topics may include the session:

- What is the new requirement for future hospital environment?
- How to build a safe hospital indoor environment with minimized infection risk?

**Seminar 114: Use of Infection Risk Calculators to Manage Building Occupancy Post-COVID**

PREZANT, Brad (1) ☑, MORAWSKA, Lidia (2), BUONANNO, Giorgio (3)

1 VA Sciences, Australia; 2 QUT; 3 University of Cassino and Southern Lazio, Italy

**Keywords:** COVID-19, SARS-CoV-2, ventilation, infection

An ISIAQ seminar led by Professor Morawska will present, describe, and discuss 12 infection risk calculators.

This workshop is intended to provide users of these calculators to demonstrate the utility of these calculators across different occupancy types. Authors and/or users of these calculators will present the experiences and outcomes of the application of these calculators to solving building occupancy issues.

- How have these calculators assisted in re-occupying buildings post-COVID?
- Have they been adopted as valid indicators of risk by cognisant public health authorities across various countries?
- Has real-world experience suggested that the infection risk estimates provided are valid?
- Are there ways that these calculators can be improved?
- Can we learn from this application of research to practice in ways that would assist better management of other indoor air quality issues?

**Workshop 143: Synergic Effects of the Exposure to Air Pollutants Indoors**

PASTUSZKA, Józef Stefan ☑

Silesian University of Technology, Poland

**Keywords:** Indoor air, Air pollutants, Synergic effects

- Objective/motivation for organizing workshop

**Motivation**

When analyzing the adverse health effects of inhaling polluted indoor air, it should be noted that residents are sometimes exposed to around a hundred air pollutants or classes of air pollutants. Therefore, rather than investigating the unique effects of specific pollutants, it has been suggested that it would be wiser to assume that it is a mixture of pollutants that could be considered harmful to health. Of course, potential interactions between pollutants appear to be the underlying problem needed to explain the relationship between human exposure to pollutants (present in various environments, including ambient air) and their health status. However, since people spend most of their time indoors, this problem seems to be of particular concern indoors. Therefore, it is important to analyze existing data on the synergistic effects of indoor air pollution, then draw conclusions and identify the most promising directions for future research.

**Objectives**

1. Synergic effects of airborne solid particles and gaseous pollutants
2. Synergic effects of biological particles and other air pollutants
3. Synergy and allergy symptoms
4. New tools in the analysis of health care of residents exposed to air pollutants (aggregative risk index, synergy of small doses of air pollutants, etc.)

- Format (presentations, round-table, invited speeches)
- Round-table
- Target audience
  Air protection professionals, environmental health researchers, environmental engineers, Ph.D. students, public health policy makers.
- Names and affiliations of proposed chairpersons and organizers
  Jozef S. Pastuszka
  Faculty of Energy and Environmental Protection, Department of Air Protection, Silesian University of Technology, Center of New Technologies, 22B Konarskiego St., 44-100 Gliwice, Poland

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**Workshop 168:** Mini course: Tracer gas analysis advanced methods

**SCHILD, Peter**

Oslo Metropolitan University, Norway

**Keywords:** Tracer gas, Ventilation efficiency, Recirculation

- Understand the different ventilation indices, their pros & cons.
  - Hands-on demonstration of multigas & tracer gas analysis with multiplexer.
  - Two specific applications: Room air exchange, and recirculation in ventilation systems and AHUs.
  - Experimental setup tips & tricks to ensure accuracy.
  - Post-processing raw measurement data to accurately calculate main ventilation indices.
  - Alternatively, this topic can be moved to the online Summer School if deemed more appropriate.

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**Workshop 193:** Multi-domain approaches to indoor environmental perception – current status and ways forward

**SCHWEIKER, Marcel (1), MAHDAVI, Ardeshr (2), BERGER, Christiane (2), DAY, Julia (3)**

1 RWTH Aachen University, Medical Faculty, Germany; 2 TU Vienna, Department of Building Physics and Building Ecology, Austria; 3 Washington State University, School of Design and Construction, USA

**Keywords:** Indoor environmental quality; Multi-domain; Interactions; Satisfaction; Perception

Building occupants are continuously exposed to multiple indoor environmental stimuli, including thermal, visual, acoustic, and air quality related factors. Moreover, personal and contextual aspects can be regarded as additional domains influencing occupants’ perception and behaviour. The scientific literature and current international standards commonly address these domains in isolation. In contrast to such single-domain approaches, multi-domain approaches consider at least two different domains and their interactions, for example, visual and thermal. This workshop is based on the work of IEA EBC Annex 79 Sub-Task 1, which reviewed the scientific literature on interactions and cross-domain effects and looked at necessary conditions for multi-domain indoor environmental quality standards. The results of these reviews suggest that existing multi-domain research is not sufficiently systematic and conclusive.

Within this workshop, the state of art regarding multi-domain research and standardisation will be presented together with barriers in both areas. The presentations are followed by a discussion of ways forward towards systematic research facilitating the establishment of conclusive findings suitable for implementation into international standards.

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**Workshop 208:** IEQ guidelines worldwide - Open database for research and practice

**JIN, Quan (1), HÄGERHED, Linda (2), CULL, Ian (3), LEE, Kiyoung (4), GUNNARSEN, Lars (5), HAVERINEN-SHAUGHNESSY, Ulla (6,7)**

1 Chalmers University of Technology; 2 University of Borås; 3 Indoor Science Inc; 4 Seoul National University; 5 Technical University of Denmark; 6 University of Oulu; 7 University of Tulsa

**Keywords:** IEQ-guidelines

A new ISIAQ scientific technical committee STC 34 continues the project that was initiated 2017 aiming to collect and share information about international and national guideline values concerning indoor environment quality (IEQ) indicators.

Currently STC34 focuses on developing a functional database pertaining to information about existing guidelines. Future objectives include review of existing guidelines and developing recommendations.

STC34 invites different stakeholders and the whole IEQ society for an open discussion regarding the use of the database for both research and practice. A beta-version of the database will be demonstrated and discussed during the workshop.
Workshop 217: Ultrafine particles (UFP): Can we filter them with conventional HVAC filters or ‘air purifiers’? A white-paper for decision-makers

HEDSTRÖM, Anders (1), MORAWSKA, Lidia (2)
1 IAQ Sweden, Sweden/Queensland University of Technology; 2 Queensland University of Technology (QUT)

Keywords: Clean air, Fresh Air, UFP particles, IAQ, White paper IAQ, Filters, Purifiers

Indoor Air Quality is essential for humans and specially when it comes to viruses and nano particles that penetrate deep into our airway systems.

Air has puzzled thinkers through the years, but still we have many misconceptions. IAQ is in focus when COVID appeared, and during my 35 years of applied science, finally humans understand that the threat the invisible can pose to us. IAQ is complex and often we give so many advice on how to clean the air indoors, so end-user get confused. In a new White paper for policy makers, Prof Lidia Morawska from QUT will explain the difference between nano and UFP and larger particles. I will explain the difference between the ways of measuring IAQ. We have solutions for filtering and taking care of IAQ, but do we do it in a correct way?

Could we as long as we have the severe air pollution outside manage to clean the air coming indoors, and do we do it in a correct way today? IAQ solutions I will discuss in my lecture and examples from QUT and WHO guidelines group how we think around what we should measure going forward and due to the standards today for filtering could we upgrade them? Are we able to recycle air with air purifiers, and which techniques are favourable?

Seminar 225: Inspection and commissioning of ventilation systems, including VAV-systems

EKBERG, Lars (1), SCHILD, Peter (2), KOSONEN, Risto (3)
1 Chalmers Univ. of Tech. & CIT Energy Management, Sweden; 2 Oslo Metropolitan University; 3 Aalto University, Finland

Keywords: ventilation, function testing, measurement

The workshop may be held as a seminar with presentations from 3 experienced professionals. The Nordic Ventilation Group (NVG) may stand as organizer. The workshop will be planned in detail by a sub-group of NVG members.

Target group: Practitioners and researchers who need an update/overview about inspection and function testing of ventilation systems. Professionals working with design, construction and/or operation of ventilations systems.

Issues addressed:
1. Functional requirements, as a basis for inspection
   - Expected/required function
   - Observations (ocular and by measurement)
   - Criteria for acceptance
2. Practical methods to document of proper function
   - Measurement methods, instruments and devices
     (pressure differential, air velocity and air flow rate)
   - Accessibility
   - System in the correct state of operation
3. Modern challenges
   - Demand Controlled Ventilation: Handover tests and functional testing
   - Understanding the principle of control of VAV systems
   - Sensor quality, precision, placement etc.

After each presentation there will be time allocated for questions and discussions, which will be documented.

Seminar 241: Legionella prevention in buildings - Are we effecting meaningful change or just checking all the boxes?

WAAK, Michael B., STRÅBY, Karolina
SINTEF A.S., Norway

Keywords: Legionella, operation & management, drinking water, plumbing, public health

Legionella bacteria are commonly found in building plumbing and drinking water. Their survival and proliferation may increase risk of severe illnesses like Legionnaires’ disease among end-users, due to droplet or aerosol inhalation via showers or other water fixtures. The day-to-day burden of Legionella prevention in buildings often falls upon facility maintenance and services personnel. Concurrently, revision to the EU Drinking Water Directive, requiring Legionella testing, may add more time and resource costs
for end-users or operators. In this workshop, an expert panel representing various stakeholders (public health regulators, building operators and managers, scientific researchers, and technical consultants) will present their diverse perspectives on current and future challenges of Legionella prevention in buildings. In the second half, a panel discussion with audience Q&A will allow workshop participants to engage with the panelists and the panelists with one another. In addition to facilitating a diverse and open dialogue across different stakeholder groups, this workshop will challenge workshop participants to rethink how they currently view Legionella prevention in building water systems---not just as a building problem but a societal challenge. Maybe---just maybe---it may even inspire innovative solutions.
Organizers

- **Corresponding Chair**: Dr. Yiliu Liu, NTNU, yiliu.liu@ntnu.no
- **Co-organizer**: Sverre B. Holøs, SINTEF Community, SverreB.Holos@sintef.no

Background & Objectives

The workshop will include presentations of a new Gemini center of *Smart, safe and sustainable healthcare - S3Care*, and state-of-art researches within the relevant fields. S3Care is jointly established by NTNU, SINTEF Community, and St. Olavs Hospital in Trondheim, Norway, involving researchers from medicine, energy engineering, information technology and safety engineering.

The presenting research topics in the workshop will be around environment management of operating rooms, ventilation and energy saving technologies in hospitals, augmented reality technologies for visualizing dynamic volumetric data such as airborne contaminants, and data analytics to minimize energy consumption.

Target audience

All researchers in healthcare facilities.

Gemini Center participants and collaborators

Format, and method of participant interaction

Presentations and open discussion

Proposed schedule or length

90 minutes

Schedule:

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<th>Subject / Activity</th>
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<tr>
<td>15</td>
<td>Yiliu Liu, NTNU</td>
<td>What is S3 Care? Objectives and opportunities</td>
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<td>15</td>
<td>Guangyu, Cao, NTNU</td>
<td>Ventilation of operating rooms and isolation wards</td>
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<td>15</td>
<td>NN, St. Olav Hospital</td>
<td>Operating room of the future: what will it be like and what requirements for ventilation</td>
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<td>10</td>
<td>Sverre Holøs, SINTEF</td>
<td>Nursing homes: understudied and underestimated?</td>
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<td>35</td>
<td>All</td>
<td>Collaboration opportunities, research needs, what should be our priorities?</td>
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<td>- How can we keep patients safe in a healthcare facility</td>
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<td>- Comfortable, healthy environments in health care: which professions need to cooperate?</td>
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<td>- How to fund research on indoor environment as complement to medical care and medication?</td>
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<td>- How can we improve cooperation between medical and environmental research?</td>
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<td>- Are the funding opportunities for patient HEALTH balanced?</td>
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Output

Short summary of discussion and slides
Seminar:
Use of Infection Risk Calculators to Manage Building Occupancy Post-COVID

Organizers

- **Chair:** Lidia Morawska  
  (QUT, Australia): l.morawska@qut.edu.au
- **Corresponding co-chair:** Brad Prezant  
  (VA Sciences, Australia): b.prezant@vasciences.org
- **Co-chair:** Giorgio Buonanno  
  (University of Cassino and Southern Lazio, Italy): buonanno@unicas.it

Background & Objectives

An ISIAQ seminar led by Professor Morawska will present, describe, and discuss 12 infection risk calculators. This workshop is intended to provide users of these calculators to demonstrate the utility of these calculators across different occupancy types. Authors and/or users of these calculators will present the experiences and outcomes of the application of these calculators to solving building occupancy issues. The overarching questions covered by the seminar include:

- How have these calculators assisted in re-occupying buildings post-COVID?
- Have they been adopted as valid indicators of risk by cognisant public health authorities across various countries?
- Has real-world experience suggested that the infection risk estimates provided are valid?
- Are there ways that these calculators can be improved?
- Can we learn from this application of research to practice in ways that would assist better management of other indoor air quality issues?
Workshop/practice session proposal:
Synergic Effects of the Exposure to Air Pollutants Indoors

Organizers
Prof. Józef Stefan Pastuszka
1Centre of Climate and Environmental Protection, Silesian University of Technology, 22B Konarskiego St., 44-100 Gliwice, Poland.
2Faculty of Energy and Environmental Protection, Department of Air Protection, Silesian University of Technology, Centre of New Technologies, 22B Konarskiego St., 44-100 Gliwice, Poland.
jozef.pastuszka@polsl.pl , Phone: + 48 - 69 80 25 740

Motivation
When analysing the adverse health effects of inhaling polluted indoor air, it should be noted that residents are sometimes exposed to around a hundred air pollutants or classes of air pollutants. Therefore, rather than investigating the unique effects of specific pollutants, it has been suggested that it would be wiser to assume that it is a mixture of pollutants that could be considered harmful to health. Of course, potential interactions between pollutants appear to be the underlying problem needed to explain the relationship between human exposure to pollutants (present in various environments, including ambient air) and their health status. However, since people spend most of their time indoors, this problem seems to be of particular concern indoors. Therefore, it is important to analyze existing data on the synergistic effects of indoor air pollution, as well as other kinds of synergy between different factors describing indoor environment, then draw conclusions and identify the most promising directions for future research.

Objectives
This workshop aims to cover the following issues:
- Synergic effects of airborne solid particles and gaseous pollutants
- Synergic effects of biological particles and other air pollutants
- Synergy and allergy symptoms
- New tools in the analysis of health care of residents exposed to air pollutants (aggregative risk index, synergy of small doses of air pollutants, etc.)
- Influence of climate change on the characteristics of air pollutants indoors

Target audience
Air protection professionals, environmental health researchers, environmental engineers, Ph.D. students, public health policy makers.

Conditions/facilities/resources
The workshop probably will be conducted digitally using Zoom.

Format, and method of participant interaction
Round-table workshop.

Proposed schedule or length
The proposed total length is 1.5 hour
## Schedule

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<th>Length (min)</th>
<th>Presenter</th>
<th>Subject / Activity</th>
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<tr>
<td>10</td>
<td>Jozef S. Pastuszka</td>
<td>Synergic effects of airborne solid and biological particles and gaseous pollutants.</td>
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<tr>
<td>5</td>
<td>Jozef S. Pastuszka</td>
<td>New tools in the analysis of health care of residents exposed to air pollutants.</td>
</tr>
<tr>
<td>15</td>
<td>Jozef S. Pastuszka</td>
<td>Influence of climate change on the characteristics of air pollutants indoors.</td>
</tr>
<tr>
<td>20</td>
<td>J.S. Pastuszka (Coordinator of the discussion)</td>
<td>Discussion and summary.</td>
</tr>
</tbody>
</table>

## Output

Proposed output/dissemination: presentations, short report.
Workshop
Mini-course in tracer gas analysis methods

Organizers

- **Corresponding chair**: Dr. Peter G. Schild, OsloMet, Norway, peter.schild@oslomet.no

Target audience

Both researchers and practitioners (e.g. consulting engineers) who wish to learn about tracing gas methods in ventilation system audits. No previous experience is needed.

Background & Objectives

There is increasing interest in the twin issues of ventilation efficiency and recirculation in ventilation systems. Tracer gas methods are a highly effective method of quantifying these. There are no available courses about this method. Although there exist standards that describe tracer gas methods (e.g. NordTest and CEN standards), these do not explain all the necessary details to guarantee accurate results. This course aims to bridge that gap, with experts sharing their knowledge of how they apply tracer gas methods.

Format, and method of participant interaction

Zoom.

Proposed schedule or length

Approximately 45 minutes. If many questions from participants, limit is 90 minutes.

Schedule:

<table>
<thead>
<tr>
<th>Length (min)</th>
<th>Presenter</th>
<th>Subject / Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>15</td>
<td>PGS</td>
<td>Operating a commercial multiplexer multigas analyser, and gas cylinders</td>
</tr>
<tr>
<td>10</td>
<td>PGS</td>
<td>Application to room ventilation: Age-of-air and contaminant removal efficiency</td>
</tr>
<tr>
<td>10</td>
<td>PGS</td>
<td>Application to air handling system recirculation &amp; flow rate</td>
</tr>
<tr>
<td>rest</td>
<td>All</td>
<td>Q&amp;A</td>
</tr>
</tbody>
</table>
Workshop:

Multi-domain approaches to indoor environmental perception – current status and ways forward

Organizers

- **Corresponding chair:** Marcel Schweiker
  RWTH Aachen University, Medical Faculty, Germany. mschweiker@ukaachen.de

- **Co-chair:** Ardestir Mahdavi
  TU Vienna, Department of Building Physics and Building Ecology, Austria. amahdavi@tuwien.ac.at

- **Co-chair:** Christiane Berger
  TU Vienna, Department of Building Physics and Building Ecology, Austria. christiane.berger@tuwien.ac.at

- **Co-chair:** Julia Day
  Washington State University, School of Design and Construction, USA. julia_day@wsu.edu

Background & Objectives

Building occupants are continuously exposed to multiple indoor environmental stimuli, including thermal, visual, acoustic, and air quality related factors. Moreover, personal and contextual aspects can be regarded as additional domains influencing occupants' perception and behaviour. The scientific literature and current international standards commonly address these domains in isolation. In contrast to such single-domain approaches, multi-domain approaches consider at least two different domains and their interactions, for example, visual and thermal. This workshop is based on the work of IEA EBC Annex 79 Sub-Task 1, which reviewed the scientific literature on interactions and cross-domain effects and looked at necessary conditions for multi-domain indoor environmental quality standards. The results of these reviews suggest that existing multi-domain research is not sufficiently systematic and conclusive.

Within this workshop, the state of art regarding multi-domain research and standardisation will be presented together with barriers in both areas. The presentations are followed by a discussion of ways forward towards systematic research facilitating the establishment of conclusive findings suitable for implementation into international standards.

Target audience

This workshop will be a Scientific Workshop targeting scientists and professionals with basic knowledge in one or more domains of human perception of indoor environmental quality.

Conditions/facilities/resources

This workshop can be conducted in a physical conference or a digital form (e.g. Zoom). In both cases, there is no practical limit to the number of people. When online, a live session is required rather than video recordings.

Format, and method of participant interaction

The intended format of this workshops include 4 short statements from the workshop organizers. This is followed by the presentation of a series of challenging and provoking statements regarding the workshop topics. Participants will be asked to state the agreement to such statements in a binary way. The result of
such vote (either online and/or in person) will then be discussed between the evolving groups being either pro or con.

The exact format of the workshop is not decided and will be discussed once the status regarding the state of current pandemic and travel restrictions are more clear.

**Proposed schedule or length**

The proposed total length is 90 minutes, including 40 minutes of short statements and 45 minutes time for round-table discussions

Schedule:

<table>
<thead>
<tr>
<th>Length (min)</th>
<th>Presenter</th>
<th>Subject / Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Marcel Schweiker</td>
<td>Welcome and introduction</td>
</tr>
<tr>
<td>10</td>
<td>Marcel Schweiker</td>
<td>Fundamentals to multi-domain approaches to IEQ</td>
</tr>
<tr>
<td>10</td>
<td>Christiane Berger</td>
<td>Critical reflections on past instances of multi-domain IEQ research</td>
</tr>
<tr>
<td>10</td>
<td>Ardeshir Mahdavi</td>
<td>Multi-criteria building quality evaluation in standards and rating systems</td>
</tr>
<tr>
<td>10</td>
<td>Julia Day</td>
<td>Selected challenges and ways forward</td>
</tr>
<tr>
<td>45</td>
<td>All (moderators)</td>
<td>Interactive discussion reflecting initial statements and ways forward</td>
</tr>
</tbody>
</table>

**Output**

The proposed output is a short report or position paper summarizing the main results of the discussion.
Seminar:
Ultrafine particles (UFP): Can we filter them with conventional HVAC filters or ‘air purifiers’?
A white-paper for decision-makers

Organizers

Chair persons
Anders Hedström IAQ Sweden AB IAQ Expert, info@iaq.se
Professor Lidia Morawska Director WHO CC centre Air Quality and Health Queensland University of Technology.

Other partners and panel members
Prof Magnus Svartengren MD, PhD, Professor Occupational and Environment Medicine Uppsala University
Prof Bertil Forsberg Umeå University, dep for clinical science
Britta Permats, Swedish Ventilation Association, MD and a wide experience in indoor air.

Why are we doing this?

The reason why we want to do this is the often misunderstood fact that IAQ is not correctly analysed. Some of the actors in the Air Quality market are trying to go the wrong way. The mission to first understand the complex Indoor Air content and then put forward solutions for the single human, not for actors within this sector selling products. Today because of the pandemic we need to reconsolidate the situation and be holistic in our minds and knowledge. The panel in this workshop is very experienced and Prof Lidia Morawska one of the major scientist working with WHO. Anders Hedström has been working with filtration in 35 years and have a wide knowledge within PM. This Workshop will inform about different techniques around mobile air purifiers and how they should be installed or not in indoor environment. Prof. Magnus Svartengren have a deep knowledge in how our body reacts to pollution and emissions and we will discuss how different particles could enter our systems. Prof Bertil Forsberg is a scientist with deep experience in pollution and clinical medicine. Britta Permats representing the Swedish Ventilation association will contribute with the HVA aspects, so we cover the most area for IAQ and will do our best to discuss coming solutions for helping us Humans to get Healthy Buildings and Healthy Humans. The UFP increasing in outdoor air gives the indoor air more numbers concerning by number. Do UFP place an important role in indoors environment and how could we protect us.

Target audience

All with a general interest in Indoor Air Quality and ventilation solutions for the future

Background & Objectives

IAQ is a mission to treat, and finally we understand that the invisible threat, now by COVID, must be handled and it’s a complex mixture of facts that we need to explain very clearly and also put forward system with regulations for Indoor Air Quality.

All of us in the panel are experienced in different areas within IAQ, which should give the audience a view going forward with all things from filtration to WHO approach in the future.

Format, and method of participant interaction

Presentations and panel discussions in a Zoom Meeting (all attendes can talk)

After presentations, the seminar will have a panel discussion (all are invited to join with Q&A): The discussion will focus on: IAQ and UFP, Ventilation Filters, Air-cleaning techniques, and the White paper
for decision makers. Also, on the issue of PM (Particulate Matter), we will discuss the issue of particle-counting versus gravimetric measurements of indoor air, and how to go forward with that.

**Proposed schedule or length**

Schedule:

<table>
<thead>
<tr>
<th>Length (min)</th>
<th>Presenter</th>
<th>Subject / Activity</th>
</tr>
</thead>
</table>
| 40 min       | A Hedström                       | Presentation about:  
- UFP and their effect in humans-  
- Air-cleaning techniques |
| 10 min       | Lidia Morawska                   | White paper: “Ambient ultrafine particles: Evidence for policy makers”:  
https://efca.net/files/WHITE%20PAPER-
UFP%20evidence%20for%20policy%20makers%20(25%20OCT).pdf |
| 15 min       | All panellist                    | Round-table with open discussion on:  
- IAQ and UFP  
- Ventilation Filters and other air-cleaning techniques  
- White paper for decision makers  
- PM: the issue of particle-counting versus gravimetric measurements |
| 15 min       | All                              | Q & A                                                                               |
| 5 min        | A Hedström                       | Closing summary                                                                    |

**Output**

After the workshop we will output

1. PPT short version
2. Full sized text of White Paper Ultra Fine Particles Evidence for decision makers
3. Paradigm Shift Science paper full text

After 1 week a document around the panellist discussion and also Q and A will be mailed in written form.
Seminar:

Inspection and commissioning of ventilation systems, including VAV-systems

Organizers

This workshop is organized by representatives of The Nordic Ventilation Group (NVG)

- **Corresponding chair:** Lars Ekberg, Chalmers, Sweden. lars.ekberg@cit.chalmers.se
- **Co-chair:** Peter G. Schild, OsloMet, Norway. peter.schild@oslomet.no
- **Co-chair:** Risto Kosonen, Aalto Univ., Finland. risto.kosonen@aalto.fi

Target audience

All professionals working with design, construction and/operation of modern ventilation systems.

Background & Objectives

The objective of this workshop is for HVAC specialists to share their best-practice experiences from auditing and commissioning ventilation systems.

Conditions/facilities/resources

Participation is on Zoom webinar enabling full interaction for all attendees.

Format, and method of participant interaction

Workshop starting with 3 presentations, each followed by discussion.

Proposed schedule or length

After the three presentations there will be time allocated for questions and discussions, which will be documented. Total time 1.5 hrs

Issues addressed:

1. Functional requirements, as a basis for inspection
   a. Expected/required function
   b. Observations (ocular and by measurement)
   c. Criteria for acceptance

2. Practical methods to document of proper function
   a. Measurement methods, instruments and devices
      (pressure differential, air velocity and air flow rate)
   b. Accessibility
   c. System in the correct state of operation

3. Modern challenges
   a. Demand Controlled Ventilation: Handover tests and functional testing
   b. Understanding the principle of control of VAV systems
   c. Sensor quality, precision, placement etc.
### Schedule:

<table>
<thead>
<tr>
<th>Length (min)</th>
<th>Presenter</th>
<th>Subject / Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 min</td>
<td>Lars Ekberg</td>
<td>● Functional requirements</td>
</tr>
<tr>
<td></td>
<td></td>
<td>● Practical methods to commission and document proper function</td>
</tr>
<tr>
<td>40 min</td>
<td>Peter G. Schild</td>
<td>VAV-commissioning:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>● Understanding VAV-system components and VAV-system configurations</td>
</tr>
<tr>
<td></td>
<td></td>
<td>● Practical experiences on how to commission and test VAV/DCV-systems</td>
</tr>
<tr>
<td>15 min</td>
<td>Risto Kosonen</td>
<td>VAV-commissioning:</td>
</tr>
<tr>
<td></td>
<td></td>
<td>● Operational challenges of modern VAV-systems. A case study</td>
</tr>
<tr>
<td>rest</td>
<td>all</td>
<td>Q&amp;A</td>
</tr>
</tbody>
</table>
Seminar:

**Legionella prevention in buildings**
– Are we effecting meaningful change or just checking all the boxes?

Organizers

- **Corresponding chair**: Michael B. Waak
  SINTEF Community, Trondheim, michael.waak@sintef.no
- **Co-chairs**: Karolina Stråby
  SINTEF Community, Oslo, Karolina.Straby@sintef.no

Target audience

We have identified different stakeholder groups to participate in our expert panel, so we hope to draw a diverse audience, which may include HVAC/plumbing workers, consultants, researchers, product suppliers, building owners/managers, policy makers and all others interested in Legionella prevention and management.

Background

*Legionella* bacteria can cause severe, if not fatal, illnesses like Legionnaires’ disease. Legionella are transmitted by drinking water and may colonize and proliferate in building cold and hot water plumbing, where vulnerable building users may then be exposed via contaminated water droplets and aerosols from faucets, showers and toilets. Increasing incidence of Legionella infection, both globally and in Europe, has resulted in increased awareness and attention from regulators, researchers, engineers, product/service providers, and building owners or managers. Despite the attention, however, the day-to-day burden of Legionella prevention often falls on building services personnel or the janitorial staff, whose time and resources may be limited despite many other diverse responsibilities. At the same time, the European Union has recently revised its Drinking Water Directive to include Legionella testing, which could subsequently add a large amount of extra work, time and expenses for end-users.

Objectives

The main objective of this workshop is to discuss various stakeholder perspectives on *Legionella* prevention in buildings, including current and future challenges. We hope to have an engaging and productive dialogue.

Conditions/facilities/resources

Zoom webinar with full attendee interaction. No limit to the number of attendees

Format, and method of participant interaction

Presentations followed by panel discussion

Programme

We anticipate the workshop will last 1.5 to 2 hours, which is flexible depending on conference scheduling. The workshop will be divided into pre-recorded presentations (assuming a digital conference format) and then a panel discussion allowing audience questions with panelist feedback.

First, a panel of experts representing different stakeholders or perspectives (i.e., regulatory, academic/research, training/consulting, and building operation/management) will address certain broad
themes and introduce key topics and challenges regarding Legionella prevention in buildings. The prerecorded presentation format will avoid internet connection issues, presentation/PowerPoint issues, and time delays, so the presentations will stay on schedule. We hope to have all speakers in digital attendance to answer questions in real time—either verbally or in the workshop chat. Audience members will be able to ask questions during (via web chat) or in between each presentation (e.g., by raising hand).

After we hear from the various stakeholder representatives, we will have a panel discussion, where audience members may ask the panel questions. We hope to have good engagement and dialogue, both among the panelists and with the audience. In the event of low audience participation (and/or to “break the ice”), we will have prepared prompts/questions to begin the discussion. We hope that audience members will help guide the discussion. We will also allow users to submit questions prior to the panel discussion (e.g., during the short break).

**Schedule:**

<table>
<thead>
<tr>
<th>Length (min)</th>
<th>Presenters</th>
<th>Subject / Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 min</td>
<td>Michael Waak and Karolina Stråby (SINTEF)</td>
<td>Opening - Introduction, objective of the workshop, topic background, and schedule.</td>
</tr>
<tr>
<td>5–10 min</td>
<td>NN (Norwegian Institute of Public Health)</td>
<td>Regulatory perspective on national guidelines and compliance</td>
</tr>
<tr>
<td>5–10 min</td>
<td>NN (Building operator or manager, or municipal representative)</td>
<td>The reality of Legionella management: Perspectives on day-to-day operation and remaining challenges</td>
</tr>
<tr>
<td>5–10 min</td>
<td>Hanne Therese Skiri (Kompa AS)</td>
<td>Training and compliance: Are we training effectively? Is the burden/responsibility being placed on the right people?</td>
</tr>
<tr>
<td>5–10 min</td>
<td>NN (Academic/research representative (e.g., NTNU))</td>
<td>Scientific perspective: Are management practices consistent with our knowledge?</td>
</tr>
<tr>
<td>5–10 min</td>
<td>-</td>
<td>Short break</td>
</tr>
<tr>
<td>45–50 min</td>
<td>all</td>
<td>Panel discussion with audience Q&amp;A</td>
</tr>
</tbody>
</table>

**Discussion topics**

- What are the challenges of Legionella management in terms of day-to-day operation?
- How do we know that we are effecting meaningful change?
- Is the responsibility of Legionella prevention being placed on the right people?
- How could we more effectively allocate resources (e.g., time and operating expenses)?
- What are the knowledge gaps in terms of Legionella prevention and how will we bridge them?
- Current challenges and the potential for innovative or novel solutions (e.g., water system design, tools/training, automation, sensors, etc.)

**Panel**

- Norwegian Institute of Public Health (e.g., Vidar Lund, Fredrik Jordhøy or Line Angeloff; NOT YET CONFIRMED)
- Building operator or manager, or municipal representative in the building operations and management division. (NOT YET CONFIRMED)
- Hanne Therese Skiri, consultant and Legionella expert with Kompa AS
- Researcher in water quality, Legionella microbiology, and/or engineering (Norwegian University of Science and Technology or SINTEF AS; e.g., Cynthia Hallé, Stein Østerhus, or another professor; NOT YET CONFIRMED)

**Output**

Through the discussion, the workshop will highlight different stakeholder perspectives regarding current or anticipated challenges. We hope initiating this dialogue between different stakeholders will mutually benefit all stakeholders, facilitate networking and future communication, and generate interest and innovative ideas.
Workshop:
Ventilation Rates in Homes

Organizers
• Corresponding chair: Yuexia Sun
  School of Environmental Science and Engineering, Tianjin University, China, yuexiasun@tju.edu.cn

Target audience
This workshop will appeal to all (both practitioners and experts) who are interested in the following:
  1) To get a scientific consensus on how to treat ventilation of homes in different climate zones;
  2) To get updated on research on ventilation of homes, with regard to energy use, health effects and technology solution.

Background
Ventilation of homes is a major determinant of public health and energy use.
From studies in Sweden (Bornehag et al., 2005) it is shown that a reduced ventilation rate in homes is a major risk factor for allergies among children. In a study of students in Tianjin University it is shown that the lower the ventilation rate in dormitories, the more allergies and infectious diseases are reported by the students (Sun et al., 2011). In cold climate it is shown that the less ventilation, the more infestation of House Dust Mites (HdM) in beds (Sundell et al., 1995). HdM is a main trigger of allergic responses. A low ventilation rate also increases the indoor concentration of pollutants from indoor sources, like formaldehyde, VOCs and SVOCs. Some of such compounds are endocrine disruptors influencing our hormonal system, and now believed to be the cause of “Modern Diseases” like asthma, allergies, diabetes, obesity, reduced sperm quality, male reproductive disorders, and neurodevelopmental disorders like ADHD, and autism (Colborn et al., 1997).
On the other hand, with development of urbanization, energy consumption for heating and air cooling system has a trend of increase. Higher ventilation means higher consumption of energy (unless heat recovery systems are used).

Objectives
We would like to get input and discussion from audience on the following
  1) How much ventilation is needed in homes?
  2) What technical solutions are used today?
  3) What new solutions can be used in the near future?

Conditions/facilities/resources
Online Zoom webinar with full interaction for all participants

Format, and method of participant interaction
Colloquim

Proposed schedule or length
Total length 90 minutes.
Organizers

- **Corresponding chair**: Dr. *Johan Mattsson*
  Mycoteam, johan@mycoteam.no
- **Co-chairs**: *Kolbjørn Mohn Jenssen*
  Mycoteam, kolbjorn@mycoteam.no

**Target audience**

The topic covers both specific methods and general evaluations of the IAQ regarding airborne particles. It is mainly planned to be a scientific workshop but depending on the number and interest of the participants, we can also focus more on practical issues.

The most important prerequisite for participation is interest in the issue, but the more knowledge and experience they have within this topic, the more in-depth discussions we can expect to have.

**Background & Objectives**

IAQ surveys can take place in different ways. Because there is no standardized method for either sampling, analysis or interpretation, there is a large variation in the results of the surveys. In addition to the uncertainty in how representative the results are in the current analysis; it is very difficult to compare results from different measurements. Because deposited dust reflects what particles that has been airborne in the room air, a standardised and systematic examination of quantities and types of particles can provide a good clarification of both exposure and sources. We have developed a standardized method (special tape) for sampling and analysis of deposited dust on surfaces. We want to have a workshop on this topic where both the method and results can be presented and where there is room for professional discussion between the participants.

**Format, and method of participant interaction**

We would like to both present techniques and experiences from the use of special tape for examination of IAQ-issues, and invite the conference participants who are interested in the issue to contribute with their own short presentations describing different methods and experiences they have of sampling and analysis of airborne or deposited particles in the indoor climate. The final layout of the workshop depends on the number of participants and how many that wants to give a presentation. It is planned that a summary text will be made which will be distributed to all participants and which will be made available to other conference participants.
Schedule

<table>
<thead>
<tr>
<th>Length (min)</th>
<th>Presenter</th>
<th>Subject / Activity</th>
</tr>
</thead>
</table>
| 15          | Johan Mattsson  
R&D Manager Mycoteam | General introduction to the exposure and examination of airborne particles. |
| 15          | Kolbjørn Mohn Jenssen,  
Director Mycoteam | Introduction to the theoretical background of Mycotape2. |
| 15          | Practical use and interpretation of results | Presentation of experiences and results. |
| 30          | All participants | General discussion and possible presentations from participants. |
| 15          | Kolbjørn Mohn Jenssen & Johan Mattsson | Further discussion and summary. |

Output

The digital workshop will be documented by video. In advance will relevant facts be available as pdf-files. Afterwards will a summary of the workshop be written and made available as pdf-file for the attendees and other participants at the Healthy Building conference.
Seminar:
Determinants and sources of indoor bacteria, and consequences for respiratory health

Organizers
- **Corresponding chair:** Randi Jacobsen Bertelsen, University of Bergen, Randi.J.Bertelsen@uib.no
- **Co-chair:** Maryia Khomich, University of Bergen

**Target audience**
Researchers and meeting participants with an interest in the indoor microbial communities

**Background & Objectives**

**Keywords:** microbiome, home environment, respiratory health, bacteria.

The indoor environment is an important source of exposure to microbial components. We spend approximately 90% of our time indoors and are exposed to a variety of airborne microbial components. The bacteria in the air we breathe are important sources for the lung microbiome, and therefore have the potential to impact respiratory health and disease. While some environments, like farms, may be associated with lower risk of atopy and asthma, as known particularly from children growing up on farms, the mechanisms or sources leading to such ‘protective’ effects are still discussed. The indoor microbiota can be of human or environmental origin but building and household characteristics may also impact the diversity and abundance of the microorganisms found indoors. During this workshop we will discuss the indoor bacteria and other microorganisms, sources and determinants of these and the potential impact on allergies and respiratory health.

**Format, and method of participant interaction**

Presentations by invited speakers (12 + 3 min); panel discussion at the end.

**Proposed schedule or length**

Total length 90 minutes.

**Schedule:**

<table>
<thead>
<tr>
<th>Length (min)</th>
<th>Presenter</th>
<th>Subject / Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 min</td>
<td>Randi J Bertelsen, University of Bergen</td>
<td>Welcome and introduction to the topic</td>
</tr>
<tr>
<td>12+3 min</td>
<td>Vivi Schlünssen, Aarhus University, Denmark</td>
<td>Bacterial abundancy and richness in cow and pig stables and the associated farmers homes in Denmark</td>
</tr>
<tr>
<td>12+3 min</td>
<td>Hesham Amin, University of Bergen, Norway</td>
<td>Comparison between indoor airborne bacterial communities in five Northern European cities</td>
</tr>
<tr>
<td>12+3 min</td>
<td>Inge Wouters, Institute for Risk Assessment Sciences (IRAS), The Netherlands</td>
<td>Bacterial exposure indoors, outdoors and at personal level for participants in the Farming and residential exposure and health study</td>
</tr>
<tr>
<td>12+3 min</td>
<td>Malin Alsved, Lund University, Sweden</td>
<td>Indoor sources of airborne viruses and dog allergens</td>
</tr>
<tr>
<td>12+3 min</td>
<td>Lidia Casas, University of Antwerp, Belgium</td>
<td>Residential green space can shape the indoor microbial environment</td>
</tr>
</tbody>
</table>
Output

Short report, review paper
Workshop: REHVA Guidebook on occupant-targeted ventilation

Organizers

- **Corresponding chair:** Arsen Melikov  
  Technical University of Denmark, akm@byg.dtu.dk
- **Presenter:** Angui Li  
  Umeå University, Sweden & Xi’an University of Architecture and Technology
- **Presenter:** Bin Yang  
  Umeå University, Sweden & Xi’an University of Architecture and Technology
- **Presenter:** Guangyu Cao  
  Norwegian University of Science and Technology, Norway
- **Presenter:** Risto Kosonen  
  Aalto University, Finland
- **Presenter:** Xianting Li  
  Tsinghua University, China
- **Presenter:** Zhang Lin  
  City University of Hong Kong, China

Target audience

Architects, Property developers & managers, HVAC design engineers & contractors.

Background & Objectives

A wide range of pollutants has been found indoors and their adverse effect on occupants’ health has been recognized. Gaseous and particulate pollutants may spread indoors from one zone to another though improperly designed airflow distribution system. Airborne transmission of respiratory infectious diseases indoors has also been recognized. Air distribution in spaces is important for transport of pollution and viruses and the exposure of occupants. At present, an increase of ventilation rate is recommended for reduction of exposure, mainly due to dilution. However, the increase of the ventilation rate leads to increase of energy consumption and need of large and costly ventilation systems. Instead, proper design and control of air distribution in spaces can be considered. This is in the focus of a new REHVA Guidebook on Target Ventilation. The guidebook and the present and future activities in its preparation will be presented and discussed. The details of the work will be reported in several presentations and during the group working on the guidebook. The goal is to inform the community and discuss the work performed so far on the guidebook and to collect rational suggestions for the improvement of the work on the guidebook.

The objective of this workshop is to present the new REHVA Guidebook on Target Ventilation, to discuss the ongoing work and to collect suggestions for its improvement.

Format, and method of participant interaction

Presentations and discussions
**Conditions/facilities/resources**

Can be conducted in a digital form (e.g. Zoom). There are not practical limit to the number of people.

**Proposed schedule or length**

<table>
<thead>
<tr>
<th>Schedule</th>
<th>Length (min)</th>
<th>Presenter</th>
<th>Subject</th>
</tr>
</thead>
<tbody>
<tr>
<td>8 min</td>
<td>Arsen Melikov</td>
<td>Opening - Objective of the workshop and the REHVA Guidebook</td>
<td></td>
</tr>
<tr>
<td>8 min</td>
<td>Xianting Li</td>
<td>Advanced ventilation by non-uniform air distribution</td>
<td></td>
</tr>
<tr>
<td>8 min</td>
<td>Angui Li</td>
<td>Attached ventilation</td>
<td></td>
</tr>
<tr>
<td>8 min</td>
<td>Zhang Lin</td>
<td>Stratum ventilation</td>
<td></td>
</tr>
<tr>
<td>8 min</td>
<td>Risto Kosonen</td>
<td>Zonal air distribution by individually controlled chilled beam</td>
<td></td>
</tr>
<tr>
<td>8 min</td>
<td>Guangyu Cao</td>
<td>Protected occupied zone ventilation</td>
<td></td>
</tr>
<tr>
<td>8 min</td>
<td>Bin Yang</td>
<td>Examples of application set-ups in practice</td>
<td></td>
</tr>
<tr>
<td>30 min</td>
<td></td>
<td>Questions and discussion</td>
<td></td>
</tr>
</tbody>
</table>

**Discussion topics**

- What are the challenges to reduce personal exposure indoors?
- How to design indoor airflow distribution to reduce the indoor exposure?
- What are these advanced airflow distribution methods to reduce exposure to indoor pollutants?
- Where these advanced airflow distribution methods may be applied?

**Output**

The discussions, comments and suggestions during the workshop will be considered for improvement of the structure and content of the guidebook. It is expected that several efficient new methods of airflow distribution for reduce indoor exposure to various airborne pollutants will be proposed for inclusion in the guidebook.
ID 320 (Symposium):


Organizers

Organizers / contact persons for planning symposium:

• Corresponding organizer: Peter Ljubetic
  Avidicare AB, Int.Sales Director, peter.ljubetic@avidicare.com

• Corresponding co-organizer: Mari Regner
  Avidicare AB, Marketing Director, mari.regner@avidicare.com

Moderators / chairpersons:

• Chair: Prof. Dr. med. Clemens Bulitta
  OTH-Weiden. c.bulitta@oth-aw.de

• Co-chair: Peter Höjerback
  CEO, Avidicare AB. peter.hojerback@avidicare.com

Contributors:

• Dr. med. Koen Defoort
  Orthopedic surgeon, Sint Maartenskliniek in Nijmegen, NL. k.defoort@maartenskliniek.nl

• Prof. Dr. med. Clemens Bulitta
  OTH-Weiden, Germany

• Prof. Guangyu Cao
  NTNU, Trondheim, Norway. guangyu.cao@ntnu.no

• PhD candidate Yang Bi
  NTNU, Trondheim, Norway. yang.bi@ntnu.no

• Associated Prof. Sasan Sadrizadeh
  KTH Royal Institute of Technology, Stockholm, Sweden. sasan.sadrizadeh@byv.kth.se

• PhD candidate Parastoo Sadeghian
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• PhD candidate Shib-Ying Chen
  KTH Royal Institute of Technology, Stockholm, Sweden. chensy@kth.se

Target audience

You are invited to this Scientific Symposium to meet some of the most prominent researchers and experts within Infection Prevention and Ventilation of the surgical suite. The Symposium is specifically developed for you as Clinical Engineer, Infection Preventionist, Perioperative Nurse, Architect or Healthcare Executive, as well as other Healthcare Professionals and Researchers.

Background & Objectives

The current pandemic, along with continuously very high costs in both lives and money from surgical site infections, have made it obvious that improved air management is needed to cope with airborne infections. It is no longer enough to just focus on hand hygiene, cleaning and disinfection as the main tools for infection prevention. There clearly is a need to come up with innovative concepts and solutions for air management and ventilation, especially inside healthcare facilities. Healthcare authorities, HVAC
manufacturers, infection prevention experts and building engineers will need to come together and focus on airflow optimization through changes to existing ventilation systems, novel air-purification and decontamination technologies as well as better airflow management.

In this Symposium you will meet both researchers from top universities and healthcare professionals from top orthopedic clinics in Europe who will introduce you to the latest insights for infection prevention, including the rationale behind and features of a modern and robust technology called Temperature-controlled airflow. The focus of the symposium will be on the most demanding area of any hospital – the surgical suite with its operating rooms.

The Symposium is sponsored by Avidicare AB. The company was founded in 2007 and currently has more than 250 installations of its unique Opragon ventilation system. Together with its partners, the company works “Towards Zero Infections” in healthcare facilities.

**Conditions/facilities/resources**

The Avidicare Symposium is a digital session and you may participate from anywhere in the world.

**Format, and method of participant interaction**

Each presentation will be followed by a Q&A session where you can ask your questions directly to the speakers.

**Proposed schedule or length**

The Symposium is scheduled to approx. 1:45 hours. See detailed schedule below.

<table>
<thead>
<tr>
<th>Schedule</th>
<th>Length (min)</th>
<th>Presenter</th>
<th>Subject / Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Moderator</strong></td>
<td>10 min</td>
<td>Peter Höjerback, CEO Avidicare AB, Sweden</td>
<td>Introduction: Towards Zero Infections</td>
</tr>
<tr>
<td><strong>Prof. Dr. med. Clemens Bulitta</strong></td>
<td>15 min</td>
<td>OTH-Weiden, Germany</td>
<td>“There is music in the air” – the complex thermodynamics of OR ventilation systems Abstract of contribution: 113 - Performance assessment and clinical validation of Operating Room ventilation systems</td>
</tr>
<tr>
<td><strong>PhD cand. Parastoo Sadeghian</strong></td>
<td>20 min</td>
<td>PhD cand. Shih-Ying Chen KTH, Sweden</td>
<td>How VR and AR technologies can boost healthcare worker awareness regarding their activity impact on the level of airborne infectious agents Abstract of contribution: 127 - Transport of Contaminated Agents in Hospital Wards - Exposure Control with a Personalized Healthcare Ventilation System: Numerical Study 212 - Visualizing bacteria carrying particles in the operating room: making invisible, visible</td>
</tr>
<tr>
<td><strong>Prof. Guangyu Cao</strong></td>
<td>15 min</td>
<td>PhD cand. Yang Bi NTNU, Norway</td>
<td>Airflow distribution and surgical microenvironment control in operating rooms Abstract of contribution: 167 - Experimental study on the surgical microenvironment in an operating room with mixing ventilation under positive and negative pressure</td>
</tr>
<tr>
<td><strong>Dr. med. Koen Defoort</strong></td>
<td>15 min</td>
<td>Orthopedic Surgeon Sint Maartenskliniek, NL</td>
<td>The innovative Operating Theatre - Our office &amp; workshop in real life Top orthopedic clinic choose Opragon in their operating rooms.</td>
</tr>
<tr>
<td><strong>Moderator &amp; All</strong></td>
<td>10 min</td>
<td></td>
<td>Open discussion &amp; questions - Closing</td>
</tr>
</tbody>
</table>

**Output**


Participants are expected to receive an up-to-date view of the latest research and technologies in the fight against airborne infections in healthcare facilities.
Avidicare will send out a summary of the scientific symposium to all delegates. The summary will also be published in a Newsletter shortly after the congress. The Symposium will be recorded and available on-demand afterwards.
Seminar: REHVA-ISIAQ guidance on measures to prevent airborne transmission

Organizers
- Corresponding chair: Dr. Atze Boerstra
  Vice-President Federation of European Heating, Ventilation and Air Conditioning Associations (REHVA), and Managing Director of BBA Binnenmilieu, The Netherlands. ab-bba@binnenmilieu.nl
- Co-chair: Professor Jarek Kurnitski
  Lead author of REHVA taskforce COVID-19 guidance, and Tallinn University of Technology, Estonia. jarek.kurnitski@ttu.ee

Target audience

Background & Objectives
REHVA acted fast in the spring of 2020 to develop evidence-based recommendations on practical COVID-19 infection mitigation measures related to e.g. the operation and maintenance of ventilation systems. We have seen that the guidance has helped owners & operators of existing buildings to make the right kind of decisions about their buildings and building service systems throughout all over Europe and beyond.

This joint REHVA-ISIAQ seminar focuses on the development and latest iteration of the REHVA requirements and their scientific evidence. The workshop complements the ISIAQ workshop on infection risk models that focusses on the more fundamental aspects related to airborne transmission of infectious diseases indoor.

Questions covered in this workshop are for example:
- What air exchange rates should be recommended?
- How about the relative importance of measures, e.g. air change rate versus HVAC servicing points, controlling pressure differentials between rooms and general sanitation measures (e.g. handwashing)?
- Why is humidification not generally recommended in the guidance document (the significance of relative or specific humidity)?
- Are droplet nuclei with (infectious) virus-laden aerosols transported via ventilation ducts and recirculation sections or enthalpy wheels (rotary heat exchangers) back to occupied rooms?
- How relevant are the present COVID-19 requirements in relation to other diseases e.g. seasonal flu (future influenza epidemics)?

Format, and method of participant interaction
Presentations with Q&A & interactive discussion at the end. The idea is to use 2/3 of the time for presentations and questions and 1/3 of the time for a group discussion that evolves around central questions and statements. Atze Boerstra & Jarek Kurnitski will act as moderator for the interactive part.
Proposed schedule

Schedule:

<table>
<thead>
<tr>
<th>Length (min)</th>
<th>Presenter(s)</th>
<th>Subject / Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>12 min</td>
<td>All</td>
<td>Kickoff, general introduction, explanation of overall program &amp; interactive session</td>
</tr>
<tr>
<td>12 min</td>
<td>Jarek Kurnitski</td>
<td>Introduction to the REHVA COVID-19 guidance document &amp; backgrounds of the requirements</td>
</tr>
<tr>
<td>12 min</td>
<td>Pawel Wargocki</td>
<td>Relative humidity impacts in COVID-19 context</td>
</tr>
<tr>
<td>12 min</td>
<td>Igor Sikończyk</td>
<td>Heat recovery systems &amp; internal leakage inspection</td>
</tr>
<tr>
<td>12 min</td>
<td>Atze Boerstra</td>
<td>Lessons learned: applying the REHVA requirements in practice (case studies)</td>
</tr>
<tr>
<td>30 min</td>
<td>All</td>
<td>Interactive discussion</td>
</tr>
</tbody>
</table>

Output

Workshop report including short summaries of presentations and main statements and conclusions. This report also will be translated at a later stage in a joint REHVA journal article.
Seminar:

Ventilation and IAQ criteria in the revised standard EN 16798-1

Organizers

- **Corresponding organizer:** Professor Jarek Kurnitski  
  Chair REHVA Technology and Research Committee, Tallinn University of Technology, Estonia,  
  jarek.kurnitski@ttu.ee
- **Co-organizer:** Professor Bjarne W. Olesen  
  International Centre for Indoor Environment and Energy, Technical University of Denmark,  
  bwo@byg.dtu.dk
- **Co-organizer:** Professor Pawel Wargocki  
  Technical University of Denmark, paw@byg.dtu.dk

Target audience

Researchers, HVAC professionals and consultants, building authorities.

Background & Objectives

EN 16798-1 serves as a major indoor climate standard with the aim to specify main design criteria for buildings with human occupancy. This workshop is limited to IAQ and ventilation, other areas of indoor climate are not discussed. In the current standard, IAQ is mainly dealt through perceived air quality that leads to ventilation sizing criteria in non-residential and residential buildings. In addition, health-based ventilation criteria is provided based on WHO listed pollutants. Revision of the standard provides a good opportunity to include and develop another evidence-based criteria being based on health effects, productivity and learning performance, sick leaves and infection risk.

The objective of the workshop is to discuss new ventilation criteria and propose directions how to develop input to the revision of the standard. The following questions will be discussed:

- That is the state of health-based ventilation criteria including non-specific pollutants, CO₂ and evidence from epidemiological studies? It has been generally seen that the lack of health-based ventilation criteria has been a barrier for authorities to set more demanding ventilation requirements in many countries.
- Productivity in office work and learning performance in schools has been widely studied. Could these results be utilised as one criterion for Category II and I ventilation rates?
- COVID-19 pandemic has brought out the importance of the infection risk control in indoor spaces. The phenomena is not new because there is good previous evidence and knowledge on sick leaves (common cold) and influenza. As any airborne virus can be described by emission rates, the question is, should ventilation criteria include ventilation sizing to some predefined infection risk probability.

Format, and method of participant interaction

Presentations with Q&A.

Proposed schedule or length

Approx 1 hour.
Schedule:

<table>
<thead>
<tr>
<th>Length (min)</th>
<th>Presenter</th>
<th>Subject / Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>15 min</td>
<td>Bjarne Olesen</td>
<td>About revision of EN 16798-1</td>
</tr>
<tr>
<td>15 min</td>
<td>Jarek Kurnitski</td>
<td>Infection risk probability application to ventilation sizing in different rooms</td>
</tr>
<tr>
<td>15 min</td>
<td>Peter G. Schild</td>
<td>Minimum demand-controlled ventilation rates in unoccupied situations</td>
</tr>
<tr>
<td>15 min</td>
<td>Pawel Wargocki</td>
<td>Health based ventilation criteria, how it differs from PAQ in residential and non-residential spaces?</td>
</tr>
<tr>
<td>all</td>
<td>Q&amp;A</td>
<td></td>
</tr>
</tbody>
</table>

Output

Workshop report including short summaries of presentations and main statements and conclusions.
Organizers

- **Corresponding Chair:** Yuwei Du,
  City University of Hong Kong, yuweidu5@cityu.edu.hk

Target audience

All who are interested in new glazing materials for smart windows

Background & Objectives

One example of smart glazing technology is Perovskite glazing, which self-adaptively switched between window mode when cool to opaque solar cell mode when it is hot and sunny.

Format, and method of participant interaction

Presentations and round-table.
Organizers

- **Corresponding chair:** Alireza Afshari  
  Department of the Built Environment, Aalborg University-AAU,  
aaf@build.aau.dk
- **Co-chairs:** Bjarne W. Olesen  
  Professor, Department of Civil Engineering, Technical University of Denmark – DTU,  
bwo@byg.dtu.dk

**Target audience**
The target audience is manufacturers, engineers, consultants and scientists.

**Background & Objectives**

Air pollution in indoor environment consists of a mixture of particles and gases penetrating partly from outdoor air and emanating partly from the indoor sources. Exposure to indoor air pollutants can cause health effects such as asthma. Measures to reduce risk of exposure to harmful air pollutants from a combination of outdoor and indoor sources generally fall into three main categories: source control, ventilation control, and removal control. In the present workshop, we focus on removal control i.e. particle filtration and gas phase air cleaning.

In many locations in the world, the outdoor air quality is so bad that ventilation decreases the quality of indoor air rather than it improves it. In these cases, the alternative to use ventilation is to substitute it with particle filtration and gas-phase air cleaning so that the indoor air can be kept at high quality. Even when outdoor air is of a good quality, the use of air cleaning substituting or supplementing ventilation could reduce the rate of outside air supplied indoors and thereby energy can be saved for its conditioning (heating/cooling) and transporting (fan energy).

Since it is expected that use of particle filtration and gas-phase air cleaning are one of the strategies to improve indoor air quality and reduce energy use for ventilation, it should be considered as a very interesting technology that can be used in the future.

Both portable units for room-size applications and in-duct devices (installed in the HVAC system) are available. These units employ various technologies (filtration, adsorption, photocatalytic oxidation, etc.) depending on the types of pollutants to be removed (particles or gaseous contaminants). Emission of harmful by-products (i.e., ozone) has been a concern for some of these technologies.

In this session, we will invite subject experts to present an overview on current technologies, performance criteria for air cleaners and the use of air cleaning devices are /are not a substitute for ventilation.

This workshop is some of the issues that is part of a new IEA-EBC Annex 78 and also the topic fits the mission of ISIAQ STC22 Air cleaning which will be covered by presentations and discussion in this session.

**Conditions/facilities/resources**
It can be conducted in a digital form.

**Format, and method of participant interaction**
Presentations and discussion
**Proposed schedule or length**

Total length: 90 minutes

**Schedule:**

<table>
<thead>
<tr>
<th>Length (min)</th>
<th>Presenter</th>
<th>Subject / Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>Alireza Afshari</td>
<td>Supplementing Ventilation with Particle filtration</td>
</tr>
<tr>
<td>20</td>
<td>Bjarne W. Olesen</td>
<td>Supplementing Ventilation with Gas-phase Air Cleaning</td>
</tr>
</tbody>
</table>

**Output**

Video
Workshop/practice session proposal:
Innovative sampling methods - The value of using low cost sensors for measuring indoor air quality

Organizers
- Matthias Vogt (NILU, Norway), Sofia Sousa (LEPABE, Portugal)

Target audience
Scientific Workshop

Background & Objectives
This workshop aims to discuss the possibilities offered by LCS for indoor use and also its limitations, from the scientist and the user point of view. It is devoted to those interested in the air quality indoors and in exploring the possibilities of using LCS for this purpose.

Indoor air quality monitoring involves measuring levels of various potential contaminants as well as conditions that determine the quality of the air we breathe. Traditionally, this assessment has been made either using mobile instrumentation or passive sampling of components of interests (e.g. CH₂O, PM₁₀). In the last years there has been a rapid increase in the use of low-cost sensors in the indoor environment, which either inform the owner on the air they breathe or serve as a control mechanism for actions (Air-purifier, Ventilation). Despite of the widespread use by consumer of those sensors, the scientific community has considered the use of LCS with caution, as there are several unanswered questions raised on how to use them appropriately, on their performance and on how to evaluate such performance.

Format, and method of participant interaction
The workshop will include presentations from invited researchers (including the COST action indairpollnet) and stakeholders. It will end up in a round-table on how to best use low-cost sensors for indoor environmental monitoring.

Conditions/facilities/resources
The workshop can be conducted in digital form and the digital form can even be beneficial in order to attract important speakers.

Proposed schedule or length
We propose a workshop of 1.5 hours with about 1 hour of presentations and 20-30 min of discussions of specific thematic questions.

Schedule:

<table>
<thead>
<tr>
<th>Length (min)</th>
<th>Presenter</th>
<th>Subject / Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>Hiten Chojer</td>
<td>Development of a low-cost indoor air quality monitoring system - Academic research of the past decade</td>
</tr>
<tr>
<td>10</td>
<td>Juliana Pinheiro de Sá</td>
<td>Commercially available low-cost sensors to monitor indoor air quality – a review on comparisons with other instruments</td>
</tr>
<tr>
<td>10</td>
<td>Maria Justo Alonso</td>
<td>Is drift a problem in low cost sensors?</td>
</tr>
<tr>
<td>15</td>
<td>Mila Ródenas</td>
<td>Measurement Techniques for Indoor Pollutants using Low-Cost Sensors</td>
</tr>
</tbody>
</table>
Output
The workshop will provide presentations for dissemination.

Questions for discussion
How can scientists use the commercial sensors for research?
Maintenance/QA-QC/Performance assessment of the installed sensors in buildings? Do we know enough?
Smart buildings: Occupants – can they use the information directly? What is the added value (beyond inputs to the operation of the technical systems)
Are there any possibilities for long-term monitoring of indoor environment? Where does all the data go?
Seminar
New understandings of “unclear” building related complaints and experiences

Organizers
- **Corresponding chair:** MD. Jan Haanes,
  Dept of Occ and Environ Med, University Hospital of Northern Norway, Norway, Jan.Vilis.Haanes@unn.no
- **Co-chair:** Prof. Steven Nordin,
  Dept of Psychology, Umeå University, Sweden. steven.nordin@umu.se

Target audience
All who work with buildings and people, irrespective of professional and scientific vs. practical background.

Background & Objectives
Most work in the field of healthy buildings relies heavily on information reported by humans. Often people have complaints or other experiences that professionals find difficult to interpret or understand, sometimes also contrary to common knowledge. This may cause frustration and conflicts. “Sick building syndrome”, “multiple chemical sensitivities” and “electromagnetic hypersensitivity” are examples of terms used for what may be seen as the “oddest” conditions. However, also more common building related complaints and other experiences are often regarded as “unclear”. In this seminar, we will address new understandings of possible underlying mechanisms – from different views. This new knowledge may be of substantial help for professionals in their understanding, interpretation, handling and actions.

Other information
The two presentations in the seminar are briefly introduced in session 11. The full papers are available as PDFs at the web site of session 11. At session 11, Nordin and Haanes also present one other paper each. Attending these presentations/ reading the papers will give important background for seminar 340.

Format and method of participant interaction
Introduction, two presentations and general discussion facilitated by chairs.

Proposed schedule or length
Total length 90 minutes.

<table>
<thead>
<tr>
<th>Length (min)</th>
<th>Presenter</th>
<th>Subject / Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>5 min</td>
<td>JH</td>
<td>Introduction, aims of the symposium. Presentation of spectre from BRI (building related illness) to “SBS” (sick building syndrome) etc. i.e. from likely building related in a traditional meaning (causality) to symptoms associated with buildings (SAEF-buildings)</td>
</tr>
<tr>
<td>20 min</td>
<td>SN</td>
<td>Presentation: Possible mechanisms underlying non-specific building-related symptoms</td>
</tr>
<tr>
<td>20 min</td>
<td>JH</td>
<td>Presentation: Understanding “Symptoms Associated with Environmental Factors” (SAEF) in buildings; e.g. “sick building syndrome”, “electromagnetic hypersensitivity” and “multiple chemical sensitivity”</td>
</tr>
<tr>
<td>45 min</td>
<td>All</td>
<td>General discussion</td>
</tr>
</tbody>
</table>

Output
Abstracts & papers
Extended Abstracts

**Paper 1.1: Impact of indoor temperature on the possible release of adsorbed Volatile Organic Compounds from sorptive materials**
Raphael BRUN, Margot GENEST, Marion CHENAL, Arnaud SOISSON, Marie VERRIELE, Frederic THEVENET

**Paper 1.2: Characterization of the surface chemistry of Activated Carbons: a tool for sorptive indoor material formulation**
Raphael BRUN, Mangesh Ramesh AVHAD, Helena KAPER, Marion CHENAL, Arnaud SOISSON, Marie VERRIELE, Frederic THEVENET

**Paper 1.3: Diffusions of essential oils in a 40m³ experimental room: from emission rates to impact on indoor air quality**
Shadia ANGULO MILHEM, Marie VERRIELE, Melanie NICOLAS, Frederic THEVENET

**Paper 1.4: VOCs emissions from the human during sleep under different ozone and air change rate levels**
Huiqi SHAO, Xiaojun FAN, Jiemian LIU, Pawel WARGOCKI

**Paper 1.5: Modeling physico-chemical processes impacting particles formation and fate indoors**
Corentin BERGER, Nadège BLOND, Alice MICOLIER, Maxence MENDEZ, Didier HAUGLUSTAINE, Jean-Luc PONCHE

**Paper 1.6: Ventilation rate in classrooms of elementary schools and its association with respiratory infections**
Yeoxia SUN, Feihu YANG, Xinyue RUO, Chaqi ZHANG

**Paper 1.7: Analysis of natural ventilation of a large educational building using parallel opening windows**
Twan VAN HOOFF, Marlies VERBRUGGEN, Bert BLOKEN

**Paper 1.8: Assessment of three experimental methods for determining the emission parameters of VOCs from a solid material**
Florent CARON, Marie VERRIELE, Romain GUICHARD, Laurence ROBERT, Frederic THEVENET

**Paper 1.9: Ventilation strategies of school classrooms against cross-infection of COVID-19: A review**
Er DING, Dadi ZHANG, Philomena M. BLUYSEN

**Paper 1.10: Experimental & Modelling Studies for the Determination of Pollutant Emissions from Cooking and Cleaning**
Ellen HARDING-SMITH, Catherine O'LEARY, Marvin SHAW, Matthew THOMPSON, Nicola CARSLAW, Terry DILLON, Archit MEHRA, Gavin PHILLIPS, Benjamin JONES

**Paper 1.11: How Does Indoor Air Chemistry Affect Outdoor Air Pollution?**
Freja ØSTERSTRØM, Toby CARTER, Nicola CARSLAW

**Paper 1.12: Characterising multi-sensor platforms performance to investigate indoor air quality events, and quantify personal exposure**
David UMBA KALALA, Nathalie REDON, Marie VERRIELE, Sabine CRUNAIRE, Nadine LOCOGE

**Paper 1.13: Experimental investigation of the local air exchange behind an obstacle in laminar flow**
Julia LANGE, Valeria HOFER, Martin KRIEGEL

**Paper 1.14: Bacterial and fungal aerosols in dwellings with domestic animals: preliminary results**
Józef Stefan PASTUSZKA, Agnieszka MLAZLO

**Paper 1.15: The indoor mycobiome in Norwegian daycares revealed by DNA high throughput sequencing**
Eva Lena ESTENSMO, Luis MORADO, Pedro Maria MARTIN-SANCHEZ, Sundry MAURICE, Ingeborg BJÖRVAND ENGH, Johan MATTSSON, Inger SKREDE, Håvard KAUSERUD

**Paper 1.16: Fungal growth on newly cast concrete floors and moisture membranes**
Sofie Kristensen KRISTENSEN, Anne Pia KOCH, Ulf THRANE

**Paper 1.17: Seasonal Distribution of Alternaria, Aspergillus, Cladosporium and Penicillium Genera Isolated from Estonian straw-bale and reed-bale dwellings**
Jane RAA METS, Aime RUUS, Mari IVASK, Lembit NEI, Karin MUONI

**Paper 1.18: Interaction effects of acoustics at and between human and environmental levels: A review on the acoustics in the indoor environment**
Amneh HAMIDA, Dadi ZHANG, Philomena M. BLUYSEN

**Paper 1.19: The challenge of finding definitions for well-being and health within the built environment**
Marcel SCHWEIKER, Rania CHRISTOFOROU, Janine BARDEY, Hannah PALLUBINSKY

**Paper 1.20: Relationships between mental health and indoor environmental quality (IEQ) in the home workplace**
Bouke BOEGHEIM, Rianne APPEL-MEULENBROEK, Dujuan YANG, Marcel LOOMANS
Paper 9.8: Analysis of workers’ tendency to answer questionnaires of positive and negative questions, along with understanding the relationship between comfort and self-efficacy
Kouki OGINO, Hiromichi NISHIDA, Tatsuo NOBE

Paper 10.6: A Practical and Efficient Testing Method for Indoor Airborne Pathogens
Dominick HESKETT, Touzong XIONG, Brian ANNIS, Tim GORDON, Braden STUMP, Mark STOLZENBURG, Marina NIETO-CABALLERO, Mark HERNANDEZ, Patricia KEADY

Paper 10.8: The potential of bio-based insulation products to support indoor air quality and reduce aerosol transmissions of contagious respiratory viruses such as SARS CoV-2 in the construction industry.
Svebor HERUC, Marijn VUIJK, Myron KOSTER

Paper 11.4: Characteristics of non-specific building-related symptoms
Steven NORDIN

Paper 11.6: Possible mechanisms underlying non-specific building-related symptoms
Steven NORDIN

Paper 12.2: CFD simulation of non-isothermal ventilation flow in a generic enclosure: Impact of inlet velocity boundary conditions
Luyang KANG, Twan VAN HOOFF

Paper 12.4: Development of an underground space using to produced cold energy in summer conditions in the building thermal conditions performance
Eusebio CONCEIÇAO, João GOMES, Mª Manuela LÚCIO, Hazim AWBI

Paper 12.6: INCHEM-Py: A new open source model for investigating indoor air chemistry
David SHAW, Nicola CARSLAW

Paper 12.7: Identification of most important factors (Building factors: artificial lights and window materials; External factors: cloud factors, season, latitude) affecting indoor photolysis rates
ZIXU WANG, NICOLA CARSLAW

Paper 13.4: FireDAVG – Fire related Damages with Attention to Vulnerable Groups. Guidance for vulnerable groups on handling of fire, soot, and smoke related damages in indoor environment.
Kent HART, Kai GUSTAVSEN

Paper 13.6: Architectural Design Modification Study for Improvement of Indoor Air Quality for Alleviation of Aeroallergen Sensitization in the Standard Naturally-Ventilated Urban Dwelling
Elke Simone Flores TIOTUICO

Paper 13.10: Chemical characterization of ultrafine particles released from 3D printers
Chi-Long TANG, Olaf WILKE, Stefan SEEGER, Sabine KALUS, Kerstin ERDMANN

Paper 14.2: Measurement and simulations of the influence of green wall systems on indoor air quality
Janine BARDEY, Marcel SCHWEIKER, Dirk MÜLLER, Marc BARANSKI

Paper 14.3: Intrinsic dimension estimation as a tool to sensor selection for an indoor air quality multisensory system
Luiz MIRANDA, Caroline DUC, Nathalie REDON, Marie VERRIELE, Bernadette DORIZZI, Jérôme BOUDY, Jugurta MONTALVÃO

Paper 14.5: Big Data in IAQ research, an example of the application in IEA EBC Annex 86
Jelle LAVERGE, Marc DELGHUST, Klaas DE JONGE, Loes LOKERE, Mathias VANDENBERGHE, Timon GRYSON, Ivan POLLET, Steven DELRUE

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Impact of indoor temperature on the possible release of adsorbed Volatile Organic Compounds from sorptive materials

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SUMMARY
This study aims at assessing a method to evaluate the impact of indoor heat event on the release of adsorbed Volatile Organic Compounds from sorptive materials. Temperature-Programmed Desorption and Isothermal Desorption are combined to study the release due to temperature of preliminarily adsorbed toluene from a model activated carbon. The minimum temperature required to induce desorption, and the temperature when all VOCs are desorbed are retrieved from Isothermal Desorption. Interestingly, these values correspond to characteristic temperatures obtained from Temperature-Programmed Desorption: $T_{\text{Start}}$ and $T_{\text{Peak}}$ respectively. $T_{\text{Start}}$ is the peak threshold temperature, and $T_{\text{Peak}}$ is the temperature reached at the peak maximum. Thus, Isothermal Desorption regimes are predictable from Temperature-Programmed Desorption, a less time-consuming approach.

Comparing the threshold temperatures determined in this study, with the actual surface temperature range of indoor materials, is used to assess the ability of adsorbed compounds to be released in indoor environment under realistic thermal conditions.

INTRODUCTION
Volatile Organic Compounds (VOCs) are key pollutants of indoor environment because of their recognized harmful impact on health (WHO 2006, WHO 2010). The use of sorptive construction materials to decrease VOC concentrations appears as a promising alternative to conventional solutions of ventilation, active air treatment systems or photocatalytic materials (González-Martín et al. 2021). Therefore, sorptive additives can be integrated in the formulation of construction materials to improve their VOC uptake capacities (Krou et al. 2015, Thevenet et al. 2018, Thevenet et al. 2021). Current issues in the development of sorptive construction materials for Indoor Air Quality (IAQ) improvement are: (i) increasing the magnitude of VOC uptake, and (ii) determining the fate of VOCs beyond the uptake under variable indoor temperature and Relative Humidity (RH). If the first issue is the central point of various research projects, the long-term behavior of the sorptive materials having VOCs on their surface has not yet been addressed indoors.

Most of the studies dealing with the depollution efficiency of sorptive constructions materials and sorbents are limited to mild and fixed ambient conditions of temperature; typically 20 to 23°C and ca. 50 % RH (Krou et al. 2015, Thevenet et al. 2018).

Despite the fact that indoor environmental conditions vary on shorter T and RH ranges than outdoor conditions, a seasonal variation of indoor temperature might be sufficient to modify significantly the sorption equilibrium of taken up VOCs.

This study aims to evaluate the impact of indoor temperature on the release of toluene adsorbed on the surface of a commercial Activated Carbon (AC) in order to predict the behavior of sorptive construction materials under variable indoor thermal conditions. Temperature-Programmed Desorption (TPD) and Isothermal Desorption (ID) are the selected methods. Results enable to (i) evaluate the ability of sorptive materials to release taken up VOCs in realistic indoor thermal conditions, and (ii) optimize the selection of sorbents for IAQ improvement solutions based on construction materials.

MATERIALS AND METHODS
Material of interest
To evaluate the influence of temperature on the release of adsorbed VOCs on indoor surface, a commercial AC is selected as reference material. Indeed, ACs are considered by several manufacturers as additives of interest for sorptive construction materials due to their high uptake ability (Krou et al. 2015).

Material characterization
The physico-chemical properties of the investigated commercial AC are characterized in terms of (i) morphology and (ii) surface chemistry.

Morphology/ Laser granulometry is performed to determine the particle size distribution. Particle shape and pore structure are characterized by scanning electron microscopy. The specific surface area ($S_{\text{spe}}$) is determined by N$_2$ sorption using the BET (Brunauer-Emmett-Teller) model. $S_{\text{spe}}$ of 1,150 m$^2$.g$^{-1}$ is obtained.
for this AC. Moreover, CO₂ sorption is used to determine the sorbent pore size distribution.

Surface chemistry/ The nature of heteroatom-based surface groups is evidenced by thermo-gravimetric analysis-mass spectrometry under nitrogen flow.

VOC of interest
Toluene is selected as model pollutant considering its ubiquity and available literature data.

Experimental set-up
The experimental setup used in this study is represented in the experimental section of (Thevenet et al. 2015).

and is composed of three distinct parts: (i) gas generation, (ii) U-shape reactor and (iii) analytical system.

Gas generation/ Non-polluted humidified air (50 ± 5 % RH at 23 ± 3 °C) is obtained by combining equivalent flows of dry zero air (catalytic generator, Claind, Italy) and zero air saturated by water vapor. Polluted air at toluene sub-ppm concentration is obtained by sending a regulated flow from a certified toluene cylinder (509 ppm in nitrogen, Messer, France) in the previously described air flow. Total flow rate is set at 1,000 ± 10 mL.min⁻¹. This setup allows obtaining a VOC concentration of 0 or from 50 to 1,000 ppb.

Reactor/ A layer of AC deposited on quartz wool in a U-shape reactor can be exposed to non-polluted or polluted humidified air.

Analytical system/ Toluene quantification at the downstream of U-shape reactor is performed using Selected Ion Flow Tube-Mass Spectrometry (SIFT-MS, SYFT Technology, New Zealand). SIFT signals are obtained by detecting a given product of the reaction between the analyte and a precursor ion (H₂O⁺, NO⁺ or O₂⁺). For toluene, the detected reaction products with precursor ion are C₆H₅H⁺ (m/z = 93) with H₂O⁺, C₆H₅⁺ (m/z = 92) with NO⁺, and C₆H₅⁺ (m/z = 92) with O₂⁺. In these experimental conditions, toluene concentration is monitored at a temporal resolution lower than 5 s, and the detection and quantification limits are respectively 5.4 and 17 ppb.

RESULTS AND DISCUSSION
First, 16.8 ± 0.1 mg of AC are exposed to 700 ± 20 ppb of toluene at 23 °C and 50 % RH, until the breakthrough of toluene at the outlet of the U-shape reactor. The total amount of toluene adsorbed on AC is 1.2 ± 0.2 mmol.g⁻¹. The reversible fraction of adsorbed toluene at ambient temperature is determined by flushing the AC sample equilibrated with toluene under zero air (23 °C, 50 % RH), until the concentration of toluene returns to zero at the U-shape reactor outlet. This experimental step enables to discriminate the reversible (Frrev) vs. irreversible (Firr) fractions of toluene at 23 °C. Interestingly, 60 ± 10 % of toluene is removed by the ambient temperature flushing, under meaning that 0.5 ± 0.1 mmol.g⁻¹ remains on the surface, and represent the so-called irreversibly adsorbed fraction at ambient temperature. The objective of this work is to address the fate of this fraction under various indoor temperatures. Two complementary experimental methodologies are used to characterize the fate of adsorbed VOCs on the sorbent under indoor conditions: (i) Temperature-Programmed Desorption (TPD) and (ii) Isothermal Desorption (ID).

Temperature-Programmed Desorption approach
TPD consists in linearly increasing the temperature of the sorbent layer covered by the irreversible fraction of toluene at ambient temperature. The release of VOCs induced by the heating is monitored at the reactor outlet. The temperature range in this work is 23 - 450 °C. Figure 1 reports the variation of toluene concentration at the outlet of the U-shape reactor during the TPD with a heating rate (β) of 5 K.min⁻¹. A typical TPD peak is observed in Figure 1, which corresponds to the gradual thermal removal of toluene from AC surface, until exhaustion.

The major interest of TPD relies in the determination of thermodynamic and kinetic parameters: adsorption enthalpy (in kJ.mol⁻¹) and activation energy of desorption (in kJ.mol⁻¹). If these parameters characterize the average magnitude of interaction between the adsorbed toluene and AC, they are not directly used to provide valuable characterization of toluene behavior under typical indoor temperature range. However, this methodology enables to determine the temperature at which VOC desorption initiates, referred as T_start in the following. In the case of toluene adsorbed on the selected AC, T_start = 30 ± 4 °C.

This result means F_start will start desorbing at this temperature, which could be reached indoor at the surface of a sorptive material during sunny days. Therefore, this parameter should be taken into account when selecting the AC to be implemented in sorptive construction materials. Note that T_peak, the
temperature reached at the maximum of the desorption peak in TPD, is determined as 150 ± 20 °C for toluene on the investigated AC.

At this point, TPD data solely provide a threshold temperature and $T_{\text{Peak}}$ cannot be directly used. Moreover, it does not provide any information on the dynamic of toluene desorption with temperature. This can be addressed by isothermal desorption experiments.

**Isothermal Desorption approach**

Isothermal Desorption is performed by increasing the temperature of the AC sorbent covered by $F_{\text{err}}$ at a given level. This level is maintained until the exhaustion of the VOC release. It corresponds to a new steady state of the sorptive system, where adsorbed toluene is equilibrated with the gas phase at the given temperature. Then, various temperature steps are applied.

Figure 2 reports the general profile of toluene desorption from the selected AC obtained from ID experiment. The plot of the total desorbed quantity of toluene from the investigated AC along ID evidences three regimes. Interestingly, the regimes defined from ID experiments are limited by threshold temperatures retrieved from TPD experiments:

1. Below $T_{\text{Start}}$, no release of toluene is observed
2. From $T_{\text{Start}}$ to $T_{\text{Peak}}$, the release of toluene linearly follows the temperature imposed to the system
3. Beyond $T_{\text{Peak}}$, the toluene release stops, as the AC is exhausted.

![Figure 2: General profile of the total quantity of toluene desorbed from AC along isothermal desorption experiment as a function of the temperature applied to the sorbate-sorbent system](image)

This result evidences the consistency and the complementarity of the two methodologies. It highlights the fact that desorption regimes, determined from ID, can be defined from TPD experiments. Indeed, based on (i) the VOC desorbed quantity at ambient temperature, (ii) $T_{\text{Start}}$ and (iii) $T_{\text{Peak}}$, not only the thresholds between the desorption regimes are predictable, but also the desorption rate of toluene as a function of applied temperature. These data can be interestingly integrated to indoor air models to encompass the release of VOC-covered indoor surfaces. From that point of view, it helps assessing the effective impact of sorptive materials on IAQ.

**CONCLUSION**

Two techniques are used in this study to assess the impact of temperature on the release of toluene from an AC-based sorbent, as well as the impact of sorptive materials on indoor air quality under variable indoor temperatures.

The main advantage of TPD methodology relies on the short experimental time, *i.e.* few hours, compared to ID needing several days or weeks to reach sorption equilibria. The experimental conditions of TPD require to heat the sorbent at a linear rate until high temperatures, poorly representative of indoor environments. The experimental protocol proposed by ID is more representative of indoor conditions.

This work evidences that both techniques are complementary. ID allows characterizing precisely and distinctively the three sorptive regimes driven by temperature. Interestingly, the two characteristic temperatures retrieved from TPD, $T_{\text{Start}}$ and $T_{\text{Peak}}$, enable to define the same regimes through temperature threshold. Therefore, the full ID curve can be predicted from TPD, a less time consuming experimental methodology.

Beyond methodological aspects, these results can be directly used to evaluate and predict the possibility of a sorptive construction material to release taken up VOCs under typical and realistic indoor conditions. If the temperature at the material surface exceeds $T_{\text{Start}}$ and ranges till $T_{\text{Peak}}$, a variable but predictable fraction of VOCs is desorbed. The exact quantity of VOCs possibly released at a given indoor temperature can be determined.

**REFERENCES**


NOMENCLATURE

VOC: Volatile Organic Compound

IAQ: Indoor Air Quality
T: Temperature
RH: Relative Humidity
AC: Activated Carbon
TPD: Temperature-Programmed Desorption
ID: Isothermal Desorption
S_{spe}: Specific surface area
SIFT-MS: Selective Ion Flow Tube-Mass Spectrometry
\beta: Heating rate in TPD
T_{Start}: Temperature at which the VOC release initiates during TPD
T_{peak}: Temperature reached at the maximum of the TPD-peak
Characterization of the surface chemistry of Activated Carbons: a tool for sorptive indoor material formulation

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SUMMARY

This study aims to better understand the interactions between carbon-based sorbents and volatile organic compounds to support the formulation of sorptive construction materials. Activated carbons enriched with nitrogen or oxygen are investigated under mild ambient conditions (50 % Relative Humidity and 23 °C) in terms of (i) total adsorption capacity and (ii) reversibility of the uptake. The impact of activated carbon surface chemistry on volatile organic compound uptake is assessed for pollutants having contrasted behavior: toluene and formaldehyde.

Whereas nitrogen- or oxygen-based surface groups are detrimental for toluene quantity taken up by Activated Carbons, formaldehyde uptake is enhanced by nitrogen-based functionalization. Reversible character of formaldehyde uptake is beneficially impacted by heteroatom-based surface groups. The determination of nature and arrangement of surface groups is used to analyze these results and to select the most suitable sorbent to implement in sorptive construction materials.

INTRODUCTION

Volatile Organic Compounds (VOCs) are key pollutants of indoor environment, because of their recognized harmful impacts on health (WHO 2006, WHO 2010). VOC removal by uptake on indoor surfaces of construction material is a promising eco-efficient alternative to conventional solutions of ventilation, active air treatment systems or photocatalytic materials (González-Martín et al. 2021). However, currently available products do not provide satisfying performances towards VOCs. Sorptive construction materials are composed of an inorganic matrix, such as gypsum or lime-based plaster, enriched with a VOC sorbent (Krou et al. 2015, Thevenet et al. 2018). Not only the uptake capacity towards a wide variety of VOCs, but also the reversibility of the process at ambient temperature are current issues (Krou et al. 2015, Thevenet et al. 2018, Thevenet et al. 2021).

Activated Carbons (ACs) are carbon-based materials obtained by pyrolysis and activation of organic precursors (Zhang et al. 2017). ACs are the most widespread sorbents for VOC removal because of their (i) low cost, (ii) high VOC uptake properties and (iii) relatively low sensitivity to Relative Humidity (RH) (Li et al. 2020, Zhu et al. 2020). The more pronounced affinity of AC surface for hydrophobic compounds, compared to hydophilic ones, is brought by the AC carbonaceous structure (Li et al. 2020, Zhu et al. 2020). The uptake capacity regarding hydrophobic VOCs can be improved by heteroatom-based surface groups: enhanced hydophilic VOC removal properties have been reported for ACs modified with sulfured, nitrogenized and oxygenated functions (Kim et al. 2006, de Falco et al. 2018).

Nevertheless, current available data on the depollution performance of such ACs have been evaluated for industrial effluents using inlet VOC concentrations exceeding typical indoor levels by 2 or 3 orders of magnitude (Kim et al. 2006, de Falco et al. 2018). As a consequence, the transfer of these results to indoor conditions can be questioned. Besides, the reversibility of the VOC uptake at ambient temperature is generally neglected.

The impact of AC’s surface chemistry is crucial in the performance of sorbents for indoor applications. In this purpose, this work aims to investigate the interactions between indoor VOCs and ACs designed with various surface chemistries. The ultimate goal is to support the selection of the most suitable ACs to implement in sorptive construction materials. The properties of a purely carbonaceous AC, and ACs with Nitrogen (N) or Oxygen (O)-based functions are explored.

First, two typical and representative indoor VOCs are used to probe ACs sorptive properties: toluene and formaldehyde. Their uptakes are characterized in terms of: (i) total amount taken up, and (ii) reversible fraction at ambient temperature. Second, surface characterization techniques are deployed. X-ray Photoelectron Spectroscopy (XPS) and Wide Angle X-ray Scattering coupled with a silver-based X-ray source (Ag-WAXS) are considered to study nature and arrangement of surface groups.
MATERIALS AND METHODS

Materials of interest

Three ACs are investigated: (i) a reference AC without heteroatom (AC no N no O), and two ACs containing (ii) nitrogen (AC N) and (iii) oxygen (AC O).

Preparation/ The detailed preparation method of the ACs is described in (Avhad et al. 2020).

Morphology characterization/ For the three ACs, particle size distribution is determined by laser granulometry. The specific surface area (S_{spe}) is determined by nitrogen sorption using the BET (Brunauer-Emmet-Teller) model. S_{spe} for all ACs ranges from 900 to 1,200 m²·g⁻¹. Pore size distribution is determined by CO₂ sorption using the Density Functional Theory.

Surface chemistry characterization/ Multiple surface characterization techniques are considered. XPS is used to determine nature of the surface groups on ACs. Ag-WAXS is used to study arrangement of surface groups.

VOCs of interest

Indoor ubiquitous VOCs having contrasted behavior are selected: (i) toluene, a hydrophobic aromatic compound, and (ii) formaldehyde, a hydrophilic and oxygenated VOC.

Experimental setup

The experimental setup used in this study is represented in the experimental section of (Thevenet, Olivier et al. 2015) and composed of three distinct parts: (i) gas generation, (ii) U-shape reactor and (iii) analytical system.

Gas generation/ Dry zero air is produced by a catalytic generator (Claind, Italy). The VOC of interest is generated by a certified cylinder containing 509 ppm of toluene (Messer, France) or 11.9 ppm of formaldehyde (Air Liquide, France) in nitrogen. Adjusting the ratio of the regulated flows of both lines ensures a controlled VOC concentration. The equivalent flow of zero air saturated by water vapor is then added to provide a RH of 50 ± 5%. Total flow rate is set at 1,000 ± 10 mL·min⁻¹ for experiments involving toluene, and 500 ± 5 mL·min⁻¹ for formaldehyde. This difference is due to dilution requirements. This setup enables to obtain a VOC concentration of 0 or from 50 to 1,000 ppb.

U-shape reactor/ Quartz wool is introduced in a U-shape reactor to allow the deposition 10.0 ± 0.1 mg of AC powder, but without restraining the air flow across the reactor. Thus, all AC particles are identically submitted to polluted or non-polluted air flow.

Analytical system/ Downstream VOC quantification is performed using Selected Ion Flow Tube-Mass Spectrometry (SIFT-MS, SYFT Technology, New Zealand). SIFT signals are obtained by detecting a given product of the reaction between the analyte and a precursor ion (H₃O⁺, NO⁻ or O₂⁻). For toluene, the detected reaction products with precursor ion are C₆H₅H⁺ (m/z = 93) with H₂O⁺, C₆H₄⁺ (m/z = 92) with NO⁻, and C₆H₄⁺ (m/z = 92) with O₂⁻. The detection and quantification limit are respectively 5.4 and 17 ppb. For formaldehyde, a single reaction product with the precursor ion H₅O⁺ is detected: CH₂O⁺ (m/z = 31). The detection and quantification limits are respectively 9.1 and 28 ppb. Under these experimental conditions, VOC concentrations are monitored at a temporal resolution lower than 5 s.

Experimental procedure

Prior to uptake characterization, the sorbent is conditioned at 250 ± 1 °C under non-polluted air at 50 ± 5% RH. This step is required to clean the sorbent surface from the potential adsorbed species, without surface modification.

The AC uptake properties in this study are characterized at ambient temperature, i.e. 23 ± 3 °C, in terms of (i) partitioning coefficient (Kₑ) and (ii) reversible (F.rev) and irreversible (F.irr) fraction. The experimental procedure used to determine these parameters is described by (Thevenet, Debono et al. 2018, Thevenet, Verriele et al. 2021).

Advantage of Kₑ relies on its independence on the pollutant concentration at typical indoor levels. Kₑ value for a given VOC on a sorbent can be used to predict the taken up amount at a VOC concentration not exceeding a few ppm. F.rev-F.irr is used to characterize the fate of adsorbed compounds at ambient temperature.

RESULTS AND DISCUSSION

The impact of AC surface chemistry on the VOC removal efficiency is addressed for (i) toluene and (ii) formaldehyde.

Toluene uptake

![Figure 1: a. Partitioning coefficient – Ke – for toluene on the investigated ACs. b. Reversible (light colors) and irreversible (dark colors) fractions for taken up toluene on the investigated ACs.](image-url)

Figure 1.a reports the values of Kₑ for toluene on the three investigated ACs. The highest value is obtained for AC no N no O (26 ± 8 m³·g⁻¹). The impact of...
heteroatom-based surface groups is undeniable: regarding toluene, the presence of oxygen- or nitrogen-based functions reduces by almost two-thirds the value of \( K_v \). This behavior is related to the fact that toluene sorption occurs preferentially on hydrophobic sites of ACs. Therefore, introducing hydrophilic O- or N-surface groups decreases the number of adsorption sites, which impacts the uptake capacity of the ACs for toluene.

In Figure 1.b, \( F_{rev} \) and \( F_{irr} \) for toluene are reported for the three investigated ACs. They show similar \( F_{rev} \) and \( F_{irr} \), 67 ± 16 % and 34 ± 7 % respectively. While O and N-based functionalization have an undisputable effect on \( K_v \), no difference between the sorbents is evidenced in terms of reversibility. This result indicates that, for these samples, the nature and the strength of the interactions between ACs and toluene are not affected by the introduction of O- or N-based surface groups.

**Formaldehyde uptake on ACs**

![Figure 2](image)

**Figure 2: a. Partitioning coefficient – \( K_v \) – for formaldehyde on the investigated ACs. b. Reversible (light colors) and irreversible (dark colors) fractions for taken up formaldehyde on the investigated ACs.**

Figure 2.a reports the values of \( K_v \) related to formaldehyde (or HCHO) for the three investigated ACs. First, compared to toluene, \( K_v \)-values for HCHO are lower by more than one order of magnitude, ranging from 0.08 ± 0.02 to 1.3 ± 0.2 m³.g⁻¹. This behavior is consistent with a lower affinity of AC surfaces for hydrophilic VOCs. Second, a significant improvement of the total quantity of taken up formaldehyde on AC is specifically noticed when N-based groups are present on the sorbent surface. XPS analysis is performed to precisely the nature of the surface groups on the investigated ACs and explain these results.

\( F_{rev} \) and \( F_{irr} \) for formaldehyde on the three ACs are reported in Figure 2.b. The total amount of HCHO initially adsorbed on AC no N no O is released as the pollution source is stopped. This behavior attests of the weak interactions between HCHO and the hydrophobic surface of the purely carbonaceous AC. Besides, albeit no impact of the introduction of O-based groups has been evidenced on \( K_v \)-values for toluene, the presence of O-based surface groups on ACs induces a slight irreversible fraction of adsorbed formaldehyde. Same observations are noticed for the N-doped AC. Again, determining the nature of the surface groups by XPS is useful to better understand the AC behavior.

**REFERENCES**


NOMENCLATURE
VOC: Volatile Organic Compound
AC: Activated Carbon
RH: Relative Humidity
N: Nitrogen
O: Oxygen
XPS: X-ray Photoelectron Spectroscopy
Ag-WAXS: Wide Angle X-ray Scattering coupled with Silver-based X-ray source
Spe: Specific Surface area
SIFT-MS: Selective Ion Flow Tube-Mass Spectrometry
Kp: Partitioning coefficient
Frev: Fraction of adsorbed VOC released at ambient temperature
Firr: Fraction of adsorbed VOC unreleased at ambient temperature
Diffusion of essential oils in a 40m³ experimental room: From emission rates to impact on indoor air quality

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SUMMARY

Essential oils have attracted increasing interest due to their antibacterial performances. They are widely promoted as easy-to-use products to improve indoor air quality through passive remediation practices associated with their purifying actions. However, the potential toxicity of essential oils released in indoor air has not been clearly established. This study aims to assess the emissions of terpenes from the diffusion of essential oils under real conditions in a real-scale experimental room. Results show that the impact of indoor essential oil diffusion varies from few hours to several days, depending on the device used. Concentration levels can exceed recommended exposure levels by more than one order of magnitude. Besides, several limitations are found regarding the evaluation of emissions using test chambers with small volumes: the concentration of emitted terpenes and their emission kinetics are noticeably dependent on the chamber volume, which evidences the interest of determining emission rates under real scale experiments.

INTRODUCTION

Essential oils are intuitively introduced in confined environments, as “ingredients of natural origin” perceived by most of consumers as safe and health-friendly. The diffusion of essential oils in confined environments have been promoted as a passive remediation practice for facing current indoor air quality problematic from a biological perspective. Tea tree oil (Melaleuca alternifolia) has been widely investigated for his acknowledged antimicrobial, anti-inflammatory and antiseptic properties. Usachev et al. reported a strong antiviral efficiency of the vapors of tea tree against viruses, highlighting the use of essential oils as natural disinfectants for the further development of air treatment technologies and indoor air quality improvement.

Nonetheless, their extensive use and positive perception do not rule out any consequences on indoor gas pollutant levels. Therefore, detailed evaluations of the corresponding emissions under real use patterns must be undertaken to evaluate human exposure to essential oil constituents.

The lack of baseline information about the release of hazardous fragrance molecules during the dissemination of essential-oils in confined environments motivates this work, providing the first insights into human exposure to fragrance chemicals. This study investigates the impact on indoor air quality from the diffusion of tea tree oil through two contrasted physical mechanisms under real consumer use patterns, and it correlates the terpene emissions in experimental chambers of different volumes.

MATERIALS AND METHODS

Essential oil and diffusers of interest A total of 38 essential oils claiming the ability to clean the air and/or neutralize toxins were identified. Among them, tea tree oil is selected not only for its reported sanitation properties but also for its extensive use and chemical composition. Interestingly, the predominant terpenes contained in this tea tree essential oil are highly reactive towards indoor oxidants, as α-terpinene.

Two different diffusers were selected after a benchmarking process in the framework of these study. (i) A ceramic heat diffuser (electric diffuser) which evaporates essential oil in few hours through a soft heat gain and (ii) a capillarity diffuser consisting of a wick-based system that combines the actions of wicking and evaporating; a beech wood stick is directly screwed on the essential oil flask, and the top of this porous stick is exposed to the air.

Experimental setup and application protocol

The set of experiments are conducted in the 40 m³ experimental room IRINA (Harb et al, 2016). This experimental room has a surface/volume ratio of 1.59 m⁻¹ and it is operated in a semi-closed mode with an average air exchange rate (AER) of 0.3 ± 0.1 h⁻¹. The inner surfaces of IRINA are fully covered with aluminum foils to minimize VOC sinks or sources from the experimental room walls. A looped air conditioning system ensure the temperature and humidity control as well as air homogenization by the recirculation of the air inside the room.

Essential oil diffusers are introduced and placed over a glass table located at the center of the room. For the electric device, 20 drops of tree tea oil are applied...
according the instructions of the manufacturer. For diffusion experiments by capillarity, the tea tree oil bottle with the diffusing sticks are introduced in the center of the chamber and placed over the glass table.

**TerVOC (terpene volatile organic compounds) measurements**

The TerVOC emitted concentrations are monitored within a short temporal resolution by employing an online analytical system, which consist of a compact gas chromatograph system (C-GC/FID Model: Global Analyzer Solutions CGC4) with a Restek-VMS column (Model: 15m x 0.32 mm ID, 1.8µm film thickness). It is coupled to a Flame Ionization Detector (FID) for the quantification of TerVOCs.

**RESULTS**

Depending on the diffusion device and on the amount of essential oil involved in the diffuser, temporal emission dynamics are strongly different. The electric device involving a limited mass of oil (typically 20 drops of oil) behaves as a punctual emission source since the low mass of oil can be diffused on short time scales. In contrast, the capillarity diffuser involving the whole flask of essential oil, typically several milliliters (mL), is classified as continuous diffuser representing finite but long term sources.

Figure 1 represents the temporal evolution of α-pinene, α-terpinene, eucalyptol, γ-terpinene, and 4-terpineol concentrations during the diffusion of tea tree oil using the electric diffuser. The concentration profiles are characterized by the same three main phases associated to the diffusion process: (i) a sharp increase of the total TerVOC concentrations attesting of their rapid vaporization from the tea tree oil until a maximum total concentration is reached, (ii) a primary decreasing trend referred to the gradual exhaust of the TerVOC source and to the removal of TerVOCs from the gas phase of the experimental room, (iii) a final decreasing stage referred to the evacuation of emitted terpenes by the air exchange and their possible losses on the inner surfaces of the room.

Interestingly, several variations are evidenced regarding the dynamics of the emission processes among individual TerVOCs. Indeed, the time positioning of the peak concentration is noticed to differ depending on the terpene molecule. The individual maximum concentrations are: 790 ± 17 ppb for 4-terpineol, 685 ± 20 ppb for γ-terpinene, 310 ± 10 ppb for α-terpinene, 110 ± 8 ppb for eucalyptol, and 100 ± 10 ppb for α-pinene.

Figure 2 shows the temporal evolution of the four predominant terpenes (α-terpinene, eucalyptol, γ-terpinene, and 4-terpineol) as well as the total TerVOC corresponding to the diffusion of tea tree oil by the capillarity device. All concentration profiles can be described by two main stages: (i) an increase of the gas concentration of TerVOCs, and (ii) a steady state concentration regime of gas phase TerVOCs inside the 40 m³ experimental room.

Compared to the electric diffusion, the diffusion of tea tree oil by capillarity leads to a maximum concentration of total TerVOCs, by one order of magnitude lower, at 430 ± 10 ppb. Noteworthy, another observed difference between the two diffusion mechanisms relies in the time span to reach the maximum concentration: they are strongly contrasted. Indeed, when using a capillary device in a real scale room, the mean time to reach the steady state concentrations might overcome 15 hours; while for the electric diffuser, the maximum concentrations are reached within only 1 to 2 hours, depending on the individual TerVOCs. This difference can be attributed to the heating of essential oils provided by the electric diffuser which definitely enhances the kinetic of the liquid to gas phase transfer.

This study provides experimental data from real-scale experiment enabling the exposure assessment associated with the diffusion of tea-tree oil indoors. Indeed, from the obtained concentration profiles, the assessment of the mass emission rates of the TerVOCs emitted along the diffusion of tea tree oil has been
performed. Data obtained from a previous study, using a 1m³ experimental chamber (Angulo-Milhem, et al. 2021) have been compared to these original data. Figure 3 reports the temporal profiles of the mass emission rate of the predominantly emitted terpene Y-terpinene, along the diffusion process by capillary device in (i) an emission test chamber of 1m³ and (ii) the experimental room IRINA of 40 m³.

The emission process of individual terpene molecules from the indoor diffusion of essential oils is confirmed to be dependent of the chamber volume. Indeed, several discrepancies observed between experimental chambers of different dimensions are mainly associated to (i) the concentration levels of released terpenes, (ii) the emission rate profiles including the duration of the emission process, (iii) the duration of impact on indoor air quality. Consequently, for an accurate estimation of the human exposure to released odor chemicals from the indoor diffusion of essential oils and their impact on indoor air quality, experimental protocols should be executed in real-scale rooms and under real conditions of use. The evaluation of the emissions in small size experimental chambers can provide information related to general trends such as major emitted terpenes, but accurate information regarding concentration levels and mass emission rates and human exposure evaluation to these chemicals requires real scale room experiments.

CONCLUSION
This real scale study confirms that the indoor diffusion of essential oils represent a significant indoor source of terpenes transiently increasing the concentration of these chemicals depending on the device employed.

The indoor diffusion of essential oils by an electric diffuser in a real-scale experimental room might transiently (few hours) rise the total terpene concentration up to several hundreds or few thousands of ppb. Using a capillary device reduce the concentration exposure level by an order of magnitude but impact the indoor air quality during a time span of several days.

The characterization of the emission processes from the indoor diffusion of essential oils requires to be executed in real scale scenarios, since it is the only experimental approach that allow to mimic a real consumer use and provide an accurate emission rate assessment that could be extrapolated for the evaluation of other case scenario.

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VOCs emissions from the human during sleep under different ozone and air change rate levels

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SUMMARY
VOCs emitted from the human is one of the main sources of indoor air pollution. It’s significant to study VOCs emission rates to improve indoor air quality. Most of the studies about VOCs emitted from occupants were conducted when they were awake. There is very limited knowledge of the VOCs emission rates from sleeping people and how environmental factors such as air change rate and ozone levels affect VOCs emissions from the human. In the present study, volunteers were recruited and slept in a specially designed capsule at three conditions combined with two ozone levels (0 and 25 ppb respectively) and two air change rates (about 7 and 20 h⁻¹ respectively). The air in the capsule was sampled with Tenax tubes when volunteers were sleeping and VOCs were determined by thermal desorption - gas chromatography-mass spectrometry (TD-GC-MS). The results showed that the presence of ozone increased the emission rates of acetone but had little influence on the emission of isoprene. Meanwhile, improving the air change rate can decrease VOCs concentrations significantly. The findings of the present study can provide directal information to further improvement of the indoor air quality.

INTRODUCTION
VOCs emitted from humans have been proved to be one of the main sources of indoor air pollution and attracted the great attention of researchers (Weisel et al., 2017). Its composition and emission rates have been investigated to study their relationship with indoor air quality (Tsushima et al., 2018), working efficiency (Zhang et al., 2017), or human healthy (Costello et al., 2014). While most of the studies were conducted when occupants were awake. There is very limited knowledge of VOCs emission rates from sleeping people. Moreover, ventilation has effects on human VOCs emissions, and the existence of ozone may react with compounds in skin oil, which will further generate more pollutants (Salvador et al., 2019) (Wisthaler & Weschler, 2010). However, how these environmental factors affect VOCs emissions from the human during sleep is still unknown. Therefore, the present study was performed in a capsule at three different conditions to estimate VOCs emission rates from sleeping people and the influence of air change rate and ozone levels.

METHODS
The experiment was conducted in a special capsule constructed of acryl board with an aluminum framework, which was placed in a climate chamber to control the temperature of 24 °C. The capsule was equipped with its own ventilation system to adjust the air change rate. Two air change rates (about 7 and 20 h⁻¹ respectively) were set to make CO₂ concentrations reach 800 and 1700 ppm respectively. An ozone generator was applied to doze a specific amount of ozone to the supply duct of the ventilation system of the chamber to secure well-mixing, resulting in the concentration of 25 ppb in the capsule. The ozone reference condition was 0 ppb, which was achieved by applying activated carbon filters in the inlet of ventilation.

Ethical review boards at Technical University of Denmark approved the use of human subjects for the present experiments. Four healthy college-age volunteers were recruited to sleep in the capsule at three different conditions in a balanced order. The same instructions for the volunteers before and during the experiment referred to the study of Bekö et al., 2020. VOCs in the capsule were sampled before and during sleep at fixed time by Tenax tubes, with the sampling air flow rate of 300 mL-min⁻¹ and sampling volume of 9L. The samples were then determined by thermal desorption - gas chromatography-mass spectrometry (TD-GC-MS) (Duan et al., 2020). The concentrations of VOCs were evaluated through the response coefficient of toluene, and the emission rates were calculated based on the mass-balance equation (Tang et al., 2016).

RESULTS & DISCUSSION
About forty compounds were detected and identified. There is a slight difference in the kinds of VOCs emitted from different volunteers due to the distinction of metabolism. Most of the compounds were alkanes, alkenes, aldehydes, ketones and acids. Two typical
pollutants produced in the process of human metabolism, which was acetone and isoprene, were selected to estimate VOCs emission rates. The chromatograms of acetone and isoprene at different conditions were shown in Figure 1.

![Chromatograms of isoprene and acetone from the subjects at different conditions](image)

Figure 1. Chromatograms of isoprene and acetone from the subjects at different conditions (Black: Condition 1, 23 °C + low ventilation; Red: Condition 2, 23 °C + low ventilation + O₃; Blue: Condition 3, 27 °C + high ventilation + O₃).

The emission rates of isoprene and acetone differed for different subjects and were around 0.08 mg·h⁻¹ and 0.06 - 0.2 mg·h⁻¹ respectively. The results indicated that VOCs emission rates from sleeping people were much lower than those from awake people, which were about 0.16 mg·h⁻¹ and 1.0 mg·h⁻¹ for isoprene and acetone respectively (Tang et al., 2016). The differences could be due to the different levels of physical activities. The adsorption of the linens, mattress, pillow, pajamas and the walls of the capsule could also make the concentrations of the pollutants lower, and then made the results of the emission rates from sleeping person lower.

To diminish the influence of individual differences on the calculating results, the average values of the emission rates of the VOCs emitted from different volunteers were calculated. The results at different conditions were shown in Figure 2.

![Concentrations in the capsule and emission rates of isoprene and acetone at different conditions](image)

Figure 2. Concentrations in the capsule and emission rates of isoprene and acetone at different conditions: (a) concentrations of isoprene and acetone in capsule; (b) emission rates of isoprene and acetone.

As shown in Figure 2(a), the concentrations of isoprene at Condition 1 and Condition 2 were almost the same, while the concentration of acetone at Condition 2 is higher than that at Condition 1. The concentrations of both acetone and isoprene are much lower than those at other conditions. Previous researches have demonstrated that acetone could be generated through the oxidation of squalene and other products on the surface of the skin by ozone (Yang et al., 2016) (Bekö et al., 2020) (Wisthaler & Weschler, 2010) (Weschler et al., 2007). Therefore, when ozone was dosed into the capsule, the oxidation process would carry on and the concentrations of acetone increased immediately. In Figure 2 (b), both dosing ozone and increase ventilation could improve the emission rates of acetone while having a slight influence on that of isoprene. Isoprene is mainly emitted through the breath of humans, which is controlled by the metabolism of the individual. The presence of ozone and the increase of air change rate had little influence on the metabolism of the human body, then led to a slight change of the emission rates at different conditions. However, the emission rate of acetone was the summation of the portion from human breath and the portion from the reaction of ozone and skin oil. Increasing the air change rate might accelerate this reaction, which makes the emission rate of acetone much higher.

CONCLUSIONS

Emissions of VOCs from humans during sleep were determined and the influence of ozone and air change rates on emission rates were studied in this research. The emission rates of VOCs from humans during sleep were much lower than that of awake people. Some pollutants could be generated not only from the breath or dermal of humans but also through the oxidation of the products on the surface of the skin by ozone, which means that the presence of ozone might lead to more emission of VOCs and worsen indoor air quality. However, improving the air change rate can significantly decrease the concentrations of VOCs in the indoor environment, which is beneficial for the improvement of indoor air quality.

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Modeling physico-chemical processes impacting aerosol formation and fate indoor

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SUMMARY

Particles inside buildings are issued from direct emissions of particles from occupants, nucleation of organic compounds, air exchange with the outdoor. The coagulation of the aerosols between them and the condensation of gases on their surfaces contribute to grow their size with time. The deposition of the particles on the indoor surfaces acts as a sink.

The model INCA-Indoor is developing to follow the evolution of the aerosols in number, mass and their size distribution in indoor air over time.

In this article, measurements issued from an atmospheric simulation chamber are used to evaluate simulation results of diesel soot formation. The model reproduces the growth of aerosols by coagulation with good agreement with the measurements. Measurements performed in unoccupied dwellings before delivery helps to quantify the influence of outdoor pollution on aerosols concentration indoors and deposition in the absence of sources.

INTRODUCTION

People spend on average 80% of their time indoors while several monitoring campaigns showed that high levels of organics and particulate matter (PM) could be reached (Morawska et al., 2017). Conventional indoor air quality (IAQ) diagnostics are based on measurements, and thus expensive and time-limited. To overcome this issue, several models simulating aerosols concentration indoors have emerged.

One of the first models which considers part of the physico-chemical processes of aerosols such as the processes of coagulation and deposition of particles, is the MIAQ model (Multi-chamber Indoor Air Quality model; Nazaroff and Cass, 1986; 1989). The ICEM model (Indoor Chemistry and Exposure Model; Sarwari et al., 2002, 2003), integrating the SOA SORGAM (Secondary Organic Aerosol Model; Schell et al., 2001) training model, as well as the INDCM model (Indoor Detailed Chemical Model; Carslaw, 2007; Carslaw et al., 2012; Kruza et al., 2017), for their part, allow the formation of SOA to be modeled from the oxidation reactions of terpene. However, no model currently considers all the physicochemical processes impacting aerosols fate indoors: nucleation, condensation, coagulation and deposition. Besides, both nucleation and condensation processes involve the passage of a pollutant from gas to aerosol phase, requiring a robust modeling of the gas phase.

INCA-Indoor model was developed to simulate the processes impacting the concentration of more than 900 chemical species in indoor air. The inter-comparisons with measurements showed a good evaluation of the model for the gas phase (Mendez, 2015, 2017a and 2017b). The objective is therefore to present the aerosol module we developed in INCA-Indoor to better characterize particles fate and formation pathways in indoor environments.

METHODS / CASE STUDY DESCRIPTION

The aerosol module that we developed is part of INCA-Indoor model previously described by Mendez et al., 2015. This module is based on a logarithmic size distribution where the mean diameter, mass and number concentrations are calculated for 30 aerosol species, including one generic species, at each time step. Aerosol concentration in each section is simulated according to different processes such as the transport between rooms or indoor-outdoor, deposition on surfaces, growth either by coagulation between aerosols or by condensation of gases onto aerosol surface, and finally the creation of particles by nucleation.

Simplified chemical mechanisms from the SAPRC-07 database (Carter, 2010) are integrated into INCA-Indoor so that the model can simulate terpene ozonolysis reactions that lead to the formation of a SOAs precursor gas. The nucleation of SOAs precursor gas is defined according to the apparent nucleation rate as proposed by Kerminen and Kulmala, 2001 and Lehtinen et al., 2007. Coagulation between particles due to their Brownian motion is implemented based on Otto et al. ’s work (1999). The Hydrophilic/Hydrophobic Organic (H2O) model
(Couvidat et al., 2012) is used to calculate the equilibrium between the gas phase and the aerosol phase. The concentration of each condensed species is determined by this equilibrium. The CONTAM model (Dols and Polidoro, 2020), a multizone indoor air quality and ventilation analysis program developed by the National Institute of Standards and Technology Technical (NIST), is coupled to INCA-Indoor to determine the flows between intra- and inter-room exchanges and therefore to identify the mass of particles exchanged. The deposition is then determined as a function of the airflow and of the particle size distribution.

In order to evaluate the robustness of INCA-Indoor modeling, simulation results are compared using two types of data: (1) measurements collected during an experiment in a simulation chamber (2) measurements collected in two dwellings. The first dataset comes from the database of atmospheric simulation chamber studies supplied by EUROCHAMP-2020 (Integration of European Simulation Chambers for Investigating Atmospheric Processes –towards 2020 and beyond). Two sets of data from the AIDA chamber (Aerosols, Interactions and Dynamics in the Atmosphere) of Karlsruhe Institute of Technology (V = 84.3 m$^3$) were selected issued from 2 different instruments, the CPC 3022, and the CPC 3010 (coupled with a DMA 3071). This AIDA experience was performed to study the coagulation from Diesel soot and is described by Saathoff et al., 2003 and Wetzel et al., 2003. This experience offers an experiment under full controlled conditions with precise indications of volumes and atmospheric conditions of rooms, similar to indoor air conditions.

The comparison of the AIDA observations and INCA-Indoor simulations are done using different statistical criteria including the Model Quality Objective (MQO) defined by Thunis et al., 2013. This indicator is based on the Root Mean Square Error (RMSE) on a model and the Root Mean Square of the measured expanded Uncertainty (RMSU) on an instrument and it allows to assess if the simulations and the measurements are in adequacy. The values of this MQO between 0 and 0.5 indicate that, in average, differences between the model and measurement are within the uncertainty range of the instrument (Thunis et al., 2012).

The second dataset is issued from measurements in two unfurnished and unoccupied dwellings (L1, a bedroom, and L2, a living room in two dwellings in the same building). Measurements of PM$_{2.5}$ and PM$_{10}$ were performed to evaluate the modelling system to simulate the transport of aerosols between rooms and outdoor, without the impact of the occupants. Measurements were made over one week. Outdoor aerosol concentrations were not simulated but retrieved from a measuring station situated at 2 km from the dwellings and used as inputs of the model (this “Airparif” outdoor station measured the mass concentration of PM$_{2.5}$ and PM$_{10}$).

**RESULTS & DISCUSSION**

After introduction of Diesel particles into the AIDA chamber, an identical growth was observed between the measurement of the SMPS and our simulation which shows that INCA-Indoor faithfully transcribes the coagulation and deposition for Diesel soot particles. The total number of particles simulated fits the measurements. Different statistical criteria were calculated by comparison between the INCA-Indoor simulation and the measurements of CPC 3022 and SMPS (CPC 3010) (Table 1). The RMSE between the observed value and the simulated value $(2.40 \cdot 10^3 - 3.02 \cdot 10^3 \text{ part/cm}^3)$ is less important than the uncertainty on the measurement U (10%). Simulations are therefore in the uncertainty interval on the observation. The growth of Diesel soot is therefore well characterized in INCA-Indoor and this type of aerosols can be found inside homes from outdoor (Funasaka et al., 2000).

In L1 and L2 bedrooms and living rooms, PM$_{2.5}$ and PM$_{10}$ mass concentrations (Figure 1, red curve) simulated by INCA-Indoor show same temporal variations as the observed outdoor concentrations over the week (Figure 1, curve cyan) and are in the same order of the concentration measured inside the dwellings, with few over- or underestimations. This shows at least how much the indoor air pollution is influenced by outdoor air pollution in this experiment.

Around the 3rd day the outdoor measuring station indicates an increase in the mass concentration of particles while this peak of concentration is not measured indoors in the two dwellings L1 and L2. We remind that since the model is forced by these data, the simulations logically simulate the concentration peak. The outdoor station is actually far from the dwellings (2km) and could have been influenced by a local source that is not influencing the dwellings.

Several concentration peaks have been measured indoors (green curve) between the 6th and the 7th day but not outdoors (cyan curve) in L2 dwelling, but not in L1 dwelling. Since the dwelling is unoccupied, the sources of this pollution are certainly coming from outside the building. PM$_{2.5}$ concentrations are low compared to PM$_{10}$ concentration, showing that the nearby source is emitted primary large particles. This event was explained by the presence of finishing work on buildings near the measure which led to resuspension or the emission of particles in the direction of L2 dwelling only.

These first comparisons in real conditions show a great potential of the modelling system, and highlight the need to well describe local outdoor pollution in order to understand indoor air pollution in some cases.
Table 1: Statistical comparisons of total number of particles concentrations modelled and observed during the growth of Diesel soot in the AIDA chamber. MQO is proposed by Thunis et al., 2013.

<table>
<thead>
<tr>
<th>Comparative measuring instrument</th>
<th>Normalized Mean Bias (NMB) (%)</th>
<th>Normalized Mean Standard Deviation (NMSD)</th>
<th>Pearson’s coefficient (-1 &lt; ρ &lt; 1)</th>
<th>Root Mean Square Error (RMSE) (part./cm³)</th>
<th>Model Quality Objective (MQO)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CPC 3022</td>
<td>-0.28</td>
<td>0.10</td>
<td>0.996</td>
<td>2.14 · 10³</td>
<td>0.31</td>
</tr>
<tr>
<td>CPC 3010</td>
<td>4.28</td>
<td>0.12</td>
<td>0.990</td>
<td>3.02 · 10³</td>
<td>0.45</td>
</tr>
</tbody>
</table>

Figure 1: Measurement (green) and simulation (red) of PM₂.₅ and PM₁₀ for different dwellings (L1 and L2) and rooms (bedroom and living room) and the measurement of PM₂.₅ and PM₁₀ by the outdoor station (cyan).

CONCLUSIONS

The INCA-Indoor model was tested using two different types of dataset issued from controlled or uncontrolled experiment. It succeeds to describe the particle growth by coagulation for diesel particles observed in a simulation chamber. This is major step forward in aerosol simulation because it allows to evaluate aerosols size growth through the coagulation and the aerosols deposition.

The comparison with data issued from instrumented dwellings have shown the importance of clearly identifying the flows between rooms and especially with the outdoor to understand indoor pollution (because one of the main causes of indoor pollution may the entry of particles from the outdoor).

Since the model is planned to determine the adequate ventilation system to ensure good indoor air quality (IAQ), the modelling system will be improved in a near future. Several sources of PM will need to be implemented in the model, such as the resuspension of aerosols by the occupants. The use of reliable sensors will be also investigated in order to correct the model. With affordable prices, these sensors allow to acquire in-situ data in and out the buildings.

The differences observed between the simulations and the measurements would be a way to detect a malfunction in the simulation, identify a change in the use of the building or update the input data.
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Assessment of three experimental methods for determining the emission parameters of VOCs from a solid material

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SUMMARY
Among experimental protocols available to determine detailed emission parameters of VOCs from solid materials for further implementation in indoor air quality (IAQ) models, C-history variants and AAVE methods require advanced assessments. Each method is deployed using the same experimental setup, conditions and reference material. Partitioning coefficients Ki, initially emitable concentrations Ci,0,i and diffusion coefficients Di are determined for each VOC emitted by particle board selected as reference material. In spite of an easier experimental implementation, the two variants of C-history method evidence a marked sensibility to the airflow regime. To that regard, the principle of AAVE is more representative of the reality of indoor air. The limited number of literature data hinders detailed comparisons; nonetheless, AAVE method appears as the most consistent method with moderate uncertainties. Therefore, AAVE method is proposed as an effective experimental approach to determine representative emission parameters for further integration in numerical simulation of IAQ.

INTRODUCTION
Elementary mechanisms involved in VOC transfer from materials to gas phase are described by three emission parameters: (i) partitioning coefficient Ki, (ii) initially emitable concentration Ci,0,i and (iii) diffusion coefficient Di. These parameters are input data for indoor air quality (IAQ) models. Relating to a VOC-material pair, emission parameters are intrinsic quantities describing the transfer of a VOC i from material to ambient air. They need to be determined for each VOC emitted by a given material in order to be implemented in IAQ (Indoor Air Quality) model.

To determine experimentally emission parameters, various methods are available in literature. The "C-history" and "AAVE" (AlTERNately Aithght and Ventilated Emission) methods attract attention since they propose to simultaneously determine the three parameters. A comparative study of the performance of the these methods is carried out based on tests involving Particle board (PB), selected for (i) its basic geometry and structure, (ii) the diversity of VOCs it emits and (iii) emission data available in literature.

Comparative evaluation of the selected experimental methods consists in applying their respective protocols, under identical experimental conditions, to the same model material. The comparison of the methods relies on the determination of the individual emission parameters of emitted VOCs: acetone, hexanal, terpenes, formaldehyde, acetaldehyde, propanal, butanal and the pentanal.

According to the literature, the two methods offer equivalent precision and performance. But, they have not been subjected to precise comparisons. The C-history method has the originality of being available in two variants depending on the aeraulic regime. It is therefore essential to evaluate and compare these methods using: (i) the same experimental set-up under identical operating conditions, (ii) the same material, and (iii) a variety of VOCs monitored. The final goal is to point at a method to provide the most reliable emission data to IAQ model.

METHODS
The "C-history" method consists in comparing the experimental concentration profile of a VOCi under defined operating conditions, with a prediction model describing the evolution of the concentration of this same VOC over time. This model involves the emission parameters (Ki, Ci,0,i, Di), determined by adjusting the experimental and modeled concentration profiles. The C-history method is based on several assumptions: (i) the source material is homogeneous, (ii) the diffusion of VOCs within the material is unidirectional and (iii) the volume of air in the experimental chamber is perfectly mixed. Two variants of the C-history method exist, involving separate analytical models, and optimized for defined aeraulic conditions: static vs. renewed.

The AAVE method proposed by Zhou et al. (2018) and relies on the repeated alternation of two VOC emission states: (i) static conditions and (ii) VOC renewed conditions. VOC concentrations are measured throughout the different phases. A linear regression of the experimental data is performed to determine the partitioning coefficient and the initially emitable
concentration ($K_i$ and $C_0$). Finally, an analytical model is used to fit the experimental concentration profile to determine the diffusion coefficient ($D_i$) using the previously determined parameters.

**Experimental setup** / All experiments are carried out in a 128-L aluminum ventilated experimental chamber with inner dimensions of 0.8x0.4x0.4 m. Inlet flow of air introduced into the chamber is controlled by BROOKS mass flow controllers, with an operation range of 0-20 L.min$^{-1}$ ± 0.25 %. The mass balance between inlet and outlet is ensured by a mass flow controller and a vacuum pump. A constant flow is maintained throughout the chamber. The air temperature around the chamber is regulated by air conditioning at 21 ± 0.5 °C. Relative humidity in the chamber is controlled by passing the inlet airflow through a column filled with water. All experiments are performed at 50 ± 5 % RH.

**RESULTS & DISCUSSION**

**ASSESSMENT OF THE "C-history" METHOD**

Results obtained from the monitoring of VOCs emitted by PB using the two variants of C-history method are reported in Figure 1, Figure 2 and Figure 3. In the three Figures, a) reports results retrieved from the static variant, b) reports results from the renewed variant. Uncertainties are standard deviations calculated from three distinct experiments.

**General trends for VOCs** / The determination of emission parameters using the two variants of the C-history methods points at the singular behavior of formaldehyde, compared to other VOCs. This specific behavior, is confirmed by both variants with contrasted partitioning and diffusion coefficients for HCHO compared to other VOCs monitored.

**Reproducibility of the C-history variants** / Considering the analytical and inter-assay variabilities of each method, the C-history method under renewed conditions turns out to be more reproducible than under static conditions due to the lower standard deviations of the three parameters for most of the VOCs. The C-history method under static conditions leads to uncertainties close to 100 % for all emission parameters of acetone and acetaldehyde, while for HCHO uncertainties exceed 66 % for partition coefficient and the initially emittable concentration; and reach 170% for diffusion coefficient.

Although, the static variant is the most commonly used in the literature (Xiong et al., 2011; Yao et al., 2011), several reasons associated with (i) its experimental implementation, (ii) the fact that static conditions poorly represent indoor environment, and (iii) the representativeness of the underlying equations for data processing, tend to discount this method for emission parameter determination.

**ASSESSMENT OF "AAVE" METHOD vs. C-HISTORY**

Possibly overcoming certain limitations observed for the C-history method, the AAVE method, developed by Zhou et al. (2018), turns out to be an interesting option: (i) by considering the different aeraulic regimes during a single test and (ii) by mostly relying on experimental determination rather than on an analytical model.

**General trends of VOC profiles** / In contrast to the previous series of tests, each AAVE experiment lasts for a full week when considering PB material. After performing the AAVE, VOC concentration profiles are plotted. Figure 4 specifically reports the concentration profiles of terpenes and formaldehyde. The terpene profile typifies the behavior of all monitored VOCs except formaldehyde, which is therefore represented separately. Figure 4 reveals two types of individual behaviour characterizing so-called ‘rapid’ and ‘slow’
The distribution of air speeds is essentially constant. Unlike the variants of the C-history method, although gathered under a single protocol, Experiment 1 showed the highest diffusion coefficient, with a value of 2.7 x 10^{-8} m^2.s^{-1}. The diffusion coefficients determined for the other VOCs vary from 1.0 x 10^{-9} to 5.0 x 10^{-9} m^2.s^{-1}. Apart from the terpenes, with a lower diffusion coefficient (standard deviation of 89.4%), the diffusion coefficients measured in the three experiments for all the VOCs remain similar to the standard deviations that are lower than 49.5%. For the majority of VOCs, the diffusion coefficients are similar to the inter-assay variability.

**CONCLUSION**

Compared to C-history method, AAVE method requires a more challenging experimental implementation but an easier data processing. In the case of particle board investigation, one week is required for each experimental assay using AAVE.

The main benefit of AAVE method relies in the fact that it takes into account both static and renewed air conditions. Therefore, unlike the variants of the C-history method, the AAVE method can encompass the sensitivity of the emission behavior of VOCs with respect to the aeraulic regime. Taking into account the emission processes under static and renewed conditions is more representative of the reality of the indoor environment where contrasted ventilation zones coexist. The distribution of air speeds is heterogeneous in an indoor environment due to the
geometry of the space, the arrangement, or the position of the air inlets and outlets. It results in the formation of so-called dead zones characterized by limited or air renewal. These conditions could be approached by the static conditions.

The AAVE method points at the singular behavior of formaldehyde compared to other VOCs. To that regard, unlike the C-history method, the AAVE method presents emission parameters consistent with the work of Caron et al. (2019) and Caron et al. (2020) on the influence of air exchange rate on VOC emissions. Moreover, AAVE method provides experimental data with lower uncertainties.

Therefore, the AAVE method appears as an effective experimental approach to provide representative emission parameters for further implementation into numerical CFD (Computational Fluid Dynamic) simulation for indoor air quality modelling.

REFERENCES


Ventilation strategies of school classrooms against cross-infection of COVID-19: A review

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SUMMARY
Under current pandemic of COVID-19, children are still spending long hours in school classrooms every day. A literature study is therefore conducted to investigate the current ventilation strategies used in schools and assess their performance of controlling contagious respiratory diseases in the indoor environment, and also to seek for future solutions. Research papers, reports and standards relevant to school ventilation, airborne transmission and complementary air distribution methods are reviewed. It is concluded that schools usually have natural ventilation (NV) or mechanical ventilation (MV), however the overall indoor air quality is not ideal. Both NV and MV can reduce the airborne transmission of respiratory droplets efficiently when designed, operated, and maintained properly, yet schools are in shortage of informative standards and guidance. Personalized ventilation (PV) has a promising potential in protecting occupants from local air contaminants, yet further studies are needed before PV can be applied to children in classrooms.

INTRODUCTION
Ever since the early stage of the global pandemic of COVID-19, researchers have been investigating the epidemiological features of pediatric patients, and it is suggested that children in general have milder symptoms than adults (Qiu et al., 2020). However, existing evidence cannot determine whether children are less frequently infected or infectious (Li et al., 2020). In fact, the large proportion of asymptomatic cases among them may become overlooked threats to susceptible individuals when sharing indoor space (Merckx et al., 2020), especially in densely occupied school classrooms. According to a recent report by European Centre for Disease Prevention and Control (ECDC, 2020), the proportion of infected children aged 12-18 to the total confirmed cases has slightly exceeded the population distribution of this age group among 11 EU/EEA countries. Considering the long hours students spend in their classrooms every day, it is therefore in urgent need to determine whether schools can provide a safe indoor environment.

Since airborne transmission (aerosols) has now been widely recognized as one of the major transmission routes of SARS-CoV-2, ventilation is hence stressed again to be an important means for cross-infection control between indoor occupants (Morawska et al., 2020). However, for most school buildings, their ventilation strategies are not initially designed for such purpose, but rather based on a balance between comfort and energy. Therefore, this literature review is aimed to (1) identify the common ventilation strategies currently in use by school buildings, (2) evaluate their efficiency of reducing infectious aerosols in the indoor environment, and (3) propose potential solutions for the future. To highlight, a full version of this literature review is in preparation and it is intended to be published later as a journal article. Hereby, only key references are presented in this short paper.

METHODS
The concepts included in the literature search of this study are listed in Table 1. Research papers are mainly acquired from databases including Google Scholar, ScienceDirect, Scopus, SpringerLink and PubMed, etc. In general, the scope of the journal, the research background of the author(s), and the publication recency are the main criteria for assessing the quality and relevance of the papers. The official websites of WHO, ISO, CEN, REHVA and ASHRAE are used for access to relevant standards and guidelines. The articles are examined and summarized into three sub-topics:

- Current knowledge of the features and indoor air quality control measures of airborne transmission of respiratory droplets.
- Patterns of ventilation strategies in schools and relevant requirements.
- Potential of personalized ventilation systems for reducing cross-infection indoors.

Table 1. Literature search concepts.

<table>
<thead>
<tr>
<th>Concepts: combine with AND</th>
<th>Synonyms and/or related terms: combine with OR</th>
</tr>
</thead>
<tbody>
<tr>
<td>concept 1: airborne transmission</td>
<td>concept 2: school</td>
</tr>
<tr>
<td>aerosol</td>
<td>classroom</td>
</tr>
<tr>
<td>respiratory droplets</td>
<td>children</td>
</tr>
<tr>
<td>droplet nuclei</td>
<td>student</td>
</tr>
</tbody>
</table>
AIRBORNE TRANSMISSION OF RESPIRATORY DROPLETS: FEATURES AND CONTROL

Normally, the cross-infection of contagious respiratory diseases like COVID-19 between indoor occupants consists of three stages: first, an infected person generates pathogen-containing droplets by respiration activities such as breathing, sneezing, coughing, and talking; then the infectious droplets spread indoors; once a susceptible person is exposed to a certain concentration of pathogens, infection may take place. (Ai & Melikov, 2018). Preliminary guidance on prevention of COVID-19 mainly stressed three transmission routes which are distinguished as close contact, fomite and long-range airborne (i.e., aerosols) (Zhang & Li, 2018). Recently experiment and simulation studies have also indicated that airborne transmission of respiratory droplets can occur both at short and long-range (Chen et al., 2020). Since the dispersion of aerosols can be easily affected by all kinds of indoor airflows, ventilation is thus widely adopted to minimize the airborne transmission (Ai & Melikov, 2018).

For natural ventilation (NV), it is confirmed that a good performance of removing aerosols can be achieved, yet its efficiency is dependent on specific conditions such as local climate, building design and occupant behaviour (Qian et al., 2010). Consequently, the air change rate of NV can hardly be determined (Hong et al., 2005). For mechanical ventilation (MV), both mixing and displacement air distribution can effectively reduce airborne transmission (Gao et al., 2008). However, their efficiency is not related to the air change rate (ACH), as increasing ACH can sometimes result in local airflow patterns with a higher exposure rate (Pantelic & Tham, 2013). It is also suggested that control measures based on steady-state conditions may not be applicable to airborne transmission during short-term events (or short-range airborne transmission) (Ai et al., 2019).

VENTILATION STRATEGIES IN SCHOOLS: GUIDELINES AND REALITY

The design criteria of required ventilation rate per occupant in school classrooms provided by several international organizations are listed in Table 2, including ISO 17772-1:2017 (2017), EN 16798-1:2019 (2019) and ANSI/ASHRAE Standard 62.1-2019 (2019).

Table 2. Design criteria of ventilation rate for classrooms.

<table>
<thead>
<tr>
<th>Standard</th>
<th>Category</th>
<th>I (l/s, person)</th>
<th>II (l/s, person)</th>
<th>III/Minimum (l/s, person)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ISO 17772-1:2017</td>
<td></td>
<td>10</td>
<td>7</td>
<td>4</td>
</tr>
<tr>
<td>EN 16798-1:2019</td>
<td></td>
<td>10</td>
<td>7</td>
<td>4</td>
</tr>
</tbody>
</table>

These criteria are in general based on theoretical assumptions, and are only valid for specific indoor environment conditions. Moreover, in most cases CO₂ concentration is used as the sole indicator for assessing indoor air quality and ventilation sufficiency in school buildings (REHVA, 2020).

According to several recent field studies on school buildings located in different countries (Table 3), it is observed that both MV and HV can achieve higher ventilation rate, lower CO₂ concentration and better academic performance than NV (Toftum et al., 2015; Canha et al., 2016), and NV is often hampered by other indoor environment control devices (Bluyssen et al., 2018). It is also noticed in some schools that HV and MV were not properly operated and adjustments were needed (Vornanen-Winqvist et al., 2018a; 2018b).

Table 3. Ventilation strategies in school buildings.

<table>
<thead>
<tr>
<th>Reference</th>
<th>Country</th>
<th>Schools (Classrooms)</th>
<th>Ventilation regime</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tofrum et al. (2015)</td>
<td>Denmark</td>
<td>389</td>
<td>NV: 52%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(820)</td>
<td>HV: 17%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MV: 31%</td>
</tr>
<tr>
<td>Canha et al. (2016)</td>
<td>France</td>
<td>17</td>
<td>NV: 73%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(51)</td>
<td>HV: 27%</td>
</tr>
<tr>
<td>Bluyssen et al. (2018)</td>
<td>The</td>
<td>21</td>
<td>NV: 48%</td>
</tr>
<tr>
<td></td>
<td>Netherlands</td>
<td>(54)</td>
<td>HV: 19%</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>MV: 33%</td>
</tr>
<tr>
<td>Vornanen-Winqvist et al. (2018a; 2018b)</td>
<td>Finland</td>
<td>2</td>
<td>HV: 50%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(4)</td>
<td>MV: 50%</td>
</tr>
</tbody>
</table>

HV: hybrid ventilation

DISCUSSION

Natural ventilation and mechanical ventilation are the major ventilation strategies used in school buildings. Although both of them have shown great potential in reducing airborne transmission of respiratory droplets (Qian et al., 2010), the overall IAQ of school classrooms is not ideal (Bluyssen et al., 2018). Natural ventilation can sometimes achieve higher air change rates, yet it requires a well-thought-out design and constantly proper operation. Mechanical ventilation can perform in a more stable manner, but it also needs careful operation and maintenance. So far, standards and guidelines are mainly based on the control of CO₂ concentration, and thus whether they are sufficient for removing aerosols under various contact scenarios between indoor occupants remains unknown.

With regard to the insufficient ventilation observed in schools, personalized ventilation (PV) can be applied to help minimizing the infectious aerosols. It is well demonstrated that the utilization of PV facilities can compensate the total volume ventilation to improve local IAQ, and thus achieve better protection for occupants exposed to an infected person (Li et al., 2013; Melikov, 2016). Moreover, researchers have proved the ability of PV to efficiently respond to short-range airborne transmission (Pantelic et al., 2009). However, previous studies mainly examined the
performance of PV systems in special room settings such as hospital wards or aircraft cabins (Nielsen et al., 2008; Melikov & Dzhartov, 2013). Therefore, further studies are required for adapting PV into school classrooms, since children have specific psychological and physiological demands on IAQ conditions different from adults.

CONCLUSIONS

This literature review is conducted to target the gap between school ventilation measures and the cross-infection control of COVID-19 among children, so as to propose future solutions. The conclusions are drawn as follows:

- School classrooms mainly have natural or mechanical ventilation, where the overall IAQ needs to be improved.
- Both natural and mechanical ventilation can reduce the airborne transmission of infectious respiratory droplets efficiently when designed, operated, and maintained properly, yet relevant standards and guidance are insufficient for school buildings.
- Personalized ventilation (PV) has a promising potential in protecting occupants from local indoor air contaminants, yet systematic studies are needed before PV can be applied to children in classrooms.

REMARK

A full version of this literature review is in preparation and it is intended to be published later as a journal article.

REFERENCES


Ventilation rate in classrooms of elementary schools and its association with respiratory infections

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SUMMARY
Classrooms in elementary schools are characterized by high occupancy levels and naturally ventilated, which makes respiratory infections easily spread among pupils. This paper is to investigate ventilation rates in classrooms and the influence on students’ respiratory infection rates. This study was conducted in 47 classes of ten elementary school in urban, suburban and rural area of Tianjin from 2018-2019. The subjects were second and fifth grade students, involving a total of 2020 people. We performed online continuous monitoring on indoor air temperature, relative humidity and CO₂ concentrations. Ventilation rate was estimated by CO₂ concentrations. The absence rate due to respiratory infections among students were reported by teachers. We used zero-inflated negative binomial model to study the associations between ventilation and respiratory infections. It was found that an increase of 0.1 h⁻¹ would reduce absence rate by 2%-4%. The same significant influence on absence rate was observed with another ventilation metric, L/(s-person). It indicated that low ventilation rate was significant risk factor for respiratory infections and airborne transmission might be an important route for infections.

INTRODUCTION
Respiratory infections refer to diseases caused by pathogenic microorganisms invading the respiratory tract and reproducing, which is one of the most common infections disease in the world. About 90% of pathogens causing infections are viruses (Templeton 2007). In western countries, respiratory infection is a major reason for hospital visits in childhood (Heikkinen and Järvinen, 2003) and on average young children can have 5–6 colds per year (Allan and Arroll, 2014; Arroll, 2011). According to a report by the World Health Organization (WHO, 2002), respiratory infections have become the second leading cause of death in children under 5 years of age, accounting for 17% of total under-five deaths.

Transmission of respiratory infections is primarily an indoor event (Marr et al. 2019). Therefore the association between building ventilation and respiratory infections has been the focus of government, the public, and research institutes. Chang et al. (2003) suggested that high occupancy level and low ventilation are important risk factors influencing the outbreak of SARS in university dormitories in 2003. Skolnick (1989) reported that people living in tight, energy efficient buildings were infected with upper respiratory diseases at rates 46% to 50% higher than a comparison group living in better ventilated houses. Sun et al. (2011) conducted a series of measurements at Tianjin University Campus, China and found that low ventilation rate were substantial risk factors for the spread of airborne infectious diseases in dorm rooms. In China, the elementary school students spend a long time in classrooms, and the density in classroom is large. This study focuses on the ventilation rates in classrooms at elementary schools and their associations with the spread of respiratory infections. Our hypothesis is that decreased ventilation rates in classrooms would be associated with increased illness absences from respiratory infections, due to increased indoor airborne concentrations of respiratory virus.

METHODS
We invited ten elementary schools to join our study. These schools were all located in Northeast China with cold winter climate. The locations of these schools covered urban, suburban and rural areas. Classrooms in these schools were all naturally ventilated. We performed online continuous monitoring on indoor air temperature, relative humidity and CO₂ concentrations, from 2018-2019. The ventilation rates were calculated on the basis of CO₂ concentrations (Stavova, 2004; Persily and De, 2017). Daily absence of students due to respiratory infections were reported by teachers in each classroom.

Considering the incubation period of respiratory viruses, we used daily ventilation rate to construct one aggregate ventilation rate metrics: average daily ventilation rates over the 7-day periods. We used zero-inflated negative binomial (ZINB) models to study the associations between classroom ventilation rates and respiratory infections. ZINB models contain two components: a zero inflated (ZI) model to estimate the probability of each observation to be nonzero and a negative binomial (NB) model to estimate the values of those observations with a nonzero probability of being positive. In ZI component models, the covariates were indoor air temperature and relative humidity. These
covariates might affect the survival and stability of respiratory viruses, thereby affecting the possibility of absence due to respiratory infections in a classroom. In the NB component models, the covariates were day of the week, grade level, male ratio, area per person, PM$_{2.5}$ concentration, temperature, relative humidity and ventilation. These covariates might affect transmission of viruses or host susceptibility, thereby affecting the degree of absenteeism due to respiratory infections.

RESULTS
Totally, 47 classes in 10 schools joined our study. Among them, 27 classrooms were for second grade and 20 rooms were for fifth grade. Students in these 47 classrooms were all involved in our study, and resulted a total number of 2020 students. The school hours for all the students were basically the same, with an average of 9 hours per day, 5 days per week. Descriptive information on selected study variables were shown in Table 1.

Table 1. Descriptive information on selected study variables

<table>
<thead>
<tr>
<th>Variables</th>
<th>Urban</th>
<th>Suburban</th>
<th>Rural</th>
<th>All</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of Schools</td>
<td>1</td>
<td>5</td>
<td>4</td>
<td>10</td>
</tr>
<tr>
<td>Number of Classrooms</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd Grade</td>
<td>5</td>
<td>14</td>
<td>8</td>
<td>27</td>
</tr>
<tr>
<td>5th Grade</td>
<td>5</td>
<td>10</td>
<td>5</td>
<td>20</td>
</tr>
<tr>
<td>Number of Students</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2nd Grade</td>
<td>178</td>
<td>478</td>
<td>403</td>
<td>1059</td>
</tr>
<tr>
<td>5th Grade</td>
<td>191</td>
<td>448</td>
<td>322</td>
<td>961</td>
</tr>
<tr>
<td>Classroom area (m$^2$)</td>
<td>48-51</td>
<td>57-70</td>
<td>50-55</td>
<td>48-70</td>
</tr>
<tr>
<td>Male ratio (%)</td>
<td>44.7-60.5</td>
<td>41.9-57.9</td>
<td>43.8-52.7</td>
<td>41.9-57.9</td>
</tr>
</tbody>
</table>

Distributions of daily CO$_2$ concentrations, air change rate per hour, ventilation rate per person and absenteeism rate are shown in Figure 1. It was found that the indoor daily average CO$_2$ concentration ranged from 400 ppm to 3914 ppm, with an average of 1798 ppm. 85% of the samples exceed 1000 ppm. Winter had the highest indoor CO$_2$ concentrations. The average daily value was 2037 ppm with 97% of samples were above 1000 ppm. The daily air change rate varied from 0.01 h$^{-1}$ to 11.2 h$^{-1}$, with a median value of 0.8 h$^{-1}$. Considering the high occupancy level in classrooms, it only had fresh air of 1 L/(s-person) in classroom. The average daily absence rate due to respiratory infections among students is 1% per day. Winter had highest absence rate.

We use zero-inflated negative binomial model (ZINB) to study the associations between classroom ventilation and respiratory infections (Table 2). Adjusted incidence rate ratio (IRR) were calculated in ZINB model with increased ventilation rate expressed as air change rate per hour and liter per second per person. It was found that an increase of 0.1 h$^{-1}$ would reduce absence rate by 2%-4%. The same significant influence on absence rate was observed with another ventilation metric, liter per second per person.

TABLE 1. Distribution of daily CO$_2$ concentrations, air change rate per hour, ventilation rate per person and absence rate by seasons

<table>
<thead>
<tr>
<th>Air change rate per hour (h$^{-1}$)</th>
<th>Ventilation rate per person (L/(s*person))</th>
</tr>
</thead>
<tbody>
<tr>
<td>IRR$^a$ (95% CI)</td>
<td>$P$</td>
</tr>
<tr>
<td>------------------------------------</td>
<td>------------------------------------------</td>
</tr>
<tr>
<td>Urban</td>
<td>0.96 (0.91, 1.00)</td>
</tr>
<tr>
<td>Suburban</td>
<td>0.98 (0.96, 0.99)</td>
</tr>
<tr>
<td>Rural</td>
<td>0.98 (0.96, 1.00)</td>
</tr>
<tr>
<td>All</td>
<td>0.98 (0.97, 0.99)</td>
</tr>
</tbody>
</table>

$^a$ Incidence rate ratio (IRR) were adjusted for PM$_{2.5}$ concentration, temperature, relative humidity, male ratio and occupancy density.

DISCUSSION
Transmission of respiratory infections is, as for viral infections generally, primarily an indoor event (Marr et al. 2019). We found that low ventilation rate was risk factor for respiratory infections. Note that after adjusting for PM$_{2.5}$ concentration, temperature, relative humidity, male ratio and area per person, the associations between ventilation rate and infections was still significant. This is in agreement with previous studies (Mendell et al. 2013). Simulation studies on aerosols produced by exhalation behavior showed that
higher ventilation increased the removal and dilution of aerosols, thereby reducing the risk of infection (Wan et al. 2009). Schulman and Kilbourne (1962) made early observations of the effect of airflow on the transmissibility of influenza viruses in a mouse model. It demonstrated that the rate of transmission decreased with increased ventilation in the closed chamber in which mice were housed. Xie et al. (2020) successfully collected active respiratory viruses from the air using a NIOSH sampler in a school. All evidence indicates that insufficient ventilation might result in increased concentrations of airborne transmitted pathogens, and consequently more infections among occupants. The strong association with ventilation in this study indicates that airborne transmission is an important and perhaps the dominant route.

CONCLUSIONS

- In China, the ventilation rates in primary schools is poor. Only 15% of the samples with CO₂ concentration were under the standard of 1000ppm, while only 4% of the samples with ventilation rate per person met the national standard of 5.56 L/s per person.

- Two ventilation metric ((air changes)/h and L/(s·person)) both had significant effects on absenteeism caused by respiratory infections per day. The strong association with ventilation in schools indicates that airborne transmission is an important and perhaps the dominant route.

ACKNOWLEDGEMENTS

This study was supported by the National Key Research and Development Program of China (2017YFC0702700), Key Research and Development Program of Tianjin Science and Technology Commission (19YFZCSN0170).

REFERENCES


Analysis of natural ventilation of a large educational building using parallel opening windows

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ABSTRACT
Natural ventilation can be used as a sustainable way of controlling the indoor environment. Natural ventilation by means of openable windows is not often applied in medium to high-rise buildings due to the possibly large wind pressures, resulting in too high indoor air velocities and possible nuisance. However, it has a strong potential to provide ventilative cooling. This study focuses on natural ventilation in a large educational building (Atlas) at TU Eindhoven. Natural ventilation is possible through parallel opening windows (POW). However, there is a lack of knowledge on the application of parallel opening windows in high-rise buildings and how to prevent nuisance and optimize ventilative cooling requires more detailed information. Full-scale on-site experiments and computational fluid dynamics (CFD) simulations are conducted. The simulations show that close to the POW very high velocities can occur. However, the incoming jet flows are dissipated within a limited distance, reducing the possible nuisance.

INTRODUCTION
Natural ventilation can be used as a sustainable way of providing fresh air to a building and removing excessive heat and pollutants. One of the high-potential applications of natural ventilation is ventilative cooling, which can reduce the building cooling demand by removing excessive heat from a building, for example during night (i.e. night ventilation or night flush; e.g. Carrilho da Graça et al. (2002)). It can also be used to reduce the cooling demand during the day in the shoulder seasons, especially in buildings subjected to large internal heat gains or solar heat gains. This paper presents computational fluid dynamics (CFD) simulations of a naturally ventilated large educational building (named Atlas) on the campus of Eindhoven University of Technology in the Netherlands. Atlas is a 42 m high, 20 m wide and 170 m long building and has recently been renovated. Atlas was originally constructed in 1963 and has a total floor area of 42,000 m². One of the key features implemented to increase energy efficiency is the possibility to provide natural ventilation by opening large parallel openable windows, which are present at random locations in all four facades (see Figure 1). The windows can be opened manually or automatically, enabling their use for personal thermal comfort and well-being during the day and large-scale ventilative cooling during the nights. However, there is not enough knowledge and information on the application of these parallel opening windows in high-rise buildings to optimize window operation and to prevent nuisance due to too high indoor air velocities. Therefore, on-site measurements (not presented in this paper) and CFD simulations are used to obtain information on the indoor air velocities behind the windows, and overall flow patterns resulting from the window opening.

METHODOLOGY
3D isothermal steady Reynolds-averaged Navier-Stokes (RANS) CFD simulations are performed to analyze the flow through the windows and inside the building in more detail. Thermal effects are not included in this first analysis and will be included in future studies. The wind-driven ventilation flow is assumed to be the main factor when looking at possible nuisance by too high indoor air velocities. The computational geometry and grid of the surroundings of Atlas are based on those used in a previous wind comfort study by Janssen et al. (2013), in which a grid-sensitivity analysis was performed as well. An overview of the buildings included in the computational domain is shown in Figure 1c. The domain sizes are based on the best practice guidelines (Franke et al. 2007, Tominaga et al. 2008). The parallel openable windows are modeled as zero-thickness wall located 240 mm in front of the facade (maximum opening). The grid is constructed using the grid-generation technique presented by van Hooff & Blocken (2010). The total grid size is 69 million cells, with about 8 million cells for the surroundings and 61 million cells for the Atlas building, including the interior.

A logarithmic mean wind speed profile is imposed at the inlet of the computational domain, with a reference velocity \( U_{ref} \) of 5 m/s at 10 m height, and an aerodynamic roughness length of \( y_0 = 0.5 \) m or \( y_0 = 1.0 \) m, depending on the wind direction considered. The inlet profile for turbulent kinetic energy is equal to \( k = u^*_{ABL}^2/\sqrt{C_\mu} \) with \( u^*_{ABL} \) the atmospheric boundary layer friction velocity and \( C_\mu \) a
Elevated indoor air velocities are also observed behind window openings in the south facade (Fig. 2b). Nonetheless, the indoor air velocities are about 3–5 m downstream of the window opening. Future work will focus on a range of aspects. Note that this paper mainly intends to visualize and quantify possible regions with high indoor air velocities. First of all, the CFD simulations are conducted for a maximum window opening configuration (240 mm). A smaller window opening, especially on higher floor levels, could prevent discomfort due to too high indoor air velocities. It is indicated that the results strongly depend on the reference wind velocity and wind direction, therefore, future work will analyze the indoor airflow for additional wind directions. For lower reference wind velocities, thermal effects become important and will thus be included in the simulations (balance between wind-driven and buoyancy-driven flow). In addition, floor level, and location and amount of parallel openable windows are influencing factors and a more detailed analysis will be performed for these parameters. Furthermore, the effectiveness of the open door policy, as in place at the moment to increase the air exchange rate during night, will be assessed by numerical simulations. In addition, a validation study will be performed using the available full-scale measurement results. Finally, a detailed control strategy will be developed, since this is imperative to prevent discomfort and to fully utilize the ventilative cooling potential of the parallel opening windows.

The CFD simulations provide detailed information on the velocities in the proximity of the open windows as well on the indoor air velocities and the volume flow rates. Figure 2 shows the dimensionless velocity magnitude for the southern side of the 10th floor, in a horizontal plane at 1.35 m above the floor (37.25 m above the ground), for two wind directions: SSW ($\phi = 210^\circ$; Fig. 2a) and SSE ($\phi = 150^\circ$; Fig. 2b). Figure 2 depicts relatively high indoor air velocities ($> 0.50$), behind the window openings in the windward facades, in this case the south and west facades for $\phi = 210^\circ$ (Fig. 2a) and the south and east facades for $\phi = 150^\circ$ (Fig. 2b). The high indoor air velocities are most pronounced for the window openings in the southern facade, where the high-velocity regions are present for about 3-5 m downstream of the window opening. Elevated indoor air velocities are also observed behind the window openings in the west (Fig. 2a) and east facade (Fig. 2b). Nonetheless, the indoor air velocities in large areas on this floor and for these two wind directions are below 0.05 (i.e. below 0.25 m/s if $U_{\text{ref}} = 5$ m/s).

**RESULTS**

The CFD simulations show that high dimensionless indoor air velocities can occur in the southern part of the 10th floor of the Atlas building, especially in the area until 3-5 m behind the open windows in the south facade for $\phi = 150^\circ$ and $\phi = 210^\circ$. In general, dimensionless indoor air velocities are below 0.05 (i.e. below 0.25 m/s if $U_{\text{ref}} = 5$ m/s).

**CONCLUSIONS AND FUTURE WORK**

Future work will focus on a range of aspects. Note that this paper mainly intends to visualize and quantify possible regions with high indoor air velocities. First of all, the CFD simulations are conducted for a maximum window opening configuration (240 mm). A smaller window opening, especially on higher floor levels, could prevent discomfort due to too high indoor air velocities. It is indicated that the results strongly depend on the reference wind velocity and wind direction, therefore, future work will analyze the indoor airflow for additional wind directions. For lower reference wind velocities, thermal effects become important and will thus be included in the simulations (balance between wind-driven and buoyancy-driven flow). In addition, floor level, and location and amount of parallel openable windows are influencing factors and a more detailed analysis will be performed for these parameters. Furthermore, the effectiveness of the open door policy, as in place at the moment to increase the air exchange rate during night, will be assessed by numerical simulations. In addition, a validation study will be performed using the available full-scale measurement results. Finally, a detailed control strategy will be developed, since this is imperative to prevent discomfort and to fully utilize the ventilative cooling potential of the parallel opening windows.

**ACKNOWLEDGEMENTS**

This work was financed by OPZuid, province Noord-Brabant and Eindhoven University of Technology. This work was sponsored by NWO Exacte Wetenschappen (Physical Sciences) for the use of supercomputer facilities, with financial support from the Netherlands Organization for Scientific Research (NWO). Twan van Hooff was a postdoctoral fellow of the Research Foundation – Flanders (FWO) during this research project and acknowledges its financial support (project FWO 12R9718N). The authors also gratefully acknowledge the partnership with ANSYS CFD.

**REFERENCES**


Figure 1. (a) View on the east facade of Atlas. (b) Parallel opening window. (c) Overview of buildings included in computational domain. (d) Impression of computational grid, including south-side of Atlas.
Figure 2. Contours of dimensionless velocity magnitude on the southern side of the 10th floor (at 1.35 m above the floor). The part in which the contours are shown is depicted in red on the left side. The top figure indicates the west façade. (a) $\varphi = 210^\circ$. (b) $\varphi = 150^\circ$. $U_{\text{ref}} = 5$ m/s at 10 m height. (c) Floor plan of 10th floor in the area included in the simulation (at same scale as figures with contours).
Effects of suspended particles, chemicals, and airborne microorganisms in indoor air on building-related symptoms: a longitudinal study in air-conditioned office buildings

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SUMMARY

We conducted a one-year longitudinal study to examine the effects of suspended particles, chemicals, and airborne microorganisms on building-related symptoms (BRSs) in air-conditioned office buildings in Osaka and Tokyo. In total, 648 subjects in 24 office rooms and 11 office buildings were recruited. Multivariable analyses revealed that BRSs strongly associated with a building, including eye irritation, upper respiratory symptoms, and general symptoms, were not significantly correlated with indoor air pollutants. In BRSs weakly associated with a building, the upper respiratory symptoms were significantly correlated with an increase in the air concentrations of benzene, ethylbenzene, and Acremonium species. The indoor air concentrations of benzene and ethylbenzene were lower than those specified in the Japanese air quality guidelines. Although the indoor air concentration of each pollutant was low, when they collectively exist in an indoor environment, they may lead to a greater combined health risk.

INTRODUCTION

Building-related symptoms (BRSs) have emerged as an occupational and environmental health issue since the early 1970s. We previously conducted three-phase studies, with two cross-sectional studies using questionnaires and environmental measurements and one longitudinal study that investigated the environmental factors associated with BRSs (Azuma et al., 2015; 2018a; 2018b). Our results suggested that BRSs were significantly associated with perceived thermal comfort, dryness, odors, dust, and noise during both winter and summer.

We previously reported the effects of thermal conditions and carbon dioxide concentrations on BRSs from the longitudinal study (Azuma et al., 2018b). Our results suggested that upper respiratory symptoms were significantly associated with a decrease in both relative and absolute humidity. In this paper, we report the effects of suspended particles, chemicals, and airborne microorganisms in indoor air on BRSs in air-conditioned office buildings.

METHODS

We conducted a one-year longitudinal study in Osaka and Tokyo to examine the effects of suspended particles, chemicals, and airborne microorganisms in indoor air on BRSs in air-conditioned office buildings. Weekly BRS was defined as symptoms experienced on at least 1 day per week in the last 4 weeks that improved when one was away from the building, suggesting that the association between health symptoms and work environment is strong. Monthly BRS showed symptoms that were experienced on at least 1 day in the last 4 weeks that improved when one was away from the building, suggesting that the association between health symptoms and work environment is weak. In total, 648 subjects in 24 office rooms and 11 office buildings were recruited. To collect information on BRSs and those indoor air pollutants in the office room, we measured the air concentrations of carbon monoxide (CO), suspended particles in air [particle counts of each cutoff size in diameter (>0.3 μm, >0.5 μm, >0.7 μm, >1.0 μm, >2.0 μm, >5.0 μm)], PM2.5, formaldehyde, acetaldehyde, volatile organic compounds (benzene, toluene, ethylbenzene, xylene, styrene, p-dichlorobenzene, and tetradecane), total volatile organic compound (TVOC), fungi, bacteria, and endotoxin in the office rooms and provided a health questionnaire once every two months for one year. The sampling interval for these compounds was 30 min in a single day. The surveys were conducted between June 2015 and February 2017. The correlations between BRSs and each data parameter were examined using a generalized linear mixed model using a logistic link and adjusting for potential variables.

RESULTS AND DISCUSSION

In total, 483 office workers (53.4% male and 46.6% female) participated in the present study. Of the 4520...
questionnaires distributed during the survey, 1800 valid responses were obtained (response rate, 39.8%). Multivariable analyses revealed that weekly BRSSs, including eye irritation, upper respiratory symptoms, and general symptoms, were not significantly associated with indoor air pollutants (data not shown). As shown in Table 1, in monthly BRSSs, the upper respiratory symptoms were significantly correlated with an increase in the air concentrations of benzene, ethylbenzene, and Acremonium species. However, the upper respiratory symptoms were significantly correlated with a decrease in the air concentrations of CO, endotoxin, and yeasts species. The association of office environment with monthly BRSSs is not strong. The results might be affected by individual health conditions in housing. The indoor air concentrations of benzene (maximum 2.3 µg/m³) and ethylbenzene (maximum 21.4 µg/m³) were lower than those specified in the Japanese air quality guidelines (benzene 3 µg/m³, ethylbenzene 3800 µg/m³). Although the indoor air concentration of each pollutant was low, when they collectively exist in an indoor environment, they may lead to a greater combined health risk.

### Table 1 Correlation of monthly BRSSs with suspended particles, chemicals, and airborne microorganisms

<table>
<thead>
<tr>
<th>Variable</th>
<th>OR unit</th>
<th>Eye irritation</th>
<th>General symptoms</th>
<th>Upper respiratory symptoms</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO</td>
<td>1 ppm</td>
<td>0.86 (0.57–1.31)</td>
<td>0.93 (0.63–1.37)</td>
<td>0.55 (0.33–0.92)</td>
</tr>
<tr>
<td>Particles</td>
<td>10⁵ count</td>
<td>1.29</td>
<td>1.01</td>
<td>1.24</td>
</tr>
<tr>
<td>0.3 µm</td>
<td>1.01</td>
<td>0.92 (0.81–1.1)</td>
<td>0.50 (0.41–0.96)</td>
<td>0.74 (0.50–1.1)</td>
</tr>
<tr>
<td>Particles</td>
<td>10⁴ count</td>
<td>1.15</td>
<td>0.94</td>
<td>1.12</td>
</tr>
<tr>
<td>0.5 µm</td>
<td>1.11</td>
<td>0.79 (0.69–0.90)</td>
<td>0.67 (0.57–0.81)</td>
<td>0.83 (0.68–1.01)</td>
</tr>
<tr>
<td>Particles</td>
<td>10³ count</td>
<td>1.13</td>
<td>0.93</td>
<td>1.13</td>
</tr>
<tr>
<td>1.0 µm</td>
<td>0.98</td>
<td>0.79 (0.67–0.92)</td>
<td>0.59 (0.42–0.80)</td>
<td>0.61 (0.47–0.78)</td>
</tr>
<tr>
<td>Particles</td>
<td>10² count</td>
<td>0.99</td>
<td>0.95</td>
<td>1.03</td>
</tr>
<tr>
<td>2.0 µm</td>
<td>0.91</td>
<td>0.88 (0.78–0.98)</td>
<td>0.75 (0.64–0.87)</td>
<td>0.79 (0.65–0.95)</td>
</tr>
<tr>
<td>Particles</td>
<td>10² count</td>
<td>0.99</td>
<td>0.97</td>
<td>0.84</td>
</tr>
<tr>
<td>5.0 µm</td>
<td>0.99</td>
<td>0.76 (0.64–0.90)</td>
<td>0.65 (0.54–0.79)</td>
<td>0.74 (0.43–1.29)</td>
</tr>
<tr>
<td>PM₂.₅</td>
<td>0.1</td>
<td>1.36 (0.84–2.20)</td>
<td>0.88 (0.53–1.43)</td>
<td>1.23 (0.70–2.17)</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>10 µg/m³</td>
<td>1.20</td>
<td>1.11</td>
<td>1.12</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>10 µg/m³</td>
<td>1.30</td>
<td>0.97</td>
<td>1.09</td>
</tr>
<tr>
<td>Benzene</td>
<td>1 µg/m³</td>
<td>1.16 (0.89–1.51)</td>
<td>1.03 (0.79–1.33)</td>
<td>1.36 (1.02–1.83)</td>
</tr>
<tr>
<td>Toluene</td>
<td>10 µg/m³</td>
<td>1.14</td>
<td>1.07</td>
<td>1.12</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>10 µg/m³</td>
<td>1.35</td>
<td>1.02</td>
<td>1.85</td>
</tr>
<tr>
<td>Styrene</td>
<td>1 µg/m³</td>
<td>1.04</td>
<td>0.98 (0.90–1.02)</td>
<td>1.04 (0.98–1.10)</td>
</tr>
<tr>
<td>p-Dichlorobenzene</td>
<td>10 µg/m³</td>
<td>1.41</td>
<td>1.16</td>
<td>0.75</td>
</tr>
</tbody>
</table>

Values are expressed as adjusted odds ratios (95% confidence interval) for participants with complete data; Significant at *p < 0.1, **p < 0.05, ***p < 0.01; Adjusted for gender, age, job category in general and skin symptoms; Adjusted for gender, age, job category, and smoking status in eye irritation; CO, carbon monoxide; OR, odds ratio; TVOC, total volatile organic compound.

### CONCLUSIONS

Monthly BRSSs were significantly correlated with an increase in the air concentrations of benzene and ethylbenzene. Similar results were observed in our previous cross-sectional study (Azuma et al., 2018a). The combined health risks of chemical pollutants with similar health effects were concerned. Further research on the total health risk due to multiple low-level indoor pollutants is required.

### ACKNOWLEDGEMENTS

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### REFERENCES


Human personal cloud associated with particles and gases in an office study: Preliminary results

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SUMMARY

Human “personal cloud” effect is defined as the concentration difference of air pollutants in the breathing zone relative to room-average levels, which is commonly encountered in indoor environments where the air is not well-mixed. It has important implications to human exposure evaluation. Yet, investigations on the nature and significance of the personal clouds remain scarce. This study aims to quantify the magnitude of personal air pollutant cloud in an office environment. In a three-person naturally ventilated office, we characterized the personal clouds of CO₂, volatile organic compounds (VOCs), ozone, total particles (10 nm to 10 μm), fluorescent biological aerosol particles (FBAPs) and airborne microbes. This paper reports preliminary results showing that the personal cloud magnitude of CO₂, individual VOCs and particulate matter can range within 0-500 ppm, 0-1000 μg/m³, and 0-6 μg/m³, respectively. These results could be valuable for refined characterization and enhanced control of personal exposure to air pollutants.

INTRODUCTION

Inhalation to elevated levels of particulate matter and gaseous pollutants is associated with important health concerns. To accurately characterize the inhalation exposure, however, one important overlooked factor is the spatial variability of indoor pollutant concentrations. Owing to the potential inconsistency among air pollutant sources, monitor location, and human breathing zone, exposure estimation based on monitor location results may introduce bias. To resolve such a potential error, the term “personal cloud” is introduced and defined as the concentration difference of air pollutants in the breathing zone relative to room-average levels. The personal cloud of air pollutants is commonly encountered in indoor environments where the air is not well-mixed. The personal cloud can result from exogenous sources such as human activities that generate localized emissions, and endogenous sources that include emissions from the human body and clothing. Previous population-weighted exposure analysis and human experiments in a chamber have demonstrated the importance of particle personal clouds.

This study aims to quantify the magnitude of personal air pollutant cloud in an office environment. The target air pollutants include CO₂, VOCs, ozone, total particles (10 nm to 10 μm), FBAPs and airborne microbes. This paper introduces preliminary results about the personal cloud magnitude of CO₂, VOCs and total particles.

METHODS

Study office

The office involved in the field test was located on the second floor of a research institute building in Switzerland. There were three occupants regularly working in the office (6.5m × 6.5m × 2.8m). A set of water-supplied radiant panels on the ceiling provided heating and cooling for the office. A thermostat was installed on the East wall for automatic control of the office air temperature. The office was naturally ventilated through two windows embedded in the north wall. The office was located in the inner zone of the building without direct connection with the outdoor atmosphere, and thus the air exchange was between the office and the inner space of the building.

Measurements and data processing

The field experiment ran continuously for two distinct weeks: 1) “standard office work without manipulation” and 2) “manipulation week”. The first-week measurement aimed to investigate the daily nature of personal cloud and the potential disparities among occupants. We measured 0.3-10 μm particles using optical particle counters (MetOne 704, MetOne, USA), individual and total VOCs using passive badges (Toxpro SA, Switzerland), CO₂ using real-time sensors (HOBO MX1102, Onset Co. Ltd., USA) at the breathing zone of the three occupants. Their concentrations were also measured at four stationary locations in the office. The objective of the second week was to probe the influence of application of personal care products, cooking activities during the lunch break, worn clothing, hand sanitizer, occupancy density and distance from other occupants. Clothing and activity of Occupant #1 were regulated in the manipulation week. During the experimental period, outdoor concentrations of the target air pollutants were also measured. Additionally, occupants’ activities were
recorded using daily questionnaire and on-site occupancy sensors. The magnitude of personal cloud effect was directly calculated as the difference between the air pollutant concentrations at personal site and room-average levels. Statistical analysis was performed to determine the significance of the difference.

**Quality control and assurance**

All the instruments had been calibrated by their manufacturers prior to the experiments. User calibration on sampling flow rate was implemented as well. A cross-correlation between each two instruments were obtained through side-by-side tests to correct the differences of measurement results.

**RESULTS & DISCUSSION**

The VOC personal cloud magnitudes during the first field test week are shown in Table 1. It can be seen that the personal cloud effect varied with specific compounds and occupants: it reached as high as 1000 μg/m³ for ethyl alcohol, which may be attributed to the use of hand sanitizer of P3. The same was also witnessed for isopropyl alcohol. Other VOCs that showed positive personal cloud effect may originate from human emissions and proximate sources, implying an elevated inhalation exposure relative to the room-average level. Noticeably, there were also negative values of personal cloud measured for several VOCs, such as -16 μg/m³ for 1-butyl alcohol, indicating a lower level in personal exposure relative to estimation based on room monitoring results. The magnitude of TVOC personal cloud varied from 35 to 192 μg/m³.

Table 1. VOC personal cloud magnitude across three occupants (P1, P2, and P3) in μg/m³. Bolded values indicate statistically significant difference between personal and room-average levels.

<table>
<thead>
<tr>
<th>Name</th>
<th>P1</th>
<th>P2</th>
<th>P3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ethyl Alcohol</td>
<td>220</td>
<td>933</td>
<td>1026</td>
</tr>
<tr>
<td>Acetone</td>
<td>9</td>
<td>15</td>
<td>20</td>
</tr>
<tr>
<td>Isopropyl Alcohol</td>
<td>21</td>
<td>85</td>
<td>177</td>
</tr>
<tr>
<td>Cyclopentane</td>
<td>-4</td>
<td>-4</td>
<td>4</td>
</tr>
<tr>
<td>1-Butyl alcohol</td>
<td>3</td>
<td>-16</td>
<td>-16</td>
</tr>
<tr>
<td>Toluene</td>
<td>0</td>
<td>-1</td>
<td>1</td>
</tr>
<tr>
<td>Alpha-Pinene</td>
<td>5</td>
<td>-4</td>
<td>14</td>
</tr>
<tr>
<td>Formic acid</td>
<td>15</td>
<td>7</td>
<td>26</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>6</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Propionaldehyde</td>
<td>3</td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>Butyldehyde</td>
<td>3</td>
<td>4</td>
<td>11</td>
</tr>
<tr>
<td>Benzaldehyde</td>
<td>6</td>
<td>11</td>
<td>0</td>
</tr>
<tr>
<td>Total (Toluen-equivalent)</td>
<td>35</td>
<td>128</td>
<td>192</td>
</tr>
</tbody>
</table>

CO₂ personal cloud varied daily with occupants, as shown in Figure 1. The excess of CO₂ concentration in the peri-human environment of P1 relative to room average level could reach as high as 500 ppm, with a mean magnitude of ~110 ppm. In comparison, CO₂ personal cloud effect was less in terms of P2 and P3. The disparity may be owing to the difference in breathing style, local air mixing and relative location of the CO₂ monitors among the three occupants.

Figure 1. CO₂ personal cloud of three occupants (P1, P2, and P3) during the first field test week.

Figure 2 demonstrates the existence of PM₁₀ personal cloud in the office environment. The magnitude of PM₁₀ personal cloud can reach as high as 6 μg/m³ for P1, with an average value at 1.6 μg/m³. P3 had lower PM₁₀ personal cloud magnitude, ranging from 0 to 1.5 μg/m³. Note that the magnitude of PM₁₀ personal cloud was comparable to the room average level (average at 2.0 μg/m³). The elevated concentration in the peri-human environment would mainly owing to particle emissions from humans.

Figure 2. PM₁₀ personal cloud of two occupants (P1 and P3) during the first field test week.

**CONCLUSIONS**

- A difference in air pollutant concentrations between personal and room site was observed in an office environment, implying potential bias in studies estimating inhalation exposures.
• The preliminary results have shown that the personal cloud magnitude of \( \text{CO}_2 \), VOCs and total particles can range within 0-500 ppm, 0-1000 \( \mu \text{g/m}^3 \), and 0-6 \( \mu \text{g/m}^3 \), respectively.

• The results are valuable for refined characterization and enhanced control of personal exposure to air pollutants.

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Experimental & Modelling Studies for the Determination of Pollutant Emissions from Cooking and Cleaning

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SUMMARY

Human exposure to air pollutants is largely influenced by the quality of air in our homes. Occupant activities such as cooking and cleaning can act as a large source of indoor air pollutants, including volatile organic compounds (VOCs) and particulate matter (PM). The ‘IMPacts of Cooking and Cleaning on indoor Air quality: towards healthy Buildings for the future (IMPeCCABLE)’ project aims to gain a better understanding of the impacts of cooking and cleaning on indoor air quality through experimental and modelling studies. Initial experiments have been performed in a realistic kitchen environment to measure emission profiles during cooking and cleaning activities. Online measurements of VOCs and PM showed enhancements in their concentrations as a consequence of cooking and cleaning.

INTRODUCTION

In developed countries, we spend around 90% of our time indoors, and much of that in our homes. Indoor air chemistry is therefore an important area of research for understanding human pollutant exposure, especially as the sources and reactions of pollutants indoors are very different compared to outdoors.

Occupant activities such as cooking and cleaning are particularly large sources of pollutants in our homes, however the impacts of such activities on indoor air quality are not yet fully understood. The majority of cooking and cleaning studies to date are focused on determining emission rates rather than exploring the wide range of species emitted and the chemistry that follows their emission. With evidence suggesting that secondary pollutants are more harmful to health than primary emissions (Buchanan et al., 2008), it is clear that further research is therefore required to develop our understanding of the sources and reactivity of indoor air pollutants.

The experiments described herein are part of the IMPeCCABLE project, which aims to enhance our knowledge of the impact of cooking and cleaning on indoor air quality through a combination of experimental and modelling studies. The objectives of the experiments described here were to measure emission profiles of VOCs and PM during high-emission occupant activities within a typical indoor environment. The data will be further probed using the INCHEm-Py model (Carslaw, 2007) to better understand the resulting indoor air quality when we cook and clean indoors at the process level.

METHODS

Experiments took place over three weeks, 17th Nov – 3rd Dec 2020, at a domestic kitchen facility within the University of York. The kitchen (4.5 m x 2.5 m) was equipped with an electric cooker and had a single window and fire door which were opened to ventilate the room between experiments. During experiments ventilation was minimized: the door was closed, and the window was ajar to allow a transfer line to run from the room to the measurement instrumentation. Room temperature and humidity were measured daily but were not controlled and therefore were subject to meteorological variability. Air exchange rate was also not controlled throughout experiments.

Online measurements of VOCs, were performed using selected-ion flow-tube mass spectrometry (SIFT-MS). The SIFT-MS was located in a van outside, and continually sampled mixed air from the centre of the room via the transfer line. Particulate matter (PM10, PM2.5, PM1) was also monitored from the same sampling location using an optical particle counter (OPC) sensor.

Cooking experiments included toasting and frying various ground and whole spices, frying different variations of bacon, and cooking a whole meal (e.g. a beef chili). A stainless-steel pan was used for all cooking experiments, and pan temperature was monitored using a surface probe thermometer. A standard procedure was established for the frying of spices based on pan and oil temperatures. The procedure for cooking the beef chili was adapted from a standard bolognese recipe which had been developed for previous cooking studies (O’Leary et al., 2019).

Cleaning experiments were performed following procedures which were defined prior to experiments taking place. Four product categories were studied (surface cleaner, bathroom cleaner, washing up liquid, floor cleaner), of which we tested four different brands,
including a market leading, supermarket own make, and two green brands (popular and upmarket). Surface and bathroom cleaners were tested by applying a defined number of sprays to the worktop counter and wiping away after 1 minute. Washing up liquids and floor cleaners were tested by diluting as instructed by the manufacturer, then hand washing dishes and mopping the floor, respectively. Product residues were removed by wiping surfaces with a damp cloth in between experiments.

Real-time measurements were performed for 10 minutes after each cooking and cleaning activity without human occupancy, followed by a period of ventilation. The SIFT-MS was used in selected ion monitoring (SIM) mode to target VOCs which were selected based on the literature, cleaning formulation chemical composition, and results from previous GC-MS analyses of certain oils, spices and cleaning products.

RESULTS & DISCUSSION

Primary emission profiles of targeted VOC’s were successfully obtained for indoor cooking and cleaning events of varying complexity. However, secondary pollutants were not monitored due to the short timescale of these experiments. The results illustrate enhancements in pollutant concentrations indoors during these high-emission events.

Emission of a range of n-alkanes, carbonyls and terpenes were detected during cooking experiments, which were attributed to emissions from oils, spices and meat. Emissions of various solvent and fragrance compounds were also observed from cleaning activities, and differences in VOC emissions between product brands for equivalent products were identified (figure 1).

Various layered experiments were performed in the kitchen, which involved cooking an entire meal followed by the use of multiple cleaning products over a short period of time. These experiments were designed to emulate typical occupant behavior. The data shows increased concentrations of many VOCs which can be attributed to emissions from the cooking and cleaning activities.

Figure 2 shows the concentration of total monoterpene emissions over the duration of the experiment. Emissions from aromatic spices and scented cleaning products can account for the observed increases, with larger emissions resulting from the cleaning episode. The presence of monoterpene at these concentrations will lead to secondary pollutant formation via reaction with oxidants (i.e. ozone) within the indoor environment. The relative concentrations of monoterpene isomers will differ between cooking and cleaning emissions, which will impact the chemistry following their emission and therefore secondary pollutant formation. Further analysis by GC-MS will be carried out to speciate isomers, and the application of results to modelling studies will enable a deeper understanding of the indoor air chemistry occurring.

![Figure 1. Total monoterpene emissions during cleaning experiments using surface cleaner products. Dashed line corresponds to the start of the cleaning event.](image1)

![Figure 2. Total monoterpene concentrations during a layered experiment. A beef chili was cooked (red), followed by cleaning with market leading products (blue). Dashed lines correspond to the following events: 1) food preparation, 2) frying of onion and spices, 3) addition of meat, 4) addition of liquids, 5) end of cooking, 6) washing up, 7) sink cleaned, 8) surfaces cleaned, 9) floor mopped, 10) ventilation of room.](image2)

CONCLUSIONS

- Results show emission profiles of cooking and cleaning activities within a typical domestic environment.
- Our findings are significant for highlighting human exposure to pollutants indoors during high-emission activities such as cooking and cleaning.
- The INCHEM-Py model will be used alongside these experiments to gain a deeper understanding of the chemical reactivity of cooking and cleaning pollutants in the indoor environment, and to identify likely secondary pollutants.
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How Does Indoor Air Chemistry Affect Outdoor Air Pollution?

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SUMMARY
Most air pollutant exposure happens indoors, particularly in our homes. Activities such as cooking and cleaning can be a large source of indoor air pollutants, with some emitted species further reacting to form secondary pollutants. Some indoor air pollutants are potentially harmful to health. Recent evidence also suggests that air pollutants released indoors can significantly impact outdoor air quality. This paper uses a detailed indoor air chemistry model to estimate the impact of indoor activities such as cooking and cleaning on outdoor air quality. We show that cooking and cleaning can enhance indoor air pollutant concentrations by a factor of 200 and provide a source of air pollutants to outdoors of a few ppb per hour. Our results suggest that as outdoor air quality improves such as through electrification of the vehicle fleet, such indoor activities will need to be considered for their impacts on outdoor as well as indoor air quality.

INTRODUCTION
Despite the fact that more than 90% of our time is spent indoors, most atmospheric chemistry research is focused on outdoor air. Indoor air chemistry is different from outdoors, particularly the sources of pollutants, the relative importance of key oxidants, and the surface area to volume ratios. Whilst an increasing number of indoor air studies have been performed recently, the complexity of indoor environments makes it a challenging system to describe. Furthermore, recent work has shown that buildings and the occupant activities within them may be an important source of outdoor air pollution (McDonald et al., 2018).

Indoor air chemistry models are useful tools to understand indoor air chemistry in the absence of observational data, or to provide further insight when used alongside measurements. For instance, the Indoor Detailed Chemical Model (INDCM) has been used to provide insight into the indoor air chemistry that follows cleaning using surface cleaners and air cleaning devices (Carslaw et al., 2017; Wong et al., 2017; Wang et al., 2017). emissions from materials, breath and skin emissions (Kruza et al., 2017; Kruza and Carslaw, 2019) and from personal care products (Yeoman et al., 2020).

In this paper the INDCM has been used to investigate the impact of indoor cooking and cleaning on indoor and also outdoor air quality. The aim of this work is to understand the importance of such indoor activities for outdoor air quality both now and as it improves in the future, such as through electrification of the vehicle fleet.

METHODS
The INDCM uses a detailed chemical mechanism called the Master Chemical Mechanism (Jenkin et al., 1997) to describe indoor chemistry, and also includes terms that describe exchange with outdoors, deposition onto and emissions from surfaces and indoor photolysis (including attenuated outdoor and indoor artificial light) (see more details in Carslaw (2007). For this work, the model has been initialized using data from the House Observations of Microbial and Environmental Chemistry (HOMEChem) field campaign in June 2018, where air composition was measured while different activities were carried out in a test house (Farmer et al., 2019). We used the concentrations of 52 volatile organic compounds (VOCs), nitrogen oxides (NOx) and ozone (O3) that were measured during the campaign, as well as measured photolysis rates, temperature and relative humidity to constrain the model (Figure 1).

Indoor activities (e.g. cooking, cleaning) were then simulated based on measurements and then the ‘aged’ air was released outdoors assuming Gaussian dispersion, where the window is assumed to be a point source for outdoor air. We then calculated the indoor to outdoor emission rates of several of the secondary species produced following cooking and cleaning activities indoors. Carbon monoxide (CO) was found to...
be a good tracer for indoor cooking, whilst glyoxal and peroxyacetyl nitrate (PAN) were good tracers for cleaning using a chlorine-based cleaner.

RESULTS & DISCUSSION

Our results focus on the 25\textsuperscript{th} June when both cleaning and cooking activities were carried out. Three cooking activities were carried out at breakfast, lunch and dinner time when sausage, beef and vegetable stir fry were cooked respectively. Cleaning with a chlorine-based cleaner then took place after all of the cooking activities had finished at around 5 PM. Other more minor cleaning activities took place in the morning, but we do not discuss those here.

Figure 2 shows the air pollutant concentrations that are generated following these different activities and subsequently leave the house. The red trace shows that CO concentrations increase following each of the three cooking events, with the biggest enhancement seen after the longest preparation time (for the chilli in the evening).

The glyoxal and PAN concentrations on the other hand are enhanced following cleaning activities, linked to the degradation of ethanol from the cleaning product. We found that these secondary pollutant concentrations were enhanced by orders of magnitude over background conditions (so in the absence of any activities). For CO, cooking enhanced concentrations by a factor of ~13, while cleaning enhanced glyoxal and PAB by factors of ~66 and ~200 respectively. Cooking generated up to 1 ppb/h of CO to the outdoor environment, whilst cleaning with a chlorine-based cleaner generated glyoxal and PAN at rates of 0.3 and 1.2 ppb/h respectively. Of course, once emitted these species will be rapidly diluted in the atmosphere, but impacts could be important at the city scale and we will focus on this aspect in future work.

CONCLUSIONS

- A detailed chemical model for indoor air has been used to investigate the impact of cooking and cleaning indoors on outdoor air quality.
- Our results show that cooking and cleaning can be a source of air pollution outdoors as well as indoors.
- As outdoor air quality improves in the future such as through electrification of the vehicle fleet, indoor sources such as these will become relatively more important for outdoor air quality. They will need to be better studied to understand their magnitude relative to other outdoor sources and should also be considered in future emission inventories.

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Characterising multi sensor platforms performance to investigate indoor air quality event and quantify personal exposure.

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SUMMARY
In the areas of Indoor Air Quality assessment and personal exposure, the use of multi-sensor systems for gas and particles measurements has become commonplace. Nevertheless, most of the studies focus on particulate matter and CO2 measurements. Regarding Volatile Organic Compounds, experiments are often limited to a rough evaluation of total VOCs, without even ensuring the capability of the sensors used to exhaustively quantify this parameter. Given their strong impact on health it is however essential to have tools capable to distinguish the diversity of VOC sources in indoor air. In this study, the metrological performances of 40 replicas of 2 types of VOC sensors: 4 MOX (Figaro, Cambridge CMOS Sensors, SGX Sensortech) and 1 electrochemical (Formaldehyde Dart Sensors), are evaluated under controlled conditions. They are exposed to 5 VOCs representative of indoor environments (formaldehyde, acetaldehyde, acetone, ethanol, limonene and their mixture) in a 1:1 scale experimental room based on their prevalence and their hazardousness summarized in guidelines. The correlation curves are established by comparison with the responses of a Selected-Ion Flow-Tube mass spectrometer (SIFT-MS). The results show that the electrochemical sensor, supposed to be dedicated to total VOCs, is acetone-blind and underestimate by a factor of 3 the real quantity of VOCs present, while MOX 1/ require pre-processing of the data to estimate reproducibility, 2/ have differentiated sensitivities by type of VOC, but without homogeneity by family of VOCs, 3/ have non-linear responses depending on the concentration ranges, 4/ can be combined with advanced statistic tools to establish a specific pollutant footprint of the VOCs considered. These results will help to interpret the data from the Qalipso campaign, during which these sensors were deployed for 4 months in 40 households in Douai city in Northern France.

INTRODUCTION
With the growth of social networks and the democratization of individual technical devices like gas and particles sensors, citizens are more and more involved in their own air quality monitoring. Many examples of experiments combining multidisciplinary approaches like social sciences, environmental sciences and deep data treatments have upsurged, bringing together researchers and citizens around the air pollution problematic.

The aim of Qalipso project is twofold: first, to demonstrate whether the provision of multi-sensor air quality monitoring systems to citizens influences or not their behaviour towards their exposure to indoor air pollutants, especially for disadvantaged populations; secondly, to study whether these systems are capable of discriminating different sources of pollutants likely encountered in confined environments. A 4-months massive field campaign, involving 40 families each equipped with the same multi-sensors systems has been launched at the close of the year (2019). Previously to this campaign, a metrological pre-qualification in laboratory in controlled conditions has been conducted, in order to i/ evaluate the metrological performances as sensitivity or reproducibility, of 4 MOX and one electrochemical sensor towards different VOC currently encountered in indoor air, ii/ estimate the degree of freedom of the multi-sensor system used, to be sure of its discriminate ability.

In this paper, we present the discrimination potentials of VOC sensors obtained during the metrological pre-qualification.

EXPERIMENTAL DEVICE AND PROTOCOL
After a tender, the Rubix-POD multi-sensor system was chosen for the Qalipso project to best fit our specifications. These concerned the type and number of sensors included in the system, the ergonomy, the communication interface, and the light indicator parametrization. RUBIX-POD includes 8 sensors dedicated to gas or particulates measurements, with complementary parameters like noise, luminosity, pressure, T and RH. The MOX sensors dedicated to VOC measurement are the MICS 5524 and MICS 5014 from SGX Sensortech, the OCS 801 from Cambridge CMOS Sensors and the TGS 8100 from Figaro. The electrochemical sensor dedicated to total VOCs is the ethanol sensor from Dart Sensors. Finally, the PODs are equipped with an NDIR CO2 sensor.

The 40 RUBIX PODs were grouped in a 12.5 m² room in which 5 different VOCs gases (selected both for their...
prevalence in IAQ environment, their typicity regarding specific pollution sources and their hazardousness summarized in guidelines) were injected separately and/or simultaneously during several experiments. Each injection consists in a 2-3 minutes puff at a designated concentration via an exhaust pipe, and then, the concentration slowly decreases depending on the natural air renewal rate which is 0.3 h⁻¹±0.1 h⁻¹ in the room. The gases injected were: Acetaldehyde (283 ppb), Acetone (128 ppb), Ethanol (284 ppb), Formaldehyde (400 ppb), Limonene (880 ppb), and a mix of all latter volatile organic compounds (745 ppb). To monitor the gas concentrations of each injections puff, a Selected-Ion Flow-Tube mass spectrometer (SIFT-MS) device is used as reference instrument. Its detection limit is 20ppb, and its time resolution is 2s, which permit to build the correlation with the sensors response. The 45 RUBIX PODs registered readings from the room on a server by 3G communication.

RESULTS AND DISCUSSION

The correlation curves are determined from the average of the response of each sensor reference on the 40 RUBIX PODs, compared to SIFT-MS. These curves allow: 1/ to establish whether the sensor responds or not to the species considered; 2/ if so, what is the type of associated modeling (linear, non-linear, saturation); 3/ to evaluate the fidelity to the model (R²) and the dispersion of the results (uncertainty); 4/ in the case of a linear model, to calculate the variability on the slope, representative of the reproducibility of each sensor reference on the 40 PODs; 5/ to determine whether there is an additive effect of mono-VOC sensitivities upon exposure to the mixture of 5 VOCs. Note that for all MOXs, the instantaneous data d taken into account corresponds to the difference between the raw measurement dᵣ under gas injection and the measurement under clean air dₒ.

Electrochemical sensor for Total VOC/This sensor is blind to acetone. For concentrations below 300ppb, it responds linearly to ethanol (slope 0.58), limonene (slope 0.3), acetaldehyde (slope 0.34) and to formaldehyde (slope 1.4). For these last two species, however belonging to the same VOC family, the response is not homogeneous. Beyond 300ppb, nonlinearity appears (limonene). In all cases, the modelling is excellent (R²>0.97), the dispersion is low (<30ppb), and the variability between PODs is good (<20% in the linearity range). Finally, it underestimates the concentration of total VOCs by a factor of 3, proving that the associated slope is not constituted in any way by a combination of mono-VOC sensitivities.

MOX MICS 5524 SGX Sensortech/This sensor is sensitive to all the VOCs tested, but exhibits nonlinearity, even saturation, which appear even at relatively low concentrations (around 40ppb for acetone, for example). Its response is linear only for ethanol (slope 3.3) and acetaldehyde (slope 3.1). For this last VOC, there is no similarity with the response to formaldehyde (slope 8.8 in the linearity range). With a dispersion of responses <300 au, R²> 0.9 and a variability on slopes <16%, the performances allow a large deployment of this type of sensor, subject to using the deviation d, and not the rough data dᵣ. Finally, the concentration of total VOCs is overestimated by a factor of 3 compared to the sum of the sensitivities and contributions of each species to the mixture.

MOX MICS 5914 SGX Sensortech/Except for the sensitivity values, 2 to 4 times higher for formaldehyde and ethanol, this sensor is a clone of the previous one. Therefore, it will be redundant in determining a VOCs pollution footprint.

MOX TGS 8100 Figaro/This sensor reacts uniformly to all the VOCs tested, with a slope between 1.5 and 2. As for the previous MOXs, non-linearity appears for acetone from 60ppb and for limonene over 300ppb. Dispersion, slope variability and model deviation are similar to MICS sensors. Finally, the response to total VOCs is linear over a wide range [0-750 ppb] and well follows the combination of mono-VOC sensitivities. Thus, this sensor is the closest one to a comprehensive and accurate measurement of total VOCs.

MOX CCS 801 Cambridge CMOS Sensors/Apart from being blind to acetaldehyde, CCS 801 behaves very similarly to TGS 8100, but with higher sensitivities: 4.4 for ethanol, 2.2 for formaldehyde. Non-linearity is found on the same compounds and at the same concentrations as for TGS 8100: acetone [40 ppb] and limonene [300 ppb]. Finally, the response to total VOCs is linear over the range [0-750ppb] and can be determined from mono-VOC sensitivities. The CCS 801 is therefore redundant with respect to the TGS 8100.

CONCLUSIONS

The metrological performances of 5 sensors to the different VOCs usually encountered in IAQ have been evaluated. The experiments show their ability to detect or not and with various sensitivities these species. For MOX, we can identify similar behavior for two pairs of them, meaning that they will bring redundant information during the field campaign. Despite a few shortcomings, they are sufficiently responsive, and reproducible to allow comparisons and identify behavioral changes to indoor air exposure targeted in the Calipso project.

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Longitudinal characterization of the human personal cloud effect associated with gaseous and particle pollutants in Switzerland

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SUMMARY
Studies on personal exposure to indoor air pollutants commonly use fixed stations as proxies. However, this method cannot effectively capture pollutant concentrations close to a person. This study examines the spatio-temporal variation of gaseous and particle pollutants in homes and offices at the personal (PEM) and stationary (SEM) levels.

Ten participants were monitored during five days with PEM and SEM stations in their homes and offices. We obtained real-time data for size-resolved particulate matter (PM) and carbon dioxide (CO₂), and time-integrated samples for PM₁₀, volatile organic compounds (VOCs), and aldehydes. We detected the personal PM₁₀ cloud in all the participants with a magnitude of 5-25 μg/m³ and it was partially detected for CO₂ and total VOCs (TVOCs). Correlations between PEM and SEM were sensitive to the location of the SEM in homes for PM₁₀ and CO₂ but not for some VOCs and aldehydes. Six contributing sources were identified in PM₁₀ samples and 33 compounds for VOCs and aldehydes.

INTRODUCTION
People in developed countries spend about 90% of their time indoors (Klepeis et al., 2001). Additionally, buildings are retrofitted to reduce energy consumption by making them airtight, which often reduces the air exchange with the outdoors. This has led to an accumulation of air pollutants of indoor origin coming from building materials, furniture and personal care products (Weschler, 2009) as well as air pollutants originating from personal activities and humans themselves (Bekö et al., 2020).

Exposure to PM has been associated with cardiovascular and respiratory diseases, allergies, asthma, and cancer (Brook et al., 2010; Fujimura et al., 2014; Wu et al., 2010). Exposure to CO₂ has been linked to a potential reduction of cognitive abilities and decision-making actions (Allen et al., 2016; Satish et al., 2012), while certain VOCs are suspected carcinogens (Rennix et al., 2005).

Exposure studies generally employ fixed monitoring stations as proxies to personal exposure. However, this approach may miscalculate the actual concentration of inhaled air pollutants. A combination of monitoring at the individual level with time-activity records has the potential to identify the effect of activities on personal exposure (Dias & Tchepel, 2018).

In the past, large-scale studies have focused on the relationships between indoor, outdoor and personal exposure concentrations. The RIOPA study found small variations in the concentration of PM₂.₅ in US residences between indoors (14.4 μg/m³) and outdoors (15.5 μg/m³), but a large contrast with personal exposure (31.4 μg/m³) (Turpin et al., 2007). Further, the PTEAM study of non-smoking residents in Riverside, California reported that PM₁₀ outdoor concentrations were weakly correlated with indoor concentrations and with personal exposure. The same study reported for the first time the existence of the “personal cloud”, defined as “excess” of air pollutant concentration close to the breathing zone in comparison to the room background levels.

A few studies have used a combination of real-time monitoring with time-integrated measurements in order to characterize and identify sources contributing to personal exposure (Turpin et al., 2007; Zhao et al., 2006). However, the contribution of each microenvironment to personal exposure is not usually contemplated; neither the distinction in indoor concentrations when the occupant is present or absent.

This study presents a new rich dataset of particle and gaseous air pollutant concentrations measured at the individual and stationary levels at home and office. The objective is to understand the spatial and temporal variability of the human personal cloud. The results offer insights that can be useful for enhancing the exposure prediction to indoor air pollutants.

METHODS
The field campaign was conducted from November 2019 to January 2020 in three cities of Switzerland: Fribourg, Zurich, and Lausanne. Ten non-smokers participants were monitored for five consecutive weeks-days in their homes and offices. They followed a semi-restrictive routine of exclusively home and office while other microenvironments were visited only when necessary (e.g. supermarkets).

The study used two types of motoring stations: PEM and SEM. The PEM station measured pollutants concentrations close to the breathing zone of the participant and it was carried in a backpack. The
participants were instructed to keep the backpack at a maximum distance of 1 m when it was not possible to wear it (e.g., while sleeping). Instead, the SEM stations measured at a fixed location in the home and the office. At home, the SEM stations were located in the room where the participant spent most of their awake time (bedroom or living room).

All the stations measured real-time data for PM in four size bins (0.3-1, 1-2.5, 2.5-10, >10 μm) (Met One Instruments Inc., model 804), CO₂, temperature, and relative humidity (HOBO, MX CO2 data logger) at a time-step of 1-min. Additionally, we collected 60 time-integrated active samples for particle size smaller than 10 μm (PM₁₀) for mass reconstitution and chemical composition determination, and 60 pairs of passive badges for VOCs and aldehydes. The stationary samples were segregated and used according to the presence of the participants in the home and the office (present and absent). Instead, for the PEM stations, the samples were divided according to the microenvironment (home and office). Thus, each participant had a total of six samples (home/office: PEM, SEM-present, SEM-absent) for each pollutant (PM₁₀, VOCs, and aldehydes).

Furthermore, the participants used a time-activity diary application (Timetrack.io) on their smartphones where they recorded their activities and locations. The application was previously customized to contain the most relevant activities and locations for the study. The records of the participants could be tracked by the investigator through an online platform. This approach facilitated the supervision of the data and the identification of inconsistencies. At the beginning of the study, the participants completed a questionnaire about their personal data and technical characteristics of their home, office, and neighborhood.

RESULTS

On average, PM₁₀ indoor concentrations at home during absent times (SEM-absent), present times (SEM-present), and personal exposure (PEM) were 18 μg/m³, 47 μg/m³, and 63 μg/m³, respectively. In the office, the average concentration was 10 μg/m³ for SEM-absent, 17 μg/m³ for SEM-present, and 24 μg/m³ for PEM. A source apportionment analysis was done using a positive matrix factorization model (EPA PMF 5.0). The results from the source apportionment analysis detected six pollutants sources contributing to PM₁₀ samples. Figure 1 shows the median of the absolute contribution of each source to PM₁₀ mass concentration by the type of station and the presence of the participant. The detected sources were: “Urban mix” which refers to the urban aerosol mixture from primary and secondary particulate matter from nitrogen oxides and sulfur oxides precursors; “Personal”, which represents organic particles originated from clothes, skin (primary) and likely secondary organic aerosols from personal-care products; “Traffic” that refers to primary and secondary particulate matter from road traffic emission including exhaust and non-exhaust particles; “Magnesium” a source contributing mainly to magnesium levels; “Biomass burning” originates from primary and secondary particulate matter from combustions of solid fuels; “Humidifier” which could be related to primary carbonates and sodium chloride particles contained in the tap water used in a humidifier. Figure 1 depicts “Urban mix” as the main contributor in all the monitoring stations, followed by “Personal” and “Traffic”. SEM-present samples had larger mass concentration than PEM samples from “Urban mix” sources in 70% of the participants at home and 40% in the office. “Personal” and “Traffic” sources contributions were higher in PEM samples than in SEM-present samples in 70% and 60% of the participants at home and 50% and 20% at office, respectively.

The personal PM₁₀ cloud was detected across all participants in the home and the office. The personal cloud magnitude for PM₁₀ was on average 14 μg/m³ at home and 8.5 μg/m³ at the office. Likewise, the average personal PM₂.₅ cloud magnitude was 6.7 μg/m³ and 2.8 μg/m³ at home and the office, correspondingly. Figure 2 illustrates the time-averaged personal PM₁₀ cloud magnitude stratified by particle size range (0.3-1 μm, 1-2.5 μm, and 2.5-10 μm). The personal PM₁₀ cloud was mainly composed of coarse particles (2.5-10 μm) except for P04 who had a larger contribution of small particles due to the use of a humidifier at home. These results are in line with the findings reported by (Licina et al., 2017), where personal exposure above room-average levels was primarily attributed to coarse particles coming from human skin and clothing. Further, we performed correlation analysis for PM₁₀ between PEM and SEM stations during present times. We considered the correlation between 0-0.3, 0.3-0.7 and 0.7-1 to be weak, moderate, and strong, respectively (Ratner, 2009). At home, there was a moderate correlation when the SEM was located in the bedroom (r = 0.64, R² = 0.42) and a weak correlation when it was in the living room (r = 0.18, R² = 0.03). At the office, the private office showed a strong
correlation ($r = 0.83, R^2 = 0.68$) while the shared offices had a moderate correlation ($r = 0.68, R^2 = 0.46$).

The average CO$_2$ levels at home were higher for the PEM station (1100 ppm) than SEM-present (990 ppm) and SEM-absent (630 ppm). However, at the office, the SEM-present had a slightly higher average level (760 ppm) than the PEM (730 ppm) and considerably higher than the SEM-absent (590 ppm). The difference between the PEM and SEM-present might be due to the accuracy of the sensor (±50 ppm) and to better-mixed air owing to the presence of other occupants.

At home, the personal CO$_2$ cloud was found in four participants from which two had the SEM station located in the living room. At the office, the personal cloud was only observed for the participants with a private office or in offices with two people. Furthermore, the PEM and SEM stations showed a noticeably stronger correlation for CO$_2$ at home when the SEM was in the bedroom ($r=0.9, R^2=0.82$) than when it was in the living room ($r=0.29, R^2 = 0.08$). The correlation in the private office was moderate ($r = 0.55, R^2 = 0.31$) and strong in the shared offices ($r = 0.84, R^2 = 0.7$).

An overall of 33 compounds were detected across de 60 VOCs and aldehydes samples. Compounds such as acetaldehyde, acetone, butyraldehyde, formaldehyde and propionaldehyde were detected in 100% of the samples at home followed by hexaldehyde, butane and D-limonene (80-90%). In the office, acetaldehyde, formaldehyde and isopropyl alcohol were the most frequent compounds (100%) followed by acetone, butyraldehyde, ethyl alcohol and propionaldehyde (80-90%). The majority of the detected compounds had concentrations under the maximum recommended limits. Personal exposure to TVOCs was under the recommended values of the FOPH in Switzerland (1000 µg/m$^3$) for all the participants. However, at home, 40% of the participants were above the recommended limits from Germany (300 µg/m$^3$) (German Federal Environmental Agency (GFEA)). The personal TVOCs cloud was partially detected among the participants corresponding to four participants at home and seven in the office. Figure 3 depicts the correlation between the PEM and SEM stations for the VOCs and aldehydes with the highest incidence in the home and office (80-100%). The compounds show a strong correlation at home ($r = 0.98, R^2 = 0.96$) despite the location of the SEM. Likewise, a strong correlation was found in private and shared offices for the same compounds.

**CONCLUSIONS**

- The personal PM$_{10}$ cloud was detected for all the participants in the home and office. The personal PM$_{10}$ cloud magnitude was relatively large (5-25 µg/m$^3$) and mainly constituted by the coarse particle for the majority of the participants. This implies that a possible strong contribution from emissions associated with human activities.
- The main contributing sources to PM$_{10}$ samples were “Urban mix”, “Personal” and “Traffic” sources.
- The personal CO$_2$ cloud (100-130 ppm) was detected in private and low-occupancy offices which suggests large spatial gradients around the participant, contrary to shared offices that had more homogeneous concentrations.
- PEM and SEM stations showed the potential to be an effective proxy of personal exposure for PM$_{10}$ and CO$_2$ at home when the SEM station was located in the bedroom. In the office, the SEM station better approximated personal exposure in shared offices than in private for CO$_2$ while the opposite trend was shown for PM$_{10}$.
- VOCs and aldehydes SEM samplers prove to be good predictors of personal exposure for compounds with the highest incidence across
participants in the home and office and regardless of their position in the home or the type of office.

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Bacterial and fungal aerosols in dwellings with domestic animals: preliminary results

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SUMMARY
The aim of the study was to determine the basic properties of bacterial and fungal aerosols in selected city apartments with small pets in comparison to reference apartments (without animals). The research consisted in the simultaneous determination of bioaerosol concentrations in dwellings with animals and in reference dwellings with the same building and hygienic characteristics as apartments with animals. The samples of airborne bacteria and fungi were collected using a 6-stage Graseby-Andersen impactor. The species identification of bioaerosols was also carried out. It was found that in homes with pets, the concentration levels of fungal aerosol were only slightly increased, while the concentrations of bacterial aerosol were 2-3 times higher compared to the control (reference) apartments. Moreover, the presence of animals in apartments also influenced the species composition of the bacterial aerosol.

INTRODUCTION
The fact that bacteria can be emitted in indoor environments from animal organisms has been well documented. Research in this matter was carried out, among others in pet stores, animal clinics, flower gardens (Jo et al., 2006), a small veterinary clinic for animals (Tisha et al., 2013) and in the zoo (Grzyb and Pawlak, 2021). Literature data also clearly indicate that the main source of bacterial aerosol in homes are usually people and the animals they breed (dogs, cats, etc.) (Wanner et al., 1993). Bacteria get into the air together with droplets of oral and nasopharyngeal secretions (e.g. when sneezing, coughing). Bacteria can be also emitted from the skin. The work carried out by Pastuszka et al. (1996) showed that also home aquarium is an important source of bioaerosol emission, including bacterial aerosol. Significant amounts of bacteria found in settled dust may also get into the air during resuspension of this dust, generated by air turbulence, e.g. due to the movement of inhabitants (Wanner et al., 1993). There is a number of papers on the relationship between the occurrence of adverse health effects in residents (especially in children) and the presence of airborne allergens emitted from animals kept in homes, such as dogs and cats (Wanner et al., 1993; Heinrich et al., 2001; McConnell et al., 2006; Janahi et al., 2006; Bakke et al., 2007). On the other hand, some research results suggest that children raised in a house with animals were less likely to become allergic to proteins in pets dander although there is still many questions regarding the mechanism of tolerance (Wypych et al., 2008; Erwin et al., 2011). So far, however, there is no quantitative study of the concentration level of bioaerosols emitted from pets in city apartments. The aim of the study was to obtain the preliminary characteristics of bioaerosols in a selected group of dwellings with small domestic animals (dogs, cats, aquarium fish) and in control dwellings, based on the study of bacterial and fungal aerosol concentrations and the identification of airborne microorganisms in these apartments.

METHODS
The research was conducted in apartments in multi-family buildings in Sosnowiec, Silesia Province, Poland. In each apartment, a questionnaire was completed, in which the detailed characteristics of the apartment and the number of inhabitants were provided. Each measurement session included bioaerosol concentration measurements in the reference apartment (without animals) and in one or two apartments with animals. The study covered 5 control flats and 10 flats with animals, including: 4 flats with dog, 3 flats with cat, 3 flats where aquarium fish were kept. The all dwellings have only gravitational ventilation. It should also be stressed that the research was conducted only in the so-called healthy dwellings, i.e. those where the residents did not complain about ailments that could be associated with the quality of the home environment and where no additional sources of aerosol emissions were found (e.g. fungal
growth on the walls). Samples were taken using the 6-stage Graseby-Andersen impactor (with aerodynamic cut-size diameters of 7.0, 4.7, 3.3, 2.1, 1.1 and 0.65 µm) located in the center of a living room at a height of 1.5 m above the floor. The total number of rooms in the studied dwellings was between 2 and 3 and the total area of these dwellings was from about 40 to 67 m². The pump provided a constant flow rate of 28.3 dm³/min during the measurement. The sampling time, following Nevalainen et al. (1992) was 10 minutes. The windows were closed during the measurements. Only one person from our team carried out measurements in each apartment. Residents were asked not to move quickly to eliminate possible re-emission of settled dust from the floor. As the sampling time was very short, it can be assumed that the indoor environmental state during the measurement was "normal" (in daylight hours) and was practically unaffected by the presence and activity of the researcher. Unfortunately, we did not continue these measurements overnight. Table 1 presents a more detailed description of the studied flats.

Microbiological studies included the following determinations:

1. Determination of the concentration of the total number of bacteria forming colonies on the Tryptic Soy agar (TSA),
2. Determination of the total number and species composition of Gram-positive mesophilic bacteria on blood agar,
3. Determination of the total number and species composition of Gram-negative bacteria on a medium with eosin and methylene blue,
4. Estimation of the total number of fungi forming colonies on Malt Extract agar (MEA).

During all measurements, air temperature and humidity were recorded.

The identification of the isolated bacteria was then carried out in two steps. The first included the morphological analysis of the colonies and microscopic analysis of the Gram-stained bacterial cells, and then the screening of the bacteria on appropriate differentiation media, e.g., Chapman, McConkey. The second stage was to differentiate bacteria based on their metabolic properties, using API tests. This analysis was assisted by the APILAB computer analysis system to identify isolated strains down to the genus and / or species level.

RESULTS AND DISCUSSION

As shown in Table 1, the average concentration of bacterial aerosol in the reference dwellings was 492 CFU m⁻³, while in dwellings with animals from 1,267 to 2,027 CFU m⁻³, and in dwellings with fish aquarium – 1,327 CFU m⁻³. This result clearly indicates the presence of additional sources of bacterial aerosol emissions in these homes, which are certainly animal organisms.

In the reference apartments studied, the concentration of fungal aerosol was between 126 to 699 CFU m⁻³. On the other hand, the concentration of fungi in the air of flats with animals ranged from 70 to 989 CFU m⁻³. A slightly increased concentration of fungal particles in homes with animals, especially dogs or cats, indicates that these animals may be an additional potential "carrier" for fungal particles from the outdoor environment.

<table>
<thead>
<tr>
<th>No. of pets</th>
<th>Air T[°C]</th>
<th>RH [%]</th>
<th>No. of people (*)</th>
<th>Concentration [CFU m⁻³] of bioaerosol</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Bacteria</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean and range</td>
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<tr>
<td></td>
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<td></td>
<td></td>
<td>Fungi</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Mean and range</td>
</tr>
<tr>
<td>1 dog</td>
<td>20 - 26</td>
<td>48 - 71</td>
<td>2 - 3</td>
<td>2027</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1773-2432</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>387</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>70-495</td>
</tr>
<tr>
<td>1 - 2 cats</td>
<td>21 - 24</td>
<td>55 - 75</td>
<td>2 - 3</td>
<td>1267</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>636-1866</td>
</tr>
<tr>
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<td></td>
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</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>169-912</td>
</tr>
<tr>
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<td>22 - 26</td>
<td>46 - 58</td>
<td>2 - 4</td>
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<td>aquarium</td>
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<tr>
<td>Ref. dwel-</td>
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<td>49 - 68</td>
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<td>492</td>
</tr>
<tr>
<td>lings -no</td>
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<td></td>
<td>125-1470</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>98-402</td>
</tr>
</tbody>
</table>

* including researcher

It was found that presence of animals in the apartments also influenced the species composition of the bacterial aerosol. Table 2 shows the viable bacterial genera identified in samples collected in the studied dwellings. It was found that in dwellings with an aquarium, a significant increase in the percentage of bacteria classified as coryneform bacteria and mesophilic actinomycetes (Actinomycetes) was observed.

In homes with a dog, an increased share (by about 5%) of Gram-positive cocci and Bacillus was observed. Moreover, an increase in the proportion of Gram-negative rods was noted in these apartments. In the apartments with the cat, an increased contribution of Gram-negative bacteria to the total species of airborne bacteria was observed in comparison to the values obtained in the tested reference / control apartments.
CONCLUSIONS

1. The values of bacterial aerosol concentrations in the tested apartments with animals were clearly higher, while the levels of fungal aerosol concentrations were only slightly increased compared to the reference/control apartments.

2. The obtained data indicate that the presence of animals in city dwellings also influences the characteristics of the bacterial aerosol present in them. In homes with a cat or a dog, a slightly increased proportion (contribution) of Gram-negative bacteria was observed. In turn, in apartments with aquariums with small fishes, there was a significant increase in the concentration of Gram-positive rods (Corynebacteria) and mesophilic actinomycetes (Actinomycetes). It was also observed that in houses with dogs, Staphylococcus intermedius, Propionibacterium avidum and bacteria from the Enterobacteriaceae family are often found, while the strain Plesiomonas shigelloides was found only in the air of dwellings with aquariums.

ACKNOWLEDGEMENTS

This work was partially supported by the Faculty of Power and Environmental Engineering, Silesian University of Technology as the part of statutory research.

REFERENCES


Table 2. Viable bacterial genera identified in studied dwellings [CFU m⁻³]

<table>
<thead>
<tr>
<th>Bakteria species and genera</th>
<th>Ref. n=5</th>
<th>With a dog n=5</th>
<th>With cats n=3</th>
<th>With aquarium n=3</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gram-positive cocci, including:</td>
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<td>Micrococcus spp.</td>
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<td>387</td>
<td>219</td>
<td>523</td>
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<td>7</td>
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<td>35</td>
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<td>Kocuria rosea</td>
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<td>-</td>
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<tr>
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<td>38</td>
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</tr>
<tr>
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<td>44</td>
<td>47</td>
<td>87</td>
<td>94</td>
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<td>Staphylococcus chromogenes</td>
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<tr>
<td>Staphylococcus epidermidis</td>
<td>116</td>
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<td>82</td>
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<tr>
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<td>Staphylococcus lugdunensis</td>
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<tr>
<td>Staphylococcus saprophyticus</td>
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<td>7</td>
<td>-</td>
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<td>Staphylococcus sciuri</td>
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<td>14</td>
<td>104</td>
<td>33</td>
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<td>Staphylococcus xylosus</td>
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<td>-</td>
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<td>56</td>
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<td>Streptococcus salivarius</td>
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<td>-</td>
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<tr>
<td>Gram-positive rods, including:</td>
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<td>Arthrobacter spp.</td>
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<td>30</td>
<td>87</td>
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<td>87</td>
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<td>Cellulomonas spp.</td>
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<tr>
<td>Corynebacterium aquaticum</td>
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<td>47</td>
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<td>Corynebacterium propinquum</td>
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<td>54</td>
</tr>
<tr>
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<tr>
<td>Microbacterium spp.</td>
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<td>-</td>
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<tr>
<td>Propionibacterium avidum</td>
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<td>17</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Actinomycetes, including:</td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Actinomycetes spp.</td>
<td>-</td>
<td>4</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Nocardia spp.</td>
<td>-</td>
<td>14</td>
<td>-</td>
<td>5</td>
</tr>
<tr>
<td>Rhodococcus spp.</td>
<td>3</td>
<td>14</td>
<td>33</td>
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</tr>
<tr>
<td>Gram-positive rods family</td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bacillaceae, including:</td>
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<td></td>
</tr>
<tr>
<td>Bacillus amyloliquefaciens</td>
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<td>3</td>
<td>-</td>
<td>-</td>
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</tr>
<tr>
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<td>-</td>
<td>2</td>
</tr>
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<td>Bacillus circulans</td>
<td>-</td>
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<td>Bacillus lentus</td>
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<td>Bacillus sphaericus</td>
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<td>Bacillus subtilis</td>
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<td>Bacillus spp.</td>
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<td>-</td>
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<tr>
<td>Gram-negative bacteria, including:</td>
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<tr>
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<td>Serratia rubidaea</td>
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<td>&lt;1</td>
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<tr>
<td>Neisseria spp.</td>
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<td>3</td>
<td>-</td>
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</tbody>
</table>


The indoor mycobiome in Norwegian daycares revealed by DNA high throughput sequencing

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SUMMARY

The aim of this study is to improve knowledge about indoor mycobiomes in daycare centers by using a high throughput DNA sequencing (HTS) approach. We analyzed dust samples collected in indoor and outdoor environments to characterize the mycobiomes at different spatiotemporal scales: within buildings, across buildings at larger geographical scales in Norway, as well as throughout different seasons. A large-scale citizen science sampling of 128 daycares distributed throughout Norway was performed. In addition, two daycares in Oslo were monitored throughout a year by biweekly sampling in different rooms. The results showed that climate, seasonality, and occupants are important factors structuring the indoor mycobiome. Thus, temporal variability throughout the seasons should be accounted for in indoor mycobiome studies and in the evaluation of indoor air quality of buildings.

INTRODUCTION

Humans have shifted from a largely outdoor based lifestyle to now spending most of their time in indoor environments. The mycobiome, which includes all the fungi present in an environment, is different in the indoor environments and this lifestyle shift may have impact on the human health. Fungi can grow in the indoor environments and act as a source of pollutants, leading to poor indoor air quality. This can lead to adverse health effects, such as allergies, asthma and other respiratory symptoms (Bornehag et al., 2001; Mendell, Mirer, Cheung, Tong, & Douwes, 2011).

In many countries, children spend considerable time in daycare centers where they may be affected by the indoor mycobiome. The indoor mycobiome is derived from both outdoor and indoor sources. Indoor sources to fungal growth includes the occupants, food, plants, and building constructions (Prussin & Marr, 2015). There is also an influx of spores from the surroundings, through doors, windows and ventilation systems. Hence, the outdoor climate and vegetation may also shape the indoor mycobiome composition. Indoor mycobiomes can be analyzed in different ways, including culturing, microscopy and by DNA analyses. DNA metabarcoding, which is based on high throughput sequencing of PCR amplified markers, is an effective approach to explore fungal communities and can also be used to analyze indoor mycobiomes (Adams, Miletto, Taylor, & Bruns, 2013; Estensmo et al., 2021; Martin-Sanchez et al., 2020; Weidt et al., 2016; Yamamoto, Hospodsky, Dannemiller, Nazaroff, & Peccia, 2015). By providing sampling material and detailed instructions, dust samples can easily be obtained by the inhabitants. This type of research, assisted by citizens, is regarded as citizen science.

In this study, we aimed to analyze the indoor mycobiomes associated with daycare centers. We first assessed which fungal groups dominate in the daycare centers, and to what degree potential allergenic fungi are present. We then assessed which outdoor and indoor factors affect the daycare mycobiomes, including outdoor climate, seasonality, building features and number of children present. To address these research topics, we performed dust sampling in different rooms of two daycares throughout a year (for details see Estensmo et al., 2021), and obtained dust samples from 128 daycare centers throughout Norway using a citizen science sampling approach (Figure 1). Norway spans extensive gradients in climate and other environmental drivers, making us able to compare mycobiomes from contrasting environments. The obtained dust samples were analyzed by DNA metabarcoding analyses of the rDNA ITS2 region.

![Figure 1. Overview of the daycares sampled in this study with a) sampling locations in the two daycares selected for the spatiotemporal study and b) the location of the 128 daycares sampled through citizen science. Only samples from main rooms and outside were obtained in the citizen science study.](image-url)
**METHODS**

For the citizen science study, dust samples were collected by sending out sample material (swabs) to 128 daycares throughout Norway, asking them to sample dust from doorframes (1) outside, (2) in the central room and (3) in the bathroom. We also performed dust sampling in two daycare centers throughout a year. These samples were collected with swabs from glass plates located 1–2 m above floor level. The sampling was performed in different rooms; auxiliary rooms (loft and basement) and main rooms (i.e. central room and bathroom). In addition, outdoor air samples were collected every week throughout a year by filtering air using an air pump.

DNA from swabs and filter samples were extracted and the fungal ITS2 region was amplified by PCR. The resulting PCR products, including technical replicates and PCR controls, were processed in different metabarcoding libraries each including 96 uniquely barcoded PCR products. The samples within each library were pooled, concentrated and purified. The libraries were sequenced using Illumina MiSeq at Fasteris SA (Plan-les-Ouates, Switzerland). The retrieved sequences were demultiplexed using CUTADAPT (Martin, 2011), and DADA2 (Callahan et al., 2016) was used for error correction. The resulting amplicon sequence variants were clustered into operational taxonomic units (OTUs) using VSEARCH (Rognes, Flouri, Nichols, Quince, & Mahé, 2016) at 97% similarity. Taxonomy was assigned to the OTU table using BLAST (Altschul, Gish, Miller, Myers, & Lipman, 1990) and the UNITE database (Koljalg et al., 2005).

Climatic variables for the 128 daycares, relevant environmental variables were obtained based on their geographic coordinates (Horvath et al., 2019). For the temporal study, climatic variables were retrieved from The Norwegian Climate and Service Center. The following months were grouped in four different seasons: winter from December to February, spring from March to May, summer from June to August and fall from September to November. The statistical analyses were performed in R.

**RESULTS & DISCUSSION**

We observed a clear difference between outdoor and indoor mycobiomes in the citizen science study (Figure 2). For the daycare centers that was sampled throughout a year, the community composition in rooms with limited occupancy (auxiliary rooms), such as the basement and the loft, was similar to the outdoor samples. The rooms with higher occupancy, such as the central room and bathroom, were clearly different in community composition (Figure 2). There was no significant difference in community composition between the different main rooms in either of the studies.

The separation in mycobiome composition of the main rooms and auxiliary rooms in the temporal study can be explained by the number of people accessing and using the rooms, suggesting that occupancy is an important factor shaping the indoor mycobiome in addition to the outdoor air. This result is further supported by the mycobiome composition of the auxiliary rooms and the outdoor samples, which were highly similar. Previous studies of indoor environments suggest that the indoor mycobiomes are highly affected by outdoor air (Adams et al., 2013; Barberan et al., 2015; Frankel et al., 2012; Martin-Sanchez et al., 2020; Pitkäranta et al., 2008). However, in these studies they did not account for indoor environments with different levels of occupancy. In a recent study of private homes in Norway, we demonstrated that the number of occupants affects the indoor mycobiome composition (Martin-Sanchez et al., 2021). In our large citizen science study of daycares, we also observed that number of children and number of departments affects the indoor mycobiome composition, supporting the importance of occupancy. In addition, we observed a strong seasonal pattern in the mycobiome composition in the two daycares that were sampled throughout a year. The mycobiome composition was mainly structured by the outdoor climate and especially moisture and temperature (Figure 3). Our observed patterns mirror those found in seasonal studies on outdoor mycobiomes (Karlsson et al., 2020; Reponen, Nevalainen, Jantunen, Pellikka, & Kalliokoski, 1992). Since the outdoor fungal community has a strong impact on indoor mycobiomes, it is expected that seasonal changes in the outdoor environment also affect which fungi occur indoor.

![Figure 2: Variation in fungal community composition displayed by NMDS in dust samples from a) the two daycare centers sampled throughout a full year, and b) from the 128 daycares throughout Norway. The color differentiates the main rooms (black) from the auxiliary rooms (grey) and the outdoor samples (blue). Only main rooms and outside were sampled in the citizen science study.](image-url)
Typical outdoor basidiomycetes in the orders Agaricales and Polyporales were more abundant during summer and fall, whereas ascomycetes of the orders Saccharomycetales and Capnodiales were dominant during winter and spring. The main rooms also contained considerably more ascomycetes compared to the auxiliary rooms and outdoor samples, which contained mostly basidiomycetes. In both studies, the mold genera Cladosporium, Penicillium and Aspergillus dominated, in addition to skin-associated yeasts including Malassezia and Candida, that were prevalent in the main rooms. Several indoor fungi are known to cause allergies and disease in humans. Therefore, it is important to understanding the spatiotemporal variation of the indoor mycobiome, as this will reflect how the children are affected by these fungal species.

CONCLUSIONS

We observed that climate, seasonality, and occupants were the most important factors structuring the indoor mycobiomes in Norwegian daycares. We therefore conclude that the temporal variability should be accounted for in indoor mycobiome studies and in the evaluation of indoor air quality of buildings.

ACKNOWLEDGEMENTS

We would like to thank the daycare centers for the sampling and for providing metadata of the usage of the daycare centers. Mycoteam AS contributed to the sampling and provided sampling equipment. The University of Oslo and the Norwegian Asthma and Allergy Association (NAAF) financially supported the research. PMMS was funded by the European Union’s Horizon 2020 research and innovation programme (Marie Skłodowska-Curie Individual Fellowship; grant agreement MycoIndoor No 741332).

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Fungal growth on newly cast concrete floors and moisture membranes

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SUMMARY
The Danish Technological Institute has during several surveys in new buildings, experienced widespread fungal growth on newly cast concrete floors, with a moisture barrier and floating flooring. Existing recommendations require that the relative humidity (RH) of air in equilibrium with the concrete, measured in the middle of the concrete floor, should not exceed 85-90% prior to mounting the top floors. However, surveys have shown that fungal growth can establish if the RH of the air between the concrete floor and the moisture membrane exceeds 75%. The present case study demonstrates that fungi can grow on newly cast concrete and on the moisture membrane if the RH at the surface is above 75%. The study finds that there is a need to revise existing guidelines for acceptable moisture content in the concrete before mounting the top floor, and maybe even change the way of constructing floors.

INTRODUCTION
Over the years, experts and scientists have become more aware that fungal growth in buildings should be avoided. Studies have found that fungal growth and moisture damage in buildings, will lead to an unhealthy indoor environment for the building occupants (Bornehag, 2001; Bornehag et al., 2004; Clark et al., 2004; Järvi et al., 2018; Wolkoff, 2018).

The Danish Technological Institute has in several studies of moisture problems in newly built residences, experienced widespread fungal growth on newly cast concrete floors, where a moisture barrier and floating flooring is laid. Fungal growth on the surface of the newly cast concrete floors is often due to an inadequate drying period. Existing Danish recommendations state that the moisture content in the concrete should not exceed 85-90% RH, measured in the air when in equilibrium with the concrete at 0.4 times the thickness of the concrete slab (Gulvbranchen, 2015; Møller, 2010). However, studies have found that fungal growth can establish on any surface, when the RH exceeds 75%, and the surface is dusty (Johansson et al., 2005; Kristensen et al., accepted).

In this study we investigate: 1. Whether xerotolerant fungi such as Aspergillus versicolor and Aspergillus sydowii can establish on newly cast concrete, 2. Whether fungi can grow on the Polyethylene (PE)-membrane when the relative humidity is higher than 75% and 3. How and where to conduct mould sampling on a newly cast concrete floor construction.

METHODS AND CASE STUDY DESCRIPTION

Six randomly picked apartments in a newly built apartment complex were chosen for a case study of fungal growth on newly cast concrete (Kristensen et al., accepted). The building complex is a five-storey concrete building with a flat roof and full cellar. The inner walls are concrete, the outer walls are brick elements. The building was erected in 2019. The floor construction consisted of a hollow core deck, with 100 mm of expanded polystyrene (EPS) concrete and a 60 mm wear layer with floor heating. The wear layer is a cement based top layer mixed on site. The top floor was a floating wooden floor with a PE moisture membrane between the concrete wear layer and wooden flooring. The top floors were all laid within six to nine weeks after the wear layer was cast. The floors were cleaned by the carpenters for visible dirt before mounting the top floor. The level of cleaning, meaning how much dust was left on the surface, was not investigated.

The Danish Technological Institute became early involved as a consultant after the building was completed and the residents were moving in. We have not seen any documentation of moisture measurements or quality control of the building process relevant to this case study. Initial measurements were carried out in all apartments in the complex approximately six months after the concrete floor was cast. These results all showed widespread fungal growth on the concrete surface when using contact agar plate sampling, but no to low fungal growth by use of sticky-tape sampling. In total 110 initial samples were taken across 55 apartments.

A case study was conducted approximately a year and a half after the concrete floors were cast and when residents were moved out for renovation of the floors (Kristensen et al., accepted). Before fungal sampling, measurements of RH and temperature were conducted between the concrete floor and the moisture membrane. After the wooden flooring was removed, a small hole was made in the moisture membrane before the sampling for fungal growth, and through the hole, a thin measuring probe (TESTO), was inserted under the moisture membrane and left until it had reached equilibrium, or for at least 30 min. The instruments were calibrated both before and after the investigations. Sampling for fungal growth on the
surface of the concrete floor was conducted with a combination of contact agar plates, containing V8 agar, for species identification and counting of viable colony forming units (CFU), and sticky-tape sampling for direct microscopy (Kristensen et al., accepted).

In the present study samples of the moisture membrane were cut out and taken back to the laboratory for further analysis. A combination of contact agar plate sampling, sticky-tape sampling and NAHA-enzyme based biomass sampling was conducted on the underside of the moisture membrane. CFU on the contact agar plates were counted and evaluated according to the following scale: - low or no growth (<10 CFU), (x) moderate growth (10-50 CFU) and x substantial growth (>50 CFU). A similar scale was used for evaluating the amount of mycelium and spores on the sticky-tape samples by microscopy at 200 times magnification. At least 15 fields of view were analysed. Each field of view has a grid of squares (50 x 50 µm) and the percentage of squares covered by mycelium and spores was recorded. Averaging the recorded percentages for each sample results in an overall evaluation of sticky-tape samples: - no or low amount (0-10% of squares covered with mycelium and spores), (x) moderate amount (10-70% of squares covered), and x substantial amount (>70% of squares covered).

Sampling and analysis by NAHA-enzyme test (Mycometer® test) were conducted as described by Aktas et al., 2018. The results of the NAHA-enzyme test are evaluated according to the following scale: - no to low growth (<25 FLU (Fluorescence Unit)), (x) moderate growth (25-450 FLU) and x substantial growth (>450 FLU) (Mycometer, 2021).

RESULTS & DISCUSSION

Table 1 illustrates a comparison of results from contact agar plate analysis on the surface of the concrete floor and fungal analysis on the underside of the moisture membrane, based on the three different sampling methods: contact agar plate, sticky-tape and NAHA-enzyme.

Moisture measurements taken at the same spot are shown alongside the results of the sampling methods. The moisture measurements are all instantaneous measurements which means that we do not know if the moisture at the surface was higher when the floors were mounted. The moisture at the surface will vary depending on the temperature of the concrete and whether the floor heating is on or off. The results of the mould samples are therefore a result of the history on the measuring point, and we do not know if the fungi are still active, but they are viable. Sample 5 shows moderate to substantial growth although the RH is low. The moisture content at this measuring point might have been higher earlier on or the measurement could have been faulty.

In six of the 13 samples, Aspergillus sydowii was the most abundant species and in six of the 13 samples, Aspergillus versicolor was the most abundant species. In one sample, no fungal growth was found across all sampling methods (sample 10).

Table 1. Comparison of results from sampling for fungal growth on the concrete floor and on the underside of the moisture membrane. - = low or no growth, (x) = moderate growth, and x = substantial growth.

<table>
<thead>
<tr>
<th>Sample no.</th>
<th>Concrete aga Contact</th>
<th>Contact agar</th>
<th>Sticky-tape</th>
<th>NAHA-enzyme</th>
<th>%RH °C</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(x)</td>
<td></td>
<td></td>
<td></td>
<td>84%</td>
</tr>
<tr>
<td>2</td>
<td>x</td>
<td>x</td>
<td>-</td>
<td></td>
<td>97%</td>
</tr>
<tr>
<td>3</td>
<td>x</td>
<td>x</td>
<td>(x)</td>
<td>-</td>
<td>82%</td>
</tr>
<tr>
<td>4</td>
<td>x</td>
<td>x</td>
<td>(x)</td>
<td>(x)</td>
<td>73%</td>
</tr>
<tr>
<td>5</td>
<td>x</td>
<td>(x)</td>
<td>(x)</td>
<td>-</td>
<td>58%</td>
</tr>
<tr>
<td>6</td>
<td>x</td>
<td>x</td>
<td></td>
<td>-</td>
<td>90%</td>
</tr>
<tr>
<td>7</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>(x)</td>
<td>96%</td>
</tr>
<tr>
<td>8</td>
<td>x</td>
<td>x</td>
<td>-</td>
<td>-</td>
<td>82%</td>
</tr>
<tr>
<td>9</td>
<td>x</td>
<td>(x)</td>
<td>-</td>
<td>-</td>
<td>88%</td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>74%</td>
</tr>
<tr>
<td>11</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>-</td>
<td>98%</td>
</tr>
<tr>
<td>12</td>
<td>x</td>
<td>x</td>
<td>-</td>
<td>-</td>
<td>84%</td>
</tr>
<tr>
<td>13</td>
<td>x</td>
<td>x</td>
<td>x</td>
<td>(x)</td>
<td>97%</td>
</tr>
</tbody>
</table>

The results show that fungal growth on newly cast concrete floors can establish on the surface of the concrete. The results also show that fungal growth can establish on the underside of the moisture membrane, if it is laid upon a moist concrete surface (85-90% RH), as the current recommendations allow (Gulvbranchen, 2015; Möller, 2010). These findings are in alignment with other studies, which have found that fungal growth can establish on any surface if the RH is above 75% (Johansson et al., 2005).

It has often been discussed if fungal growth can establish on newly cast concrete, due to the relatively high pH of 12-14. Though most fungi grow at a pH range of 3-8, some species, e.g., Aspergillus versicolor and Aspergillus sydowii, can grow just as well at a pH above 10 (Wheeler et al., 1991), which the present case study also demonstrates. The objective of our consultancy work was to carry out moisture measurements and sampling for fungal growth, thus no measurements of pH were carried out. It would, however, be relevant to carry out further studies on the
influence of pH on the fungal growth on the surface of the concrete floors.

When sampling for fungal growth on a newly cast concrete floor, the Danish Technological Institute has experienced that some sampling methods are unsuitable, e.g., the NAHA-enzyme based biomass sampling method will often not show a response when used on newly cast concrete. Likewise, sticky-tape sampling will, compared to agar plate sampling, often give a lower result, or even show no sign of fungal growth. This is the case even if moderate to substantial growth is found by contact agar plate sampling at the same sampling point (Kristensen et al., accepted). The comparison in Table 1 shows concordance between contact agar plate sampling on the concrete floor and on the underside of the moisture membrane. At approximately half of the sampling points, there is a concordance between sticky-tape samples and agar plate samples conducted on the underside of the moisture membrane, as well as contact agar plate samples from the concrete floor. However, there is no, or low, concordance between NAHA-enzyme based sampling and the other sampling methods. The poor comparability between the NAHA-enzyme based sampling method and the other sampling methods, could be due to a low amount of biomass on the surface. Further studies on this subject should be conducted.

Direct microscopy of the sticky-tape samples showed that the fungal growth on the underside of the membrane was at an early stage and scattered unevenly over the surface. Despite the limited growth, the fungi produced a substantial number of spores leading to colony forming units on the contact agar plates. Even though there is no strong concordance between the contact agar plate samples and sticky-tape samples, the advantage of the sticky-tape sampling is, that by direct microscopy it is possible to verify that the viable fungi found by agar plate sampling are in fact growing on the surface. All the apartments have been inhabited approximately a year before the measurements were carried out. Traffic on the floors will therefore have released all mature spores from the mycelium. The extra air turbulence dismantling the wooden floor is not expected to have made any difference. The moisture barrier was not removed until the time when samples were taken.

The results of the present study indicate that thorough understanding of the complex circumstances surrounding fungal growth in connection to newly cast concrete floors, should be considered when selecting sampling methods. It is recommended to use a combination of sampling methods, e.g., contact agar plate sampling for counting CFU and species identification, and sticky-tape sampling for evaluation of fungal biomass. The present study further demonstrates that sampling must be conducted on both the concrete surface and the underside of the moisture membrane.

The results of the present study also raise the question of how to conduct accurate moisture measurements of newly cast concrete floors. To minimize the risk of fungal growth on the underside of the moisture membrane, and on the concrete floor, knowledge of the RH at the surface of the concrete floor is essential, since this is one of the controllable parameters that affect the conditions for fungal growth in the layer between the concrete surface and the moisture membrane. The results of the present and other studies find that a RH above 75% will support fungal growth on any surface if the surface is dusty (Johansson et al., 2005; Kristensen et al., accepted.). Therefore, the current guidelines for measuring moisture content in the concrete, and acceptable limits for moisture content before mounting the floor should be revised. This will possibly affect the entire building process since new construction designs or methods ought to be considered to avoid long drying periods.

CONCLUSIONS
In this study we have demonstrated that:
1. Xerotolerant fungi such as Aspergillus versicolor and Aspergillus sydowii can establish on newly cast concrete floors.
2. Fungi can grow on the PE-membrane when the RH is higher than 75% and if the membrane is laid upon a newly cast concrete floor.
3a. Surveys of floor constructions ought to include both contact agar plate sampling for identification and counting of fungal colonies, and sticky-tape sampling for evaluating the amount of fungal growth.
3b. Sampling must be carried out on both the concrete surface and the underside of the moisture membrane. Therefore, the current guidelines for acceptable moisture content in the concrete, before laying of the flooring, should be revised. To minimize the risk of fungal growth in new buildings, and thereby reduce the eventual risk for impact on the indoor climate, materials and methods for design and construction of floors should be revised.

ACKNOWLEDGMENTS
Thanks to Julie Koch Sheard for proof reading of the paper and valuable input to the discussion.

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Airborne mould community in the bedrooms of straw-bale and reed-bale residential dwellings

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SUMMARY
The aim of this study was to evaluate the presence of airborne mould community over a two years in the bedrooms of reed-bale and straw-bale residential houses in Estonia.

For fungal spore concentration sampling in the air, samplers with plates containing Malt Extract agar (MEA) and dichlorane 18% agar (DG18) media. Four parallel samples with both media were collected in each bedroom. The corresponding outdoor air samples were applied as reference. Lactophenole blue was used as a staining agent, the cultures were identified to the genus level.

In total four major genera were identified. Seasonal colony-forming unit dynamics in the bedrooms of all the studied dwellings were similar, but there was a difference in the number of colony-forming units. The microbial community was the most abundant in the straw-bale and reed-bale dwellings in summer and least abundant in winter. The levels of CFUs were similar in spring and autumn.

INTRODUCTION
In terms of limited resources, building sector is interested about eco-friendly building materials, which are locally available (Marques et al., 2020). Straw is on such agricultural by-product, which could potentially be used as a renewable resource (Barbieri et al., 2020). Reed can be one renewable alternative for building as well and it has been used for centuries (Al-Jumeily et al., 2018).

Straw and reed are materials which use carbon dioxide for photosynthesis when they grow, and their application in construction is increasing (Cornaro et al., 2020). Biomass-based materials capture carbon dioxide from the environment and improve it (Barreca et al., 2019; Cornaro et al., 2020) As they are biodegradable materials, it is important to know the microbial communities accompanying these materials and their possible harm on indoor air and building envelope (Brambilla and Sangiorgio, 2020; Raamets et al., 2020).

People spend most of their day in indoor environments and they are exposed to indoor pollutants (Kallawicha et al., 2020). Most of people indoor time is spent asleep and indoor air pollutants, such as moulds are affecting health and sleep quality as well (Mishra et al., 2018; Boor et al., 2017). Sleep has an important role to play in human welfare (Canha et al., 2019), as it helps to increases productivity, recover from fatigue, and overall wellbeing (Krueger et al., 2016).

Many studies have shown a connection between respiratory health issues and exposure to mould (Ginestet et al., 2020). The indoor air quality of 20%–40% of buildings in Europe and North America are influenced by mould, which bring different health problems (Laborel-Préneron et al., 2018). Mould species are more frequently cultured in damp indoor environments and they can potentially release mycotoxin, allergens and unpleasant smells to air (Wu and Wong, 2020)

The aim of this study was to evaluate the presence of airborne mould community over a two years period in the bedrooms of reed-bale and straw-bale residential dwellings in Estonia.

MATERIAL AND METHODS
During the study the data was collected from four straw-bale and four reed-bale houses, which were 2-7 years old. No visual moisture damage or mould growth was not detected. Some of the houses were structures, where walls were bearing the weight of the roof and some with a framework, where straw or reed had an important role in insulating. One straw-bale house was built using factory manufactured modules. All the structures had been designed and built by qualified experienced building companies. All the studied structures had high plinths and wide eaves. The average wall thickness was 50 ± 5 cm except for one dwelling which wall was 100 cm thick. All the structures had plaster (clay or lime plaster) on internal and external walls (5 cm on the internal and external walls). In two buildings the plaster thickness was different. For one dwelling the thickness was 7 cm on the internal and external wall (lime plaster), the other dwelling had a 10-cm-thick plaster on the internal and a 12-cm-thick plaster on the external wall. The residents of the dwellings were asked not to ventilate their bedrooms for 6 hours prior to sampling. The medium (Malt Extract Agar (MEA)) was prepared and the samples taken in compliance with the ISO 16000-18 standard (EVS-ISO 16000-18, 2011). The culture media were weighed with the analytical
balance AB] 120-4M (measurement accuracy ±0.2 mg, produced by Kern & Sohn, Balingen, Germany). The media were autoclaved using the autoclave HMT 260 MB (HMC Europe, Tüssling, Germany). The culture media plates were poured within the glove box (Retent AS, Nõo, Estonia). The data was collected with the air sampler Mirobio MB2 (Cantum Scientific, Dartford, UK).

The samples were collected with the air samplers Mirobio MB2 (Cantum Scientific, Dartford, UK) on 9 cm Petri dishes 4 times a year (in spring, summer, autumn, and winter) in bedrooms at 1 meter from floor level. The sample collecting time was 1 minute and the air volume 100 litres per sample. Four parallel samples with both media were collected in each room. Four parallel air samples were taken from outside air at 1.5 m from ground level for reference values. The collected samples were processed in compliance with the ISO standard 16000-17 (EVS-ISO 16000-17, 2012).

The moulds were identified on the basis of their morphological characteristics with a microscope (SP100, Brunnel Microscopes LTD, Chippenham, UK). Lactophenole blue was used as a staining agent. The cultures were identified to genus level.

The data were collected on carbon dioxide (CO₂) content, temperature and relative humidity in each bedroom with the datalogger Green-Eye Model 7798 (accuracy ± 50 ppm for carbon dioxide, ± 0.6 °C for temperature, ± 3% for humidity) (10–90%), manufactured by TechGrow, The Hague, The Netherlands.

All the chemicals and reagents were purchased from HNK Analüüsitehnika OÜ (Tallinn, Estonia). Soy Peptone (≥99%, Fluka), Potassium dihydrogen phosphate (KH₂PO₄) (purity of ≥99%, Sigma Aldrich), Magnesium sulfate heptahydrate (MgSO₄·7H₂O) (purity of ≥99.5%, Sigma Aldrich), D-(+)-glucose (≥99.5%, Sigma Aldrich), dichlorine (2,6-dichloro-4-nitroaniline) (purity of ≥96%, Sigma Aldrich), Chloramphenicol (purity of ≥98%, Sigma Aldrich), glycerol (purity of ≥99.96%, Sigma Aldrich), water (deionised, Sigma Aldrich). Agar (Sigma Aldrich), Malt Extract (Sigma Aldrich), lactophenole blue agent for mould staining (Sigma Aldrich) were in compliance with the standard ISO 16000-18: Detection and enumeration of moulds - Sampling by impaction. (EVS-ISO 16000-18, 2011). The equipment for microbiological culturing were purchased from KRK-Labor OÜ (Tartu, Estonia).

**RESULTS & DISCUSSION**

Seasonal colony forming unit (CFU) dynamics in the bedrooms of the residential dwellings made of straw-bale and reed-bale was similar (Table 1) - there was a difference in the number of colony-forming units. Microbial community was the most abundant in the straw-bale residential houses in summer, when the number of cultivated colonies was on average 537±102 CFU m⁻³. The same relation was observed with the reed-bale buildings when the number of cultivated colonies was 858±106 CFU m⁻³ on average. At the same time the number recorded in outside air was 289±32 CFU m⁻³ at straw-bale dwellings and 353±41 CFU m⁻³ at reed-bale dwellings. In spring and autumn, the test results of indoor and outdoor air on selected medium were comparable.

<table>
<thead>
<tr>
<th>Sampling site</th>
<th>Spring</th>
<th>Summer</th>
<th>Autumn</th>
<th>Winter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Straw-bale (indoors)</td>
<td>298±100</td>
<td>537±102</td>
<td>307±99</td>
<td>149±29</td>
</tr>
<tr>
<td>Reed-bale (indoors)</td>
<td>518±45</td>
<td>858±106</td>
<td>548±155</td>
<td>380±136</td>
</tr>
<tr>
<td>Straw-bale (outdoors)</td>
<td>197±43</td>
<td>289±32</td>
<td>168±34</td>
<td>94±19</td>
</tr>
<tr>
<td>Reed-bale (outdoors)</td>
<td>198±48</td>
<td>353±41</td>
<td>212±34</td>
<td>118±15</td>
</tr>
</tbody>
</table>

During the study the moulds indoors were identified by genera (Figure 1). According to Adams et al (2016), Alternaria, Aspergillus, Cladosporium and Penicillium are genera, that are present in atmospheric environment and commonly found in residential dwellings (Adams et al., 2016). In spring the most abundant mould genus was Cladosporium (79%) followed by Penicillium (8%), Aspergillus (8%) and Alternaria (3%) genera. 2% of the moulds did not belong to any of the genera mentioned previously. In spring in reed-bale buildings the sequence of mould genera was the same as in straw-bale dwellings, but there were differences in the abundance: Cladosporium (81%), Penicillium (7%), Aspergillus (7%) and Alternaria (3%). 2% of the mould did not belong to the previous genera.

In summer the most abundant mould identified belonged to the genus Cladosporium (84%), followed by Penicillium (7%), Alternaria (6%), Aspergillus (2%); 1% of the mould did not belong to the previously mentioned genera and were identified as „Others”. The sequence was the same in the reed-bale dwellings where Cladosporium (86%) was the most abundant genus followed by Penicillium (6%), Alternaria (5%) and Aspergillus (1%) genera. 2% of the mould did not belong to the previously mentioned genera.

In autumn the most abundant identified mould in straw-bale buildings belonged to the genus Penicillium (31%) followed by Cladosporium (30%), Aspergillus (23%) and Alternaria (8%). 8% of the mould found in straw-bale dwellings did not belong to the previously mentioned genera. In autumn the most abundant mould species belonged to the genus Penicillium (37%), followed by the mould belonging to Cladosporium (26%), Aspergillus (20%) and Alternaria (9%) genera. 4% of the mould did not belong to any of
the previously mentioned genera. The identified mould distribution in outdoor samples by genus was in accordance with the samples taken from indoor air.

![Percentage (% of share) of different mould genera in indoor air](image)

**Figure 1. Seasonal differences in mould genera in indoor air**

In winter the most abundant identified mould belonged to the genus *Penicillium* (74%), followed by moulds belonging to *Aspergillus* (17%), *Alternaria* (1%) and *Cladosporium* (1%) genera; 7% of moulds did not belong to any of the previously mentioned genera. In the reed-bale buildings the sequence across genera was the same, but there were differences in proportions: *Penicillium* – 70%, *Aspergillus* – 19%, *Cladosporium* – 6%, *Alternaria* – 1%; 4% of the moulds found did not belong to any of the mentioned genera.

In the studied buildings the temperature was between 19°C-21°C, relative humidity was between 36%-44%. Carbon dioxide was measured during the whole study period and the results enable us to conclude that level was in the desired range (≤800ppm (ISO, 2019)) belonging to indoor climate class II (≤800ppm) on the basis of ISO standard EVS-EN 16789-1:2019 (ISO, 2019) in all the studied dwellings. The values of temperature indicators and relative humidity in the bedrooms of the studied houses were too low to promote mould growth. In the reed-bale buildings, the values of colony forming units (CFU) were higher than in the straw-bale buildings which could refer to possible microbial growth. There are no recommended limit values for moulds in the indoor environment in Estonia (Pilt, 2017), but recommended limit values have been established in Finland (Soumaa and Pekuri, 2009). In Finland has been stated that the recommended values are up to 500 CFU/m³ in winter and up to 2,500 CFU/m³ in summer (Soumaa and Pekuri, 2009). In the current study the concentration of colony forming units during the whole testing period was 323 ± 80 CFU m⁻³ in the straw-bale dwellings 576 ± 94 CFU m⁻³ in the reed-bale buildings. In summer there were some results higher than 1000 CFU m⁻³, but it can be concluded that in straw-bale and reed-bale residential dwellings in Estonia the colony forming unit values are in recommended range.

The concentration of mould was higher in indoor air than in outdoor air during every season. The mould genera identified in the indoor air of the buildings did not differ from the mould genera found in outdoor air. In the boarders the concentrations were very low in the measured areas and their distribution to families similar to the identified families in indoor and outdoor air. There were no significant differences in the mould distribution to genera and their percentage share. Similar dynamics in indoor interseasonal air sampling as in this study has been noted in previous studies on the indoor climate of buildings (Adams et al., 2016; Raamets et al., 2020).

**CONCLUSIONS**

- Moulds belonging to four different genera were identified during the study (*Alternaria*, *Aspergillus*, *Penicillium*, and *Cladosporium*) which may pose a risk to humans (allergies, chronic rhinitis, cough, respiratory diseases).
- Higher colony forming unit (CFU) values were registered in the reed-bale buildings during the study. In the straw-bale buildings the same values were lower.
- The study carried out revealed that the indoor air of the straw and reed-bale dwellings includes more colonies than the outside air.
- No visual mould growth was detected during the study.

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Interaction effects of acoustics at and between human and environmental levels: A review of the acoustics in the indoor environment

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SUMMARY
People spend around 90% of their time indoors, where they are exposed to various physical stressors, such as unpleasant sounds, odours, temperature, and lighting, which may cause annoyance and discomfort. This literature review is focused on substantial studies that emphasize noise as a physical stressor in the indoor environment. Previous studies showed that background noise has a significant impact on human health. Adding to that, several other studies showed significant cross-modal effects between noise and other environmental stressors. However, various previous studies focused on quantifying the indicators of the indoor environmental quality (IEQ) factors rather than studying the differences of each occupant on their preferences and needs. Hence, this literature review highlights studies that take into account the interaction effects of acoustics at and between human and environmental levels. This review study aimed at identifying the key indicators to be taken into account for evaluating acoustical quality.

INTRODUCTION
People spend the majority of their time (around 90%) in the indoor environment. Staying indoors is not beneficial to human health, therefore, it is important to promote an indoor environmental quality (IEQ) that provides a healthy and comfortable environment (Bluyssen, 2020). IEQ includes four main factors (which are thermal comfort, lighting quality, acoustical quality, and air quality) that play a vital role in the human senses and wellbeing (Bluyssen, 2009). Physical stressors, such as unpleasant sounds, odours, temperature, and light, which are sensed by human sensory receptors, can contribute to annoyance and discomfort (Bluyssen, 2014). Noise was the major environmental stressor at primary schools, affecting 87% of the school children surveyed (Bluyssen et al., 2018). Noise is a physical stressor that stimulates both the sympathetic and endocrine systems. It is recommended to investigate the relation between the noise source and health risk characterization (Babisch, 2002). Noise exposure may induce changes in stress hormone levels and sleep disturbances. Besides, oxidative stress in chronic noise exposure results in noise-induced hearing loss (Bluyssen, 2014). In addition, chronic noise exposure to background noise (external and internal noise sources) can affect individuals’ performance and attention (Shield & Dockrell, 2008). Thus, this study aims at identifying the key indicators at both human and environmental levels to be considered for assessing the acoustical quality.

METHODS
A literature review of scientific articles published between 2000 and 2021 was carried out.

Databases:
Various databases were browsed for finding the most recent articles, including Google Scholar, Scopus, and the TU Delft library. Relevant articles were found in journals such as Building and Environment, Applied Acoustics, and Indoor and Built Environment. Besides, conference papers were found in the domain of this study.

Keywords:
The keywords that were used for finding the relevant scientific articles are: cross-modal effect (combined effects and multisensory interaction), effects (physiological effects, comfort, and annoyance), acoustical conditions (noise exposure and noise level), indoor environmental quality, and methods (lab study, experimental study, and environmental chamber).

RESULTS & DISCUSSION
Cross-modal effects of acoustics and other IEQ-factors
Previous studies revealed that there are cross-modal effects between acoustics and the other IEQ-factors.

Acoustics and thermal comfort
Yang et al. (2018) demonstrated that psycho-acoustical parameters were affected by indoor thermal conditions, while the fan noise perceptions were found to be independent of thermal conditions (Yang et al., 2018). Also, Yang and Moon (2018) indicated that thermal conditions did not affect loudness and noise. However, the thermal comfort was decreased by increasing the noise levels (Yang & Moon, 2018).

Acoustics and visual comfort
In terms of acoustics and visual comfort/lighting, a study conducted by Liebl et al. (2012) demonstrated that individuals performed better when they were exposed to low background noise levels combined with
static lighting (Liebl et al., 2012). In terms of visual factors, Hasegawa and Lau (2021) found that the greenery factor followed by water as a visual factor reduced the noise annoyance as perceived by individuals in the indoor environment (Hasegawa & Lau, 2021). Similarly, in an experimental study, it was shown that visual stimuli of sea view reduced the annoyance equivalent to a 1dB reduction in total sound pressure level (SPL) (Chau et al., 2018).

**Acoustics and indoor air quality**

With regards to the interaction effects of noise and odours, in a study, it was found that the effect of odour on noise perception caused neither synergism nor antagonism, but simple additivity, while noise level decreased the responses to odour (Pan et al., 2003).

**Acoustics and other IEQ-factors**

In a lab study on the interaction effects of acoustics with other IEQ-factors, involving primary school children in the Netherlands, it was found that the perception of smell was significantly related to draught, sound, and light perception. Smell was evaluated the worst with sound type ‘children talking’ (Bluyssen et al., 2019). Wu et al. (2020) conducted an experiment in a test chamber and revealed that the temperature had a crossed effect on both acoustical and visual comfort, and both sound level as well as illuminance had crossed effect on thermal comfort. The effect of acoustical satisfaction was the greatest on the overall satisfaction (Wu et al., 2020). Furthermore, Bourikas et al. (2021) assessed the cross-modal perception between thermal, acoustic, and air quality perceptions on occupants’ comfort and satisfaction in university office buildings. This study used post-occupancy evaluation, a comfort survey, and concurrent environmental conditions monitoring. It was found that thermal sensation was influenced by both air quality and noise. However, the cross-modal effect of air quality and noise on the thermal sensation was not clear (Bourikas et al., 2021).

Based on the previous studies, several indicators at the environmental level are presented in Table 1.

<table>
<thead>
<tr>
<th>IEQ-factor</th>
<th>Indicator</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acoustics</strong></td>
<td>Sound level, Sound pressure level (SPL)</td>
</tr>
<tr>
<td></td>
<td>Noise/sound type</td>
</tr>
<tr>
<td></td>
<td>Reverberation time</td>
</tr>
<tr>
<td></td>
<td>Material absorption coefficient</td>
</tr>
<tr>
<td></td>
<td>Speech transmission index (STI)</td>
</tr>
<tr>
<td><strong>Air quality</strong></td>
<td>Ventilation type</td>
</tr>
<tr>
<td></td>
<td>Odour type</td>
</tr>
<tr>
<td><strong>Thermal comfort</strong></td>
<td>Temperature</td>
</tr>
<tr>
<td></td>
<td>Relative humidity (RH)</td>
</tr>
<tr>
<td></td>
<td>Predicted Mean Vote (PMV)</td>
</tr>
<tr>
<td><strong>Lighting/visual comfort</strong></td>
<td>Air velocity</td>
</tr>
<tr>
<td></td>
<td>Lighting type</td>
</tr>
<tr>
<td></td>
<td>Illuminance intensity</td>
</tr>
<tr>
<td></td>
<td>Illuminance level</td>
</tr>
</tbody>
</table>

**Interaction effects of acoustics at the human level**

The interaction effects of acoustics occur at the human level by three major health effects; physiological, psychological, and performance. In terms of physiological effects, an experimental study showed that exposure to a combination of heat and noise could cause changes in blood pressure (Dehghan et al., 2017). Abbasi et al. (2020) also found that the combined noise and air temperature affected human neurophysiological responses (heart rate and respiratory rate) significantly. It was indicated that the combined effects of both noise and air temperature were more noticeable than the effects of each of them alone on human neurophysiological responses (Abbasi et al., 2020). Additionally, Alvarsson et al. (2010) examined the effect of sound types on stress recovery in an experimental study. The results of this study showed that the skin conductance level (SCL) recovery was faster during exposure to natural sound compared to exposure to a noisy environment (Alvarsson et al., 2010). Also, laboratory experiment results showed that the noise level resulted from different floor impact sound sources had significant physiological responses. These responses represented changes that occurred in both electrodermal activity, and respiration rate that led to noise noticeability and high sound levels induced noise annoyance (Park & Lee, 2017).

Furthermore, it was observed that indoor acoustics can affect individuals’ performance. For instance, in a lab study with primary school children conducted by Zhang et al. (2019), significant interactions between the effect of sound type and SPL on children’s phonological processing performance were seen (Zhang et al., 2019). In terms of psychological effects, Ma and Shu (2018) concluded that soundscape elements that are considered as pleasant had a positive effect on fatigue restoration as well as mitigating the annoyance, and had a significant influence on psychological restoration (Ma & Shu, 2018). Thus, soundscapes that are perceived as pleasant and restorative by individuals play a vital role in improving the cognitive performance of students in classrooms.

In Figure 1, a summary of indicators at human level to assess indoor acoustical quality is presented.
**CONCLUSIONS**

The relevant literature on the interaction effects of acoustics with other IEQ-factors was reviewed in this paper. Previous studies showed that there are significant interaction effects between acoustics and temperature. The interaction effects of acoustics and visual comfort have also been studied. However, few studies focused on the interaction effects between acoustics and indoor air quality. Some key indicators for assessing acoustical quality at the human level were presented. To enhance the acoustical quality, it is recommended to take into account the cross-modal effects of noise/sound with other IEQ-factors and the effects (positive and negative) of the acoustical environment at the human level.

**REMARK**

A full version of this literature review will be published somewhere else later in a journal paper.

**REFERENCES**


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**Figure 1. Effects and indicators of acoustical conditions at human level**


The challenge of finding definitions for well-being and health within the built environment

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SUMMARY

While research on health and well-being is further increasing in numbers, a plethora of definitions for the terms health and well-being exists in scientific literature. These definitions are influenced by individual preferences and objectives, hence to some extent demonstrating the individuals' view on both concepts. As such the analysis of definitions deployed is beneficial for the understanding of the key concepts influencing them.

The objective of this study is the identification and analysis of definitions of well-being and health within and beyond the field of built environment. This short paper summarizes two approaches for such analysis. Firstly, by means of a Rapid Evidence Assessment definitions used in scientific research are summarized and categorized. Secondly, through a qualitative survey among laymen, the expert definitions are contrasted with the subjective definitions of laymen.

INTRODUCTION

During the last two decades, health and well-being have attracted the attention of numerous researchers, professionals and individuals within the marketing department because of the alarmingly increasing rates of health difficulties presented within the population (Northridge, Sclar, & Biswas, 2003). Studies have shown that there are both environmental and social factors determining health, which often co-occur, suggesting that more interdisciplinary studies are needed (Alvarez, Appleton, Fuller, Belcourt, & Kubzansky, 2018). However, despite the ubiquitous exposure to these topics, there is yet the absence of a solid and universal definition of health and well-being, that one might expect. For example, health determinants within the built environment are conceptualized within the limits of indoor air quality, access to daylight, noise dampening and other environmental stressors (Rohde, Larsen, Jensen, & Larsen, 2019). On the contrary, social determinants of health are associated with education, income, and social networks (Braveman & Gottlieb, 2014). Although some of the social aspects are often referred to the definitions of health and well-being, the environmental aspects are neglected or if mentioned are less specific. These differences indicate a gap within the conceptualization of a more holistic definition of health and well-being, but also a lack of specificity in the definition of health and well-being with regards to the built environment. At the same time, the analysis of definitions deployed permits insights into underlying paradigms by those developing or using them.

The aim of this study is to identify and cluster published definitions of well-being and health within and beyond the field of built environmental research and practice and to contrast them with laymen opinions on this topic. On the one hand, the outcomes from this analysis could potentially help in understanding individual conceptual understandings of the terms. On the other hand, the comparison may show aspects over- or underrepresented in scientific research compared to peoples' daily perception.

METHODS

Methods for data collection consist of a Rapid Evidence Assessment (REA) review (Watt et al., 2008) and a qualitative survey.

The REA review was conducted to identify definitions for well-being and health applied in scientific literature. This review covered research work from a wide range of disciplines such as architecture, engineering, health, psychology and social sciences. Search strings including "well-being + defin*", "health + defin*", or "health + architect*" and were used in PubMed, EBSCOhost and Google Scholar. Following the PRISMA scheme, titles and abstracts were screened according to their suitability, followed by full text analyses.

For the qualitative survey, forty non-expert participants (42.5% females) were recruited online via Mturk and Prolific. Inclusion criteria included being 18 years or above and having good knowledge of the English language for better understanding of the questions. Before their participation, participants were provided with information about the survey and were given the opportunity to ask questions. After obtaining an informed consent, participants were asked to answer a series of qualitative questions about their
definitions of health and well-being, separately, and how could the built environment contribute positively or negatively to someone's health and well-being. Lastly, participants were asked to complete the WHO-5 Well-Being Index (World Health Organization, 1998), a subjective measure of their health and structured questions on demographics, such as age, gender, marital status, education, cultural background and employment. At the end of the survey, participants were compensated with a small monetary reward (~3.90 €) for their time and effort. The outcomes from the qualitative questions were analysed using thematic analysis (Braun & Clarke, 2012). Descriptive and frequency analyses were conducted for the descriptive statistics of the sample.

RESULTS

Review of definitions in scientific literature:

The database search led to 1785 abstracts of which after exclusion 40 full texts were included in the analysis. The most cited definition of health (mentioned by 35% of reviewed full texts) is that by the World Health Organization (WHO) (World Health Organization, 1946), which defines health as "a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity". Despite its wide spread usage, this definition has been criticized as an "utopian vision" and an "idealistic view", since it is very difficult to maintain a complete state of physical, mental and social well-being (Miselbrook, 2014; Wylie, 1970). Although WHO recognizes that recent definitions of health do not require the complete absence of a disease, the definition has still not been revised.

Alternative suggestions for definitions of health include narrower biomedical models, defining health by norms and facts (health as the absence of biomedical abnormalities) and more functional models, considering a state of health as being able to overcome obstacles (Miselbrook, 2014). In line with the latter, a time factor is inherit in several definitions highlighting health as a dynamic state which can exist at one given moment but not in the next one. Examples are health as
- a "dynamic state of wellbeing characterized by a physical, mental and social potential, which satisfies the demands of a life commensurate with age, culture, and personal responsibility" (Bircher, 2005),
- "the perfect, continuing adjustment of an organism to its environment" (Wylie, 1970),
- an "elastic concept" described by the ability to resist threats of disease (Wylie, 1970),
- an "ongoing outcome from the continuing processes of living life well" (Davies, 2009), or
- "the ability to adapt and self-manage in face of social, physical, and emotional challenges" (Nobile, 2014).

In addition, definitions list individual aspects to be considered for health, e.g.
- "the integration of body, mind, and spirit", and considering "significant influences of sociologic, environmental and behavioural factors" (Bradley, Goetz, & Viswanathan, 2018)
- "including subjective feelings of contentment and security" (Koren & Butler, 2006), as well as
- "wealth, relationships, coherence, fitness, and adaptability" (Davies, 2009).

Others directly reverse the WHO definition, by viewing health "as a central component of well-being" (Koren & Butler, 2006). Worth to mention is the paradigm of health as an "open-ended concept", in which "health becomes an asymptote, an ideal on the horizon that can be approached but never reached" (Wylie, 1970).

Another criticism on the WHO definition of health is the existence of many terms which need a definition themselves (Wylie, 1970). One of these terms is well-being, which itself is defined in a variety of ways. The analysis of the REA review showed that the term well-being is usually split into different categories when defined, referenced or examined such as
- eudemonic well-being (positive functioning) and hedonic well-being (emotional well-being), (e.g. Emanuele, Santi, & Di Sivo, 2018; Hanc, McAndrew, & Ucci, 2019; Huppert & So, 2013; Magyar & Keyes, 2019; Ross et al., 2020; Watson, 2018)
- physical, emotional, social, spiritual and material well-being, e.g. in (e.g. Emanuele et al., 2018; Huppert & So, 2013; McAbee, Drasgow, & Lowrey, 2017; Sheehan, 2015)

Furthermore, well-being is often defined, referenced or examined for specific groups or contexts, e.g. communities (Coburn & Gormally, 2020; Roy et al., 2018), African-American men (Griffith, Brinkley-Rubinstein, Bruce, Thorpe Jr, & Metzl, 2015), older adults (Song & Kong, 2015), students (Barkham et al., 2019), deaf adults (McAbee et al., 2017) or adolescents (Ross et al., 2020).

Interestingly, definitions of health and well-being are usually based on expert knowledge and not defined by participants or laymen. Exceptions are
- Griffith et al. who collected definitions of health by African American men (Griffith et al., 2015), and
- Sheehan who asked participants to select one definition of well-being out of a set of given examples (Sheehan, 2015)

In summary, the REA review confirmed that there is a multitude of definitions of well-being and health. While in parts being inconclusive and contradictory, most definitions are too general to be applied to well-
being and health within interdisciplinary research and particularly with regards to the built environment. Noteworthy exceptions is the review by Hanc et al. aiming to establish the most prevalent and insightful definitions and dimensions of well-being in buildings (Hanc et al., 2019) and a recent workshop among 60 experts from engineering and health related research discussing elements of a definition of well-being in the built environment (O’Neill, Becerik-Gerber, Wen, Wu, & Pedrielli, 2021).

Summarizing laymen definitions of health and well-being:
The majority of the participants in the survey were Caucasian males, between the ages 18 to 30 years old, married or in a cohabitating relationship, with an undergraduate degree, working full-time and reported being in the middle economic class. Participants’ main areas of expertise were engineering and computer science. The majority of participants reported having no diagnosis and a generally good health status. The outcomes from the Well-being Index (World Health Organization, 1998) demonstrated an average score of 18.82 (SD = 5.69).

Common themes were identified between the definitions of health and well-being, which included physical health, mental health, social connectedness, and engagement in a healthy lifestyle. Interestingly, spirituality was associated with the definition of health, while factors such as environmental satisfaction, financial security, quality of life, self-efficacy and stability were associated to the definition of well-being.

Common themes between the two concepts were also identified with regards to the factors influencing them, including healthy habits, the built environment, financial security, social influences and physical comfort. Unique to the definition of health were the following themes: genetics and access to medical care. A particularly common code for the definition of well-being was the experience of being happy and having a sense of purpose in life.

Thirty participants (75%) acknowledged that there is a difference between the two terms, while the rest of the participants reported that the two terms are interchangeable and that it is difficult to distinguish them, since they have common roots.

Specifically asked about the positive and negative contribution of the built environment on health and well-being yielded common themes.

The positive contribution of the built environment on both concepts was associated to encouragement of social interactions, better living conditions, reduction in mental and physical illnesses, increase in productivity, increase in safety, providing a space to relax and have fun. Unique positive contribution of the built environment to the concept of health was the reduction in mortality and morbidity.

The negative contribution of the built environment was referred to according to the following themes: reduction in physical activity, overstimulation, uncomfortable living and working conditions, negative social interactions and increased risk of physical and mental illnesses depending on the conditions. Some of the participants also reported not knowing the negative contribution of the built environment on health and well-being.

Discussion:
Comparing expert and laymen definitions of health and well-being reveals common aspects such as sociological, environmental and behavioural factors. Contrasts highlight a more pronounced dynamic view on health by experts compared to a static, right-here, view of laymen.

At the same time, further research and analysis is required to conceptualize differences in the definitions and underlying paradigms of both groups, and to evaluate whether a) researchers should consider additional or other aspects constituting health and well-being or b) laymen would need to be informed about findings from research with respect to key influences on their health and well-being not considered in their definitions.

CONCLUSIONS
• Common definitions of well-being and health are inconclusive and are often too general to be applied to well-being and health within the built environment.
• First attempts towards definitions of well-being within the built environment exist.
• The survey distributed among laymen revealed useful insights into their paradigms and factors considered important.
• All together, the outcome from the literature review and the survey help revealing individual conceptual understandings of these concepts terms.
• Further analysis and research is necessary to establish a common framework for health and well-being within the built environment and between the built environment and other disciplines.

ACKNOWLEDGEMENTS
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Relationships between mental health and indoor environmental quality (IEQ) in the home workplace

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SUMMARY
The understanding of mental health in the context of the physical workplace's indoor conditions has not yet received much attention, even less related to employees that are teleworking. Therefore, this study aimed to identify potential relationships between indoor environmental quality (IEQ) conditions and workplace mental health while working from home.

Data was collected through a cross-sectional survey; repeated momentary surveys; and IEQ sensors. Participants worked full-time from home during the measuring period. Datasets were analyzed using bivariate and path analyses.

The findings indicate that both subjective experience and objective IEQ conditions, as well as workplace suitability and distraction are related to workplace mental health.

This study is one of the first to explore workplace mental health in relation to simultaneously assessed (perceived and measured) multiple IEQ parameters in the home workplace. Working from home is expected to be more common in the post-Covid world. Therefore, additional research is required.

INTRODUCTION
The influence of the indoor environmental quality (IEQ; air quality, thermal comfort, lighting, and noise) on humans is evident and often associated with health outcomes (Hanc et al., 2019). While physical and social health in relation to the workplace are commonly studied, mental health in the context of the physical workplace remains underexposed (Hoisington et al., 2019; Mujan et al., 2019). It is difficult to quantify mental health due to its subjective nature. Previous studies demonstrated significant relations between IEQ conditions and their perception (Mujan et al., 2019), but are limited in identifying potential mental health consequences. Both objective and subjective IEQ should be reviewed, as they are not always aligned. In addition, in most research solely one IEQ construct is tested against one other variable and all others are assumed to be constant (Parkinson et al., 2019). By using a holistic approach including all four IEQ parameters, both direct and indirect effects can be reviewed.

Since the outbreak of the Covid-19 infection, the workplace at home has suddenly become more relevant than ever. However, research on teleworking so far has neglected IEQ conditions at home. Research in the context of mental health while working from home is nearly non-existent. Therefore, this research aims to identify relationships between IEQ conditions and employee mental health while working at home.

CONCEPTUAL MODEL
Based on the examination of scientific literature a network of relevant variables was constructed, which functioned as a conceptual model (see Figure 1). Distinguished variable groups are personal characteristics; objective IEQ conditions; workplace at home aspects; subjective IEQ conditions; and employee mental health. This conceptual model has been the basis for the subsequent analyses.

METHOD
To collect data, 36 Dutch consultants participated in April 2020. These participants were recruited via an open request to engage in the study on the intranet of one consultancy firm. Due to governmental stay-at-home orders to prevent the spread of Covid-19, all participants worked full-time from home. Environmental satisfaction as well as mental health concepts were captured by short, two-daily point-in-time (PIT) surveys in a five-business day measuring period. At the end of the week a reflective extensive survey covered variables not being subject to changes during the day. Moreover, the actual IEQ conditions were measured continuously by wireless sensors on participants' work desks at their homes.

The four main IEQ parameters included in this study were overall illuminance (both daylight and artificial light), sound pressure level, temperature, and CO2-concentration as a proxy for general air-quality. The distinguished workplace mental health (MH) concepts and corresponding measurement scales were obtained from a larger research project at the authors’ university (see acknowledgements). This included stress, fatigue, sleep quality, concentration, productivity, engagement, mental wellbeing, emotional exhaustion, depression, mood. In addition, a workplace satisfaction measure was included. Distraction was covered by 6 questions on whether a participant was distracted by voices, movement of people around, children or incoming emails, phone calls or social media. Suitability of the workplace was questioned by 5 statements on different topics.

Data collection resulted in 36 MH surveys and 321 momentary PIT experiences, an average of almost nine
experiences per participant. Data sources were connected by means of pseudonyms in the surveys and timestamps from the sensor data.

In order to explore any significant relationships between pairs of variables, bivariate analysis was conducted. Secondly, the significant pairs were used as input for a path model. The path model enabled to analyze the interaction with the network of variables simultaneously.

RESULTS & DISCUSSION

The bivariate analyses have been conducted on both a participant level (using the cross-sectional survey, MH N=36) and the experience level (using the momentary survey, PIT N=321). The outcomes of those analyses showed no significant relations of the personal characteristics with any of the dependent variables, so these were not taken up in the path model. In addition, some of the workplace mental health concepts did not appear to depend on the workplace conditions and perceptions. Especially the sound levels and perceived noise showed multiple significant relations with mental health concepts, while no significant relations were found for the carbon dioxide concentration nor the satisfaction with air quality.

A follow-up path model showed acceptable goodness of fit indices (see Table 1) when including variable pairs significant on the 0.01 level from the bivariate analysis only. Moreover, low r-squared regressions and insignificant paths have been excluded from the model stepwise. Because one critical rule of thumb was breached (a minimum of 200 cases), the outcomes provide insights and give direction to future research but must be interpreted with care.

Table 1. Path model goodness of fit indices

<table>
<thead>
<tr>
<th>Degrees of freedom</th>
<th>34</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chi-square</td>
<td>0.168</td>
</tr>
<tr>
<td>Chi-square/degrees of freedom</td>
<td>0.005</td>
</tr>
<tr>
<td>Comparative Fit Index (CFI)</td>
<td>0.989</td>
</tr>
<tr>
<td>Root mean square error of approximation</td>
<td>0.027</td>
</tr>
<tr>
<td>P-value for test of close fit (RMSEA &lt; 0.05)</td>
<td>0.941</td>
</tr>
<tr>
<td>Standardized Root Mean Square Residual</td>
<td>0.038</td>
</tr>
</tbody>
</table>

The path model outcomes are visualized in Figure 2. The findings indicate that both subjective experience and objective IEQ conditions, as well as workplace suitability and distraction are related to workplace mental health.

First of all, the path model demonstrates higher engagement when working in a well-illuminated workplace (>572 lux, 0.14 and 0.16). Also, being distracted negatively affects the level of engagement (-.34) and self-reported mental wellbeing (-.19) as well. A self-perceived suitable workplace at home leads to diminished fatigue (-.38), which improves Mental wellbeing (-.40). Higher levels of engagement increases mental wellbeing too. On the contrary, fatigue would result in diminished concentration (-.18) which results in decreased productivity (78). An average sound pressure level above 58dB resulted not only in diminished satisfaction with the noise level (-.10) but also in a decreased mood (more tension arousal, -.16). Being satisfied about the noise level increases concentration (.20), self-reported wellbeing (.16), engagement (.10), and diminishes tense arousal (-.14).

This study has a few limitations. First, the use of CO₂-concentration as a proxy for air quality at the workplace at home is questionable. Since odors; volatile organic compounds (VOCs); and fine particle matters (PMs) might play a crucial role as well. The CO₂-concentration is mainly a proxy related to the number of people, and thus more suitable to measure the office environment. Also, it should be noted that the current study was executed during governmental stay-at-home orders due to the Covid-19 pandemic. This situation is very different from being able to freely choose your work location. In addition, this study did not account for reduced mental wellbeing of participants due to the Covid-19 situation. Nonetheless, this research stresses the importance of IEQ for supporting workplace mental health both for employers and employees. The outcomes give insights in valuable interventions concerning noise and/or lighting levels to increase mental wellbeing of employees. Which potentially results in increased (business) performance as well.

CONCLUSIONS

This study is one of the first to explore workplace mental health in relation to multiple and both objective and subjective IEQ conditions in the home workplace environment. Although the results should be validated with larger samples, the outcomes give valuable insights in the complex network of variables influencing employee mental health. Since working from home is expected to be more common in a post-Covid world, the relevance and importance of future research is obvious. Future research could make a comparison between working in an office and at home in relation to both work-life balance and workplace mental health.

ACKNOWLEDGEMENTS

This work was part of the master thesis of Bouke Boegheim (Boegheim, 2020). Many thanks to TwynstraGudde for providing the sensor equipment and to all employees that participated in the research. The mental health concepts and corresponding measurement scales were obtained from a larger research project of the 2nd author and her colleagues Minou Weijs-Perrée and Lisanne Bergefurt on office mental health.

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the workplace at home: an explorative case study using both subjective IEQ experience and objective IEQ sensor data during the COVID-19 pandemic”. Master thesis Eindhoven University of Technology. https://tue.on.worldcat.org/oclc/1226760756


Figure 1. Visualization of the conceptual model.

Figure 2. Visualization of path model outcomes.
Analysis of workers’ tendency to answer questionnaires of positive and negative questions, along with understanding relationship between comfort and self-efficacy

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SUMMARY
In this study, measurements and surveys were conducted in the office area of a building to which a pneumatic radiant air conditioning system (hereinafter referred to as "pneumatic radiant air conditioning") was applied, with respect to the indoor air quality of the office; the focus was on the comparison of psychometric surveys. The purpose of this study is to clarify whether the content of the responses obtained from the workers differed depending on whether the questions were asked in a positive or negative manner. In addition, the four elements of self-efficacy namely, "control experience," "agency experience," "social persuasion," and "physiological state" (physical and physiological state were incorporated into the questionnaire, with the aim of determining the truly comfortable space by comparing the scores. We found major differences in the response to the type of questionnaire used (positive/negative).

INTRODUCTION
In recent years, in Japan, the view that environmental, social, and corporate governance considerations are necessary for corporate management and growth (e.g., ESG) has become an important element in architecture, and the need to reduce environmental impact while ensuring user comfort, health, and resilience has become a necessity.

Current indices for measuring indoor space comfort include thermal environment assessment, such as the predicted temperature, cold declaration PMV (predicted mean vote), and standard effective temperature (SET*). However, these indices are used in a steady state, and there are many points to be considered when these indices are used directly as an evaluation index in a non-steady state (such as the actual office space), where the spatial components are constantly changing. Therefore, to measure the comfort of the office in a realistic way, it is effective to ask the workers directly about the space they are working in.

To improve the comfort of the office, it is necessary to extract the workers' complaints about the office environment; it is important to conduct questionnaires that focus on the psychological elements of the workers and their living and working patterns, in addition to measuring the physical environment elements. However, human beings sometimes unconsciously understand the intentions of others and act in response to them. Even in response to questionnaires, they are unable to collect accurate opinions; for example, they try to predict the purpose of the research and respond in a perceived "better" direction. This is called the demand characteristic. To gain the most out of a study like ours, it is important to take measures against demand characteristics and collect accurate opinions from the workers/administrators.

Furthermore, we make a mention of self-efficacy. Self-efficacy is composed of four components: "control experience" (the experience of overcoming obstacles and completing things), "agency experience" (the experience of watching others like you persevere and succeed), "social persuasion" (the experience of being told that you are capable of learning a certain behavior and being encouraged to do it), and "physiological state" (physical and physiological state (physical and mental state)). We also investigated whether there is a relationship between self-efficacy and comfort.

METHODS
The thermal environment was measured in an office room on the 4th floor of the K building. The following is an overview of the equipment and items used to measure the indoor comfort. Figure 1 shows an outline of the measured building. The subject building is the TG Kannai Building (hereinafter referred to as "K Building") located in Yokohama City, Kanagawa Prefecture; the building has an exhibition space on the lower floors and office spaces on the middle and upper floors. In the offices that occupy this building, the ratio of male to female workers was approximately 7:3. The measurement period of our study was from August 19, 2019 to August 28, 2019 in summer and from December 9, 2019 to December 18, 2019 in winter.
Table 1. Content of the questionnaire

<table>
<thead>
<tr>
<th>Selection type answer (5-point scale)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Environmental assessment</strong></td>
</tr>
<tr>
<td>1. You can feel (or not feel) the effect of air conditioning right away.</td>
</tr>
<tr>
<td>2. I rarely (often) feel hot.</td>
</tr>
<tr>
<td>3. Little (much) variation in temperature depending on seating location.</td>
</tr>
<tr>
<td>4. I rarely (often) feel damp.</td>
</tr>
<tr>
<td>5. I rarely (often) feel cold.</td>
</tr>
<tr>
<td>6. I rarely (often) feel too dry.</td>
</tr>
<tr>
<td>7. The airflow is rarely (if ever) perceived as too weak or too strong.</td>
</tr>
<tr>
<td><strong>Self-efficacy</strong></td>
</tr>
<tr>
<td>8. I think (don’t think) I can eliminate my own discomfort by changing the temperature setting.</td>
</tr>
<tr>
<td>9. I often hear (or don’t hear) stories of discomfort being resolved by changing the temperature setting.</td>
</tr>
<tr>
<td>10. I think (don’t think) that it is recommended to change the temperature setting.</td>
</tr>
<tr>
<td>11. Today’s conditions are good (or not so good).</td>
</tr>
<tr>
<td><strong>Satisfaction</strong></td>
</tr>
<tr>
<td>12. I am satisfied (dissatisfied) with the indoor environment on this floor.</td>
</tr>
</tbody>
</table>

Table 1 presents the questions on the paper-based questionnaire. Two questionnaires, one asking positive questions (hereinafter referred to as “positive type”) and the other asking negative questions (hereinafter referred to as “negative type”), were used to investigate the psychological quantity of the office workers and their sense of self-efficacy. First, the basic indoor environment was determined by asking the respondents to answer 11 questions, including four questions on the four elements of self-efficacy regarding the change in temperature settings and seven items on the evaluation of the indoor environment, on a five-point scale. In this scale, one represented “not applicable” and 5 represented “applicable.” For the negative type, the score was reversed. In addition to the fill-in-the-blank format for the perceived temperature, humidity, and airflow and the free description of the indoor environment, the respondents were asked to indicate their level of satisfaction to obtain a more detailed understanding of what they wanted from the indoor environment. We had 104 respondents for the summer term and 88 respondents for the winter term.

RESULTS

Figure 14 shows the percentage of responses for satisfaction on a 5-point scale for the summer season, and Figure 15 shows the percentage of responses for satisfaction on a 5-point scale for the winter season. In both summer and winter, there were more “Neither satisfied nor dissatisfied” responses in the negative type than in the positive type. In the summer season, the major difference between the positive and negative types was mainly in the percentage of “Unsatisfactory” responses, but in the winter season, there was a large difference overall.

In the evaluation of the indoor thermal environment in summer, the percentages of “Satisfactory,” “Slightly satisfactory,” and “Cannot say either” were about the same for the positive type, or “Cannot say either” accounted for about half of the total. However, more than one-third of the respondents answered “Not applicable” or “Not really applicable” to the questionnaire’s “5. rarely feel cold.” In the negative type, more than 70% of the respondents answered “a little satisfied” and “Neither satisfied nor dissatisfied.” The overall score was higher for the affirmative type. In the positive type, 22% of the respondents were dissatisfied with whether they felt hot or not, but in the negative type, nearly half of the respondents answered “a little true” or “True” to question 2. In addition, 19% of the positive respondents were dissatisfied with
regardless of the temperature variations, but more than half of the negative respondents answered “Slightly true” or “True” to question 3.

With regard to the evaluation of the indoor thermal environment in winter, the total percentages of “Not applicable” and “Not really applicable” were high in the positive type, at 35% and 39%, respectively, for question 2. The total percentage of “Not applicable” and “Not really applicable” for “7. I rarely feel too dry” also exceeded 40%. In the positive type, 35% of respondents were dissatisfied with whether they felt hot or not, but in the negative type, 58% of respondents answered, “Somewhat true” or “True” to the question 2. Conversely, 39% of the positive type respondents were dissatisfied with whether they felt cold or not, but 25% of the negative type respondents answered “Slightly true” or “True” to the question 2.

With regard to the fill-in-the-blank questionnaire, the number of negative responses dropped considerably compared to the affirmative responses that were distributed at the beginning of both the summer and winter seasons, probably because the questions were similar in format. Notably, the response rate for temperature was the highest, and that for airflow was the lowest.

As for the open-ended responses, in the positive type, there were a number of responses related to the difference in temperature; it was found that the difference in the perceived comfortable temperature occurred depending on gender. In the negative type, there were responses to the questionnaire itself, such as “I feel it is difficult to answer a questionnaire about dissatisfaction” and “The questions are complicated and difficult to answer.”

As for the satisfaction rating, regardless of the temperature variations, but more than half of the negative respondents answered “Slightly true” or “True” to question 3.

The results of the multiple regression analysis, in which the level of satisfaction was set as the objective variable and the other items were set as explanatory variables, are shown below.

<table>
<thead>
<tr>
<th>Question</th>
<th>Correlation Coefficient</th>
</tr>
</thead>
<tbody>
<tr>
<td>2. I rarely feel hot.</td>
<td>0.399 *</td>
</tr>
<tr>
<td>7. The airflow is rarely perceived as too weak or too strong.</td>
<td>0.220 *</td>
</tr>
<tr>
<td>3. Little variation in temperature depending on seating location.</td>
<td>0.209 *</td>
</tr>
</tbody>
</table>

**Figure 16. Results of multiple regression analysis (positive)**

- **Relationship between each question item and satisfaction level (winter)**

Figures 18 and 19 show the results of multiple regression analysis with positive and negative satisfaction as the objective variables and other items, respectively. The results of the multiple regression analysis, in which the objective variable was the level of satisfaction and the explanatory variables were other items, showed that there were significant differences, and the correlation coefficients were high. However, some items were indirectly related to the level of satisfaction. For example, in the affirmative type, “I rarely feel that the airflow is too weak or too strong” has a strong correlation with satisfaction. It is thought that the improvement of these items will ultimately lead to higher satisfaction.

**Figure 17. Results of multiple regression analysis**

- **Comparison with other properties**

Figure 20 shows a comparison with the relationship between self-efficacy and satisfaction with other properties. This graph is the result of averaging the scores of satisfaction and self-efficacy from the same self-efficacy questionnaire applied to the four
properties. It can be inferred that there is a positive correlation between self-efficacy and satisfaction.

- **Correlation between self-efficacy and satisfaction in this study**

  Figure 21 shows the relationship between self-efficacy and satisfaction, with respect to the positive and negative types questionnaires. In the positive type, significant correlation was not observed.

  A correlation existed in the negative type. From the respondents’ point of view, it can be inferred that subtle differences in the context of the questionnaire affect the results.

CONCLUSIONS

In this study, a difference in each question between the positive and negative types was observed, although the differences were small and large. In addition, a correlation existed between self-efficacy and satisfaction scores, suggesting that the stronger the feeling of self-efficacy in a thermal environment, the higher the level of satisfaction. In this case, “whether or not you feel hot” was deeply related to the level of satisfaction in both the summer and winter seasons, and those who felt hot had a lower level of satisfaction.

REFERENCES


A Practical and Efficient Testing Method for Indoor Airborne Pathogens

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SUMMARY
The global COVID-19 pandemic has heightened interest in monitoring for the presence of aerosolized SARS-CoV-2 virus and other airborne pathogens in indoor spaces. Here we describe a new approach for effectively recovering bioaerosols using condensation growth tube (CGT) capture. The CGT’s engineered temperature zones create water vapor supersaturation that forces condensation onto particles to form microdroplets. These droplets are gently collected in a way that keeps viruses, bacteria and fungal spores intact. The unique advantages of the CGT are: (1) high collection efficiency (>95% of particles from <10 nm to 10 µm), (2) instant preservation of genomic materials; and, (3) sample concentrations compatible with high-throughput genomic sequencing, with diagnostic work flow identical to that used in nasal and buccal swabs.

INTRODUCTION
The COVID-19 pandemic has been a global scourge, infecting over 110M people and killing more than 2M in its first year. As devastating as this pandemic has been, it will not be the last; other novel pathogens will undoubtedly emerge. Like the SARS-CoV-2 virus, some will be highly transmissible as aerosols. Even the less-feared seasonal influenza kills hundreds of thousands of people every year, while tuberculosis still kills about the same number of people as COVID-19 –1.5-2M each year. All of these diseases are transmitted primarily via infectious airborne microbes. Instruments capable of rapidly detecting airborne pathogens can help efforts to mitigate disease transmission.

Condensation Growth Tube Capture
Laminar-flow, thermally-diffusive water condensation particle growth was introduced in 2005 (Hering & Stolzenburg 2005) and first applied to measurement of the number concentration of ultrafine aerosol particles. In this technique aerosol is directed through a wet-walled growth tube. The cold first section of the CGT (“Conditioner” in Figure 1) establishes consistent thermal conditions regardless of ambient temperatures or humidity. The aerosol then passes through a heated “Initiator” section where water evaporates from the wet walls into the aerosol stream. The water vapor diffuses faster than the thermal energy, creating a condition of vapor supersaturation in the airstream. This unstable condition forces water vapor to condense onto seed particles as small as 5 nm and rapidly grows them into super-micron droplets.

In 2014, a new design was introduced that added a third temperature stage called a “Moderator” (Hering et al. 2014). The moderator again cools the air which continues droplet growth while simultaneously removing water vapor to the wet walls reducing the dew point at the exit of the growth tube and avoiding unwanted condensation in the downstream plumbing. To count the individual particles, the droplets are passed through a focusing nozzle and detected with an optical laser sensor.

Using the CGT for bioaerosol particle collection, the grown droplets are passed through an acceleration nozzle and gently impacted onto a solid surface or into a small volume of liquid (Pan et al, 2016). The condensing water forms droplets, which helps protect virions and microorganisms from mechanical collection stresses; and, depending on the collection medium, helps maintain viability. This new approach to bioaerosol sampling has been effectively employed in research-grade instruments used to sample viable SARS-CoV-2 in the environment. A team from the University of Florida (USA) was the first to confirm that viable SARS-CoV-2 virus was airborne by using a CGT sampler in the hospital room of infected COVID patients (Lednicky et al. 2020). A University of Colorado team showed the protective effect this approach offers for efficiently collecting viable airborne bacteria as well (Nieto-Caballero et al. 2021).

In response to the need for broader access to effective sampling devices, we have developed the new BioSpot-GEM™ bioaerosol sampler (Figure 2), which is affordable, compact and quiet. This device offers automated sample timing in a simple operation platform suited for bio-surveillance in hospitals, nursing homes,
schools, and transportation centers by indoor air quality professionals as well as by researchers.

This new CGT sampler is the only device that collects biological particles directly onto a sterile swab (patent pending). The swab is easily inserted into the sampler in less than a minute, with low potential for contamination. After sample collection, the swab tip is removed from the shaft and inserted into a vial for traditional microbiological processing, either genomic (RT-PCR, DNA/RNA sequencing, Figure 3) or culture-based (viability). The swab tip can be pre-treated with a genomic preservative (Nieto-Cabellero et al. 2018, patent pending) or artificial saliva prior to sample collection to preserve sample fidelity at the moment of capture. The genomic preservative inactivates infectious pathogens making the sample safe for operator handling and transportation. The stabilized aerosol samples can be stored at room temperature for up to a month, and up to a year in cold storage.

Growth Tube Modeling

The primary design goal for our new sampler was to achieve high collection efficiency for particles from <10 nm to 10 µm in the most compact instrument size possible. To this end, we used finite element analysis (FEA) to model flow, heat/mass transfer and condensation-driven droplet growth to optimize the design of the sampler. Our model determines where condensation of supersaturated vapor begins along a particle’s trajectory and then calculates the subsequent droplet growth, accounting for the Kelvin effect on the equilibrium vapor pressure over a curved surface and non-continuum regime transport of both vapor and latent heat from the droplet.

Comparison of the solid and dashed red traces in Figure 4 demonstrates that the size of the starting seed particle has essentially no effect on the size of the droplet; the droplet formed from the 20 nm seed particle rapidly grows to the same size as the droplet from the 120 nm seed as they move through the initiator. Due to the parabolic velocity profile in the cylindrical growth tube, droplets closer to the wall (r/R=1) move more slowly and therefore have more time to grow larger than droplets at the center of the growth tube (r/R=0), as is evident from the blue and red curves in Figure 4. Our model also shows that lowering the initiator temperature (black curve vs. red curve) reduces the supersaturation in the growth tube, which results in less droplet growth.

Next, we used FEA to model growth tube collection efficiency across a range of droplet sizes. These results were integrated with the modeled droplet size distribution (from extending the analysis in Figure 4 to many values of r/R) to predict the overall instrument collection efficiency. As demonstrated in Figure 5, the model results closely mirrored the measured collection efficiencies over a range of initiator temperatures. Overall, this analysis enabled us to significantly reduce the instrument footprint, while retaining excellent collection efficiency.

Figure 2. Prototype unit sampling from a large (10 m^3) bioaerosol test chamber.

Figure 3. Removal of the swab-sample tip into a vial for genomic characterization.

Figure 4. Modeled droplet growth for four different scenarios. \(D_{0,0}\) is the diameter of the seed particle at the inlet, init is the temperature of the initiator (the conditioner is 5°C) and r/R is the radial position. The locations of the conditioner (0-46 mm), initiator (46-61 mm) and conditioner (61-115 mm) are indicated by the dashed vertical lines.

Figure 5. Measured and modeled collection efficiency for different initiator temperatures.
Pilot-Scale Experimental Validation

The BioSpot-GEM sampler was challenged side-by-side against a multiple orifice uniform deposit impactor (MOUDI, TSI Inc.) for its ability to recover live airborne coronavirus in a controlled laboratory chamber (10 m³). The particle size distribution carrying live airborne murine coronavirus was engineered to mimic that shed by infected humans (Figure 6).

Figure 6. Distribution of Coronavirus RNA recovered from respirable particle sizes segregated by MOUDI in mean aerodynamic diameter bins (largest D_{10} presented on x-axis) at two different RH levels (■ = 25%; ■ = 60%).

Through a humidity range germane to conditioned indoor air (25% < RH < 60%), the recovery of airborne coronavirus with a BioSpot-GEM sampler was significantly higher than that recovered from a MOUDI operating under identical conditions (qRT-PCR).

Table 1. Virus recovery from MOUDI and BioSpot-GEM samplers using qRT-PCR (Avg RNAcopy/m², n=3; 25% RH)

<table>
<thead>
<tr>
<th>MOUDI (Σ stages)</th>
<th>BioSpot-GEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.1 x 10⁸ ± 2 x 10⁵</td>
<td>1.3 x 10⁹ ± 2 x 10⁵</td>
</tr>
</tbody>
</table>

CONCLUSIONS

- Adapting CGT sampling for bioaerosol recovery on hydrophilic swabs is compatible with rapid workflow paradigms used in high-throughput genomic characterizations
- Finite element analysis permitted optimization of the CGT for efficient particle collection in a compact device form factor
- Swab-based bioaerosol recovery with CGT capture can be at least as efficient as impaction in classic high-efficiency aerosol samplers (MOUDI) using widely accepted quantitative genomics (qPCR).

ACKNOWLEDGEMENTS

This work was supported by the U.S. National Science Foundation (awards 1853240, 2027696). We thank Susanne Hering, Steve Spielman and Gregory Lewis (Aerosol Dynamics Inc) for their assistance with condensation growth tube finite element modeling. CGT capture technology is exclusively licensed from Aerosol Dynamics Inc with US patents 6712881, 7736421, 8801838, 9610531, 9658139, 9658139, German Patent 10392241, Japanese Patent 5908475 and China Patent 201180052428.5. Other patents pending.

REFERENCES


The potential of bio-based insulation products to support indoor air quality and reduce aerosol transmissions of contagious respiratory viruses such as SARS CoV-2 in the construction industry

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1. INTRODUCTION

The aerosols in which the SARS CoV-2 is present are much lighter than the vapour and can therefore easily be absorbed in it. "Fennelly (2020)". SARS CoV-2 and other respiratory viruses present in it can be absorbed along with the water reducing the risk of contamination.

Due to their properties, the biobased materials can absorb water vapour containing aerosols. "Heruc & Koster & Heeren (2021)". Therefore the possibility of presence of the malign pathogen concentrations (Like SARS-CoV-2) in respiratory fluids are less with buildings who are inside build with walls from biobased materials.

At the start of this year, our institute started a study, in collaboration with the Technical University of Eindhoven (F. Gauvin, M. Gourvennec) and HU University of Applied Science Utrecht, to investigate moisture transport in walls build from biobased materials. For this study TU Eindhoven carried out absorption tests on 7 biobased materials.

<table>
<thead>
<tr>
<th>Samples</th>
<th>Weight before [g]</th>
<th>Weight after [g]</th>
<th>Water uptake [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Falm</td>
<td>25.3</td>
<td>39.8</td>
<td>16.4321670</td>
</tr>
<tr>
<td>Hempiflax</td>
<td>26.7</td>
<td>154.8</td>
<td>80.192785</td>
</tr>
<tr>
<td>Hampetest</td>
<td>130.2</td>
<td>238.15</td>
<td>45.744498</td>
</tr>
<tr>
<td>Cork BD</td>
<td>38.34</td>
<td>45.23</td>
<td>15.233223</td>
</tr>
<tr>
<td>Cork MDF</td>
<td>51.78</td>
<td>56.1</td>
<td>7.70933476</td>
</tr>
<tr>
<td>MBC</td>
<td>78.7</td>
<td>154</td>
<td>48.0961036</td>
</tr>
<tr>
<td>Gramatherm</td>
<td>20.6</td>
<td>195.1</td>
<td>89.413121</td>
</tr>
</tbody>
</table>

Table 1. Weight measurements before and after the water absorption test (48h)

The table shows that the water uptake is between 7.7 and 89.4 % with Gramatherm (an insulation made from grass fibers and various herbs) showing the highest water uptake and therefore the highest potential contributor to a reduction of malign pathogen concentrations in indoor environments.

There are many factors that can affect health and absenteeism in the built environment. Factors affected by biobased materials are microbial risks, the Volatile Organic Compounds (VOC) as well as the formaldehyde emissions. The microbial risks can be significantly reduced with the right treatment. Research has identified that due to the carbon-based chemical makeup of biobased materials potential for VOC is increased. Further research is being proposed to investigate how well biobased materials can absorb VOCs as well as Formaldehyde. These aspects are deemed promising, further research is needed on the impact of these compounds on health. "Maskell., et al. (2015)".

Biobased insulation materials are currently more expensive than the fossil or mineral based materials “de Visser, van Wijk & van der Voort (2015)”. The link with absenteeism as well as productivity for businesses can be a significant contributor to the added value of biobased. For the city council of Venlo in the Netherlands, the positive effect their new building had on the employees’ health was rather unexpected. In the first year since the new building was taken into use, absenteeism of the staff fell by 2%. This resulted in cost savings which were about five times higher than the cost saved on energy usage “Koster & Schotenboer (2021)”. These anecdotal findings are confirmed by Milton, Glencross & Walters (2000), they studied 40 buildings with 3,700 employees and found that an increased airflow from 11-13 l/s/p to 23-25 l/s/p can reduce the CO2 values from 800-900 ppm to around 600 ppm. The short-term absenteeism was reduced from 4.9% to 3.2%, which is an absolute reduction of about 1.7% and a relative reduction of 35%.

The costs associated with sick leave are estimated to be $480 per employee per year “Milton, Glencross & Walters (2000)”. Increasing the ventilation levels to 23-25l/s/p can reduce the cost with approximately 35%. This comes down to a potential saving of around $165 per employee per year.

Productivity is another factor that has a relation with ventilation rates, the relation seems to be 1.7% increase of productivity for every doubling of the ventilation rate “Wargocki et al. (2000)".

Next to these indirect monetary benefits there is also the subjective or experiential benefit of healthy living. From a market research by the World Green Building...
Council (WGBC) it became clear that an average of 60% worldwide of the 15,000 respondents is willing to pay more for a healthy living environment. With 70% willingness this holds even stronger for people in the age groups of 20-29 and 60-69 “Alker, Malanca, Pottage & O’Brien. (2014)”.

2. CONCLUSIONS

Influenza type of viruses are responsible for half of the absenteeism. Reducing airborne viruses can have a relatively large impact on absenteeism. Our goal is to try to confirm the contribution of biobased vapour-open constructions reducing the contamination and hope that we can show that the biobased materials can reduce 1-2% of respiratory viruses which will be in the line of the study of “de Visser, van Wijk & van der Voort (2015)”. What will happen with the COVID-19 pandemic is currently unclear. It is clear that our life and work is changing. Continuous attention to ventilation and the risk associated with incorrect or insufficient ventilation remain crucial. This argues for a demand for carrying out integrated comfort and health analyzes during the design process of buildings. A good example of this is the IES-VE suite “Issa (2018)”. Where in addition to the currently usual daylight and energy simulation, ventilation analyzes must be added too. “Claessen & Meijer & Deijzen & Zha & van der Aa & Kift & Shaik (2020)”

In the context of SARS CoV-2 and other deadly viruses the ventilation analyzes in the future should request an approach that is adjusted to the assessed situation. The interplay between room layout, use of space. The ventilation concept must be integrally assessed and preferably tested in a way that is can be directly compared to earlier research.

An interesting idea for further air purification and conditioning could be Active Living Walls (ALW) and their operational principle. By ventilating the indoor air thru the inside structure of a wall, passive air conditioning could be accomplished according to “Pérez-Urrestarazu & Fernández-Calnero & Franco & Egea (2015)”. The described procedure also accelerates the moisture transport in the construction. Further research should be conducted to see if this effect is also achievable with biobased insulation materials.

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Characteristics of non-specific building-related symptoms

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SUMMARY
Non-specific building-related symptoms (NBRS) are common in the general population, calling for better understanding regarding characteristics for prevention and treatment. The present objective was to review the characteristics of NBRS with respect to basic aspects, symptoms and quality of life, and comorbidity. Among the findings, the review suggests that unmarried women with low education constitute a particular risk group for NBRS, and that it is common to have had NBRS for a long period. Symptoms considered to be typical for NBRS (general, mucosal and skin) are reported by 3-4% of the general population, and the impact on quality of life includes daily activities, harassing attitudes and consequences for working life. Comorbidity with NBRS includes other environmental intolerances, inflammatory diseases, functional somatic syndromes and psychiatric conditions. These characteristics imply that assessment for prevention and treatment should include the individual’s life situation and comorbid conditions in a broad sense.

INTRODUCTION
There is no universally accepted clinical definition for NBRS (occasionally called “sick-building syndrome”), but these are commonly referred to as health symptoms from the indoor air that are not caused by toxins, and show no organ pathology (Hodgson & Addorisiò, 2005). NBRS falls within the umbrella term symptoms associated with environmental factors (Haanes et al., 2020). NBRS is a challenging condition since the symptoms may not be specific to a certain pollutant, may occur in buildings in which only minor or no deficiencies are found, and may be resistant to extensive building renovation.

NBRS is a common health problem in the general population. For example, in a Swedish and Finnish adult population-based study 1.3 and 1.4%, respectively, reported having a physician-based diagnosis of NBRS, and 4.8 and 7.2%, respectively, reported being bothered more than normal or having NBRS-related symptoms (Karvala et al., 2018a).

Based on the scientific literature, the objectives of the present paper was to characterize NBRS with respect to (i) basic aspects, (ii) symptoms and quality of life, and (iii) comorbidity.
had changed workplace to cope with their NBRS, and 20% drew disability pension due to persistent symptoms (Edvardsson et al., 2008).

NBRS is likely to share underlying mechanisms with chemical intolerance (e.g., multiple chemical sensitivity) due to considerable overlap in prevalence and trigger factors (Palmquist et al., 2014; Claeson et al., 2018b), suggesting that quality of life in NBRS may be similar to that of chemical intolerance. Hence, being limited in participating in society, having difficulties with housing conditions, being socially isolated and dependent on significant others, as reported in chemical intolerance (Gibson et al., 1996; Ternestedt-Hasséus et al., 2007; Larsson & Mårtensson, 2009; Skovbjerg et al., 2009; Gibson, 2010; Söderholm et al., 2011) may also be the case in persons with NBRS.

COMORBIDITY

Persons with NBRS, compared to those without NBRS, are more likely to perceive their general health as poor (Karvala et al., 2018b), which partly may be due to comorbidity. Comorbidity, or overlap in prevalence, can be viewed from two perspectives: how common it is in the population to suffer from more than one health condition, and how prevalent other conditions are in a subsample with the specific condition. Regarding the first perspective, results from a Swedish population-based study showed that (i) 2.8, 0.8 and 1.1% had both self-reported NBRS and self-reported intolerance to chemicals, electromagnetic fields, and sounds, respectively, (ii) 1.1% had at least two of these intolerances in addition to NBRS, and (iii) 0.2% also had all three intolerances. Corresponding comorbidities from the second perspective were 58.2, 15.8, 23.0, 23.0 and 3.6% among those with NBRS (Palmquist et al., 2014). This suggests very large comorbidity in NBRS with other environmental intolerances.

In a similar vein, 2.1% of the general population have been found to report both NBRS and a diagnosis of asthma and/or allergy, and that 43.0% of those with NBRS also report asthma and/or allergy (Lind et al., 2017). In addition to allergic asthma, allergic rhinitis and non-allergic asthma, the comorbidity includes other inflammatory diseases such as chronic sinusitis and chronic obstructive pulmonary disease (Claeson et al., 2018a).

Comorbidity among persons with NBRS in the general population has also been reported regarding diagnoses of functional somatic syndromes (fibromyalgia, irritable bowel syndrome, migraine and tinnitus) and psychiatric conditions (anxiety, depression and exhaustion syndrome; Karvala et al., 2018b). However, whereas a bidirectional causal relation between NBRS and these diagnoses appears reasonable, this remains to be addressed in future research.

CONCLUSIONS

- Persons in the general population with NBRS are more likely to be unmarried, be of female sex, and having had the condition for a long period, and close to half of them have sought medical care for NBRS.
- In the general population 3-4% show typical symptoms of NBRS, and inflammatory symptoms are particularly common.
- Impact of NBRS on quality of life include various daily activities, harassing attitudes and consequences for working life, such as sick-listing, change of workplace and disability pension.
- NBRS shows large comorbidity with other environmental intolerances, asthma/allergy and other inflammatory diseases, functional somatic syndromes and psychiatric conditions.

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Possible mechanisms underlying non-specific building-related symptoms

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SUMMARY
Non-specific building-related symptoms (NBRS) can be referred to health symptoms from the indoor air that are not caused by toxins, showing no organ pathology. The consequences of NBRS for the afflicted individual and society calls for preventive and therapeutic measures, which should be based on mechanisms underlying NBRS. The objective of this paper is to provide a brief overview of theoretical and empirical support for protective psychobiological mechanisms that may underlie NBRS. These mechanisms are neural sensitization, neurogenic inflammation, classical conditioning, symptom misattribution and somatosensory amplification, and nocebo.

INTRODUCTION
NBRS (occasionally called "sick-building syndrome") is commonly referred to as health symptoms from the indoor air that are not caused by toxins, and show no organ pathology. Apart from the suffering of the afflicted individual, its high prevalence in the population and impact on working life (Edvardsson et al., 2008; Karvala et al., 2018) result in very high costs for society (Mendell et al., 2002). NBRS constitutes a challenge to practitioners since the symptoms may not be specific to a certain pollutant, may occur in buildings in which only minor or no deficiencies are found, and may be resistant to extensive building renovation.

Prevention and treatment of NBRS should rest on its underlying mechanisms. Based on the scientific literature, the present objective is to describe such possible mechanism for which there is theoretical and empirical support. These mechanisms are protective and psychobiological in nature and include (i) neural sensitization, (ii) neurogenic inflammation, (iii) classical conditioning, (iv) symptom misattribution and somatosensory amplification, and (v) nocebo. These mechanism are further described in Nordin (2020).

NEURAL SENSITIZATION

Neural sensitization is a neural-based response amplification in which a cellular receptor becomes more likely to respond to a stimulus. There are several types, of which central sensitization, and in particular kindling are relevant for understanding NBRS.

Central sensitization

In central sensitization nociceptive neurons in the dorsal horns of the spinal cord become sensitized by peripheral tissue damage or inflammation (Ji et al., 2003). This may result in altered sensory processing, malfunctioning of descending inhibitory mechanisms, increased activity of descending facilitatory pathways and temporal summation of sensory stimuli. Accordingly patients with chemical intolerance have shown secondary hyperalgesia after intradermal injection of pain-inducing capsaicin (Tran et al., 2013).

Kindling

In kindling, repeated stimulation of neurons in the limbic system leads to response amplification and lowered threshold for activation. According to the olfactory-limbic model of kindling (Bell et al., 1992), time-dependent sensitization of CNS pathways follow repeated, low-level exposure to environmental chemicals, regulating attention, memory, emotions and somatic function. There is reason to believe that the rostral anterior cingulate cortex plays an important role in this context as it regulates amygdala-dependent fear conditioned learning that may result in sensitization in other brain regions.

Sensitization may also take place at a cognitive-emotional level due to sustained attention and cognitive bias (Eriksen & Ursin, 2004). This may result in lack of habituation to a stimulus, which is a form of non-associative learning that counteracts sensitization. Apart from empirical support from animal models (Sorg et al., 1996), several prerequisites for olfactory-limbic kindling have been met according to human studies. This includes belief among the afflicted of the exposure being hazardous (Bailer et al., 2008), cognitive bias and sensitization or lack of habituation (Andersson et al., 2009, 2017) and cross-sensitization (Palmquist et al., 2014; Karvala et al., 2018).

NEUROGENIC INFLAMMATION

The most common symptoms in NBRS result from basic protective mechanisms against the exposure: reducing intake of it (e.g. nasal congestion and asthma), expelling the exposure (e.g. sneezing and coughing), encourage avoidance of the exposure (e.g. mucosal irritation and headache), and encouraging recovery (e.g. fatigue). These symptoms have in common that they are caused by inflammation as a result of substances interpreted as threats, and thus acting as stressors. The CNS interacts with the immune system with neuropeptides, neurohormones and neurotransmitters, which, in turn, feed back to the CNS to induce sickness responses such as symptoms. In neurogenic
inflammatory somatic and autonomic nerves containing inflammatory neuropeptides cause a local inflammatory reaction in response to external and internal stressors.

Inflammatory neuropeptides (e.g. substance P) are involved in nociceptive pathways and autonomic afferents, and are released in response to nontoxic levels of chemical irritants that activate C-fibers as part of the chemosomatotransient system, with nociceptors in the nasal mucosa, oral cavity, cornea and throat (Meggs, 2017). These pungent, stinging and burning sensations trigger protective physiological reflexes, making the individual alert for danger. Practically all chemical substances can activate the chemosomatotransient system if sufficient in concentration. Neurogenic inflammation may lead to remodeling (Yilmaz & Yuksel, 2016) in which lowering the threshold for chemical reactivity causes hyperreactivity to chemical irritants. Various mechanisms involving neurogenic inflammation are described below.

**Neurogenic switching, ANS activation and axon reflex**

In allergy, immunologic switching explains why exposure to an allergen in one tissue causes inflammation in another part of the body (e.g. allergy causing rhinitis). A corresponding mechanism, neurogenic switching, may be taking place in NBRS. Here, the afferent signal in the chemosomatotransient C-fiber, evoked by chemical irritants (e.g. in the nasal cavity), prolongs to the CNS, releasing neuropeptides at a second site, producing inflammation (Meggs, 1995).

Chemical irritants may also elicit symptoms through the ANS due to efferent signals from the CNS activating the sympathetic and parasympathetic systems (Bascom et al., 1997). C-fiber stimulation with chemical irritants may also initiate a peripheral axon reflex, releasing neuropeptides and thus inflammatory symptoms (McKay & Bienenstock, 1994).

**Allergens and chemical irritants in interaction**

NBRS and allergy show overlap in symptoms, trigger factors and comorbidity, and these two causes of inflammation have been suggested to be flip sides of the same coin. In an allergic reaction histamine release can bind to the chemosomatotransient C-fibers, a process called cross-over network, resulting in neurogenic inflammation (Meggs, 2017). In another type of cross-over, release of substance P caused by chemical irritants results in an immunological inflammation (Cavagnaro & Lewis, 1989). These networks may explain the overlap in NBRS with allergy, and partly perhaps also its comorbidity with functional somatic syndromes.

**Psychosocial stressors and chemical irritants in interaction**

Psychosocial stressors are commonly reported in NBRS (Hedge et al., 1996; Lu et al., 2017). Importantly, psychosocial factors can also cause neurogenic inflammation, involving higher cortical areas relayed through the limbic system, projecting to the hypothalamus. Such pathways include (i) the hypothalamic–pituitary–adrenal axis, (ii) the sympathetic nervous system, and (iii) stimulation of neuronal growth and alteration in neuropeptide and neurotrophin expression (Hunter et al., 2013). Here, inflammatory mediators are released by stress hormones (e.g. catecholamines, growth hormone and corticosteroids). One may speculate as to whether lowering of the threshold for chemical reactivity (remodeling) caused by neurogenic inflammation due to chemical exposure may be enhanced by neurogenic inflammation caused by psychosocial stress.

**CLASSICAL CONDITIONING**

Classical conditioning is a form of associative learning in which a conditioned stimulus (e.g. an odor) is paired with an unconditioned stimulus (e.g. a stressor) that elicits a response (e.g. symptom) until the conditioned stimulus alone is sufficient to elicit a conditioned response (e.g. the symptom).

Olfaction is particularly prone to classical conditioning since only one pairing of an odor with an unconditioned stimulus is needed to develop conditioning. As for asthma, fear conditioning is likely to play an important role in NBRS, and there is compelling evidence for classical conditioning underlying NBRS (Van den Bergh et al., 2001).

Generalization of the initial conditioned stimulus (e.g. mold odor) may cause other stimuli (e.g. odor from furniture textile or visual stimuli in the building) to be conditioned. This may explain why symptoms can continue to be attributed to a specific building even after considerable reconstruction.

**SYMPTOM MISATTRIBUTION AND SOMATOSENSORY AMPLIFICATION**

**Symptom misattribution**

In conditions of ill-health we attempt to determine whether the symptoms are attributable to a specific illness. Such attributions are strongly affected by media reports and the Internet (Faasse et al., 2012), and may contribute to misattribution. Notably, health impact of environmental exposures reported by media and the Internet almost always convey negative messages, and such messages have been shown to lead to symptom misattribution (e.g. Witthöft & Rubin, 2013). A systematic review shows that it is the odor and visual perception of mold that predominantly contributes to mold being a risk factor for asthma (Mendell et al., 2011). This is not surprising since odorous and visual indicators, together with symptoms, are those factors that most commonly make people aware of poor air quality (Bickerstaff & Walker, 2001), thereby paving the way for attribution, and possibly misattribution. Notably, at least one common NBRS symptom is
present on a weekly basis by 96% of the general population (Petrie et al., 2014), making these symptoms available for (mis)attribution.

**Somatosensory amplification**

Stress-induced physiological arousal may in persons sensitive to threat result in symptoms and enhance misattribution of normal bodily sensations to causes of ill-health, and also increase attention to the body. The attention, in turn, will lower the threshold for perceiving bodily sensations, enhancing further misattribution (Barsky & Wyshak, 1990). Anxious persons constitute a particular risk group since they tend to attend automatically and preferentially to threat information, and since anxiety is associated with increased risk of persistent intolerance to chemical exposure (Skovbjerg et al., 2015).

**NOCEBO**

Nocebo is a mechanism opposite to placebo in that it is based on negative rather than positive expectations. It is highly relevant for NBRS when there are expectations of the indoor air being hazardous. Nocebo induces anticipatory anxiety, which activates the hypothalamus-pituitary-adrenal axis and the cholecystokinin system (Enck et al., 2008), contributing to symptom elicitation. The strongest predictors of a nocebo effect are perceiving high dose of the exposure, explicit suggestions that the exposure triggers arousal or symptoms, observing others experiencing symptoms from the exposure, and high expectations of symptoms (Webster et al., 2016).

A systematic review of provocation studies with active and sham substances suggest that evoked symptoms may not be due to the chemical exposure per se, but to expectations and prior beliefs (Das-Munshi et al., 2006). The nocebo effect is associated with activation of the anterior cingulate cortex, prefrontal cortex and insula (Enck et al., 2008), which together with related regions constitute a “salience network,” that is activated in person with chemical intolerance when exposed to chemo-sensory stimuli (Andersson et al., 2017).

Further support for a nocebo effect being a possible mechanism in NBRS comes from epidemiological studies of health effects from nontoxic odorous air pollution (e.g. Claeson et al., 2013). In line with this, results from well-controlled exposure studies show that informing healthy participants that the chemical exposure is potentially hazardous results in symptoms (Dalton, 2002; Andersson et al., 2013).

**DETERMINING THE MECHANISMS**

How can the practitioner get an idea of possible underlying mechanism without testing the individual that would require a well-controlled laboratory setting with specialized instrumentation and considerable time? Below are some suggestions that the practitioner may have use of when investigating cases of NBRS. It is important to bear in mind that each mechanism is not exclusive in NBRS. In fact, the mechanisms may instead enhance each other, and additional conditions may interact as well.

As noted, cross-sensitization is a common phenomenon of neural sensitization. Hence, if the afflicted person experiences other forms of functional somatic syndromes (conditions without identifiable organic cause) this may be indicative of neural sensitization. Symptoms such as nasal congestion and asthma (reducing intake of the exposure), sneezing and coughing (expelling the exposure), mucosal irritation and headache (encourage avoidance of the exposure) and fatigue (encouraging recovery) may indicate neurogenic inflammation, although, importantly, these symptoms may have other etiologies.

As mentioned, generalization of the initial exposure in the indoor environment may cause other stimuli to be conditioned through classical conditioning. This mechanism may explain situations in which symptoms continue to be attributed to a specific building, even after considerable reconstruction.

A discussion with the afflicted individual may be fruitful regarding (i) symptomatology prior to onset of the NBRS, (ii) anxiety, and (iii) beliefs and attitudes regarding the specific indoor environment at hand. Symptoms being present in the afflicted individual prior to the developed NBRS may be a sign of symptom misattribution, and high level of anxiety may have contributed to somatosensory amplification. If the individual’s beliefs and attitudes imply that the environment is perceived as hazardous, and if there is no reason to believe that the environment is toxic, it may suggest nocebo as an underlying mechanism. Then again, these indices should be considered as indices of the mechanisms rather than as evidence.

**CONCLUSIONS**

- Two types of neural sensitization may underlie NBRS: central sensitization (nociceptive neurons in the dorsal horns of the spinal cord becoming sensitized by peripheral tissue damage or inflammation) and olfactory-limbic kindling (time-dependent sensitization of CNS pathways from repeated, low-level exposure to environmental chemicals, regulating attention, memory, emotions and somatic function).
- Various mechanisms involving neurogenic inflammation may explain NBRS, including neurogenic switching, ANS activation, axon reflex, allergens and chemical irritants in interaction as well as psychosocial stressors and chemical irritants in interaction.
- Other protective mechanisms that may contribute to NBRS are (i) classical conditioning (a form of associative learning), (ii) symptom misattribution, (iii) somatosensory amplification (bodily sensations enhanced by attention to the body), and (iv) nocebo (effect of negative expectations).
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Development of an underground space using to produced cold energy in summer conditions in the building thermal conditions performance

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ABSTRACT
The aim of this numerical work is the application of underground spaces and Dual Skin Facades (DSF) to improve comfort conditions in a virtual chamber. This virtual chamber, similar to a real experimental chamber, is equipped with an underground space and three DSF installed in front of windows located in the southern surroundings. A numerical model that simulates the Building Dynamic Response is used. This model considers an energy and mass balance integral equations system used to estimate the air temperature and the mass of contaminants inside the virtual chamber and DSF and the temperature in the different elements of the virtual chamber and DSF. The evolution of the air temperature of the virtual chamber, DSF and spaces are obtained and indoor air quality and thermal comfort level are evaluated. The indoor air quality level is acceptable and the thermal comfort level is acceptable according to the international standards recommendations.

INTRODUCTION
DSF is a constructive technique applied to buildings, consisting of two glazed surfaces with an air cavity between them. The air in this space can be ventilated in a natural, mechanical or hybrid way. DSFs are often used to ventilate interior spaces in buildings. More details and some applications can be seen in the works of Poizaris (2004) and Ghaffarianhoseini et al. (2016).

In order to evaluate the indoor air quality and the thermal comfort a numerical model, which simulates the building dynamic thermal response, is used. The carbon dioxide (CO₂) concentration is used in the indoor air quality evaluation (Conceição et al., 2008a). The CO₂ release by the people can be used as reference of indoor air quality in occupied spaces, as was demonstrated in the work of Asif et al. (2018). The Predicted Mean Vote (PMV) index and the Predicted Percentage of Dissatisfied (PPD) index are used to assess the occupants thermal comfort level in spaces aclimated by HVAC systems (ISO 7730:2015). The thermal comfort level and the local thermal discomfort were evaluated in detail in the work of Conceição et al. (2010), in the application in ventilated spaces.

The building thermal response numerical model used in this work numerical simulations was developed by the authors over the last years. As example, the work of Conceição et al. (2000) presents some of the coefficients applied in the numerical model, and the work of Conceição & Lúcio (2010) presents all equations of the numerical model. This numerical model uses heat and mass transfer coefficients by convection to assess the thermal phenomena that occur in buildings. For example, it was applied in buildings thermal response for different orientations of the building (Conceição & Lúcio, 2009), for buildings with internal greenhouses (Conceição et al., 2008), for buildings with control based on preferred temperature (Conceição et al., 2009) or PMV index (Conceição et al., 2018).

When ventilation indoor spaces, it is important to use technological solutions that are low energy consumption. The use of techniques that allow the use of energy stored in underground spaces to cool indoor spaces in summer conditions can contribute to this objective. A DSF system is also used to allow air to be renewed. In addition, each DSF has a Venetian-blind type that will function as a shading element. In this sense, this numerical work aims to present and evaluate a solution that uses this type of resources to improve the conditions of occupants’ thermal comfort and the indoor air quality in summer conditions. It is used an underground space and a virtual chamber with three DSF installed in front of the south-facing windows and four air isolated spaces adjacent to the DSF. The thermal comfort and indoor air quality conditions will be evaluated by a whole building dynamic thermal response numerical model.

MODELS AND MATERIALS
This numerical work uses a building thermal dynamic response research software based on a system of first order integral balance equations. More details can be seen in the works of Conceição et al. (2000) and Conceição & Lúcio (2010). The validation of this software was done for summer and winter conditions, respectively, in the works of Conceição & Lúcio (2006) and Conceição et al. (2004).

The system of first order integral equations that defines the energy balance in transitory conditions is
used to estimate the air temperature inside the spaces (virtual chamber and DSF) and the temperature in the different elements of the virtual chamber and DSF, namely, Venetian blinds, transparent glasses, opaque (door, walls, ceiling) and interior (seats, table) bodies. The system of first order integral equations that defines the mass balance in transitory conditions is used to estimate the concentration of water vapor and contaminants (as the CO$_2$ concentration) inside the DSF and the virtual chamber.

These equations consider the conduction, convection, evaporation, and radiation phenomena. Dimensionless coefficients are used to calculate the heat transfer by natural, forced, and mixed convection. Incident solar radiation, solar radiation absorbed by glass and transmitted through glass are taken into account in the determination of the heat exchanges by radiation.

The studied virtual chamber is presented in Figure 1. The virtual chamber is 4.50 m long, 2.55 m wide and 2.50 m high. It was built in wood and insulated with extruded polystyrene with a thickness of 40 mm. In the south-facing surroundings, three DSFs were installed in front of the windows and below the virtual chamber an underground space was created (Figure 2). In the space adjacent to the DSF and in order to fill the entire southern façade of the chamber, closed spaces were created in order to operate as insulation. In each DSF, a Venetian blind type was installed which, in summer conditions, will be used as a shading device, thus limiting the entry of solar radiation into the virtual chamber and the heating of the interior space. During occupancy, the DSF will also allow the heated air to be extracted from inside the virtual chamber to the outside environment.

The underground space has the same dimensions of the virtual chamber and it will be used to cool the air to be supplied into the virtual chamber. The dimensions of each DSF are 0.6 m long, 2.50 m high and 0.2 m wide. It is constituted by two transparent surfaces (glasses) 4 mm thickness. In the air cavity located between the 2 glasses is placed an adjustable set of 24 Venetian blind. Each Venetian blind has an average thickness of 10 mm, 0.60 m long and 0.12 m wide. The air cavity space has a width of 0.12 m.

The virtual chamber is occupied by 2 persons between 8 a.m. and 12 a.m. and between 2 p.m. and 6 p.m. In the calculus of the PMV index, it was used a metabolic rate of 1.2 met and a clothing insulation level of 0.5 clo (typical average value for summer conditions).

The simulation was carried out for six days considering clean sky and the external conditions (air temperature, air relative humidity, wind velocity and wind direction) obtained experimentally during a typical summer day by a weather station located in the region. The outdoor air temperature varies between 21.1°C, obtained during the night, and 34.8°C, obtained in the afternoon. The outdoor air relative humidity varies between 31.8% and 72.0%. The wind velocity varies between 0.5 m/s and 6.4 m/s during the day. When presenting the results, only the last 24 hours of the simulation are considered.

In this work, two cases were numerically simulated:

- Case A, taken as a reference, in which only the virtual chamber is occupied and a usual mixed ventilation system is used;
- Case B, where the occupied virtual chamber has the proposed solution implemented, a combination of a DSF system with the use of an underground space as a source of cooled air to supply the mixed ventilation system.

For these cases, the airflow rates used in the numerical simulations are as follows:

- Case A, during occupancy, an air change rate of 0.0194 m$^3$/s, a value recommended by the standards for 2 persons; during non-occupation, 1 air change rate;
• Case B, during occupancy, an air change rate of 0.0194 m$^3$/s, a value recommended by the standards for 2 persons; during non-occupation, 6 air change rate during night and 1 air change rate during lunch time.

Cross ventilation, with an airflow rate of 6 air change rate, is used at night to cool the underground space and the interior surfaces of the virtual chamber.

**RESULTS AND DISCUSSION**

In this point the results obtained for indoor air quality, indoor air temperature, and PMV index are presented and discussed. The results are obtained for a typical summer day conditions and for the two situations mentioned above (Case A and Case B).

**Indoor air quality**

The evolution of CO$_2$ concentration in the virtual chamber was obtained for two situations under study: Case A and Case B. The results show that during occupancy, in both situations, the indoor air quality is acceptable due to CO$_2$ concentration values below 1800 mg/m$^3$, a limit defined by the ASHRAE 62.1:2016 standard. Therefore, the airflow rate used in the ventilation system is adequate.

**Indoor air temperature**

In Figure 3 the evolution of the mean indoor air temperature in the virtual chamber is presented for two situations under study: Case A and Case B. In the same Figure 4, the evolution of temperature in the underground space and outside are also presented.

Table 1 shows the minimum and maximum air temperature values obtained in the various spaces analysed, outside and inside the virtual chamber for the two situations studied (Case A and Case B).

<table>
<thead>
<tr>
<th>Location</th>
<th>Minimum air temperature (°C)</th>
<th>Maximum air temperature (°C)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Outside</td>
<td>26.7</td>
<td>34.8</td>
</tr>
<tr>
<td>Indoor (Case A)</td>
<td>28.1</td>
<td>32.8</td>
</tr>
<tr>
<td>Indoor (Case B)</td>
<td>26.5</td>
<td>30.3</td>
</tr>
<tr>
<td>Underground space</td>
<td>26.2</td>
<td>30.1</td>
</tr>
<tr>
<td>Insulated air space</td>
<td>27.2</td>
<td>39.3</td>
</tr>
<tr>
<td>DSF</td>
<td>27.0</td>
<td>47.4</td>
</tr>
</tbody>
</table>

During the period between 8 a.m. and 6 p.m., the air temperature in the underground space is lower than the outside air temperature, on average, of 3.25°C. The difference between these temperatures is most significant from noon. When using the proposed ventilation system (Case B), the air temperature inside the chamber decreases by an average of 2.42°C, compared to the situation in which the current ventilation system (Case A) is used. This decrease, on average, is slightly greater in the afternoon than in the morning (2.52°C vs. 2.27°C), because the air temperature outside is higher in the afternoon than in the morning.

In fact, the results show that the proposed system contributes to the air temperature inside the virtual chamber decreasing during the occupation period to values below to the outside air temperature. Thus, it allows a better adaptation of the occupants to the interior environmental conditions by reducing the impact of the difference between exterior and interior air temperatures perceived by people regarding their thermal comfort conditions.

**PMV index**

In the assessment of thermal comfort perceived by the occupants, the PMV index is used. In Figure 4 the evolution of the average PMV index in the virtual chamber is presented for two situations under study: Case A and Case B. Note that the average value of PMV index depends, in terms of environmental parameters, on the average values of indoor air velocity, indoor air temperature, indoor air relative humidity and Mean Radiant Temperature, obtained at each time interval. During occupancy, on average, the indoor air velocity is 0.41 m/s for both Cases, the indoor air temperature is 31.6°C for Case A and 29.3°C for Case B, the indoor air relative humidity is 41.7% for Case A and 50.1% for Case B, and Mean Radiant Temperature is 29.2°C for Case A and 27.3°C for Case B.

During the period between 8 a.m. and 6 p.m., the air temperature in the underground space is lower than the outside air temperature, on average, of 3.25°C. The difference between these temperatures is most significant from noon. When using the proposed ventilation system (Case B), the air temperature inside the chamber decreases by an average of 2.42°C, compared to the situation in which the current ventilation system (Case A) is used. This decrease, on average, is slightly greater in the afternoon than in the morning (2.52°C vs. 2.27°C), because the air temperature outside is higher in the afternoon than in the morning.
In the situation where a current ventilation system (Case A) is used, during occupancy, the level of thermal comfort of the occupants is not acceptable due to positive values of the PMV index (PMV > 0.7) (ISO 7730: 2005). With the use of the proposed system (Case B), the level of thermal comfort improves, on average, 31.4% in relation to Case A, between 24.5% in the late afternoon and 44.3% in the early morning. The improvement is sufficient to place the level of thermal comfort, given by the PMV index, at least within the category C (ISO 7730: 2005) during almost all occupancy, except between 4 p.m. and 6 p.m., although it was situated close by.

CONCLUSIONS
In this numerical work, an underground space combined with a DSF system were applied in the improvement of the comfort conditions inside a virtual chamber. This solution was compared with the use of a conventional ventilation system in order to assess its impact on the conditions of thermal comfort and air quality obtained inside the virtual chamber occupied with two virtual occupants.

Whereas the study was developed for summer conditions, using the proposed solution, the results obtained allow us to conclude the following:

- The level of indoor air quality is acceptable for CO₂ concentration values below 1800 mg/m³;  
- The air temperature inside the virtual chamber decreases, on average, 2.42°C;  
- The PMV index improves, on average, 31.4%, being sufficient to obtain an acceptable level of thermal comfort according to Category C (ISO 7730: 2005) almost all occupancy.

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CFD simulation of non-isothermal ventilation flow in a generic enclosure: Impact of inlet velocity boundary conditions

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SUMMARY

When aiming for an accurate simulation of indoor ventilation flows with buoyancy effects and a complex air supply system geometry, the settings at the inlet boundaries can have a significant influence on the resulting flow field and temperature distribution. To investigate the impact of inlet velocity boundary conditions on indoor airflow simulation results, computational fluid dynamics (CFD) simulations of non-isothermal ventilation flow in a generic enclosure are performed in this study. Three different methods of generating inlet velocity boundary quantities from the experimental data are tested, i.e., (1) uniform quantities, (2) fitting profiles, and (3) prescribing values.

Simulation results demonstrate that for the definition of the velocity at the inlet, only the last method, i.e. using available experimental data to prescribe detailed values at the inlet, can provide a good agreement between numerical results and experimental results throughout the studied enclosure. It is recommended that for future CFD validation studies, the measured data near the air supply opening, if available, is directly applied as the inlet boundary conditions, especially when the geometry of air supply system is complex.

EXPERIMENTAL SETUP

A benchmark experiment for non-isothermal jet developing near the ceiling in a thermally controlled room was presented by Gresse et al. (2020). Measurement data files are available in Mendeley database under the DOI 10.17632/hp2cx64vw6.1. The dimensions of the experimental room are shown in Figure 1.

In this study, CFD simulations of non-isothermal ventilation flow in a generic enclosure are performed. A high-quality indoor ventilation experiment from the literature, with detailed information of all relevant parameters near the air supply openings, is used to find the proper settings of inlet velocity boundary conditions. Three different methods of generating velocity boundary quantities from the experimental data are tested, which are the methods of (1) uniform quantities, (2) fitting profiles, and (3) prescribing values.

INTRODUCTION

Computational fluid dynamics (CFD) simulations are widely used to predict indoor airflow in enclosed spaces (e.g. Li and Nielsen, 2011; Nielsen, 2015). It is well-known that CFD simulation results can be sensitive to many computational parameters and settings (Chen and Srebric, 2002; Kang et al., 2018; van Hooff et al., 2018). In most past studies, due to the absence of experimental data at air supply openings or for the sake of simplification, uniform hypotheses of inlet boundary conditions (e.g. Susin et al., 2009; van Hooff et al., 2013; Kobayashi et al., 2017; Kosutova et al., 2018) or air jet relations (e.g. Huo et al., 2000) for velocity, temperature, and turbulence parameters were commonly applied. However, when aiming for an accurate simulation of indoor ventilation flows uniform or jet-relation settings at the inlet boundaries can be insufficient, even with a highly accurate simulation approach such as large eddy simulation (LES).

In their experiments, air temperature, velocity and turbulence quantities over the vertical central plane were measured using temperature probes and a hot-wire anemometer. The resolution of temperature probes was ±0.4 °C, and the resolution of the anemometer is ±0.5 m/s. The experimental boundary conditions are shown in Table 1. The measured mean inlet velocity is 1.19 m/s and the maximum inlet velocity is 1.52 m/s. The scenario of cold air supply is used in this study to validate the simulation results. The temperature
difference between the inlet and the internal wall surfaces is around -8.3°C. The corresponding Archimede number is -0.014, and the Reynolds number is 11,760 (Gresse et al., 2020), which implies the room airflow is in a fully turbulent regime.

Table 1 Experimental conditions of the non-isothermal test

<table>
<thead>
<tr>
<th>Maximum inlet velocity (U_{\text{max}})</th>
<th>Inlet temperature (T_0)</th>
<th>Internal mean surface temperature</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.52 m/s</td>
<td>12.7°C</td>
<td>Inlet wall 22.6°C</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Others Around 21°C</td>
</tr>
</tbody>
</table>

NUMERICAL MODEL

Computational geometry and grid
A generic enclosure from the experiment of Gresse et al. (2020) is used as the simulation object in this study. Room geometry and the locations of CFD inlet and outlet are illustrated in Figure 1. The computational grid consists of 6.65 million cells and is based on a grid-sensitivity analysis, which is not shown here for the sake of brevity. The maximum dimensionless wall distance \((y^*)\) is equal to 3.7.

Boundary conditions
Since the ventilation flow in the room space is of most concern, air supply and outlet system are not explicitly modeled in this study. The wall temperatures, as shown in Table 1, are adopted in the CFD simulations. In many past studies, uniform inlet velocity or jet relation was commonly used for indoor airflow simulation. Thus in this study, Three different methods of generating inlet velocity boundary conditions from the experimental data are tested, i.e. (1) uniform quantities, (2) fitting profiles, and (3) prescribing values from the experimental data in the vicinity of the inlet opening. To fit the inlet velocity profiles to the measurement data, an exponential relationship is used.

Solver settings
A series of steady Reynolds-averaged Navier-Stokes (RANS) simulations are performed using the SST \(k-\omega\) turbulence model (Menter, 1994). The Boussinesq approximation is used for buoyancy. The Coupled algorithm (ANSYS Inc, 2017) is used to couple pressure and velocity. The discretization schemes used for all variables except the pressure term is the second-order upwind scheme. For pressure, a staggered scheme called PRESTO! (ANSYS Inc, 2017) is applied. Convergence is assumed to be reached when the scaled residuals levelled off and monitored air temperatures and velocities became constant.

RESULTS & DISCUSSION
Figure 2 shows the simulation results of dimensionless velocity magnitude \((U/U_{\text{max}})\) and dimensionless air temperature \(((T-T_0)/T_0)\) along five vertical lines in the vertical center plane. Since the air supply from the inlet opening is more than 7°C colder than the mean air temperature in the room (20.1°C), air flows downwards in the room space due to buoyancy effects. However, when a uniform velocity or a fitting profile of velocity is used for the inlet boundary condition, the locations of maximum velocity magnitude or the minimum temperature for the profiles from \(X = 1.0\) m to \(X = 2.2\) m are much higher than the experimental results, which indicates the underestimation of the negative vertical velocity component. For the same non-isothermal room airflow experiments, similar simulation results (i.e., underestimation of downward flow) were also obtained by Kuznik et al. (2006, 2007).

In contrast, the prescribing-value method for inlet velocities provides the best agreement both for the velocity and air temperature. Only minor deviations can be observed for velocity magnitude along the second and third vertical line in the area below the maximum value for the velocity and minimum value for the air temperature.

In the study of simplified numerical models for complex air supply diffusers (Srebric and Chen, 2002), it was also found that flat velocity profile for the tiny box method, namely uniform velocity profile used in this study, cannot accurately predict the jet flow in room space. Therefore, measured velocity profiles are recommended to be used for the inlet velocity boundary conditions in the indoor simulations.

CONCLUSIONS
- For the definition of the velocity at the inlet, only the last method, i.e., using available experimental data to prescribe detailed values at the inlet, can provide a good agreement between numerical results and experimental results throughout the studied enclosure in this particular case.
- Measured data near the air supply opening, if available, is recommended to be directly applied as the inlet velocity boundary conditions in the CFD simulation of indoor airflow, especially when the geometry of the air supply system is complex or the flow is non-isothermal.
- If detailed measurement data of inlet conditions is not available in validation studies, care should be taken when drawing conclusions on, for example, the performance of turbulence models and other solver settings.
Figure 2. Simulation results at five profiles in the vertical central plane. (a) Dimensionless velocity magnitude and (b) dimensionless air temperature.

ACKNOWLEDGEMENTS
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INCHEM-Py: A new open source model for investigating indoor air chemistry

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SUMMARY

The new open source INdoor CHEMical model (INCHEM-Py) has been created to give indoor air researchers the ability to gain deeper insight into the chemical processes that occur indoors. The mechanisms and methods employed have been in development for the past 15 years with the model having previously been of limited accessibility due to its reliance on expensive proprietary software. This short paper will briefly describe the construction of INCHEM-Py, including assumptions made, and give examples of usage. We look forward to working with the indoor air chemistry community on the collaborative development of this software.

INTRODUCTION

INCHEM-Py is a python refactor and development of the internationally recognised INdoor Detailed Chemical Model (INDCM) (Carslaw, 2007). It is an open source and accessible 1D box model that examines the complex air chemistry of indoor environments. A unique element in this model is the incorporation of an explicit chemical mechanism that considers the step by step degradation of around 150 common volatile organic compounds. The model also considers indoor photolysis (combination of attenuated outdoor plus artificial lighting), exchange with outdoor air, and emissions from/deposition to surfaces. The chemical detail allows users to understand key reaction pathways and identify the species that accumulate to high concentrations for a range of conditions that are commonly encountered indoors.

INCHEM-Py takes the Master Chemical Mechanism (MCM) (Jenkin et al. [1997, 2003], Saunders et al. [2003], and two further gas chemistry input files; a compilation of indoor relevant mechanisms developed over the past 15 years to investigate indoor events, and a custom input file for users to develop and test their own mechanisms. These are parsed into the model and formed into a series of stiff and highly coupled first order Ordinary Differential Equations (ODEs), generalised for the concentration (C) of species i in equation 1. The Jacobian of the system is also calculated to improve integration times.

\[
\frac{dC_i}{dt} = \sum_{j=1}^{n} R_{ij} + (\lambda_r C_{i,\text{out}} - \lambda_r C) - \nu_d \left( \frac{A}{V} \right) C
\]

The chemical mechanisms are represented with the first term in equation as a sum of all the reactions with species i. Each equation also gains terms representing indoor/outdoor exchange (second term) and surface deposition (third term). All species within the model are assumed to egress with a specified air exchange rate (\(\lambda_r\)), some species with constant or diurnal outdoor concentrations (\(C_{i,\text{out}}\)) also ingress at the same rate. Some species are also assumed to irreversibly deposit on to surfaces with a specified individual deposition velocity (\(\nu_d\)) given the surface area to volume ratio (A/V) of the simulated space. Indoor emissions are not applicable to all species they can be set in the input mechanism files. The full chemical mechanism solved by INCHEM-Py, before any additional user mechanisms are added, includes over 6000 species and over 19000 reactions.

Photolysis is dealt with using calculated rates 1 m from multiple indoor light sources and attenuation factors of sunlight through different glass types. The solar photolysis outdoors is calculated following a two-stream model from Hough (1988), calculations of the indoor source rates and glass attenuation factors are detailed in Wang and Carslaw (2021). Users choose an indoor light type (Incandescent, Halogen, LED, and a range of fluorescent sources), the times at which the lights are on or off, and a glass type to attenuate sunlight (a standard glass transmitting light down to 315 nm, a low emission glass (cut-off at 330 nm), or a low emission glass with a reflective film (cut-off at 380 nm)) allowing a wide range of scenarios to be simulated. Alternative attenuation factors can be added by users.

Both the outdoor concentrations and the photolysis rates depend on time. In order to maintain this for any location on the surface of the Earth the model uses local solar time to both run the model and provide outputs. The date and latitude of the simulation are required as inputs to calculate the solar zenith angle. Some outdoor species concentrations are provided from sample locations (London, Milan, and Bergen) which are fits of averaged measurements.
from July to September 2018 taken from the [European Environment Agency (2021)](https://aqportal.discomap.eea.europa.eu/products/data-download/download-e1a-e2a-for-previous-year/) and from [Carslaw et al. (2015)](https://dx.doi.org/10.1021/acs.est.5b02241). Adding further diurnal outdoor concentrations is also possible and instructions are given with the manual provided with the software.

Initial species concentrations are set either manually through a text file or automatically using the output of a previous model run. No conservation methods are used and the model will reach an equilibrium state rapidly after initialisation. Other inputs required from the user are the temperature (K), the relative humidity (%), and the number density of air (molecules cm$^{-3}$).

Additional to any surface emissions that occur for the duration of the simulation, the model also accepts emissions for a shorter duration. Emissions of species can be defined with a rate (molecule cm$^{-3}$ s$^{-1}$), a start time (s) and an end time (s). This allows for short term indoor events, such as cooking or cleaning, to be simulated.

INCHEM-Py outputs concentrations (molecule cm$^{-3}$) for all species that are integrated, photolysis rates (s$^{-1}$), summations of concentrations such as peroxy radicals (molecule cm$^{-3}$), and also reactivity (s$^{-1}$) and production rates (molecule cm$^{-3}$ s$^{-1}$) of species are included. Copies of input settings and mechanisms are also saved alongside the system of ODEs and the Jacobian for future analysis and model validation.

**CONCLUSIONS**

Due to the nature of open source models, INCHEM-Py provides a solid base for future work in the indoor air community, for users of all abilities. Confident users can edit the model to run their own tailored scenarios, but there is also the option to use pre-set scenarios for which only slight modifications are required. As an open source model, no process within INCHEM-Py is hidden and users are able to fully understand how the outputs are created. We also hope that users will make or suggest future improvements, so INCHEM-Py continues to evolve into the future to meet user demands. We look forward to continuing our collaboration with a growing community of indoor air scientists, nurturing a collaborative model development environment.

**ACKNOWLEDGMENTS**

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**REFERENCES**


Identification of most important factors affecting indoor photolysis rates

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ABSTRACT
This paper investigates the impacts of different artificial lights, glass composition, cloudiness, time of year and latitude on indoor photolysis rates and hence predicted indoor air pollutant concentrations. The results show that predicted hydroxyl radical concentrations are most sensitive to changes in these factors, varying by up to 142% depending on the input conditions. The concentrations of NO and O₃ vary by between 19-56%, whilst other species such as NO₂ and HCHO vary by less than 10%. The most important determinant was found to be the cut-off wavelength of the glass in the window, followed by the level of cloudiness outdoors, the time of year and the location on the planet. These controlling factors are discussed, as well as their impacts on indoor air chemistry.

INTRODUCTION
The importance of photolysis for outdoor air chemistry is well established, but the role of indoor photolysis is less well studied and hence quantified. Although photolysis is diminished indoors (e.g. by glass in windows and coverings on light sources), it still occurs, particularly for reactions that occur at longer wavelengths. This means that it is possible to form radicals indoors and also potentially harmful secondary pollutants. It is therefore important to study indoor photolysis and its impacts. Indoor photolysis can occur both via artificial lights and also by attenuated sunlight that can move into indoor environments through windows and skylights. The amount of light that can penetrate indoors is influenced by many factors, including the type of window, the meteorological conditions and the building direction and location. Blocquet et al. (2018) used both modelling and experimental tools to research the spatial and spectral distribution and intensity of indoor sunlight, which passed from outdoors through windows. This study indicated that the type of glass was the primary factor that influenced the amount of transmitted light and the cut-off wavelength of that light. Different types of window will have consequent impacts on indoor photolysis rates, as atmospheric species (whether indoors or outdoors) absorb light at different wavelengths with differing efficiencies. Furthermore, the intensity of indoor natural light is influenced by the sky condition and time of day and year (Blocquet et al., 2018).

The contribution of artificial light to overall photolysis indoors depends on the location of the light within the room, the geometry of the room and the type of light. A recent paper by Kowal et al. (2017) measured the intensity and wavelength dependence of several different light sources (halogen; incandescent; compact fluorescent lamps; covered or uncovered fluorescent tubes; LED; and attenuated sunlight). The results demonstrated that it was possible for significant production of radical species such as hydroperoxyl (HO₂) and hydroxyl (OH), particularly for uncovered fluorescent lights bulbs. For instance, HONO (nitrous acid) and HCHO (formaldehyde) were both photolyzed by uncovered fluorescent lights to form OH (photolysis rates between 10⁶ and 10⁷ molecules/cm³/s) and HO₂ (photolysis rates around 10⁴ molecules/cm³/s) respectively (Kowal et al., 2017). The study also showed that the production rate was influenced by the distance from the source.

The aim of this paper is to investigate the impacts of cloud, latitude, season, window material and artificial light on indoor air chemistry. The specific objectives are to:
- Investigate how cloud conditions affect concentrations of the key indoor species.
- Investigate the impacts on indoor air chemistry as the latitude changes.
- Investigate the impact of different seasons on the concentration of key indoor species.
- Investigate the effects of different types of window materials on photolysis rates.
- Explore the influence of 2 distances to 7 different indoor artificial lights on indoor air chemistry.

METHOD
The model used in this study is the INDCM (INdoor air Detailed Chemical box Model), which has been described in previous studies (Carslaw, 2007; Carslaw et al., 2012; Kruza et al., 2017). It is a detailed chemical box model, with a chemical scheme based on a comprehensive chemical mechanism (the Master Chemical Mechanism, MCM v3.2, http://mcm.leeds.ac.uk/MCM/). This chemical mechanism includes around 20,000 reactions and 5,000 species, representing the near-explicit degradation of ~ 143 VOCs (volatile organic compounds) in the gas-phase (jenkin et al., 1997; Jenkin et al., 2003; Saunders et al., 2003; Bloss et al,
The reaction of each VOC with OH, NO\textsubscript{2} and O\textsubscript{3} and photolysis where relevant, is considered as the first step in the oxidation chain. The products generated from the first step undergo further reactions, until the final oxidation products of CO\textsubscript{2} and H\textsubscript{2}O are formed. Additional reactions describe surface loss by deposition, emission rates of VOCs, partitioning between indoor gas and particle phases, and exchange of species with outdoors (Carslaw, 2007; Carslaw et al., 2012).

In the original model, the INDCM assumed flat transmission of light in the UV and visible wavelength ranges, with only one type of indoor lighting (incandescent) assumed. The previous model also assumed that 3% of UV and 10% of visible light from outdoors passed through the windows and ended up indoors. However, recent studies have found that different artificial lights have unique spectral characteristics (Kowal et al., 2017) and the transmission of outdoor light will vary depending on the window type (Blocquet et al., 2018).

The model was therefore updated to incorporate this new information. The photolysis rate coefficients for the 35 species and for 7 different indoor artificial lights (1 m away and adjacent to the light sources) were calculated, whilst transmission factors for the same species for three different window glasses with very different cut-off wavelengths (‘Glass C Sacht Self-cleaning’ (transmission from 315-700 nm), ‘Low Emissivity’ (transmission from 330-700 nm) and ‘Low Emissivity With Film’ (transmission from 380-700 nm) based on Blocquet et al. (2018)) were also calculated.

For the simulations investigating the impact of latitude on model results, indoor lighting was assumed to be off and the overall photolysis rate coefficients were based on attenuated sunlight only and calculated between 0 and 65°. For all model simulations, the outdoor daily average concentrations of NO, NO\textsubscript{2} and O\textsubscript{3} were 6.2, 15.0 and 22.9 ppb respectively and assumed to be the same for all times of the year and at all latitudes.

**RESULTS & DISCUSSION**

Figure 1 shows the differences in predicted OH concentrations before and after the model update for indoor artificial lights. The profiles of OH exhibit higher concentrations for UFT lights, then FT lighting, followed by the old model representation and then the other light sources. The new photolysis coefficients for O\textsubscript{3} and HONO are approximately 5.0 and 1.8 times higher than that with the old representation for UFT and FT respectively and consequently, there is a more pronounced effect on radical production.

Figure 2 shows the concentrations of OH between 0° and 65°N for June 21\textsuperscript{st} and December 21\textsuperscript{st} for the case with no internal lighting. In winter (December 21\textsuperscript{st}), the maximum concentrations of OH decrease as the latitude increases, owing to more sunlight at the Equator. In summer, more sunlight reaches the Earth’s surface, leading to smaller differences in concentrations of key indoor species. Peak concentrations of OH are highest at mid latitudes (between 30°N and 40°N). This is due to the combination of daylight hours and amount of sunlight maximizing at these latitudes to produce favourable photolysis rates and hence OH concentrations.

**CONCLUSIONS**

In summary, window material (glass type) was found to have the highest impacts on the vast majority of studied key chemicals, whilst artificial lights had the lowest impacts. The level of cloudiness and time of year were also important for most of the chemicals.

In addition, the greatest impacts from variations in these controlling factors were found for OH (141.9% average difference from the baseline), followed by NO (55.6% average difference from the baseline) and then H\textsubscript{2}O\textsubscript{2} (27.9% average difference from the baseline) and O\textsubscript{3} (19.2% average difference from the baseline). There were relatively small impacts on RO\textsubscript{2} (10.1% average difference from the baseline) and HONO (6.9% average difference from the baseline), whilst those for NO\textsubscript{2} and HCHO were less than 5%. Concentrations of NO\textsubscript{2} and HCHO were determined by other factors, such as exchange rate, deposition rate and outdoor concentrations.
REFERENCES


Figure 2. Concentrations of OH at equator (0°), 10°N, 20°N, 30°N, 40°N, 50°N, 60°N and 65°N with no internal lighting for from left to right, the 21st of June and December respectively.
**INTRODUCTION**

Uncontained combustion events generate fire and flue gases and particles that will affect the indoor environment at home. Even if you manage to extinguish before the building is completely damaged, such substances will still be present, however in smaller amounts. These substances and particles can adhere to porous materials such as furniture, textiles, plasterboard, insulation, wood and more and will remain in the indoor environment for a long time.

Modern homes are well equipped with electronics, various plastics and synthetics that may release toxic compounds when burned. Such particles and gases produced from combustion not only cause unpleasant indoor odors but is also likely to be harmful to human health during permanent or prolonged exposure. The exposure to fire, soot, and smoke can be a serious incidence for anyone, but can also contribute to aggravating existing illnesses and ailments in vulnerable groups.

Targeted and well-planned measures, such as cleaning and vacuuming, may in some cases be useful for restoring the damaged site. However, in many cases a partial or even total rebuild of the affected areas must take place. This involves almost every damaged surface and underlying structures to be removed and rebuilt, as the soot, particles, and flue gases affect too much of the building's construction and inventory.

A steady public demand for counseling related to fire, soot or smoke damaged homes.

The national and publicly available counseling service "Rådgivningstjenesten" is hosted and administered by The Norwegian Asthma and Allergy association (Norges Astma- og Allergiforbund, NAAF). This is a government funded counseling service that offers free advice and guidance to the public as well as members of the organization on topics covered by NAAF. The service is open four days a week, whereas one day a week is dedicated to indoor environment counseling, a specific field receiving approximately 40-50 inquiries per month.

Over a decade NAAF has received many inquiries from people experiencing their homes being damaged by fire, soot, and smoke. Various ailments often follow in conjunction to the damages. For some, the problems emerge after the damages of their residence has been repaired. Other inquirers are in the beginning of the process of having their homes restored and seeks guidance to ensure that the best choices are made. Those who reach out to NAAF are often individuals or representatives of family members with special needs.

The publicly available information online on relevant topics is fragmented or very specialized towards fields such as law, insurance and building renovation, and the user threshold can be considered somewhat high.

As the problems reported to NAAF have stayed consistent over time, a need for a user-friendly guide bringing all these terms together in a more populistic framework have emerged. Through funding from the Dam Foundation, NAAF has developed a catalogue of resources available in Norwegian language under the title: "Veileder ved brann-/sot-/røykskader for sårbare grupper". For practical reasons, this title is translated in an English express and abbreviation: **Fire related Damages with Attention to Vulnerable Groups – FireDAVG**.

**FireDAVG** offers guidance to people, and vulnerable groups affected by fire / smoke / soot injuries in their own homes as well as provision of neutral advice and
tips on how they can achieve a smooth and productive process related to such issues. FireDAVG can be found online at: https://naaf.no/brannveileder.

METHODS
Structuring and compiling the information in FireDAVG.

A project group has worked on retrieval, sorting, and interpretation of information on the various topics according to the three main areas for targeted user situation described in further detail later. Along with the retrieval and writing process several relevant parties were consulted and involved in discussing the various topics. To compile the preparatory advice for FireDAVG, several public national resources were used as they provide established and concise information e.g. Norwegian Fire Protection Association, The National Federation of House Owners in Norway and The Tenancy Organization. Chapters related to utilizing standards or renovation principles in the renovation works were also included, e.g. NS 3515:2021, a national standard addressing handling of water damages in buildings (to be released in 2021), and the principles behind Clean Dry Building, RIF (2007), addressing the importance of systematic cleaning in building processes. Only a condensed and non-exhaustive list of resources used in FireDAVG is presented here, as FireDAVG may be subject to future updates and changes.

The writing process also benefited experiences from the counseling service exploring real-life situation counseling on topics relevant for the project. Prior to the final compilation of the FireDAVG, the authors interacted with homeowners, which kindly contributed to the project with valuable real-life data. Two representative cases are described below.

Case 1.

A homeowner in a home damaged by soot filed an insurance claim which was executed with repairs according to the appraiser. The family experienced various ailments after the repairs had been made. Filing complaints did not result in additional repairs being offered. In response to the rejection of the complaint, a private initiative was made where several of the affected walls and roofs were torn down. This revealed significant amounts of additional soot deposits behind as well as embedded into the torn down materials. A larger section of the house needed rebuilding than estimated by the appraiser in the initial insurance claim. The homeowner engaged an advocate that took the case further to insurance discretion, resulting in almost full compensation of the extended repairs. However, the family spent over 1.5 years on this process before the house was sufficiently repaired and habitable. NAAF interacted with the family via the counseling service at various points over the course of time.

Case 2.

A homeowner experienced a forced reverse flow of smoke and soot through the chimney during a storm, largely affecting the living room and ground floor. The family's child (kindergarten age) was diagnosed with asthma and suffered ailments soon after the incident and could therefore not stay in the home. The homeowner was resourceful and initiated several parallel dialogues with the insurance company and the various contractors involved in repairs and appraisal. An active dialogue with NAAF was established via the counseling service. However, soon after the initial attempt of repairs were made, when the family moved back in, the child's condition worsened. A pediatrician declared the house's state not yet suitable for the child to live in due to the child's clinical presentation. This resulted in a far more thorough renovation of the home ultimately resolving the family's situation.

The final structure of FireDAVG was implemented on NAAF's web pages.

The information has been compiled with the following structure targeted to the user situation and launched as part of NAAF's indoor climate web pages [1]:

1. Part one. Preparation prior to damage. Preparatory tips to avoid fire and tips to get a good and suitable overview of assets and your own life situation.

2. Part two. When damage has occurred. Tips and advice on how to maintain and communicate a factual and productive dialogue to achieve the best possible process and plan for the reconstruction of the home.

3. Part three. Post damage. Tips and advice for following up the work to be done. Complaints to works and important follow-up points. Tips are also given on realistic expectations for the final work and the limitations that lie in it. Any negative health responses should always be directed toward medical attention.

To almost every section, both an introduction to the topics or subtopics and an advice or tip are suggested. The range of the content is limited to the project description's aim and scope. Visitors to the website is invited to browse through these three main categories, and find advice and tips linked to the information or situation that is relevant to them.

RESULTS & DISCUSSION

FireDAVG is the result of NAAF identifying the need for a structured means of public information on fire, soot and smoke damages in homes. The desired primary effect is to better aid people in the search for information and counselling. The desired secondary effect is to reduce some of the resources allocated by NAAF on assisting the public on these relevant topics.

In the first part of FireDAVG, preparation is the key. This includes raising awareness of the importance of...
fire prevention strategies and drills as well as getting acquainted with the insurance policies, documenting user possessions as well as any special accommodations or installations that may be present in homes for those who live there. Photo documentation of user possessions as well as copies of important documents in secure online storage or the paper originals in bank deposit boxes are all examples of sound strategies to tell the insurance companies what is lost.

The second and third parts of FireDAVG is for those who experience fire related damages to their homes. These sections address damage control, restoration strategies and communication with professional parties involved in restoration of the building.

One key element in an insurance claim is the chain of events taking place from the point of damage to the point when insurance company engages various third parties involved in renovation events, which may ultimately be leading up to the desired end-result. If the specified tasks are insufficiently described, executed or not properly checked out, e.g. leading to complaints, the end-result cannot be expected to harmonize with the original order.

FireDAVG will also be able to contribute to increased attention to specifying and documenting health and quality focused choices, in conjunction with the damage restoration work. Some of the chapters point out that attention should be paid to the potentially harmful substances that may form during the fire damage process. There is a need to reach a common agreement and understanding of which materials can be saved and which materials must be replaced for the homes to be safe to live in again.

Who can use the online resource tool?

Private homeowners and tenants are the main targets. If fire, smoke of soot affects your home, there are numerous things that must be done to repair the damages. FireDAVG aims to assist with useful tips and sound advice. It is a main goal that private homeowners should be better prepared to communicate with the insurance companies and claims remediation companies and better identify and make responsible for the various parts involved, also including the homeowner. FireDAVG may be useful for other groups such as:

- Insurance customers with asthma, respiratory allergies, or other relevant diseases i.e. hypersensitivities in the airways.
- Representatives of building renovation companies.
- Other parties involved in the investigation and rehabilitation of damaged homes by fire and smoke.
- Public health coordinators - as supplement to their preventive health work.
- Municipalities and the municipalities' service centers.
- The fire service in all municipalities - guidance material for the injured party.
- GPs and other health professionals - as support to doctor-patient interaction with people who experience health problems after home renovation.

Determining the impact of FireDAVG.

The effects of FireDAVG have not yet been determined or accurately measured as this short paper was written close to the publishing date. Preliminary feedback, gained from a limited number of homeowners that have reached out to NAAF’s counseling service after the publishing date, indicate that the public have received the information well, and found the contents of FireDAVG useful. Future communications will give more insight into this.

It is expected that the primary group that utilize FireDAVG is people who already have experienced damages to their homes, and they will most likely be looking for the information found in parts two and three, primarily. However, it is necessary to present a comprehensive preparatory part, as many of the advice in part two and three depend on the level of preparedness and awareness that any given homeowner have reached.

FireDAVG is not a scientific work based on analysis and interpretation but is provided as a publicly available service. The content is offered in a systematic manner based on information that is relevant and available. In addition, relevant experiences and insights gained by NAAF from the counseling service on the various topics are used in fine-tuning the information. The intrinsic scientific value of FireDAVG is therefore low, but as a means of creating awareness and connecting various sources of knowledge together with the public demand for this type of information should raise FireDAVG’s socially beneficial value and impact.

FireDAVG is planned to remain as an online free resource and available to the public. Active means of marketing involves awareness created by NAAF public counselling service as well as directly targeted information to other interest organizations and news media that may share an interest in the topics covered by FireDAVG.

Awareness of FireDAVG’s existence will increase over time leading to more knowledge about how the public respond to it. It is therefore not yet possible to state if the tool is precise or comprehensive enough to help the targeted groups. Feedback is needed and sought after, and any adjustments or necessary additions may easily be accommodated or incorporated to ensure a good quality service.

Any plans to expand or develop FireDAVG further has not been established. However, NAAF will remain open.
to any suggestions or wishes for collaboration to develop FireDAVG further.

CONCLUSIONS
The project started with ambitions to fill a visible need by offering a broader and more concise advice in connection with fire, smoke, and soot damages in homes. The focus was to gather relevant advice and enhance such guidance towards vulnerable groups. The advice will also be universal for the general population, although the vulnerable groups will be expected to respond to a greater extent to problems in connection with repair / return of the scene of the accident. There is also an added value in making this guide available to other users in society who relate to the main target group’s issues, in which they can more easily and quickly be assisted if they become involved in such services. One of the key messages is to make the various users more responsible for their given tasks and duties, this includes the homeowner. Nevertheless, it is up to the individual users to contribute to a good and constructive dialogue to achieve the best solutions. There are many good opportunities to further develop FireDAVG. Damage remediation after a fire affects not only private individuals who are policyholders, but also those who offer insurance, companies that assess, analyze or repair damage, lawyers, advisers, municipalities and many more. Here, there are many opportunities to engage in interdisciplinary environments to create an even better service that can increase the accuracy and quality of what is related to fire prevention and damage remediation. A few remarks of the article include:

- Homeowners should keep an updated inventory of possessions and get properly acquainted with the layout and design of their properties.
- Understanding the insurance legal terms and duties when any damages occur may speed up most processes.
- Communication is key. Assist the insurance company and other third parties to keep them properly enlightened about your property and your situation. The homeowner knows the home and needs of the residents best in most cases.
- Ask for descriptions of any assignment or task planned for in the renovation process. Make complaints if the result does not match the description.
- The insurance companies do not always know if the services they coordinate through third parties deliver the promised results. Follow up and make complaints if the end results do not fit the description.

ACKNOWLEDGEMENTS
The project would like to thank everyone involved in the development of FireDAVG, and especially those who actively contributed with their real-life experiences in connection to the public counseling service.

FireDAVG is developed by NAAF with support from the DAM Foundation under project 2018/HE1-215438 and was launched online on 1 December 2020.

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SUMMARY
Management of allergic rhinitis, asthma, and atopic eczema can negatively affect a patient's life as the burden of symptoms are partly due to the urban environmental pollutants they are exposed to daily. Existing clinically advised environment modification studies have shown direct correlations in the suppression of air pollutants, using mechanical air filtering and home behavioral and sanitation practices, with the alleviation of allergic symptoms — but there is a lack of research on whether similar results can be achieved in a naturally ventilated indoor environment, which is more sustainable and economically accessible compared to the installation and maintenance of mechanical ventilation systems. The design of spatial elements, namely an air filtering building façade and a cross-ventilated space plan, as guided by architectural design practices and indoor air quality methods can be explored and then tested in a standard-sized dwelling unit using Computational Fluid Dynamic Simulations.

INTRODUCTION
An increase in prevalence of chronic allergic disorders allergic asthma, allergic rhinitis, and itching skin allergic disorder atop dermatitis is observed in the urbanized regions of Asia due to the rapid changes in the region's ambient air quality and environment. 25%-34.5% of Asian individuals are affected by one or more allergic disorders. This Asia-specific statistic is consistent with prevalence rates in the Philippines, where allergic rhinitis and asthma affect between 20-27.4% of Filipinos, while atop dermatitis continues to steadily gain new cases every year at an average growth of 3.7% in the city of Manila alone reported in Kim et al (2016). A published study from Song & Wong (2017) on the control measures and management practices of asthma in Asia notes the prevalence of asthma increasing with age, mostly associated with smoking, and notably, associations with urban residence, and exposure to occupational irritants. Asthma was shown to be more common in developed or urbanized regions of Asia such as Hong Kong, Japan, and Singapore in a survey from Strachan et al (1997). Low to middle-income countries in the Asian region such as the Philippines are significantly affected by air pollution due to large concentrations of traffic emissions, and a lack in more renewable sources of energy as traditional solid and fossil fuels widely used in the domestic unit and industrial hubs expel hazardous gases. 69% of the Philippines’ ambient air pollution in 2016 is attributed to vehicle emissions according to the Department of Environmental and Natural Resources DENR (2018), where 90% of which is concentrated in the country's urban capital Metro Manila. Increase in air pollution both ambient and indoor further exacerbate the symptoms and feed into the burden of allergic disorders, namely their economic burden, and the development of other chronic disorders such as anxiety and depression, according to a paper from Kankaanranta et al (2016). Patients in the Asia-Pacific region spend about 4,191 USD per person annually according to a 2015 survey on the economic burden of allergic disorders, with reduced productivity majorly contributing to the economic burden of respiratory diseases in the form of indirect cost, according to Ghosal et al (2016) Existing clinically advised environment modification case studies from Lee (2011) and Crain (2002) have shown direct correlations in the suppression of air pollutants using mechanical air filtering and home behavioral and sanitation practices with the alleviation of allergic symptoms. There is a lack of research on whether similar results can be achieved in a naturally ventilated indoor environment, which is more sustainable and economically accessible compared to the installation and maintenance of mechanical ventilation systems. A healthier, more controlled indoor environment inducing cleaner naturally ventilated air can be a solution to be explored through spatial and ventilation design of a unit modeled after a standard urban dwelling, which can then be tested of its air pollutant suppression abilities and natural airflow performance through Computational Fluid Dynamic (CFD) simulation. The designed elements with which the urban dwelling unit case study will be modified and then simulated with are namely; an air filtering façade and natural ventilation-focused space planning, following two of the three main methods for good indoor air quality in the book Modeling, Design, and Optimization of Net-Zero Energy Buildings by Athienitis & O’Brien (2015): (1) ventilation, and (2) filtration of contaminants.
METHODS

Combining field measurements with CFD simulations, this study followed two separate case studies. The first is a simulation study from Sarkar (2019) of natural ventilation in affordable residential units in Mumbai, India for optimization of indoor environmental quality, and the second is a study on green façade effects on thermal environment in transitional space by Hankun, Yiqiang, Florian, & Yao (2019). The air pollutants to be measured will be limited to particulate matter or dust (PM2.5, PM10), total volatile organic compounds (TVOCs), and carbon emissions (CO2e), as these are the most prominent controllable allergens in the Asia-Pacific Region aside from pet dander, roaches and mold reported in Tham, Lee, & Bever (2016). The main factors for comparison in the CFD simulations would be the air pollutant filtration and air velocity performance of the architectural design elements that will be added to modify the indoor air quality of a standard urban dwelling unit.

Field Measurements

Field measurements for both ambient air and indoor air pollutant samples of TVOCs, PM2.5 and PM10 were taken in a busy marketplace street location in the city of Angeles, Pampanga in the Philippines (coordinates 15.1391807, 120.5873175), using a handheld multifunction air quality detector (JBL-B600) during the traffic peak hours of 12pm and 4pm every day for 7 days from February 9 to February 15, 2021. Ambient air was measured at a pedestrian crossing, and indoor air was measured in an unused classroom in a technical school building directly adjacent to the ambient air sampling spot. Carbon emission data from the local area was taken separately by requesting an emissions inventory report from the Angeles City Disaster Reduction Management Office (ACDDRMO). Local wind velocity data for the week of February 9 to February 15 was also requested from the Philippine Atmospheric, Geophysical and Astronomical Services Administration (PAGASA), Clark Weather Station. The resulting air pollutant field measurements of TVOCs, PM2.5, PM10 and the existing local carbon emission data and the local mean wind velocity of 2.29 m/s were used as input data for the CFD simulations. Wind direction followed the assignment of wind “inlet” in the computational domain in the CFD, illustrated in Figure 3. Total mean values for each pollutant are recorded in Tables 1 and 2.

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>Indoor Air Mean Concentration</th>
<th>Ambient Air Mean Concentration</th>
</tr>
</thead>
<tbody>
<tr>
<td>PM2.5</td>
<td>3.4 µg/m³</td>
<td>11.4 µg/m³</td>
</tr>
<tr>
<td>PM10</td>
<td>7.2 µg/m³</td>
<td>17.1 µg/m³</td>
</tr>
<tr>
<td>TVOCs</td>
<td>0.262 mg/m³</td>
<td>0.554 mg/m³</td>
</tr>
</tbody>
</table>

Table 1 Field Measurement Results of PM2.5, PM10, TVOC Concentrations in Indoor and Ambient Air

Table 2 2017 Base Year Carbon Emissions from Mobile Sources in Angeles City from ACDDRMO

<table>
<thead>
<tr>
<th>Pollutant</th>
<th>2017 Base Year Emissions</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO2e (Carbon Emissions)</td>
<td>84,307.61 mt</td>
</tr>
</tbody>
</table>

3D Study Model Design

An actual sized (5.23 x 4.29 x 3.28 meters) 3d model of the unused classroom was generated using Rhino 3d modelling software and was used as the shelf for the urban dwelling unit study model, with an inlet opening measuring 2.50 x 1.46m and an existing outlet opening opposing the inlet positioned 2.10 meters from the floor measuring 2.97 x 0.30 m. Basic geometry to represent studio unit furniture such as a bed, mini-kitchen, and desk were placed in the model. A duplicate of the study model was then modified with a double-skin vertical green façade as advised in the case study by Hankun, Yiqiang, Florian, & Yao (2019) with green façade structure design referencing a separate case study by Yang (2018), both cases proving a green façade’s potential for passive cooling. This design decision was also made with reference to the case study by Pettit, Irga, & R. (2019) on an active green wall’s installment for reduction (72%) of TVOCs. A second filtration component was added to the façade in the form of layered metal mesh screens referencing the particulate matter filtering findings of layered metal mesh from Kawara (2016). The screens were designed as vertical louvers controllable by the user of the space at the window opening. The metal mesh screens follow a staggered square layout, assumed to be made up of two different sized aperture stainless steel meshes layered on top of each other. The first layer of mesh is assumed to have 1.2 µm sized apertures with wires of 0.6 µm in diameter, and the second layer of mesh is assumed to have 2.5 µm sized apertures with wires of 1.1 µm in diameter. A partition wall about 1.00 meter away from the window opening was also added in the interior space plan as a spatial boundary for the bed, as advised by the findings on partition walls in passive cooled dwelling units in the case study by from Sarkar (2019), it was further optimized in this study with diagonal louvers to direct air towards the unit’s natural air outlet. The modified unit’s air inlet was modified to be of floor to ceiling height to accommodate the metal mesh screen louvers measuring about 3.00m while the air outlet’s original height was enlarged by 0.20m. Both models are illustrated in Figure 1. All elements of the design were also guided by architectural ventilation design literature by Koch-Nielsen (2002) specifically in choosing the vertical orientation of the louvers and foliage grips on the green façade to induce accelerated air velocity, and in the positioning of elements such as the cavity between foliage and mesh screens and the partition wall to create “buffer zones” for air to circulate.
CFD Simulations

The cloud-based, OpenFOAM-based, simulation platform compatible with Rhino 3d modelling, Simscale was employed as the CFD simulation software. An incompressible-type simulation using the SIMPLE algorithm was created for each study model and set to use the RANS standard K-ԑ turbulence model to simulate the steady state natural ventilation of the unit as executed in Sarkar (2019). The study models were each enclosed in a computational domain measuring 72.68 x 42.20 x 17.4 meters with the model’s façade positioned about 8 meters away from the airflow inlet boundary, following CFD best practice guidelines by Frank (2007).

RESULTS & DISCUSSION

Natural Ventilation Performance

Indoor air velocity rates in the control model averaged below 0.9m/s, concentrated nearest the ceiling of the model observed in diagram CR1 of Table 3. Air velocity rates in the modified model remained in the same range as that of the control model’s with some values a little over 0.89m/s, represented by the cyan to green colored bands in diagram MR1 of Table 3. More evident changes are observed in the distribution of airflow in the modified model compared to the control model, which can be attributed to the intentionally modified factors such as the enlargement of the inlet opening height, positioning of vertical mesh screen louvers at the inlet, and the placement of the louvered or partition wall bordering the bed.

Pollutant Filtration

Air pollutants are assumed to be carried into the indoor environment through ambient airflow coming from the wind inlet face of the computational domain, thus they were assigned as 4 individual passive scalars in both simulations. The surface area of the bed (1.99 x 0.94m), positioned 1.20m from the window opening, was made as sample area for measuring the average flow rate of each pollutant concentration within the indoor environment. A consistent 95.64% decrease in the flow rate of each pollutant was measured in the indoor environment of the modified model, as compared to the control model. More concentrated pollutant flow is observed to be trapped in the spatial cavity between the partition wall and window opening in the modified model represented by the green colored bands in diagrams MR2 – MR5.
CONCLUSIONS

- The combination of cross-ventilation design with the use of vertical louvered design elements in the window façade and in partition walls within the plan can aid in distributing airflow throughout the space.
- Metal mesh screens and green façades are potentially feasible as practical dust filtering devices but is advised to be incorporated within a cross-ventilated or generally well ventilated system.
- 95.64% decrease in indoor air pollutants was measured in this study’s modified model using a double-skin green façade, metal mesh screens, and louvered partition wall.

RECOMMENDATIONS

- This study did not take other environmental factors such as thermal conditions or humidity into account, to place full focus on the filtration and transport of air pollutants in the indoor environment.
- The study would benefit from further iteration of the CFD simulations to reach convergence of the velocity values, as well as validation of the grid independence.
- The incorporation of a simulation to prove the carbon sequestering properties of the double skin green façade would appropriately supplement the goals of this study.
- The metal mesh screens could also benefit from a self-cleaning attachment or coating for ease of maintenance such as a rainwater catchment system or Titanium Dioxide coating.

ACKNOWLEDGEMENTS

This expanded abstract constitutes the main research portion of the author’s undergraduate thesis for the De La Salle – College of Saint Benilde, in partial fulfillment of the requirements for the degree of Bachelor of Science in Architecture. Provision of the air quality detector used in the study and mentorship is courtesy of DLS – CSB Architecture faculty member, Arch. Erika Vixeen Dia. The unaffiliated Philippine organizations PAGASA, ACDRRMO and DENR, solely aided in this study through their provision of air quality data, any options, other findings, and conclusions or recommendations expressed in this study are those of the authors and do not necessarily reflect the views of the aforementioned organizations or the school.

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Chemical characterization of ultrafine particles released from 3D printers

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SUMMARY
Previous studies have shown that desktop 3D printers (Fused Filament Fabrication) emit high numbers of particulate matter, mainly as ultrafine particles (UFP, particle diameter less than 100 nm). However, the chemical composition of emitted particles has been less extensively investigated. In this study, we therefore focused on the chemical composition of particles emitted from 3D printing. The measurements were conducted in a 1 m³ emission test chamber. Emitted particles were sampled by a 13-stage low-pressure cascade impactor onto aluminum foils and then analyzed by TD-GC/MS to identify their organic compounds. Nine commercial filaments made from basic polymers such as Acrylonitrile Butadiene Styrene (ABS), Acrylonitrile Styrene Acrylate (ASA), Polycarbonate (PC), Poly(methyl methacrylate) (PMMA), Nylon, High Performance Polystyrene (HIPS) and a copper-filled Polylactide (PLA) were investigated. The results show that the organic components of the particles are primarily plastic additives such as plasticizer, antioxidant agents, lubricants, UV-absorbers and UV-stabilizers from the filaments.

INTRODUCTION
In the past, many 3D printing emission studies focused on the quantification of UFP. Usually, quantitative measurands like PER (particle emission rate) or TP (total number of emitted particles) are determined from the particle number concentration and considering experimental conditions such as particle losses and air exchange rates in test chambers (see e.g. German ecolabel Blue Angel test guideline DE-UZ 205 and Seeger et al. (2018)). Only a few studies have conducted a chemical characterization of released particles, for instance Gu et al. (2019). The toxicological risks associated with exposure to particles are determined by the exposure level but also by the particle size distribution and chemical composition, which are all influenced by the source. The diversity of pristine or reprocessed filament basic polymers in combination with a plenitude of - in most cases unspecified - organic and inorganic additives such as dyes and fillers are huge, and the emission characteristic of a single filament product cannot be generalized. To properly evaluate potential health risks with 3D printing, it is necessary to investigate quantities (e.g. PER, TP) as well as chemical compositions of emissions from many filaments.

METHODS
All experiments were performed with the desktop 3D printer (Model Craftbot 2, CRAFTUNIQUE Kft., Hungary) which originally has a not airtight cover, which was for better comparability removed for the measurement. Nine commercial filaments made of diverse polymers and additives were tested using specific printer temperature settings (Table 1). In contrast to other studies, we decided to only extrude the filament instead of printing a 3D object in order to focus on the material dependency of the emissions. 800 nm of each filament was extruded with constant extrusion speed of 68 mm/min which results in extrusion durations of about 12 minutes. The heating phases varied due to filament-specific temperature settings as given in Table 1.

Table 1: Filament list

<table>
<thead>
<tr>
<th>Filament</th>
<th>Description; (analyzed particle sizes)*</th>
<th>T1</th>
<th>T2</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABS_1</td>
<td>Green ABS; (5 stages)</td>
<td>250</td>
<td>100</td>
</tr>
<tr>
<td>ABS_2</td>
<td>White ABS; (8 stages)</td>
<td>230</td>
<td>100</td>
</tr>
<tr>
<td>rABS</td>
<td>Recycled black ABS; (8 stages)</td>
<td>250</td>
<td>80</td>
</tr>
<tr>
<td>ASA</td>
<td>White ASA; (8 stages)</td>
<td>255</td>
<td>100</td>
</tr>
<tr>
<td>PC</td>
<td>White PC; (5 stages)</td>
<td>260</td>
<td>105</td>
</tr>
<tr>
<td>CF</td>
<td>Copper-filled PLA; (8 stages)</td>
<td>210</td>
<td>60</td>
</tr>
<tr>
<td>PMMA</td>
<td>Black PMMA; (5 stages)</td>
<td>240</td>
<td>100</td>
</tr>
<tr>
<td>Nylon</td>
<td>Transparent Nylon; (5 stages)</td>
<td>255</td>
<td>60</td>
</tr>
<tr>
<td>HIPS</td>
<td>Grey HIPS; (5 stages)</td>
<td>250</td>
<td>100</td>
</tr>
</tbody>
</table>

1 Applied extruder temperature in °C
2 Applied print bed temperature in °C
* see text below for further information on the size ranges

The measurements were conducted in a conditioned 1 m³ emission testing chamber (T=23°C ± 2 K, RH=50% ± 5% and air exchange rate=1 h⁻¹ ± 5%) which complies with the standard ISO 16000-9: 2012-11 and the DE-UZ 205 and ensures controlled condition

Emitted particles were sampled for one hour with a low-pressure cascade impactor (LPI, DLPI10™, Dekati LTD., Finland) at a sample rate of 10 L/min onto aluminum foils as substrates. The impactor has 13 stages with cut-points (D50) from 0.03 µm up to 10 µm. Only the lower five (D50: 0.03-0.27 µm) or eight stages (D50: 0.03-0.95 µm) with visible deposits were taken for the chemical analysis (see Table 1). The impacted particles were evaporated from the substrates by direct thermal desorption at 290°C for 5 min (TDS3
**RESULTS & DISCUSSION**

Identified organic particulate matter primarily consisted of plastic additives such as plasticizer, antioxidant agents, lubricants, UV-absorbers and UV-stabilizers (see Table 2). Moreover, two relevant precursors, bisphenol A (BPA) for the synthesis of polycarbonate and caprolactam for nylon synthesis, were detected. Bis(2-ethylhexyl) phthalate (DEHP) and bis(2-ethylhexyl) terephthalate are frequently detected plasticizers. It seems that these two are commonly used by filament manufacturers. DEHP and BPA are critical substances with endocrine disrupting properties and are toxic to reproduction according to REACH (Registration, Evaluation and Authorisation of Chemicals) which should be used with caution. The use of DEHP has been subjected to authorisation in the EU since 2015. A REACH limit value of 0.1 % by weight of the plasticized material is effective since 2020. Furthermore, polymer antioxidants such as Irganox 1076, and 2,4-di-tert-butylphenol were identified. Gu et al. (2019) found both substances in particle samples as well. Uvinul N 539 T is a UV-absorber and Tinuvin 770 a UV-stabilizer. UV-additives are often used to enhance the weather resistance for indoor and outdoor applications. The lubricant erucamide occurred in five filaments. Butyl stearate and oleamide were only detected once. Furthermore, hexadecanoic acid and octadecanoic acid were determined most frequently (6 out of 9 filaments). Hexadecanoic acid is a lubricant and octadecanoic acid is utilized as a heat stabilizer.

**CONCLUSIONS**

- Major identified organic compounds in airborne particles from FFF-3D printing are plastic additives and precursors including harmful substances such as DEHP and BPA.
- DEHP seems to be used frequently despite the obligation to obtain authorisation in the EU.
- Printing with filaments from same basis polymer, e.g. ABS, reveals non-uniform chemical compositions of particulate emissions.
- Investigations should provide a more comprehensive overview for a better risk assessment.

**ACKNOWLEDGEMENTS**

The German Federal Environmental Agency (UBA) is gratefully acknowledged for its financial support of the UFOPLAN project FKZ 3717622060.

**REFERENCES**


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**Table 2: Identified organic compounds in particulate emission from 3D printing**

<table>
<thead>
<tr>
<th>Application</th>
<th>Substrate [CAS Number]</th>
<th>ABS_1</th>
<th>ABS_2</th>
<th>rABS</th>
<th>ASA</th>
<th>PC</th>
<th>CF</th>
<th>PMMA</th>
<th>Nylon</th>
<th>HIPS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Precursor</td>
<td>Bisphenol A (BPA)[80-05-7]</td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Precursor</td>
<td>Caprolactam [105-60-2]</td>
<td></td>
<td></td>
<td>X</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasticizer</td>
<td>Bis[2-ethylhexyl] phthalate (DEHP)[117-81-7]</td>
<td>X</td>
<td>X</td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasticizer</td>
<td>Bis(2-ethylhexyl) terephthalate [6422-86-2]</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Plasticizer</td>
<td>Bis(2-ethylhexyl) adipate (DEHA)[103-23-1]</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
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<td></td>
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<tr>
<td>UV-stabilizer</td>
<td>Tinuvin 770 [52829-07-9]</td>
<td></td>
<td></td>
<td>X</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>UV-absorber</td>
<td>Uvinul N 539 T [6197-30-4]</td>
<td>X</td>
<td></td>
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<tr>
<td>Antioxidant</td>
<td>Irganox 1076 [2082-79-3]</td>
<td>X</td>
<td></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>Antioxidant</td>
<td>2,4-Di-tert-butylphenol [96-76-4]</td>
<td>X</td>
<td>X</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Lubricant</td>
<td>Butyl stearate [123-95-5]</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>Lubricant</td>
<td>Erucamide [301-02-0]</td>
<td>X</td>
<td>X</td>
<td>X</td>
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<tr>
<td>Lubricant</td>
<td>Hexadecanoic acid [57-10-3]</td>
<td>X</td>
<td>X</td>
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<td></td>
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</tr>
<tr>
<td>Lubricant</td>
<td>Octadecanoic acid [57-11-4]</td>
<td>X</td>
<td>X</td>
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<td>X</td>
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</tbody>
</table>

*Identified substances within the analyzed impactor stages are marked with an X*
Measurement and simulations of the influence of green wall systems on indoor air quality

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SUMMARY
To contribute to resource savings without sacrificing indoor air quality (IAQ) this study evaluates and compares the performance and interaction of a green wall and a heating, ventilation and air conditioning system (HVAC) inside a controlled real office environment.

The analysis was conducted using experiments and simulations. Effects on concentration of CO₂, volatile organic compounds (VOC), particulate matter (PM) of two sizes, relative humidity (RH) and temperature (T) were considered in the process.

The results show a strong effect of the green wall on VOC concentration, relative humidity and temperature. As the CO₂ degradation is small, the used green wall cannot serve as standalone solution but can contribute to IAQ and resource savings.

INTRODUCTION
The ventilation concept has a large influence on the IAQ and thus health. To ensure health, well-being and low resource demand, the influence of novel and alternative air conditioning systems need to be tested and optimised.

A new approach in research and industry is to embed plants into these systems. These new systems must also meet the technical requirements of building automation systems in order to be integrated in existing systems. Criteria and tools are needed for the comparison between different system configurations and to evaluate the efficiency of plant-based systems.

Research regarding plant-based systems developed from the investigation of the effects of individual potted plants to the evaluation of complex plant-based systems (Irga et al., 2018).

This paper continues this line of research by investigating the performance of green walls within a real-life office environment. The aim is to quantify the potential contribution of plant-based systems to resource savings and IAQ improvements in comparison to and in combination with conventional HVACs.

METHODS
To evaluate the potential of plant-based systems in human living and working environment, the performance of a green wall is examined in a real office environment.

The methodology involves both experimental testing and simulations based on the experimental results.

Experimental setup
The experimental setup consisted of an office room with mechanical ventilation, a green wall and a source of pollution as shown in Figure (1).

Figure (1). Schematic side view of the experimental setup

The room volume is 56 m³. Either a test person or a printer were used alternately as typical pollutant sources of an office environment (Karl-Josef Albers, 2017). The occupant serves as source of CO₂ and VOC (Fenske & Paulson, 1999; Liu et al., 2016) while the laser printer was used as PM source (HP Deutschland GmbH, 2020; S.C. Lee et al., 2001). The green wall tested, includes an automated watering and fan system, which increases the exchange between growth medium and indoor air (Naava, 2020).

The study design
IAQ is evaluated and represented by concentration of CO₂, VOC, particulate matter for 0.35-2.5 μm and 2.5-10 μm, relative humidity, and temperature. Based on the temporal behaviour for this set of parameters the
The time dependent behaviour of the IAQ parameter $c_{\text{eq}}$, the coefficient of change $k$ and the incoming concentration $c_{\text{in}}$

$$c_{\text{out}} = c_{\text{in}} \pm k \left( \mp c_{\text{in}} \pm c_{\text{eq}} \right) \quad (1)$$

The Equation can be applied to all IAQ parameters except the change of air temperature inside the green wall which is modelled according to the evaporation of the water:

$$T_{\text{out}} = T_{\text{in}} - \frac{h_{\text{evap}}(X_{\text{out}} - X_{\text{in}})}{c_p \cdot \text{Water} \cdot X_{\text{out}} + c_p \cdot \text{Air}} \quad (2)$$

where:

- $T_{\text{in}}$ and $T_{\text{out}}$ are the in- and outflow temperature [°C],
- $X_{\text{in}}$ and $X_{\text{out}}$ are the absolute humidities at in- an outflow [g/kg],
- $h_{\text{evap}}$ is the evaporation enthalpy of water [J/(kg·K)],
- $c_p$ is the heat capacity of water or air [J/kg·K].

**Model Parametrisation**

Based on the measured time series the model was parametrised and validated manually in an iterative process. The parametrisation is performed first for no ventilation, and afterwards for only green wall and only HVAC. The model including all ventilation systems is used to validate the interaction of the different systems by applying the beforehand evaluated parameters. The parametrisation allows to consider the influence of the different ventilation systems independently from each other.

## RESULTS AND DISCUSSION

### Indoor air quality:

Figure (2) shows experimental and simulation results for VOC. It serves as an example for parameterising the model according to the measurements. The VOC example is chosen as it has the largest deviations between measurement and model. The Figure clearly shows the effect of green walls on VOC concentration while simultaneously demonstrating the problems and complexity of measuring a sum of different VOC with only one sensor.
The simulated temporal course of the considered IAQ parameters and the four ventilation combinations are summarized in Figure 3 and 4.

![Figure 3. Simulation results for CO₂ and VOC, temperature (T) and relative humidity (RH)](image)

The experiment and the simulation show that the green wall has a supporting effect on humidification (Figure 3 upper left) and reduction of VOC (Figure 3 lower right). The effect of CO₂ reduction is small (Figure 3 lower left). For the two PM sizes in general a stronger filtering influence is shown on the bigger particle size (Figure 4).

![Figure 4. Simulation results for PM produced of the laser printer](image)

**Modelling**

A green wall model for Modelica was developed and is available in the Modelica AixLib library. This model enables the comparison of the resource efficiency for water and energy of the green wall with other building systems, to estimate its effects on the overall building resource demand.

**Resource consumption**

The energy and water demand of green wall and HVAC are compared for a scenario of 24 h including 8 h occupation time (See Table 2 and 3). The values of the green wall are based on measurements and extended by the equation of the power for evaporation of water $P_{\text{hum}}$ (Equation 3). The consumption of the HVAC is based on assumed boundary conditions for a winter day, Equation 3 and Equation 4 for the fan power $P_{\text{fan HVAC}}$.

$$P_{\text{hum}} = \dot{V}_{\text{water}} \cdot \rho_{\text{water}} \cdot h_{\text{evap}}$$

where:
- $\dot{V}_{\text{water}}$ is the volume flow of evaporated water [m³/h],
- $\rho_{\text{water}}$ is the density of water [kg/m³],
- $h_{\text{evap}}$ is the evaporation enthalpy of water [J/(kg K)].

$$P_{\text{fan HVAC}} = \frac{\dot{V} \cdot \Delta p}{\eta}$$

where:
- $\dot{V}$ is the air volume flow [m³/h],
- $\Delta p$ is the pressure difference over the fan [Pa],
- $\eta$ is the fan efficiency.

**Table 2. Electric consumption** (for the HVAC fan a pressure difference of 100 Pa is assumed)

<table>
<thead>
<tr>
<th>green wall</th>
<th>HVAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>$P_{\text{fan}}$ in W</td>
<td>3 (24 h)</td>
</tr>
<tr>
<td>$P_{\text{light}}$ in W</td>
<td>22 (15 h)</td>
</tr>
<tr>
<td>$P_{\text{pump}}$ in W</td>
<td>40 (7.5 min)</td>
</tr>
<tr>
<td>$P$ in W</td>
<td>17</td>
</tr>
</tbody>
</table>

**Table 3. Water and energy for humidification demand for 5 g/kg absolute outdoor humidity and 21 °C indoor temperature**

<table>
<thead>
<tr>
<th>green wall</th>
<th>HVAC</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\dot{V}$ air in $\frac{m^3}{h}$</td>
<td>50</td>
</tr>
<tr>
<td>$q_{\text{in}}$ in %</td>
<td>60</td>
</tr>
<tr>
<td>$\dot{V}_{\text{water}}$ in $\frac{kg}{h}$</td>
<td>0.18</td>
</tr>
<tr>
<td>$P_{\text{hum}}$ in W</td>
<td>124</td>
</tr>
<tr>
<td>$P_{\text{hum}}$ in W</td>
<td>124</td>
</tr>
</tbody>
</table>

The consumption of electric components of the green wall is higher due to additional lighting and water circulation. The highest amount of energy is used for humidification by evaporating water. For the HVAC energy and water demand are highly dependent on the volume flow. This means combining HVAC and green wall might lead to lower volume flows according to the air cleaning effects of the green wall. This might compensate for the higher consumption of electric components of the green wall or even save energy. Furthermore, it can be considered that the green wall draws the evaporation energy from the indoor air temperature, while a steam humidifier is working by boiling water using electricity.

**Limitations**

The setting of a real office environment offered on the one hand the opportunity to evaluate the green wall interaction under realistic conditions but on the other hand led to an under-determined setting for the model parametrisation. Therefore, the identified parameters of the models might not be fully representing the real behaviour and need to be further validated by more detailed experiments.

Furthermore, a better fit of parameters might be achieved by using an automatic calibration tool.
Concerning the choice of IAQ parameters, the high amount of parameters offers an overview over their temporal behaviour under similar conditions. However, this is achieved at the expense of a small number of measurements per combination of IAQ parameter and ventilation configuration, which results in high uncertainties when it comes to evaluating and comparing the performance of the ventilation configurations quantitatively.

The analysis of consumption is done for only one setting and includes only resource costs during operation. Therefore, an additional live cycle assessment could give a full picture on the consumption. In addition, the models could be used in a next step to figure out the most efficient combination of these different systems.

CONCLUSION

- This work comprised an experimental and a simulation part investigating the interactions between plant-based air conditioning systems and HVAC systems in an office environment.
- The experiments and models covered a wide range of IAQ parameters including CO₂, VOC, PM, humidity and temperature to evaluate the effects of different ventilation configurations on their temporal behaviour.
- The results point out the opportunity to enhance indoor air quality by using a green wall in addition to the HVAC. This effect especially relates to VOC and humidity. The small improvement of the CO₂ and PM concentrations by the green wall might prove to be significant with higher numbers of experimental runs or higher number of green walls.
- Due to its wide range of parameters, this model allows testing of how green walls can be used in different building and pollution situations.
- Furthermore, it would enable a model predictive integration of green walls into room automation systems.

ACKNOWLEDGMENTS

I would like to thank my colleagues of all involved institutes for the constructive comments and sharing their knowledge, as well as Naava and E.ON SE for providing equipment and expertise.

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Intrinsic dimension estimation as a tool to sensor selection for an indoor air quality multisensory system

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SUMMARY
To estimate the minimum number of sensors necessary in an indoor air quality monitor capable to discriminate hazardous volatile organic compounds (VOCs) an intrinsic dimension (ID) estimator was used. Considering the sensors as dimensions, ID estimators often find a smaller number of dimensions than the original number of sensors, indicating that some sensors provide redundant information. An ID estimator was applied to the signals collected by 45 commercial multi-sensor indoor air monitors (Rubix PODs) using 16 different sensors in 6 different situations in which 6 different gases were injected in the room in which the PODs were in. The resulting estimation was 3 dimensional, meaning that, for this experiment, 3 specific sensors would be enough to identify each of the 6 gases injected. This experiment, however, is very simple compared to what multisensory systems face during day-to-day use. More experiments in realistic scenarios should provide a better understanding of which sensors are really needed.

INTRODUCTION
One of the current trends on the study of Indoor Air Quality (IAQ) is to continuously monitor Indoor Air Pollution (IAP) in different possible environments, such as offices or homes (Tran, Park & Lee, 2020). Much research is being done in developing systems that are capable of detecting the target pollutants of IAQ while keeping them affordable (Saini, Dutta & Marques, 2020). The main cost of these systems are the sensors, and, as highly selective sensors have a higher price, the selected sensors tend to be cheaper but non-selective (Saini, Dutta & Marques, 2020b). The use of low-cost sensors creates the need to employ several different sensors to achieve a good degree of selectiveness and versatility (Feng et al., 2019). However, these sensors are selected often by the information provided by the manufacturer, which can be unreliable (Rackes, Ben-David & Waring, 2018), or by availability. This work proposes a tool to aid in the selection of sensors to be used in IAQ monitoring systems by estimating the Intrinsic Dimension (ID) of the sensors readings.

Intrinsic Dimension of sensors readings
Consider an IAQ monitoring system with number of sensors equals to D. When processing signals in this type of system, the number of sensors corresponds to its dimensionality (Hines, Llobet & Gardner, 1999), if the ID of these signals is estimated, the result approximates how many sensors provided significative information for the task they were exposed to (Camastra & Staiano, 2016; Bennet, 1969). As the sensors used in IAQ monitoring systems are, in general, non-selective and based on the same detection mechanism, it is very likely that two or more sensors provide the same kind of information or at least show some level of redundancy. Then, it is not unreasonable to expect that the ID estimated for these kinds of systems is a value d<D.

There are some methods of estimating ID, as it can be seen in (Camastra & Staiano, 2016), but the method selected to be used in this work was the one proposed by Grasberger & Procaccia (1986) with the implementation suggested in (Montalvão, Canuto & Miranda, 2020). This method was selected due to its versatility and facility to implement and understand. This technique was then applied to the results of a set of experiments to determine the minimum number of sensors necessary to identify certain types of gas, this experiment is described in the next section.

The experiment
45 commercial multi-sensor indoor air monitors (Rubix PODs) were grouped in a 12.5 m² room in which different gases were injected during several experiments. Each POD contained at least 16 different sensors to measure various sources of IAP and ambient parameters (temperature, humidity, etc.). The experiment that generated the dataset used in this work consisted in 6 different days in which each day a different gas was injected in the room at a designated concentration and for a given period of time. Then the gas was ejected from the room via an exhaust pipe. The PODs registered readings from the room during all experiments and saved the data for later processing.
An example of one of these readings is presented in Figure 1.

The gases injected were volatile organic compounds (VOCs) representative of IAP: acetaldehyde (283 ppb), acetone (128 ppb), ethanol (284 ppb), formaldehyde (400 ppb), limonene (880 ppb) and a mixture of 6 VOCs (acetaldehyde at 204 ppb, acetone at 108 ppb, ethanol at 125 ppb, formaldehyde at 64 ppb, limonene at 131 ppb and toluene at 113 ppb). These compounds have been selected for their ubiquity in indoor environments and/or for their sanitary impact and/or to represent typical indoor pollution activities.

After the experiment the resulting dataset was arranged in a way that made the six days of the experiment became a single large experiment, that is, the data was chained together. This made possible to evaluate the resulting dataset as a gas separation task.

The data from all the sensors were considered, and rescaled so its readings are between 0 and 1, this was done so the different scale of measurements did not affect the ID estimation. In Figure 1 it can be seen an example of the resulting process.

**Results and Discussion**

With the dataset pre-processed the ID estimation method was applied to it, resulting in a 3-dimensional ID. This meant that three ideal sources of signal would be enough to generate the signal produced by all 16 sensors present in the PODs during the experiments.

To determine what sensors influenced the most the ID estimation the following procedure was done: (i) one sensor would be removed from the dataset; (ii) the ID would be estimated again; (iii) if the resulting ID was lower, the sensor would be re-introduced to the dataset, if not, the sensor would be kept out of the dataset for the next steps. These steps three were repeated until no more sensors could be removed.

After doing this procedure, 4 sensors remained in the dataset, all of them were metal oxide semiconductor (MOX) gas sensors. This means that the essential information for the proposed task (gas separation) is contained in these 4 sensors. It is important to notice that these sensors do not yield independent signals, but they form the best subset of available signals that still yields the ID estimated with all sensors. Moreover, to have a visual representation of how the gases could be separated, the readings of the remaining sensors were plotted using each sensor as an axis.

Due to the 3-dimensional limitation of human vision only three sensors could be represented in each plot, so four different plots representing all possible combinations of the 4 sensors were made, the plot using sensors MOX1, MOX3 and MOX4 was the one that showed a higher degree of separation between gases, that is, groups of gases are farther apart as it can be seen in Figure 2. Because of that, those three sensors were considered sufficient to separate the different gases injected in this experiment.

**Conclusions**

The use of Intrinsic Dimension (ID) estimation was proposed as a tool to aid the selection of sensors for a given task (in this work, a gas separation task) in Indoor Air Quality (IAQ). Its use was illustrated by experiments using a commercial IAQ monitoring system in a 12.5m² room. The experiments showed that, by using only 3 of the 16 sensors, it is possible to separate different IAP gases in an experimental setup. On the other hand, to be able to do this task in a situation that is more representative of the day-to-day use of IAQ monitors, more experiments are need along with deeper study of the behavior of the sensors in the presence of IAP.

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**REFERENCES**


Big Data in IAQ research, an example of the application in IEA EBC Annex 86

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SUMMARY

In the IEA EBC annex 86 project, we are developing a classification/reporting guideline on IoT-data for energy efficient IAQ management strategies.

We are exploring the potential of the new generation of IoT connected devices (both standalone and embedded in eg. AHU's) for smart IAQ management. What can we learn from big data? Can we benchmark system energy and IAQ performance based on this data? How can we make sure that the data is available and can be accessed? Can we update what we think we know about what happens in dwellings based on what we see in big data rollouts? What are the best protocols and ontologies? How to create viable services out of the data/business plans? How can we integrate data with smart grids?

These issues will be addressed by reporting experiences from a series of implementation case studies and overview of available (types of) datasets.

We address these questions by exploring real life case studies and deriving 'lessons learned' and good practices. In this paper, we use a case study where we analyse CO2, Humidity and TVOC concentrations measured through the onboard sensors of an IoT connected residential air handling unit as an example of this methodology.

In this particular case study, we were able to check common assumptions on occupancy and pollution loads at a cross-sectional level with highly time resolved data for a full year, based on the data of over 1000 units.

INTRODUCTION

In this short paper, we introduce the work within the big data subtask of IEA EBC Annex 86 based on a case study where we analyse CO2, Humidity and TVOC concentrations measured through the onboard sensors of over 1000 residential air handling unit to check common assumptions on occupancy and pollution loads at a cross-sectional level.

What is IEA-EBC annex 86?

A central boundary condition in constructing energy efficient buildings is doing so while maintaining a healthy, acceptable and desirable indoor environment. While ventilation is the main strategy that is adopted for IAQ management, other technologies influencing IAQ (e.g. air filtration) are available as well and a large number of ventilation strategies exist. There is, however, no coherent assessment framework to rate and compare the performance of IAQ management strategies.

IEA-EBC Annex 86 “Energy Efficient Indoor Air Quality Management in Residential Buildings”, is a new international research collaboration effort under the auspices of the IEA Energy in Buildings and Communities program that will start its 3 year operation period in June 2021 and will propose an integrated rating method for the performance assessment and optimization of energy efficient strategies of managing the indoor air quality (IAQ) in new and existing residential buildings.

To achieve this, we will gather the existing scientific knowledge and data on pollution sources in buildings, study current and innovative use cases of IAQ management strategies and develop road maps to ensure the continuous performance of the proposed solutions over their lifetime.

The scope of the annex is focused on residential buildings because they represent the largest section of the building stock. They are also understudied and have the broadest range of (non-specific) uses. Additionally, residential building projects often lack the funds for extensive bespoke engineering and therefore require robust cost-effective standardized solutions that can be implemented at large scale.

For the study of specific IAQ management strategies we will mainly focus on the use of smart materials (materials that have an ability to actively or passively influence IAQ in the space) and smart ventilation (as defined by AIVC VIP nr. 38 (Durier et al. 2018)), since these are strategies that have a high energy efficiency potential. Air cleaners are already studied in a Annex 78 and are therefore not studied in detail in annex 86.

We bring experts from mechanical engineering, building science, chemistry, data science and environmental health together with other stakeholders to work towards consensus on the basic assumptions that underlie such a performance assessment and practical guidelines and tools to bring the results to practice. So far, 41 institutions from 24 countries have provisionally joined the annex.
Big Data work within IEA-EBC annex 86

One particular focus within the annex are the opportunities that spring from the rise of IoT connected sensors.

In ‘subtask 5’, we are exploring the potential of the new generation of IoT connected devices (both standalone and embedded in eg. AHU’s) for smart IAQ management. What can we learn from the big data they provide? Can we benchmark system energy and IAQ performance based on this data? How can we make sure that the data is available and can be accessed? Can we update what we think we know about what happens in dwellings based on what we see in big data rollouts? What are the best protocols and ontologies? How to create viable services out of the data/business plans? How can we integrate data with smart grids?

These issues will be addressed by reporting experiences from a series of implementation case studies and overview of available (types of) datasets. As a start of this work, we have organised 2 webinars during the AIVC spring workshop in April 2021 (AIVC 2021) discussing 3 research applications and 4 commercial applications of IoT devices. In this short paper we show an analysis at cross-sectional level of the data available to researchers through one of these industrial applications.

CASE STUDY DESCRIPTION

The data presented in the results section below are captured by the sensors of an IoT connected, demand controlled residential ventilation unit. The unit is equipped with CO2/RH/T/TVOC sensors for every exhaust vent, depending on the type of room the exhaust vent is located in. The sensors are located on the damper valves that connect each duct to the unit.

The dwellings are mainly new or renovated single family dwellings located mainly in Belgium. The data was collected in 2018 and 2019, so the presented data is not affected by the lock down measures imposed during the pandemic.

RESULTS & DISCUSSION

In this short paper, we focus on the mould growth risk and the concentration of TVOC in wet spaces (bathrooms and toilets) in the first 500 and 1000 units that were online in this case study. The total amount of units now included in the study is over 5000. The TVOC concentration is measured using a MOS sensor.

In Figure 1. a heat map of the measured monthly mean temperature and relative humidity is shown, together with the limit values for mold growth risk established by VTT (Hukka & Viitanen 1999). The data clearly shows that the ventilation provided by the system, even though it operates at relatively low flow rates most of the time compared to the nominal flow rate (the design flow rate of 25 m3/h for a toilet and 50 m3/h for a bathroom) (see figure 2), is enough to maintain conditions below the established limits.

On the other hand, there is also a small amount of situations that do not satisfy the limits, especially in the toilets. These conditions occur mainly at very cold temperatures. A likely explanation is that the occupants leave a window to the outside open in these toilets.

Related to the challenges and the goals addressed in STS of Annex 86, this observation suggests that there is value in adding a feature to the control logic where the occupants are made aware of the impact of this open window, both in terms of IAQ and Energy use.

Figure 1. mold growth risk in bathrooms (top) and toilets (bottom)

Figure 2. percentage of time the ventilation system is operating at minimum (MF) or nominal (NF) for the different spaces where the venthole is located, including 4 in between categories
The time resolution of the data also makes it possible to discern individual occupancy events in these relatively low use spaces. Figure 3, shows that the frequency of use of these spaces varies considerably between dwellings, from on average 1 time a day to 10 times a day, with a noticeable increase in average use frequency for dwellings with higher toilet/bedroom ratios.

This difference in use intensity is also reflected in the distribution of the measured TVOC concentration in the toilets shown in Figure 3. The concentration is clearly shifted to the right for the more densely used 3 bedroom toilets.

From the perspective of subtask 5, this result suggests that the increase in design flow rate suggested in EN 16798-1 for dwellings with a toilet/bedroom ratio of 4 and higher may actually be underestimating the real ventilation requirements in such spaces, or that the control logic of demand controlled ventilation systems should take into account the frequency of use to avoid cross exposure between subsequent uses of the toilets.

CONCLUSIONS

In this short paper, we demonstrated the use of IoT connected devices and the big data they generate to better understand the real conditions in residential buildings, focusing on mold risk and TVOC concentration in toilets as an example. We have shown that window airing is a potential cause for mold growth risk in toilets and that current ventilation standards may underestimate the real ventilation requirements for toilets in dwellings with higher occupancy. From this example, we can conclude that the use of big data for cross-sectional studies can inform the design of better control logics, either through engineering or through AI applications, and the development of better boundary conditions and requirements for performance based ventilation assessment.

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SUMMARY

An important factor for a good IAQ in homes is adequate air change rate of the premises. Strikingly often there is significantly poorer air change than the requirement of at least 0.5 turnover / hour.

It is not possible to exactly feel how good the air change is, so it must be a standardized method to measure and document the relevant air change. We have tested a practical method for air change rate measurement.

The method is technically easy to perform, inexpensive and relatively quick to implement since it provides sufficient clarification during measurement during a day. A representative number of CO2 loggers is placed in different areas in the home before the rooms are filled with enough CO2 gas. Logging how fast the CO2 values decrease down to the natural background levels due to the existing ventilation provides an accurate basis for calculating the actual air change rate. Although the method is not new, in our experience it is little known in Norway and thus in very limited use. This article shows how well the method provide an important clarification and documentation on a very deficient air change rate in different rooms in an apartment.

INTRODUCTION

CO2 is formed by combustion and metabolism in living organisms and is therefore found in human exhaled air. CO2 does not cause any health damage at the concentrations that are usually found in schools, kindergartens and other types of buildings. In rooms where many people stay over time, a high CO2 level will indicate that the air exchange is too poor in relation to the number of people. This will mean that other pollutants can accumulate in the indoor air. A high CO2 level often gives a feeling of heavy and unhealthy air and a bad smell. High CO2 values are therefore often used as an indicator of generally poor air quality.

Today, a recommended norm value (upper limit) is used for the CO2 concentration in the indoor environment. (National Institute of Public Health 2015).

Ventilation of buildings is important to remove among other things, odours, water vapor and airborne dust that are naturally produced by the people staying in the home. In addition, inadequate ventilation can lead to undesirably high radon values in parts of the homes (Norwegian Radiation and Nuclear Safety Authority 2020).

The need of proper ventilation was at least already known in 1858 when Max von Pettenkofer described the need of proper ventilation to achieve a good indoor environment (Pettenkofer 1858). It is still a key factor in today’s requirements for new buildings (Norwegian Building Authority 2017). Norwegian technical requirements are based on functional requirements, but when it comes to ventilation, there are several established values for calculation of sufficient air supply. Building regulation code (Norwegian Building Authority 2017) states that in a dwelling unit, rooms for permanent residence shall have ventilation that ensures a supply of fresh air of at least 1.2 m3 per. hour pr. m² floor area when the rooms or living unit are in use and a minimum of 0.7 m³ per. Hour pr. m² floor area when the rooms or living unit are not in use.

Bedrooms must be supplied with a minimum of 26 m³ of fresh air per. hour pr. bed when the room or accommodation unit is in use.

Kitchens, baths and toilets shall have an exhaust with satisfactory efficiency.

It should be noted that 1.2 m³ per hour is normally the same as 0.5 air exchange per hour (ceiling height 240 cm) and 0.7 m³ per hour corresponds to 0.3 air exchange per hour. This shows that the practical level of air exchange is and has been at least 0.5 turnover / hour.

It is not possible to feel how good the air exchange is, so it must be a standardized method to measure and document the relevant air exchange. To our experience, it is common to see that recommendations are given that the air change rate should be satisfactory and that it should be checked, without any good recommendations being given on how this is done (SINTEF Community 2015). It is therefore difficult for house owners to figure out how this can be done by a simple, but reliable method.

We have tested a practical method for how air exchange measurements can be carried out in an objective and accurate way. The basis for the method is previously described by Benedettellia et al. (2015).

Even though this is a method that has existed for a long time, it is little known and in practice not used by building surveyors. With this study, we want to show that this method is technically easy to perform,
inexpensive and relatively quick to implement since it provides sufficient clarification during measurement during a day.

This article describes with a specific case how the method is used in practice and how the results are interpreted and evaluated. It gives also a comparison with a method where the air change is measured in the exhaust duct.

METHODS / CASE STUDY DESCRIPTION

The measurement is carried out during normal ventilation of the home, but without anyone present while the measurement is in progress.

Before CO₂ is emitted, CO₂ loggers (Rotronic CP11) are started outdoors to record the background value of CO₂. The loggers are then placed evenly distributed in the home. The logger is placed correspondingly 1-1.5 meters above the floor on a table / shelf. To ensure measurement of the normal value of CO₂ indoors, logging must start before the tracer gas is released. In our measurements, the loggers are set up to log every 5 minutes. We therefore wait a minimum of 15 minutes from the time the loggers are deployed until the trace gas is released. The gas is released until the level in all room is around 2000 ppm CO₂.

After completing the trace gas measurement, the loggers can be left for 2-3 days to clarify how the air exchange is in relation to the current indoor climate load with users present.

RESULTS & DISCUSSION

The theoretical reduction of CO₂-levels at various air exchange levels is shown in figure 1.

![Figure 1. Theoretical decrease of CO₂ in a room at various air exchange levels.](image)

We have compared trace gas measurements and air exchange measurements by measuring the amount of supply air and exhaust air and seen that there is a good connection between the values of the two methods. We also look at the water content in the air as an additional check to see if there are deviating values that indicate inadequate air exchange. These two conditions ensure a quality assurance of the tracer gas measurements.

Safety

We use trace gas in the form of CO₂. This has many advantages, and the gas is harmless at the concentrations used because it is much lower than any critical values.

Each CO₂-bottle contains 425 g of CO₂ - that is, if a bottle is immediately emptied into a room of 20 m², the CO₂ content will increase to just under 5000 ppm - which is completely unproblematic regarding to any health aspect (National Institute of Public Health 2015). Several countries have 5,000 ppm as the upper limit of the weighted average for an 8-hour day. The upper limit for CO₂ is 30,000 ppm which should not be exceeded for more than 10 minutes - and these are values we do not come up with the modest use of CO₂ that is needed as trace gas.

In addition, in any case, no persons shall be present at the measurement to ensure that there are no sources of error due to the use of the rooms and the exhalation of CO₂.

Practical experiences

The results shown in this article come from a measurement in a modern block of flats. The reason for the investigation was a suspicion that there was inadequate ventilation of the apartment.

Five CO₂-loggers were placed in different rooms and CO₂-gas was released. The monitoring of decrease of CO₂ is shown for one logger in figure 2.

![Figure 2. Typical monitoring results from an CO₂-logger.](image)

To check how representative the logger results were, the graphs for all loggers were plotted in a figure (figure 3).
Logger example, affordable, and safe.
also provides better and more detailed information
illustrative documentation provides a good and detailed clarification as well as an
of air
Assessment of the method
Our experience of using CO₂ as a tracer gas at control
air change in different rooms, we achieve an even distribution of the gas. The
regular graphs we usually get show that there has been
a good spread of the gas in the rooms even though it is
heavier than ordinary air.
The advantage of CO₂ is also easily available, cheap, and
non-toxic. This ensures a simple, affordable, and safe
implementation of the surveys.

**CONCLUSIONS**
The use of CO₂ gas as trace gas to clarify the air
change rate in buildings has been shown to give good
and clear results. It has also been shown to be a good
alternative to other methods for examining air change
rate because it provides a clarification of the actual air
change rate in different rooms and not just what
applies in the actual ventilation opening. Our
experience is that it is a good and safe method that
can be easily performed. Despite this, the method is
not used as a routine in Norway for surveys of air
exchange. This indicates a need to convey the
applicability to relevant users. We hope that this
article will help increase the interest in using the
opportunity for a good clarification of actual air
exchange in homes.

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*Figure 3. Comparison of five log values of declining CO₂ through time.*

Calculation of the air exchange showed that there were
very similar values in the five measuring points (table
1).

**Table 1. Calculated air change based on the monitoring values in figure 3.**

<table>
<thead>
<tr>
<th>Place</th>
<th>Air change/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 – Bedroom 1</td>
<td>0,11</td>
</tr>
<tr>
<td>2 – Livingroom</td>
<td>0,12</td>
</tr>
<tr>
<td>3 – Bath</td>
<td>0,13</td>
</tr>
<tr>
<td>4 – Office</td>
<td>0,13</td>
</tr>
<tr>
<td>5 – Bedroom 2</td>
<td>0,12</td>
</tr>
</tbody>
</table>

The calculated air change rate from the CO₂-logging
corresponded to approx. 24% of recommended airflow. On a later occasion, we checked with a Fluke
922 Airflow Meter which air was extracted from the
apartment via the ventilation ducts. Based on the air
volume in the apartment, the measured air volume was
calculated to correspond to approx. 30% of
recommended airflow. This shows that the two
methods gave a relatively similar result. Our
assessment is that CO₂-logging was better even though
it took longer time. The reason for this interpretation
is that it provided a more detailed clarification of the
actual air change in different rooms, while the same
time as the measurement in the exhaust ducts was a
momentary information with clear variations over
time and by repeated measurements.

**Assessment of the method**
Our experience of using CO₂ as a tracer gas at control
of air change rate is that this method gives and
provides a good and detailed clarification as well as an
illustrative documentation. We see that the method
also provides better and more detailed information
than instantaneous measurements of air volumes in
ventilation ducts.

By walking around the homes and actively spreading
the gas from ceiling to floor and in all parts of the
rooms, we achieve an even distribution of the gas. The
regular graphs we usually get show that there has been
a good spread of the gas in the rooms even though it is
heavier than ordinary air.

The advantage of CO₂ is also easily available, cheap, and
non-toxic. This ensures a simple, affordable, and safe
implementation of the surveys.
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Downscaling from material flow analysis to indoor CFD for health risk assessment associated with DEHP exposure

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SUMMARY
It is essential to develop a method for evaluating individual exposure of chemicals in terms of creating healthy indoor environment. We focused on Material flow analysis (MFA) and Computational fluid dynamics (CFD) as a method for evaluating individual exposure that is not based on only on-site measurement. The purpose of this study is to propose newly developed integration method of MFA and indoor CFD with computer simulated person (CSP) for health risk assessment. We focused on Diethyl-hexyl phthalate (DEHP) and estimated the amount of DEHP accumulation in Japan by conducting a dynamic MFA. In addition, we conducted DEHP emission rate measurement by micro-chamber method. With the results of MFA and micro-chamber method as boundary conditions for CFD, the individual exposure in a general house was quantitatively evaluated. The potential risk of individual exposure was clarified by assuming the worst-case scenario estimated from the results of MFA and micro-chamber method.

INTRODUCTION
Individual exposure to indoor air pollution and consequent health impacts must be quantitatively assessed for creating a healthy indoor environment. Indoor air pollution caused by chemical substances has been a serious problem in terms of human health. The Ministry of Health, Labor and Welfare of Japan has established guideline concentrations for 13 chemical substances. Among the chemical substances whose guideline values are shown, the target of this study is set to be Diethyl-hexyl phthalate (DEHP). In the evaluation of DEHP individual exposure in the indoor environment, it is generally conducted on-site measurement and indirectly evaluate using the measured value. It is necessary to establish an evaluation method that is not based only on-site measurement because there are various restrictions on-site measurement.

MFA using macro statistical data is a reasonable method for grasping the actual state of chemical substances on a wide scale. However, there is no rational way to predict and evaluate indoor air pollution and especially individual exposure from social stock data by MFA. The purpose of this study is to propose a numerical method for evaluating health risk in indoor environment that integrates inhalation exposure analysis using CFD–CSP coupled analysis with MFA. In this integrated analysis, the target room was assumed to be covered with DEHP-containing products. The individual dermal and respiratory exposure in the target room is quantitatively analyzed using a CSP integrated with a respiratory airway model.

Method
Material flow analysis (MFA)
Evaluation target was 11 DEHP-containing products that is used as a plasticizers-general film, agricultural vinyl, leather, industrial materials, wire cladding, hosing, floor material, wallpaper, footwear, paints, and others. The life cycle of DEHP-containing products was divided into five phases-production, manufacturing, use, disposal, and recycling. We conducted MFA using the DEHP shipment data in Japan and the life function considering the product lifetime. The life function \( F(x) \) was used the Weibull distribution as Eq. (1)

\[
F(x) = \left(\frac{u}{v}\right)^{\frac{x}{v}} \exp\left[-\left(\frac{x}{v}\right)^{\frac{1}{\alpha}}\right] \tag{1}
\]

where, \( u \) is the shape parameter, \( v \) is the scale parameter.

The equation for the amount of waste \( W(t) \) and the amount of accumulation \( S(t) \) in the use stage in \( t \) years are shown in Eqs. (2) and (3), respectively:

\[
W(t) = \int_0^t \left(I(t') \cdot F\left(t - t'\right)\right) dt' \tag{2}
\]

\[
S(t) = \int_0^t \left\{ I(t') \cdot (1 - F\left(t - t'\right))\right\} dt' \tag{3}
\]

where, \( t \) is the evaluation year, \( t' \) is the shipment year based on the year \( t \). \( F(t-t') \) represents the disposal rate of products shipped in \( t' \) in year \( t \). \( F(t-t') \) represents the amount obtained by subtracting the processing loss in year \( t' \) from the sum of the DEHP shipment in year \( t' \) and the recycling amount in year \( t' \).

Micro-chamber method
Micro-chamber method was standardized in ISO 16000-25 to measure SVOC emission rates. The measurement sample was 7 vinyl products—PVC leather, general film, wallpaper A, B, floor material A, B, and wire cladding seal. These measured emission rate was used as boundary condition of Indoor CFD analysis.

**Indoor CFD analysis**

Figure 1 shows the analysis room model. This model was assumed to be single room in the housing model in Japan. This model was created with a supply inlet (0.09×0.09m) in the wall and exhaust outlet (0.91×0.015m) in the lower part of the door. The CSP was located at the center of this model. Metabolic heat generation from the human body was reproduced by integrating Fanger’s one-node model as skin surface boundary condition. In addition, the breathing cycle was assumed to be steady breathing. Table 1 shows the outline of cases. Two cases were set based on the result of MFA, a worst-case environment in which DEHP-containing products were used on all surface (Case1) and a realistic environment in which DEHP-containing products were used only on the wall (Case2).

<table>
<thead>
<tr>
<th>Case</th>
<th>Ventilation [l/h]</th>
<th>Inflow velocity [m/s]</th>
<th>DEHP emission rate [µg/m³/h]</th>
<th>Floor</th>
<th>Wall</th>
<th>Ceiling</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0.5</td>
<td>0.41</td>
<td>16.86</td>
<td>19.85</td>
<td>19.85</td>
<td>adsorption</td>
</tr>
<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>adsorption</td>
</tr>
</tbody>
</table>

**Results & Discussion**

Figure 2 shows the results of the transition of mass-based DEHP accumulation in the use phase. The DEHP accumulation increased after the 1950s, reaching a maximum value of approximately 2.7 million t in 1997. After reaching this peak, it decreased to approximately 1.8 million t in 2019. This could be converted from a mass-base to an area-based value. After that, the DEHP accumulation per house was estimated using house usage ratio. The results indicated that DEHP accumulation per house in 2018 for general film, wallpaper, and building materials were 12.99m², 50.37m², and 9.58m², respectively.

Table 2 shows the analytical results of volume-averaged concentration in the model and total exposure of CSP. Figure 3 shows the results of DEHP adsorption flux distribution in CSP and airway surface of worst-case. Comparing the analysis value of average indoor concentration in this study with the measured values of previous studied, Case1 was overestimated and Case2 was similar to the previous studies.

**CONCLUSIONS**

We proposed the method of downscaling from MFA to indoor CFD for health risk assessment. We clarified that general film, wallpaper, and building materials are DEHP potential risks of indoor air quality. Moreover, using the results of MFA and Micro-chamber method, DEHP individual exposure was predicted and discussed quantitatively.

**ACKNOWLEDGEMENTS**

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A method to visualize and quantify "aerosols" of outward leakage around the perimeter of barrier masks

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ABSTRACT
Due to the SARS-CoV-2 pandemic, several strategies have been proposed to reduce its transmission, from social distancing, regularly disinfecting items and hands, and wearing barrier masks. Guidelines and standardization propose certain tests for the filtration of the masks, or visual inspections to check the materials. However, no standards exist to test the outward leakage through the face seal perimeter of the masks. Therefore, the aim of this study was to develop a method to visualize and quantify respiratory droplets, simulated by 'mist', exhaled by a mask wearer.

A setup was developed with fluorescent ink, UV lights, background subtraction, to highlight the mist and its footage. Mist was quantified with a software, and one-way ANOVAs and t-tests were conducted on the means, to assess the reliability of the method. The results of the statistical tests suggest that the method is reliable to visualize and quantify the mist.

INTRODUCTION
SARS-CoV-2, the virus responsible for COVID-19, has a size of 120 nm diameter (Morawska et al., 2020). It tends to be embedded in water drops or droplets, which depending on the size, can be categorized as aerosols. Exhaling, singing, sneezing, coughing, and talking will cause the release of the respiratory droplets, which can contain the virus (Chen, Zhang, Wei, Yen, & Li, 2020). Although the load of virus contained in droplets, and the amount of virus needed for a person to develop COVID-19 is still not well known, it has been suggested that masks can reduce the risk of spread of such droplets, in addition to social distancing to avoid direct projectiles (Buonanno, Morawska, & Stabile, 2020; Morawska et al., 2020). Cases in which infections via aerosol have been documented have occurred in Germany and the USA (Mitze, Kosfeld, Rode, & Wälde, 2020; Van Dyke et al., 2020).

Wearing a facemask has become obligatory in most countries as it has shown to reduce contagion (Chu et al., 2020). Barrier masks are designed as a preventive measure to protect people surrounding the wearer, in case the wearer is a carrier of the virus. This type of mask has been encouraged to be worn by the public over medical masks, and companies have capitalized on the public’s need to wear them to put on the market a wide range of masks.

Official guidelines exist in certain countries specifying different types of tests to be performed on masks, such as visual inspections (tears, looseness, fit, etc.), filtration, resistance material for daily wear, and filter breathing resistance. However, tests specific to the performance and leakage through the face seal perimeter of the mask or fit tests have not been specified in guidelines yet.

Current standards and guidelines, whether international or national, seem to be limited in the type of tests to be performed in masks in order to assess their quality and performance. AFNOR (AFNOR, 2020), NEN (NEN, 2020) and CEN (CEN, 2020) suggest that consumers should pay attention to the fit, by observing a tightness in the perimeter of the mask in contact with the skin. In Ireland, SWIFT (SWIFT, 2020) proposes that masks should be tested in different head types, sizes, and ages, to ensure the best fit. Visual tests are also encouraged, by checking from scratches, proper elastic and attachment, adequacy of materials, and comfort of seams and nose pieces. Similarly, guidelines from other countries also propose that manufacturers carry visual inspection of the materials, ensuring that there are no defects, tears, detachments, or deformations of the materials. The guidelines also propose that consumers should perform the same type of visual inspection before donning (AFNOR, 2020; CEN, 2020; NEN, 2020).

Some studies have attempted to visualize outward leakages in several ways. Typically, visualization of flows and turbulences has been done with several techniques in different fields (Smits, 2012). These can be divided into three main categories: bubble visualization, dye visualization, and smoke visualization.

Bubble visualization requires a generator from a probe, proper illumination, typically with angled backlighting (Sabatino, Praisner, Smith, & Seal, 2012). Bubbles can be photographed and processed with quantitative instrumentation, such as Laser Doppler Anemometry or Particle Image Velocimetry (PIV), in order to provide quantitative data of the flows. The technique has recently been used to visualize infections aerosols indoors (Bluyssen, Ortiz, & Zhang, 2021).
Dye visualizations have typically been used to study flows in water. Typical dyes used have been food coloring, milk, ink, fluorescent ink, fluorescein, or laundry brightener (Smits, 2012). While smoke visualizations are the typical method for flows in the air. Smoke can be of different sources, glycol, water vapor, or titanium tetrachloride. Mask performance has been studied with smoke visualization. Darby et al. (2021) used synthetic aerosol made of NaCl in water from a nebulizer. UV-lights and fluorescent dye was used by Maruyama et al. (2020) to assess droplets dispersal during endoscopy. The same technique was used by Teichert-Filho, Baldasso, Campos, and Gomes (2020) to assess aerosol and droplet dispersal during dental procedures. Other studies used distilled water and glycerin to imitate cough and sneeze aerosols (Verma, Dhanak, & Frankenfield, 2020a, 2020b).

Real droplets expelled by people have also been visualized, mainly with the use of sophisticated equipment, such as backlighting and high speed cameras; in such studies, the flows, turbulences, speeds, and distances traveled are measured (Bourouiba, Dehandschoewercker, & Bush, 2014; Scharfman, Techet, Bush, & Bourouiba, 2016).

Other studies, have also envisaged to quantify outward leakages. This has mainly been done by tracking particles or counting them. Particles from coughed aerosols to assess mask efficacy by producing aerosols of nebulized KCl and collecting it with an Andersen impactor for quantification based on based on the aerodynamic diameter of the particles (Lindsay, Blachere, Law, Beezhold, & Noti, 2020).

PIV has been widely used with combination of tracer particles and smoke (Kähler & Hain, 2020) in order to track and quantify aerosol particles. While particle counting has also been used to detect and count particles based on their size (Wendling, Fabacher, Pébay, Cosperec, & Rochoy, 2021).

As a method of both visualizing and quantifying does not seem to have been developed, at least as a rapid response study or with simple, yet reliable equipment, this study attempted to develop a method for doing so. Additionally, as mentioned before, no standards or guidelines exist for the assessment of leakage of masks, therefore, the aim of this study is to design a method to visualize and quantify respiratory droplets simulated by ‘mist’ exhaled by a mask wearer, to assess the outward leakage of barrier masks.

METHODS

A setup was created by simulating the exhalations of a human, by connecting a bellows pump to a Styrofoam manikin head of the size of a male adult. The inside of the head was carved in such a way to duplicate the volume of the respiratory cavities of an average adult head. Fluorescent water mist was produced to visualize the exhalations, with the use of an ultrasonic nebulizer and a combination of nine parts of water with one of fluorescent ink. This mist was produced in a container chamber positioned below the head, which also acted as a build-up chamber for the mist. The chamber was connected to a duct connecting it to the aforementioned bellows pump. For the optimal visualization of the fluorescent mist, the space was equipped with six ultraviolet lights and the surfaces were covered with black paper and plastic foil, so as to avoid any reflections and to increase the contrast between the mist and the background. Additionally, during the experiments, all lights, except for the UV lights, were turned off. The location of the experiments was the Experience Room of the SenseLab, in Delft. A camera was placed at a distance of 2.5 meters away from the head, at two positions, the side and the front, in order to have footage of the leaked mist from two perspectives. Footage was taken in a time-lapse mode, by taking a picture every two seconds, so a total of 60 pictures per test were obtained. The camera used was a GoPro Hero 8 with a wide-angle lens of 130 degrees. Figure 1 shows the setup of the experiment.

A total of fourteen different masks were chosen to be tested, varying from characteristics typically found in commonly available face masks. These features were: materials, number of layers, woven vs non-woven materials, cheek flaps, and filter type.

Every mask was tested a total of four times and footage of the leaked mist was taken twice from the side and twice from the front. The procedure for testing each mask followed the next steps: turn on camera. Turn on UV lights, turn off ambient lights, put mask on the manikin head, turn on ultrasonic nebulizer, build up mist in chamber for 1 minute, start recording footage, turn on bellows pump and count two minutes of exhalations, turn off pump, stop nebulizer. The procedure was repeated for each of the masks. In order to analyze the leaked mist, a series of processes were performed. First, the resulting images from the time lapse were processed with the FFmpeg software, with which background subtraction was performed (figure 2). Background subtraction is a method that compare a sequence of images with a static background, in which the static background is removed, only highlighting the moving objects, which in this case is the leaked mist.
The images with subtracted background were then analyzed with Image Color Summarized v.0.77; which gives descriptive statistics of the colors of the image. In this study, two percentages were produced: that of the subtracted background and that of the mist. This was done with the pictures taken in the 40th, 50th, 60th, 70th, 80th, and 90th seconds of the tests, as it is when the mist had reached a stable state.

From those color percentages, means of the percentages were calculated as well as sums of the percentages. In order to validate the sturdiness of the test, the mist percentages were compared between the two runs of the same camera position. Next, independent sample t-tests and one way ANOVA's were conducted with SPSS v. 26.

More specifically, the ANOVAs were performed in order to determine whether statistically significant differences exist between the two test runs of each side, per side, between the 40th and 90th seconds. The t-tests were performed to determine if the means of the two runs per side were statistically the same.

RESULTS & DISCUSSION

The results, which are presented in Ortiz and Bluyssen (2021), suggest that statistically significant differences exist between the four tests, and also between the two means of the side and front test runs. Also, differences were shown between the 14 tested masks for the front view and in three of the 14 from the side view. As a result, for those particular masks it can be hypothesized that their means are different.

Further tests should also take into account different head sizes, to emulate different genders, ages, or ethnicities, as well as facial hair.

CONCLUSION

The proposed method could be a valuable addition to the aforementioned tests in order to ensure the better protection and information to the consumers. This technique allows to visualize and quantify mist that leaks out in a cost-effective manner, while enabling to see the routes of leakage and improvement points for different mask types.

ACKNOWLEDGEMENTS

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Trihalomethanes in indoor swimming pools: estimating exposure and assessing carcinogenic risk among non-competitive attendees

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SUMMARY

Health risk estimation for exposure to trihalomethanes (THM) in indoor swimming pools would represent a useful tool for public health management. The aim of this study was to estimate the carcinogenic health risks from exposure to THM through multiple pathways among non-competitive swimming pool attendees. Exposure factors of participants were collected via questionnaires and THM levels were obtained from water quality records. According to the results of this study, chronic daily exposure for total THM considering all pathways (ingestion, dermal absorption and inhalation) for male and female participants was $5.19 \times 10^{-3}$ and $3.15 \times 10^{-3}$ mg/kg/day, respectively ($p=0.073$). Inhalation was found to be the most relevant pathway and chloroform was the compound contributing the most to total THM chronic daily exposure. The mean values of lifetime cancer risk (LCR) for total THM and through ingestion, inhalation and dermal contact was found to be higher than U.S. EPA acceptable value ($1 \times 10^{-6}$) for both genders.

INTRODUCTION

Health risk assessment from exposure to different trihalomethanes (THM) in indoor swimming pools through multiple exposure pathways is of great importance to strengthen the knowledge needed to define effective regulatory approaches for public health protection. The THM have been proven to be potentially genotoxic and mutagenic for human in the case of long-term exposure (Villanueva et al., 2004). A series of previous epidemiological studies has provided estimates of the relationship between long-term exposure to THM and colorectal cancer (Malcom et al., 1999), renal cell cancer (Havelaar et al., 2000) and bladder cancer (Malcom et al., 1999; Attias et al., 1995). According to Evlampidou et al. (2020), the estimated annual bladder cancer cases attributable to THM exposure ranged from zero in Denmark to 1482 in Spain; Spain (22.6%), the United Kingdom (20.7%) and Romania (16.0%) accounted for the largest estimated number of attributable cases. Although swimming pool activities are frequently recommended by physicians as a form of exercise and improved physical activity, few epidemiological studies have focused on the potential health risks of THM in indoor swimming pools (Peng et al., 2020; Wang and Dong, 2020; Gouveia et al., 2019; Pándics et al., 2018; Hang et al., 2016; Chowdhury, 2015; Catto et al., 2012). The best of authors’ knowledge, in Portugal health risk assessment associated to exposure to THM in indoor swimming pools has only been carried out by Gouveia et al. (2019) that examined a group of elite swimmers with high-intensity long-term exercise and repeated exposures to chlorine-rich atmosphere when compared to the general pool attendees. Thus, this study was developed to investigate the lifetime cancer risks from exposure to THM through multiple pathways including oral ingestion, dermal contact and inhalation among non-competitive swimming pool attendees from public indoor swimming pools in Portugal.

METHODS

THM data collection and study participants

Data were obtained from 10 public indoor swimming pools in the northern region of Portugal over 7 months (January to July 2018). THM concentrations in swimming pool water was collected from the latest routine report (trimester basis) of water quality monitoring program (DGS, 2009) of each indoor swimming pool and a questionnaire survey was carried out to obtain the exposure factors (duration of the activity, practice frequency and exposure duration; i.e., number of years of non-competitive practice) and other individual physiological characteristics (sex, age, body height and body weight). Information related to the ventilation systems of pool facilities and total number swimming pool users was not obtained. A total of 395 subjects were invited to participate in this study; 300 were enrolled. Pool workers (n=24; e.g., administration staff, trainers/instructors and lifeguards) and elite swimmers (n=7) were excluded as well as participants with missing information on the exposure duration (n=31). A final sample of 238 non-competitive swimming pool attendees was considered for this analysis. All subjects participated voluntarily and signed the informed consent form.
This study was submitted for ethical review to the Ethics Committee of Centro Hospitalar de São João/Faculty of Medicine University of Porto, Porto, Portugal and approval was obtained (reference number 296/16). Every procedure was in accordance with the Helsinki Declaration.

**Multi-pathway exposure and risk assessment**

Based on the exposure factors reported by study participants and THM data from water quality reports, an exposure assessment was conducted using the Swimmer Exposure Assessment Model (SWIMODEL) version 3.0 (U.S. EPA, 2003) to evaluate the potential THM uptake via oral ingestion, dermal contact and inhalation. The approach to the total lifetime cancer risk (LCR) of THM was calculated, through the three mentioned pathways, by incorporating the exposure assessment and toxicity values (slope factors). The acceptable limit value of LCR recommended by the U.S. EPA is $1 \times 10^{-6}$ (U.S. EPA, 2006, 1989).

**Statistical analysis**

Statistical analyses were performed using SPSS (version 26). Mann-Whitney U test and Kruskal-Wallis test were used ($p<0.05$) in order to evaluate the differences in mean values. The concentrations of THM below the quantification limits (LOQ) were defined as 50% of LOQ.

**RESULTS & DISCUSSION**

A total of 238 non-competitive swimming pools attendees (69% female) were included. On average, female swimming pool attendees were younger than male participants (61.0 vs. 64.3 years, $p=0.017$). Male attendees showed higher frequency and years of practice (101 vs. 84 event/year, $p=0.005$; and 11.4 vs. 8.8 years, $p=0.039$; respectively), and a larger skin surface area compared with females’ participants (1.90 vs. 1.76 m$^2$; $p=0.001$). There were no differences between the two groups regarding the duration of the activity at the swimming pool (h/event) ($p=0.889$).

The difference of chronic daily exposure for total THM through ingestion between males and females was not significant ($1.36 \times 10^{-6}$ vs. $7.27 \times 10^{-7}$ mg/kg/day, respectively). No significant differences were also observed between both genders via inhalation ($5.18 \times 10^{-3}$ vs. $3.15 \times 10^{-3}$ mg/kg/day, respectively). However, males had a significantly higher exposure of total THM through dermal contact than females ($5.86 \times 10^{-6}$ vs. $3.58 \times 10^{-6}$ mg/kg/day, $p=0.028$). Taking into account all exposure pathways, the mean value of chronic daily exposure for total THM was $5.19 \times 10^{-3}$ for males and $3.15 \times 10^{-3}$ mg/kg/day for females ($p=0.073$). Chloroform presents a significant role in the chronic daily exposure in both genders (>95%). The findings also indicated that inhalation is the main human exposure pathway accounting for more than 99.8% of total THM intake in indoor swimming pools in both genders.

Previous studies reported lower (Gouveia et al. 2019) and higher chronic daily exposure values (Chowdhury, 2015; WHO, 2006, Lévesque, 1994) compared to those obtained in the current study. These discrepancies might be explained by differences in THM concentrations in swimming pool waters, age of study population (Pândics et al., 2018) and exposure factors (e.g., number, frequency and duration of exposure). In addition, Dyck et al. (2011) refers differences related with mass-transfer models used to calculate the concentrations of THM taken into the body.

The results indicated that the LCR of males for total THM via ingestion or dermal contact were slightly higher than that of females ($4.93 \times 10^{-8}$ vs. $1.83 \times 10^{-6}$; $p=0.151$ for oral ingestion and $1.21 \times 10^{-7}$ and $8.22 \times 10^{-6}$; $p=0.113$ for dermal absorption); but lower than the acceptable risk ($1 \times 10^{-6}$). Nevertheless, U.S. EPA acceptable risk was surpassed for total THM exposure via inhalation pathway in both genders ($4.16 \times 10^{-4}$ for males and $2.71 \times 10^{-4}$ for females’ participants; $p=0.071$). For all exposure pathways, mean LCR for all THM of males vs. females ($4.16 \times 10^{-4}$ vs. $2.71 \times 10^{-4}$; $p=0.071$) were higher than $1 \times 10^{-6}$, indicating that the carcinogenic effects cannot be neglected. Furthermore, unequivocally, the most important THM in terms of risks of exposure was chloroform (>95%) and the main exposure pathway for study participants was through inhalation (99%).

In brief, the current study, the chronic daily exposure for total THM estimates led to high potential carcinogenic risk for pool attendees, above the U.S. EPA acceptable risk, mainly due to high exposure to chloroform via inhalation; which is consistent with the findings reported in Gouveia et al. (2019) in Portugal and in other countries (Wang and Dong, 2020; Pândics et al., 2018; Dyck et al., 2011). This might be due to the high concentrations of chloroform found in swimming pool water, since chlorine is the main disinfectant used to treat swimming pool water and municipal water was used as primary source of water in the majority of the studied public indoor swimming pools, thereby, contributing to the occurrence of correspondingly high levels of chloroform in the indoor air of the swimming pools, taking into account its high volatility. To be notice that, there is currently no legislation for the concentration of THM in indoor air of swimming pools in Portugal, contrasting with the existing regulation in water (DGS, 2009). Thus, the findings of the present study support that it is urgent to establish relevant health-based values for specific THM in the air of swimming pool facilities.

The results reported herein should be considered in the light of some uncertainties and limitations. The simulation model used estimate probabilistic risk assessment for swimming pool attendee’s exposure only based upon intake of THM that occur during pool
activities. Additionally, the model does not consider other disinfection by-products (e.g., haloacetic acids, haloketones and chlorophenols) with differences in volatilities and modes of toxicity (Wang et al., 2013; Xiao et al., 2012; Zwiener et al., 2007), which are likely to bias exposure and risk estimates (Rice et al., 2009). The lack of data on drinking water, showering and other regular daily activities (e.g., hand washing, dishwashing) and on THM in the air are additional limitations of this study. Furthermore, the default value for lifetime used in the present study (70 years). However, interpreting such a metric is far from straightforward given the uncertainties in past and future exposures and the multifactorial nature of carcinogenesis, with cancer risks increasing with age (Grellier et al., 2015). The use of this adjustment to exposures occurring only in later periods of the adult life may overestimate the calculated risk. On the other hand, this 70 year-lifetime does not reflect the longer lifespan of most western populations.

Despite these uncertainties and limitations, there are a number of major strengths. Firstly, default values regarding adult swimming pool attendees and their physiological and exposure factors were replaced by human-based information reported by a large sample of study participants. Additionally, sex-stratified data was used, due to the importance on differences in gender and behavioral factors to the estimates.

The obtained knowledge sheds light on the understanding and controlling health risks from exposure to THM in indoor swimming pools through multiple exposure pathways and provides useful information for risk management decisions. Further studies should address if and how ventilation systems affect THM exposure in a swimming pool facility.

CONCLUSIONS
Understanding the public health implications of exposure to THM in indoor swimming pools is important for societies and their decision-makers. From the results of exposure assessment and attributable cancer effects it is necessary to reduce the risk in the indoor swimming pools, where inhalation dramatically increased the uptake of THM, namely chloroform, in non-competitive swimming pool attendees. Further efforts are needed in order to establish relevant health-based values for specific THM in the air of swimming pool facilities.

ACKNOWLEDGEMENTS
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Oxidative stress in individuals with Building Related Intolerance after exposure to acrolein

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Introduction
Oxidative stress is described as an imbalance between production and/or exposure of reactive oxygen species (ROS) and the body’s ability to counteract or detoxify the harmful effects. The damage caused by oxidative stress has been associated with several diseases involving chronic inflammation and is often discussed in relation to health effects from outdoor air pollution (Shutt et al. 2017).

A few studies have pointed towards the importance of oxidative stress as a mechanism behind health effects from indoor air chemical exposures (Kwon, Park, Kim, Kim, & Lee, 2018; Lin, Chuang, Liu, Chen, & Chuang, 2013; Lu et al. 2007). However, no individual compound or group of compounds have been identified as a probable cause of these health problems. The lack of correlation may be due to the low concentrations of volatile organic compounds (VOCs) in indoor air. Chemicals are often far below the occupational threshold limit value and sometimes the concentration is below known sensory irritation detection thresholds. Most of the identified VOCs are non-reactive and are therefore not believed to be the only cause of the perceived sensory irritation reported in building related intolerance (BRI).

Reactions between indoor air chemicals change the chemical composition. The pollutants in indoor air can possibly react with pollutants from sources outside, such as O₃ or NOx from exhaust or ground-level O₃. A variety of reaction products such as ROS, various aldehydes (e.g. formaldehyde, acrolein) and acids (acetic and formic acid) have been identified as possible products from such reactions. All these are probably more relevant from a health perspective and known to cause oxidative damage to lipids, proteins and nucleic acids, resulting in oxidative stress and possibly decreased sensitivity to certain compounds (Bessac & Jordt 2008). Acrolein have been identified to be associated with indoor air health problems (Golden & Holm, 2017; Logue, Mckone, Sherman, & Singer, 2011; Sakellari et al. 2020). Exposure to acrolein is known to cause oxidative stress in the airways and the toxicity are partially dependent on the redox-balance (i.e available antioxidant defense such as glutathione, GSH).

BRI is a significant work-related and public health problem. These problems entail a large cost for the society in terms of decreased productivity Wargocki, Wyon, Baik, Clausen, & Fanger (1999) and a large cost for the individuals who is often forced to make extensive, unwanted changes in their lives Gibson, Placek, Lane, Brohimer, & Lovelace (2005). To increase the understanding for indoor air health problems it is important to identify a marker that reflects the exposure to certain air pollutants. This paper addresses a possible association between exposure to the reactive indoor air pollutant, acrolein (as a representative of possible reactive chemicals in the indoor air) and markers of oxidative stress. Preliminary data from an ongoing study is presented.

Methods
Individuals with self-reported BRI (n=21) and controls without BRI (n=16) were exposed in an exposure chamber. Each participant took part in two exposure conditions—one with heptane (the masking compound), and one with heptane and acrolein. The exposures lasted for 80 min and the participants were blind to the exposure condition. During exposure, participants rated pleasantness and unpleasantness and their ratings did not differ between the two exposures (p=0.42 and p=0.16, respectively). This implies that the masking was successful; however, it cannot be ruled out that there were perceptual differences between the conditions. The mean temperature during exposure was 21.8±1°C and the mean relative humidity was 19.3±3%. Carbon filtered air entered the chamber through an inlet close to the floor and exited through the ceiling. The air exchange rate was set to 7.5/h (approximately 330L/min). A metered amount of stimulus material was continuously vaporized through a nebulizer entering the air stream at a flow rate of 4L/min. The concentration of acrolein was 0.05±0.08 mg/m³, which is below previously reported sensory irritation threshold value (i.e. 0.11-1.2 mg/m³; Dwivedi et al. 2015; Kuwabara, Alexeef, Broadwin, & Salmon, 2007; Weber-Tschopp, Fischer, Gierer, & Grandjean, 1977). The concentration of heptane was 10.6±1.5 mg/m³. An independent sample t-test showed that the measured concentrations of heptane did not differ between the two exposure conditions (p=0.88). The concentration of acrolein and heptane in the exposure chamber was monitored by direct injection onto a gas chromatograph with a flame-ionizing detector, GC-FID.

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Glutathione (GSH) is an important scavenger of oxidative stress and reacts directly with acrolein. A lowered ratio between GSH and its oxidized form glutathione disulfide (GSH/GSSG) is a commonly used marker of oxidative stress. A consequence of oxidative stress is an imbalance between the parasympathetic and the sympathetic systems. This can be monitored by heart rate variability (HRV). In this study, the redox couple GSH/GSSG and HRV was used as indicators of oxidative stress. HRV was monitored by collecting electrocardiographic (ECG) data by attaching disposable electrodes to the non-dominant wrist and ankle. Root mean square of the normal-to-normal heartbeat interval difference (RMSSD) were calculated. This is a good measure of the parasympathetic system in a specific time-window. Blood samples were collected before entering the exposure chamber and directly after exiting in order to measure the level of GSH/GSSG in plasma according to a method previously developed Claeson, Gouveia-Figueira, Stenlund, & Johansson, (2019). The normalized ratio between GSH/GSSG was used as a measure of oxidative stress (normalization was performed between the two exposures and the two measurements post/pre).

Results & discussion

Two recent studies indicate an association between chemical compounds and indoor air health problems (Sakellaris et al. 2020; Veenaas et al. 2020). Among other compounds, the reactive aldehyde acrolein is pointed out as a risk factor for symptoms reported in indoor air. Acrolein may be a previously overlooked risk factor for asthma Golden & Holm (2017) and is known to induce sensory irritation in a time-dependent manner at a concentration below previously reported detection levels (Claeson & Lind, 2016; Claeson & Andersson, 2017). Acrolein together with other similar compounds are therefore of relevance to study further in relation to health problems in indoor air.

Preliminary results from an on-going exposure chamber study show that individuals with BRI have a significantly lower HRV (RMSSD) during exposure to acrolein compared to healthy individuals and during exposure to heptane (F(1,20)=4.97 p<0.0001). The normalized ratio between GSH/GSSG was also significantly lower in the BRI group compared with referents during acrolein exposure (p<0.01, see Figure 1).

A reduced GSH/GSSG ratio is a marker of oxidative stress and the oxidative stress may contribute to the autonomic imbalance indicated by the decreased HRV (RMSSD).

Conclusions

- Increased oxidative stress in individuals with BRI due to exposure to acrolein was identified.
- The results indicate a disturbed antioxidant balance in individuals with BRI, increasing the sensitivity towards certain chemical exposures such as acrolein.

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The effect of thermal conditions during working hours on thermal perception at home – methodological considerations

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SUMMARY
During European summers, when outdoor temperatures rise above 30°C, the gap between thermal conditions during daytime working hours indoors (down to ~21°C with air-conditioning (AC), according to e.g. ASHRAE55-recommendations (ASHRAE, 2013)), and thermal conditions outdoors or in naturally-ventilated (NV) buildings (e.g. private homes), can easily be greater than 10K. Spending hours in AC-spaces likely affects human thermoregulation and subjective thermal perception of NV/outdoor conditions, however, structural information regarding these medium-term effects is lacking. Therefore, the present study aims to assess the impact of a workplace in an AC- vs. NV-building on thermal perception and human thermoregulation throughout day and night. In the process of setting up this study protocol, a series of methodological questions have arisen, amongst other things regarding time management, monitoring frequency and intensity, type of equipment and user-friendliness. Within the scope of this conference paper, methodological considerations, and decision-making for the study set-up will be elaborated on and discussed.

INTRODUCTION
People working in public and commercial spaces are often exposed to thermal conditions that differ greatly from naturally occurring outdoor temperatures. Large temperature differences likely affect thermal perception when people return home after work, as most dwellings in Western Europe are naturally-ventilated (NV). Consequently, thermal conditions outside air-conditioned (AC) spaces may be perceived as less comfortable and warmer in the evening after exposure to cool conditions during the daytime. In contrast, people working in NV spaces (or even outdoors) will benefit from natural acclimatisation effects, and may be less affected by large differences in thermal conditions during and after work. The difference in thermal exposure between daytime and evening may also have an effect on sleep quality in people working in AC vs. NV buildings. The omnipresent availability of AC in public and commercial buildings as well as offices is likely also affecting people’s choices and behaviours at home: if natural acclimatisation in spring and summer during daytime is prevented by the use of AC, it is likely that people would be inclined to usage of AC at home. Hitherto, it is not known whether medium-term effects such as being exposed to particular thermal conditions during working hours will influence perception and physiology in the later course of the day. Therefore, the present study seeks to evaluate the effect of cool versus warm conditions in a simulated office environment, representing a workplace in an AC vs. NV building, on thermal perception and thermal physiology in the evening at home. This conference paper discusses methodological considerations and decisions that were made in the process of designing this study, with respect to e.g. the study population, equipment, scheduling and measurement timing and frequency.

STUDY DESIGN AND METHODOLOGICAL CONSIDERATIONS
To assess effects of AC vs. NV on thermoregulation and thermal perception in healthy volunteers, we decided to design a hybrid study with a controlled laboratory and an observational field part. To perform such study with a medium-large participant group, within a time frame of just a few weeks due to the timing being limited to the summer season, a multitude of aspects concerning scheduling, the frequency and intensity of monitoring, availability of measurement equipment, and other practical details have to be balanced against each other. A selection of the considerations made and the decisions taken to perform this hybrid study will be presented and discussed in the scope of this short paper.

Participants: In order to reduce the required sample size without sacrificing power, a paired-testing, within-participant design was selected. A sample of 32 generally healthy male and female participants will be included in the study based on an a-priori sample size calculation \(^{(G^*\text{power} (Faul, Erdfelder, Lang, & Buchner, 2007))}\) with \(\alpha=0.05, \beta=0.8, \eta^2=0.5\) (medium effect size). This results in a total population of 27, which we
increased by 20% to include drop-out and to even out group size. A young and a middle-aged group will be included in the study, to gauge the effect of age in this context as well (Schweiker, Hubner, Kingma, Kramer, & Pallubinsky, 2018). Therefore, two subgroups of 16 participants from 20-35 and 40-65 years of age will be recruited. Participants will be screened on their general health status to assess eligibility for the study.

**Study design:** The study will consist of two parts: a simulated workday at the Aachen Work Place Simulation Laboratory, and subsequent field observations at the participant's private homes. The strength of a combination of laboratory and observational branches of an experiment is that parameters can be measured in a very controlled setting on the one hand, but on the other hand, also under free-living conditions. These free and natural living conditions bring along the disadvantage that evening and night-time thermal conditions are not controllable, which will increase the complexity of the data analysis. The great advantage of the natural setting is, however, that participants will be in their habitual evening routine and night-time environment, which avoids known negative influences on sleep quality due to sleeping in unknown surroundings. If otherwise simulated in a laboratory, one would require individually-tailored day-, evening-, and night-time environments. However, since the measurements will be performed at two separate days, the effect of the 'unknown environment' would be supposedly higher during the first than the second night, which we do not believe could be solved through a balanced design.

In order to account for differences in the order of exposures, a cross-over design was selected, where all participants will undergo one cool (21°C) vs. one warm (28°C) condition, representing an AC and an NV office day.

**Timing:** With a group of 32 participants, a total of 64 measurement days (one with AC and one with NV conditions) will have to be performed within the summer season. Presuming that weather will be sufficiently warm in our Western European summer, approximately 12 weeks between June and August 2021 will be targeted as measurement period. To perform 64 measurements within 12 weeks, assuming 60 working days (Monday to Friday), 1-2 measurements per day would have to be performed, if one participant would be measured per day. To measure multiple participants per day at the same time, in the same laboratory, would help reducing the scheduling pressure, but has to be carefully considered, as the mere presence of another human has the potential to influence an individual's thermal perception (Schweiker & Wagner, 2016). For this study, it was decided to have two participants in the laboratory simultaneously, to relieve the scheduling pressure. The potential influence due to the presence of another (unknown) person was considered as acceptable, because the main interest is on the perception in the evening when participants will return to their private environment. However, it was also determined that two participants would be coupled for both sessions, to avoid, for example, an influence of personal preferences towards an individual on (one of) the outcome parameters.

**Study outcomes, measurement equipment and monitoring intensity:** To assess the effect of AC vs. NV on thermal perception, modified ASHRAE-scales with continuous visual analogue scales (VAS) will be used for thermal comfort and thermal sensation. Moreover, thermal preference, thermal acceptance, sweating and shivering will also be queried with VAS scales. Alertness, valence, arousal and dominance will be assessed with the Karolinska sleepiness scale (Åkerstedt & Gillberg, 1990) and self-assessment mannequins (Lang, Greenwald, Bradley, & Hamm, 1993) respectively. All subjective parameters will be assessed every hour during the day, at two times during the evening (after arrival at home and before going to bed) and the morning after the test day. All questionnaires will be prompted and recorded using an online application, to ensure high levels of compliance and convenience for the participant.

Regarding physiological outcomes, it had to be considered that participants need to be able to take the equipment home, that the sensors are easy to (re-)apply (in case the participant would have to re-attach a lost sensor), lightweight and multifunctional. However, even though a single commercially-available device would have been able to measure all desired outcomes (see below), the consequence would have been a serious trade-off regarding the accessibility of raw data. Unfortunately, most companies offering smart watches and health-monitoring devices employ their own algorithms and pre-calculation to the data, so that it is not really clear how a particular value is composed, raw data is not offered. To be able to retrieve original raw data, we had to compromise and will use multiple sensors and systems: mean skin temperature (ISO, 2005) will be measured using wireless temperature sensors (iButtons®, Maxim Integrated, USA), heart rate and heart rate variability with a smart watch and chest strap (Polar Vantage M2 & Polar H10, Polar Electro GmbH, DE) and physical activity with an accelerometer (MOX, Maastricht Instruments, NL). Physiological parameters will be recorded continuously every minute throughout the entire measurement period.

Thermal conditions in the laboratory room will be assessed using an environmental monitoring kit (Testo SE & Co, DE). Moreover, participants will be equipped with a portable, visually attractive environmental monitoring station to be used at their homes, to control for environmental conditions throughout the observational part of the study. The device can be carried around, and participants are instructed to keep...
it in close (but not too close) proximity of their whereabouts. The device will not have a display in order to avoid any influence of environmental measurements on subjective perception and survey results.

Confounding behaviours: Another important aspect to consider is the habitual diet and physical activity of a participant. Feeding behaviour and physical activity should represent the individual participant's life as closely as possible, but should not interfere with the measured parameters. After careful consideration, we decided not to restrict the participant too much by prescribing meals and activity throughout the day, but to use a diary to match the meals and physical activity the day before and the day of the measurements as closely as possible. However, an additional activity protocol during the laboratory part will be enforced (e.g. with scheduled periods of sitting, standing and stepping exercises), to ensure comparability between the participants. For the observational part, participants will be instructed to avoid endogenous and exogenous sources of thermal extremes, for example to not sit in direct sun radiation or to engage in strenuous physical exercise. Should they not comply with our requests, we would be able to pick up outliers in the data of the physiological sensors and the activity diary, and then use them to our advantage in relating them to subsequent deviations in thermal perception.

CONCLUSIONS
This short paper discusses the methodology of a novel approach to studying interactions between daytime and evening thermal perception and physiological reactions in a hybrid experimental design. The discussion demonstrates the importance to consider the methodological sacrifices and compromises made to achieve the highest possible quality of data, while balancing usability of equipment for both researchers and participants, minimising invasiveness and optimising time management of the study. The proposed experimental design aims to achieve a balance between these requirements. The implementation and practical application of this thorough discussion will be analysed upon completion of the data collection.

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Exposure to high concentrations of Particulate Matter (PM) is known to negatively affect health. Especially in commercial kitchens, a good exhaust is important to reduce exposure to PM. For this reason, we studied the influence of different exhaust systems and the influence of the preparation of different meals on the chef’s exposure to PM2.5. Laboratory experiments were conducted in which the PM concentration in the room and in the breathing zone of the chef was measured during the preparation of three different types of meals. Also, one of the meals was prepared using two types of exhaust hoods. It was concluded that both hoods were effective in reducing the PM-concentration in the room when used at the high setting. Still the chef was exposed to increased PM2.5 concentrations (>25 µg/m³) during cooking. The lower setting of both hoods reduced the efficiency significantly, thereby demonstrating the need for sufficient exhaust ventilation in commercial kitchens.

The study was carried out in the laboratory of Halton (Béthune, France). During the experiments PM2.5 was measured continuously in the breathing zone of the chef, using a personal device provided with the inlet at the collar of the chef (TSI Dusttrack AM510, measurement interval 1 seconds). Also PM2.5 was measured at two locations in the room (AirVisual Pro, measurement interval 10 seconds) at a distance of 0.25 meter and 2.0 meter from the stove or grill (see Figure 1).

The influence of the type of meal (Hamburgers, Pancakes, Chinese style wok) that was being prepared was tested using a canopy hood at two different settings (“high” (C1) and “low” (C2)). The influence of the type of hood (Canopy and Backshelf) was tested at a “high” and “low” setting when baking hamburgers on a grill. Table 1 provides an overview of the combinations tested in the experiments.

The measured concentrations were compared with the WHO annual limit for the general public of 25 µg/m³ and the WELL building standard limit for commercial kitchens of 35 µg/m³.

For this reason, we studied the influence of different exhaust systems and the influence of the preparation of different meals on the chef’s exposure to PM2.5.

The aims of the study were:

• Objectify the PM exposure of a chef in an ideal situation (in terms of ventilation).
• Investigate the effect of different cooking techniques on PM exposure concentrations.

Figure 1: Picture of the measurement set-up.
RESULTS & DISCUSSION

The results of the concentration measured in the breathing zone are presented in Figure 2. The concentrations measured during the “high” setting (C1 and B1), the ideal situation in terms of ventilation, were compared with the WHO limit. In the breathing zone the limit was exceeded 23% of the time. In the lower setting (C2), peak values reached 528 µg/m³ in the breathing zone when baking pancakes, but were considerably lower when baking hamburgers (30 µg/m³) and stir frying (149 µg/m³). In the room the concentration remained low (<25 µg/m³ for >99% of the time) for all meals prepared (Figure 3).

In comparing the different cooking styles, pancakes resulted in the highest PM2.5 concentrations in the breathing zone for both ventilation settings. During the high ventilation setting (C1) the median concentration in the breathing zone during baking pancakes was 24 µg/m³, while it was 12 µg/m³ during baking hamburgers and 7 µg/m³ during stir frying. The median PM2.5 concentration for the pancakes during the low setting (C2) was 49 µg/m³. For the same ventilation settings, the median value during the hamburgers was 31 µg/m³ and 10 µg/m³ during the Chinese style wok.

In comparing the canopy and backshelf hood both with the highest setting (C&C values C1 vs B1), the PM2.5 exposure in the breathing zone during the hamburger baking was slightly but significantly higher during the canopy cooking session as compared to the backshelf cooking session. This while the percentage of time the PM2.5 concentration exceeded the WHO limit of 25 µg/m³ in the breathing zone, was higher during the backshelf (15%) as compared to the canopy (9%). In the "low" setting, the canopy was more effective than the backshelf hood. The highest PM concentrations were measured in the breathing zone when using the Backshelf hood without the capture jet (“low setting”, median value of 384 µg/m³).

CONCLUSIONS

It was concluded that both hoods were very effective in reducing the PM-concentration when used in the high setting. Still the chef was exposed to increased PM2.5 concentrations (>25 µg/m³) during cooking, mainly caused by movements of the head of the chef above the stove or grill. The lower setting of both hoods reduced the efficiency significantly. Also in field studies, concentrations were considerably higher as compared to the those measured at the high setting. Thereby, this study demonstrates the need sufficient exhaust ventilation in commercial kitchens.

ACKNOWLEDGEMENTS

The project was financially supported by Halton and TVVL (the Dutch HVAC association). Marcel Loomans (TU/e) is acknowledged for his advice and contribution.

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Figure 2: Boxplots of the PM2.5 exposure in the breathing zone, per meal and ventilation rate in relation to WHO limit.

Figure 3: Boxplots of the PM2.5 in the room 2 meter from the stove per meal and ventilation rate in relation to WHO limit.
Evaluating the Influence of Ventilation Strategies on Energy Consumption and Indoor Air Quality in Residential Dwellings

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INTRODUCTION
The International Energy Agency (IEA, 2014) identified that energy efficiency is a vital energy resource, highlighting that the "energy use avoided" by IEA member countries was more prominent than any other single supply-side resource. While there is potential for significant health and well-being benefits associated with improved energy efficiency, it is also documented that if energy efficiency measures are implemented incorrectly, they can have negative impacts on indoor air quality. Regulatory measures need to ensure that multiple objectives are achieved in order to avoid policy failures. A realistic view of the trade-offs (thermal comfort, indoor air quality and energy performance) is required, if current policies are to be effective. An integrated approach is required to simultaneously achieve energy efficiency while also maintaining good indoor air quality. With a limited number of exceptions, the vast majority of studies focus on a single outcome at a time (thermal comfort, indoor air quality or energy consumption).

The potential negative impact of building energy conservation measures on indoor environmental quality (temperature, relative humidity, indoor air quality, thermal comfort, risk of overheating and the presence or absence of sick building syndrome) is widely acknowledged (Broderick et al., 2017, Vardoulakis et al., 2015, Collignan and Powaga, 2017). Studies have reported inadequate indoor air quality, insufficient use of purge ventilation, the presence of mould growth, significant variances in heating patterns and the occurrence of sick building syndrome symptoms (McGill et al, 2015a, McGill et al., 2015b). Fletcher et al. (2017) found that, even with a large temperature difference between the internal and external environment, overheating occurred when the dwellings were not managed correctly. McGill et al. (2017) also reported differences between non-MVHR and MVHR domestic dwellings, where non-MVHR dwellings had higher average and peak temperatures during February and April compared with MVHR domestic dwellings, which had significantly higher mean temperatures in August; these often exceeded the adaptive comfort values.

The current study proposes to examine the three criteria simultaneously and fill knowledge gaps to overcome the human comfort vs energy efficiency dilemma. A computational study presents an opportunity to perform a multi-factor assessment to examine the implications for the different metrics under a range of different ventilation guidelines reflective of energy-efficient dwellings.

METHODS / CASE STUDY DESCRIPTION
An advanced modelling framework was developed that incorporates EnergyPlus (EnergyPlus 9.1.0, United States Department of Energy, Washington, D.C., U.S.), CONTAM (CONTAM 3.4, NIST, Gaithersburg, Maryland) and IAPPEM (McGrath et al, 2014). Each model has unique attributes that focus on a range of factors: indoor temperature profiles, energy consumption, airflow patterns, pressure values, and the distribution of indoor air pollutants. The need to balance energy performance and ventilation in highly energy-efficient dwellings requires that a combined approach be employed. This process captures the interdependencies between airflow, heat transfer and overall energy consumption.

Three different archetypes (bungalow, semi-detached and a terrace dwelling) were utilised that were previously developed by the project team (McGrath et al., 2021). Simulations investigate varying outdoor location (meteorological conditions, geogenic radon potential and outdoor air pollution concentrations), different occupancy scenarios, building characteristics, airtightness (1, 3 and 5 m³/hr/m²) and ventilation characteristics (natural vs mechanical control). The ventilation parameterisation is based upon the recently released Irish Technical Guidance Document Part F – Ventilation and Part L – Conservation of Fuel and Energy – Dwellings (DHPLG, 2019a). The ventilation regulations require that habitable rooms (living room and bedroom) operate by supplying external air into the dwelling.

In naturally ventilated dwellings, the supply vent is an opening on the external wall, where the airflow is driven by the pressure differentials between inside and outdoors, as well as the wind speed and direction. In wet rooms, the extract ventilation is typically
intermittent mechanical extract activated by occupant presence. By contrast, mechanically ventilated dwellings require continuous extract in the wet rooms and continuous supply in the habitable rooms. In this situation, the required supply and extract airflow rates vary per room and are determined based on the overall floor area, the number of wet rooms and estimated occupancy of the dwelling.

The indoor temperature modelling is performed via EnergyPlus as a whole building energy simulation program which makes use of several inputs: physical parameters, heating systems and operation schedules (Department of Energy's (DOE) Building Technologies Office (BTO), 2019).

All the thermal and energy performance criteria are based on the Irish Technical Guidance Document Part L for each archetype (DHPLG, 2019b). The building energy performance focused on three categories: thermal characteristics, building elements, lighting system, and heating system. The first category focuses on the thermal conductivity of exterior walls, roofs, exterior doors and windows, double-glazing systems with lower U-values in each model. The second category focused on LED lighting systems as an optimized option for energy-efficient cases. The third category incorporated the heating system’s performance that utilized heat pumps with a COP of 2.2 as the primary heating source for each building (DHPLG, 2019b, Egan et al, 2018).

The indoor air quality components focus on modelling humidity, carbon dioxide, TVOCs, PM2.5 and radon during various household activities, including breathing, sleeping, cooking, cleaning, and other combustion events.

RESULTS & DISCUSSION

Due to the scale of the simulated data, only a selection of the results are presented in this paper. Table 1 presents data that corresponds to a four-person occupancy scenario in a 120 m² single-story dwelling based on suburban Dublin (53°25'N 6°15'W) weather patterns. A cooking profile is simulated for a 24-hour period, which is replicated over the year. The conditions reflect three air permeability scenarios for the dwelling, 1, 3 and 5 m³/hr/m² for the mechanical ventilation and natural ventilation scenarios, respectively. These scenarios are based on Irish Building regulations. All other inputs remain constant across both sets of simulations.

While data are generated for all rooms within the dwelling, the results in Table 1 focus on year-long averages for a single room.

While the data presented mainly reflects the simulated occupancy, emission scenarios, and outdoor air pollution concentrations, valuable observations can be determined from the simulations. In both ventilation scenarios, as the building’s air permeability decreases, TVOCs and CO₂ concentrations increase. However, there is a reduced impact on PM₂.₅ due to mechanical ventilation, possibly due to the balance between indoor and outdoor concentrations. The PM₂.₅ concentrations can be highly variable and reflective of outdoor concentrations, the cooking duration and the emission source.

Table 1. A summary of a sample of outputs from the modelling framework. The values represent yearly averaged pollutant concentrations for the kitchen in the bungalow dwelling.

<table>
<thead>
<tr>
<th>Air permeability (m³/hr/m²@50%RH)</th>
<th>1</th>
<th>3</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Ventilation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM₂.₅ (µg/m³)</td>
<td>30</td>
<td>28</td>
<td>26</td>
</tr>
<tr>
<td>R.H. (%)</td>
<td>45</td>
<td>45</td>
<td>46</td>
</tr>
<tr>
<td>TVOCs (ppb)</td>
<td>137</td>
<td>130</td>
<td>125</td>
</tr>
<tr>
<td>CO₂ (ppm)</td>
<td>588</td>
<td>570</td>
<td>555</td>
</tr>
<tr>
<td>Mechanical Ventilation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>PM₂.₅ (µg/m³)</td>
<td>13</td>
<td>13</td>
<td>14</td>
</tr>
<tr>
<td>R.H. (%)</td>
<td>38</td>
<td>38</td>
<td>39</td>
</tr>
<tr>
<td>TVOCs (ppb)</td>
<td>103</td>
<td>99</td>
<td>95</td>
</tr>
<tr>
<td>CO₂ (ppm)</td>
<td>597</td>
<td>564</td>
<td>544</td>
</tr>
</tbody>
</table>

Overall, the lower concentrations for the mechanical ventilation are explained by the rationale that the system is ‘always running’ with constant airflow rates. Natural ventilation is more variable and influenced by different meteorological conditions. Simulations focusing on other outdoor locations will help provide a clearer context in this regard.

Interestingly, the natural ventilation scenarios have higher CO₂ concentrations for the air permeability combinations of 3 & 5 m³/hr/m² compared with the mechanical ventilation scenarios. Although for 1 m³/hr/m², mechanical ventilation has a higher concentration. The same effect is not noticed for the other pollutants, which could be an example of the influence of intermittent extract ventilation, which is driven by occupant presence. The intermittent extract ventilation has higher airflow rates for short durations, which could result in reduced occupant exposures as they move throughout the dwelling.

CONCLUSIONS

The initial results highlight the comparison between different ventilation scenarios in the recently updated Irish Building Regulations. For most pollutants, the mechanical ventilation system performed better; however, the results highlight the impact of intermittent ventilation strategies. Further simulations are focussing on the impact of the energy consumption of the mechanical ventilation compared with natural ventilation, indoor temperatures during the summer period, and the potential need for cooling,
different outdoor meteorological conditions and air pollutant concentrations.

ACKNOWLEDGEMENTS

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Indoor Exposure to Fine Particulate Matter and Practical Mitigation Approaches – a U.S. National Academy of Sciences Workshop

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SUMMARY

The U.S. National Academies of Sciences, Engineering and Medicine (National Academies) conducted a workshop on the state-of-the-science on exposure to fine particulate matter (PM$_{2.5}$) indoors, its health impacts, and engineering approaches and interventions to reduce exposure risks, including practical mitigation solutions in residential settings. The workshop took place in April, 2021 and comprised three sessions featuring talks from experts on these topics. Sessions were webcast, including remote participation by viewers; archived online for later reference; and will be summarized in a publication that will be released in fall 2021.

INTRODUCTION

Particulate matter (PM) dominates the known health impacts of air pollution. Most exposure to PM from both indoor and outdoor sources takes place in indoor environments, a circumstance exacerbated by the COVID-19 pandemic. Exposure to fine particulate matter (PM$_{2.5}$) is especially concerning because a large and growing body of scientific literature indicates that it is associated with adverse health outcomes, including respiratory, cardiovascular, reproductive, and cognitive effects.

In 2020, the U.S. Environmental Protection Agency (EPA) requested that the National Academies convene scientific experts in a workshop to address these issues. The workshop featured invited presentations and panel discussions. It included consideration of:

- the key implications of scientific research and engineering practice for public health, including potential near-term opportunities for incorporating what is known into practice; and
- where additional research will be most critical to understanding indoor exposure to PM$_{2.5}$ and the effectiveness of interventions.

Opportunities for advancing research by addressing methodological and technical barriers and enhancing coordination and collaboration between the science, medical, and engineering communities were also given attention.

The workshop built on series of National Academies efforts on indoor environment and health topics, including studies of indoor exposures and asthma (IOM, 2000), damp indoor spaces and health (IOM, 2004), the effect of climate change on the indoor environment (IOM, 2014), an examination of built-environment microbiomes (NASEM, 2016b), and an earlier workshop on the health risks of indoor exposure to particulate matter (NASEM, 2016a). A separate study evaluating the emerging science on indoor chemistry is also currently being carried out (NASEM, 2021a), and a study of the health risks of indoor exposures to fine particulate matter and practical mitigation solutions was initiated in summer 2021 (NASEM, 2021b).

METHODS

To fulfill EPA’s request, the National Academies formed a planning committee of engineering, public health and medicine experts led by Richard L. Corsi of Portland State University. He was joined by Seema Bhangar, WeWork; Wanyu Rengie Chan, Lawrence Berkeley National Laboratory; Elizabeth Matsui, University of Texas at Austin; Linda A. McCauley, Emory University; Kimberly A. Prather, University of California San Diego; David Y.H. Pui, University of Minnesota, Minneapolis; Jeffrey Siegel, University of Toronto; and Marina Vance, University of Colorado, Boulder.

In order to facilitate an online format, the event was broken up into three sessions covering the following topics:

- sources of indoor fine particulate matter;
- indoor exposure to fine particulate matter: health, metrics, and assessment; and
- mitigation of indoor exposure to fine particulate matter.

Twenty-two leading researchers and practitioners in these subject areas were identified and recruited to present at the sessions, participate in roundtable discussions with the committee, and answer questions submitted by online attendees. They shared their knowledge and the results of cutting edge research on such topics as:

- the influence of sources of indoor fine particulate matter on the characterization of exposure and evaluation of health effects;
- the health burden of indoor PM$_{2.5}$ exposure;
- the state of knowledge on indoor particulate measurement science, technology, and policy;
- outdoor-to-indoor transport mechanisms and particle penetration through building envelopes;
• the utility, use, and misuse of low-cost consumer indoor particulate matter sensors;
• portable indoor air cleaners and human behavior; and
• fine particulate matter filtration in indoor environments

Live online broadcasts took place on 14, 21, and 28 April, 2021. Approximately 600 persons logged in to each of the webcasts, with participants from across the U.S. and from 30 other countries. Details on the workshop and this project are available at https://www.nationalacademies.org/our-work/indoor-exposure-to-fine-particulate-matter-and-practical-mitigation-approaches---a-workshop.

RESULTS

Videos of the workshop sessions and PDF copies of the presenters’ slides have been posted at the following websites:

14 April: Sources of Indoor Fine Particulate Matter

21 April: Indoor Exposure to Particulate Matter: Health, Metrics, and Assessment

April 28: Mitigation of Indoor Exposure to Fine Particulate Matter

A rapporteur working in consultation with planning committee and National Academies staff will prepare a summary of the workshop proceedings that will be subject to peer-review before publication. It will be released in fall 2021 and made freely available for download in PDF format at The National Academies Press website (www.nap.edu).

ACKNOWLEDGEMENTS

The workshop is sponsored by the U.S. Environmental Protection Agency. The planning committee and this author gratefully acknowledge the contributions of time and expertise provided by the workshop session speakers.

REFERENCES


Office Design: a review of health effects of different office concepts.

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SUMMARY
Flexible and open office concepts have seen rising popularity the last years. These office designs are questioned during the pandemic due to risk of infections among the users. This paper summarizes international research on sick leave and disability retirement when working in flexible or open office concepts, as compared to cell offices. Seven studies were identified from relevant sources. The evidence quality was assessed according to GRADE.

The main outcomes were:

- Increased risk of sick leave in flexible office concepts (very low evidence quality).
- Increased risk of sick leave in open office solutions (low evidence quality).
- No basis to conclude regarding risk of disability retirement in flexible office concepts.
- Increased risk of disability retirement in open office solutions (low evidence quality).
- There was no basis to conclude in sick leave or disability retirement risk between open-plan offices of different sizes.

The small number of studies, their potential limitations in scope and quality, the heterogeneity in the field, and the present evidence quality of the findings, indicate a need for further research investigations into these topics.

INTRODUCTION
The Covid-19 pandemic has led to changes in how office work is carried out. The use of flexible and open office concepts is now called into question regarding risk of infection. This has merged with the pre-pandemic discussion regarding office concepts' risk for sick leave and disability retirement, creating an increased focus on how office concepts influence the health of employees.

To our knowledge, no review of the literature exists on the topic of sick leave and disability retirement in open and flexible office concepts. As this is a topic of importance to all who work in offices, such a review is highly needed. Sick leave is absence from paid work due to own illness. Disability retirement is earlier retirement due to certified injury or illness.

Office concepts are often characterized along three dimensions:

- Number of persons in the room (space): Generally, whether you work in an individual room alone (typically cell office or individual office) or with others, and if so, how many (which gives a division into shared offices, small open office landscapes, medium-sized office landscapes, etc.). In addition, there are many other layout aspects that also affect the workplace and the experience of working there, such as whether you have a window place and the availability of retreat rooms and meeting rooms. Also, whether the work zones you potentially can choose from have different character and function.

- Formal and informal rules regarding the use of the space: This pertains to whether employees have their own dedicated workstation, or the opportunity to choose between several places to work (within the workplace). Other terms for no dedicated workstation are free seating, shared seating, hot-desking, and activity-based working. An umbrella term that is often used in research on these concepts, is flexible office concepts.

- Location: Whether the work is performed at the workplace (owned or rented by the employer) together with colleagues, in your own home, on the go, or in places that vary.
The aim of the current study is to summarize published international empirical research on the relationship between working in flexible or open office concepts, and the risk of sick leave and/or disability retirement.

METHODS
Relevant studies were identified from existing literature reviews, database searches using PubMed and Google Scholar, contact with experts in the field, and reference lists. We included all studies that:

- were empirical, and
- investigated the relationship between flexible or open office concepts, and sick leave or disability retirement.

The quality of the evidence was assessed according to the GRADE framework, which distinguishes between four levels of evidence quality: very low, low, moderate, and high levels of evidence quality. Note that findings based on observational studies are classified as low evidence quality, but the level may be upgraded to moderate evidence quality if (i) the effect is of large magnitude, if (ii) there is a dose-response gradient, or if (iii) all confounding factors have been accounted for.

We identified seven potentially relevant articles. Among these, one was based on summarized data from some of the other included articles. This article was excluded, leaving us with six relevant studies.

RESULTS & DISCUSSION
The included studies all investigated sick leave or disability pensions for employees working in the same room as others (shared office or open office solutions) as compared to employees working in individual rooms (cell offices). Some studies also noted if the employees worked in a flexible office concept, and the number of employees in the room.

The findings are therefore divided in three categories for each outcome variable: flexible office concepts, open office concepts, and office concepts of different sizes.

Sickness absence
Five studies investigated sickness absence in various office concepts. As compared to cell offices, we found increased risk of sick leave (very low evidence quality) among employees working in flexible office concepts. This risk is possibly higher for men than for women. Furthermore, there was also increased risk of sick leave (low evidence quality) for employees working in open office solutions, with a potential higher risk for women than for men.

Regarding open-plan offices of different sizes, the evidence was too scattered to conclude in neither direction.

Disability retirement
One study investigated disability retirement in various office concepts. Based on this study, we conclude there is increased risk of disability retirement for employees working in open office solutions (low evidence quality). Since the effect is of rather large magnitude (i) and most known confounders were taken into account in the analyses (ii), one may question whether the evidence quality could be upgraded to moderate. For open-plan offices of varying sizes, the evidence is not sufficient to conclude. As the study did not include flexible office concepts, there was no basis to conclude regarding flexible office concepts either.

The results of our studies indicate that flexible and open-plan office concepts are related to potential detrimental health effects on workers.

Implications for future research
“Low” (according to the GRADE framework) was the highest level of evidence quality the current review found. For three of the investigated topics (disability retirement in flexible offices, and both sickness absence and disability retirement in open offices of various sizes), there was no basis to conclude at all.

This is a field of research where the main method of investigation is the observational study. According to the GRADE framework, research questions investigated by observational studies can reach no higher level of evidence quality than moderate. So, this must be the aim for this field of research. Only then can we be somewhat confident in the conclusions we draw.

To get there, more research is needed. There are clear knowledge needs regarding (1) the risk of disability retirement in various office concepts, (2) the health effects of open-plan offices of various sizes, and (3) the health effects of working in flexible office concepts. There is a particular need for studies on the connection between work in flexible solutions and the risk of disability retirement.

Furthermore, office design is something that can be done in a large variety of ways. Aspects of the design such as variations in aesthetics, noise levels, air quality, and prevalence of windows and concentration rooms, can all potentially influence health outcomes. These are therefore potential confounders for the relationships between office concepts and health...
outcomes and should be controlled for. The included studies in this review all controlled for potential third variables, but only those that related to the individual, such as health concerns and level of income.

Each office concept should ideally be adapted to the type of work performed, and the employees’ work tasks. This is probably not sufficiently considered in relevant research so far.

It is important that future studies satisfy requirements for adequate scientific quality.

Adequate scientific quality in this context means: experimental or prospective designs, no risk of selection bias (i.e. companies not selected on basis of office concepts or use data from representative, national surveys), adequate number of participants, control of confounding from potential third variables (including both individual-level variables and aspects of the physical workplace), objective data on sickness absence and disability pension, and division of exposure into several well-defined office categories (which include both flexible office concepts, open landscapes of various sizes, degree of home office use, or working remote).

Implications for practice
The findings of the current review indicate that future use of flexible and open-plan offices should be considered very carefully. The current research, though somewhat limited, indicate that flexible and open-plan office concepts, such as they typically have been designed until now, are related to higher risk of detrimental health outcomes. Until further research is available, it is recommended that care is taken to avoid pitfalls in office design that may be likely to increase the risk of ill health.

Study limitations
There are some limitations of the current study. As the literature search was not systematic, relevant studies might have escaped us. However, we hope to have mitigated this by basing the search on existing reviews, including a recent scoping review, and close contact with experts in the field. A further limitation is the lack of meta-analysis on the included data. However, as this is likely a field of extensive heterogeneity, it is desirable with a higher number of studies to include before conducting meta-analysis. Future reviews on the topic may well consider conducting meta-analyses.

A last limitation is the lack of focus on working from home. The current situation with extensive use of home offices, is expected by many to continue after the Covid-19 pandemic. As of such, the relationship between home working and sick leave or disability retirement is a topic of vital importance.

CONCLUSIONS
Based on current and limited international research, we concluded that there is:

- increased risk of sick leave among employees who work in flexible office concepts (very low evidence quality).
- increased risk of both sickness absence and disability retirement among employees working in office concepts where several employees share a room (low evidence quality).
- no basis to conclude regarding the importance of open-plan office size for risk of sickness absence or disability retirement
- no basis to conclude regarding the risk of disability retirement in flexible office concepts.

There is a clear need for more research on all these topics. Also, on the specific factors that could contribute to sickness absence and disability retirement among office workers.

ACKNOWLEDGMENTS
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How well are health institutions prepared for pandemics, in terms of ventilation and protective equipment?

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SUMMARY
The purpose of this paper is to highlight some measures that could help circumvent the discussion of whether a pandemic caused by a virus is transmitted via droplets or aerosols.

During pandemics health care institutions require, among other things, good ventilation and necessary protective equipment. Discussions about the route of disease transmission can get in the way of good discussions on how best to protect health care workers.

To ensure proper access to respiratory protection in a situation of shortage of disposable respirators, health care institutions should facilitate the use of reusable respiratory protection. This however requires locations that enable their maintenance, cleaning, and disinfection.

Hospitals and other health care institutions need to be better prepared to respond to a pandemic in terms of building stock and technical measures.

INTRODUCTION
The current pandemic has been a wake-up call for many, for example when it comes to ventilation and personal protective equipment. Experience from the field of occupational hygiene has resulted in different stories and experiences from the ventilation industry, and not all are positive. The reason for the bad experiences has not been studied. It could be both due to poor competence of ordering or specification of requirements, poor advice from the ventilation companies, and user error. Regardless the reason, the first advice is always to check functionality of the ventilation system when there are complaints about the indoor air quality.

When dealing with a pandemic, one must focus on several different preventive measures. It is not enough to just make changes at the source, or protect the surroundings, but also to consider the pathway from the source to the susceptible host. Social distance, wearing a face mask, and good hand hygiene all focus on source control and measures at the susceptible host.

Proper ventilation will be a measure that affect the path between source and receiver. It dilutes the polluted air and if designed correctly, reduces exposure to the receiver. Route of transmission (contact, droplet, air) will be important for which measures will be most effective, but in the event of a pandemic with an unknown dose-response relationship and an unresolved degree of aerosol infection, it is important to include all levels of measures.

From a point of view of occupational hygiene, it is more important to find good measures higher up in the hierarchy of control than personal protective equipment, which is located at the bottom of the hierarchy and has proven to be less effective in the long term (National Institute for Occupational Safety and Health, 2015). This seems to be the opposite of what people working in the field of infection control focus on, where ventilation is mentioned as a supplement to personal protective equipment (Folkehelseinstituttet, 2004). Ventilation is a part of the engineering controls in the middle of the hierarchy, and is therefore more effective, partly because they do not rely on human activity in the same way as personal protective equipment.

The differences in approach to solutions by different professions is reflected in a gap in knowledge and perceptions about the source of infection/pollution. The mode of transmission of SARS-CoV-2 was early defined as droplet infection by The World Health Organization (WHO). Other professional communities disagree with this, and this seems to be a major international disagreement (Brosseau, March 2020, Morawska & Milton, 2020). One reason is the different ways of considering droplets and aerosols. It is not a sharp distinction between drops and aerosols at a particular size, but a smooth transition. Humans produce droplets/aerosols in all sizes whether we are talking, singing, coughing, or sneezing (Chen et al., 2020, Han et al., 2013, Morgenstern J, April 2020).

Airborne transmission can be found at short distances as well, not only over long distances like WHO defines it (Brosseau, March 2020, Morawska & Cao, 2020, Gralton et al., 2011, World Health Organization, 2014, World Health Organization, 2020).

In occupational health, risk assessment is always the basis when evaluating measures to reduce exposure to hazardous issues. From a health and safety perspective, it is important to take measures that reduce a possible risk of infection. Especially when we
are dealing with new and partly unknown sources of infection such as a new virus.

If a pandemic caused by a virus infection that is defined as droplet infection, but turns out to be transmitted by air, as with SARS, MERS and other influenza viruses (Yu et al., 2004, Kim et al., 2016, Lindsley et al., 2015), WHO should consider transmission by air. Requirements for airborne infection isolate already exist, and could be implement to pandemic plans.

**Ventilation**

In general, the number of air changes per hour affects how quickly after a pollution episode a room can be used without personal protective equipment, or how long it takes before the pollution level is at an acceptable level.

The insulation guide from Folkehelseinstituttet (2004) and infection prevention guidelines from World Health Organization (2014) states the desired air changes in patient rooms on airborne insulation to 12 air changes per hour. Ordinary patient rooms may have an air change of 4-6 times per hour (Escombe et al., 2019, ASHRAE, 2019). When dealing with an airborne infection, it will take much longer in ordinary patient rooms before the polluted air is diluted to the same degree as it is with 12 air changes per hour (AHSERAE, 2019).

Air changes per hour is one way to control ventilation systems. Cubic metres per hour or litres per second per human are units to calculate ventilation volume. This illustrate that there is no standard method to compare ventilation volume in a simple way, without additional calculations. This can generate problems as soon as ventilation is a part of suitable measures for proper management of a pandemic.

If suitable ventilation resolutions are arranged at the planning stage for new health care institutions and hospitals and implemented in pandemic plans, it will be possible to bypass the discussion regarding mode of transmission route. Like Morawska & Milton, 2020 says, "In order to control the pandemic, pending the availability of a vaccine, all routes of transmission must be interrupted."

**Respirators**

It is important to do a systematic risk-based approach for the selection of personal protective equipment (PPE) against infectious agents regarding transmission routes in health care settings (Jones et al., 2020). Face mask protect from splashes and large aerosols (droplets) that project onto the face (conventionally droplet precautions). Respirators protect from inhaling aerosols and from projected droplets (airborne transmission). Face masks are loose fitting, while respirators are tight-fitting or with loose-fitting hoods. Tight-fitting respirators must be adapted to the individuals using qualitative or quantitative fit-tests (Lawrence et al., 2006).

Respiratory protection may be meant for single or repeated use. Disposable respirators, like FFP3 and FFP2/N95, can be used up to one shift at a time and discarded after use. This is easy for maintaining infection control. Reusable respirators can be used over many shifts, over months and years, with filter changes as needed. However, reusable respirators must be cleaned and disinfected before reuse if used in an infection situation.

Reusable respirators that are appropriate to use in hospitals and health care institutions are elastomeric half mask respirators (EHMRs) and powered air purifying respirators (PAPRs).

The advantages of disposable respirators are that they require no maintenance and are discarded after use so that you easily get rid of the contaminated items.

Disadvantages of disposable respirators are that there is a high probability that a shortage situation will arise during a pandemic, and that it may be difficult to find one respirator that suits many workers (Føreland et al., 2019).

Some advantages of using reusable respirators are that you only need a small number of respirators compared to disposable respirators. One or two respirators per employee is enough, and it is less likely to result in a shortage situation. Reusable respirators are available in several sizes within the same model, and will therefore more easily fit many workers (Lawrence et al., 2006). The disadvantages are that they require disinfection and maintenance, which in turn involves extensive logistics.

If we compare elastomeric half mask respirators to powered air purifying respirators some will prefer one and some will prefer the other, depending on what the workers are used to (Hines et al., 2019). Powered air purifying respirators do not need to be fit-tested to ensure good fit, unlike elastomeric respirators. EHMRs and PAPRs do have different procedures for disinfection, and both the equipment and cleaning costs can differ a lot. The differences need to be investigated further to find the most cost-effective alternative.

**Logistic and location**

Reusable respirators require good disinfection routines, and the routines require location that enables their maintenance, cleaning, and disinfection.

Every health care worker does need storage for their respirator, whether it is EHMR or PAPR, that is easy to access before shift. After shift, they have to clean and disinfect the respirators, either themselves or by dedicated personnel. The respirators have to air dry, which require room for them to do so. After drying, they have to be placed in proper storage, ready for the next shift. All these procedures need proper facilities. Lack of room in general is common for health care institutions and hospitals.
Separate rooms for disinfection of respiratory protection equipment should become a standard that could be implemented as a requirement in new buildings of hospitals and health care institutions. If so, the conditions may be better suited for emergency preparedness and the next pandemic. Maybe we can avoid big discussions of whether something is infected through droplets or air because we are already prepared for airborne infections and can secure the health care workers in the best possible way.

CONCLUSIONS

- Ventilation systems in hospitals and health care facilities must be designed so that they can handle airborne infection (over short and long distances) and reallocation of premises during a pandemic.
- Elastomeric respirators are a good alternative to FFP3 during a pandemic when a deficiency situation can occur.
- Arrangements must be made, already in the planning of health care institutions and hospitals, for areas for storage, and for handling disinfection of reusable respirators.

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REFERENCES


Evaluation of the physiological effect on human subjects of different odorant environments

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ABSTRACT

Different molecules or combinations of molecules can be used to formulate odorant products. Even if the commonly used methodology involving expert panelists is designed to reduce interindividual differences, the odorant sensitivity differs from one person to another. In this study, the physiological effect of different odorants was investigated by using sensory and physiological measurements. Chemical measurements of the exposure environment were also made simultaneously. The objective was to investigate the benefits of the addition of physiological data to discriminate the effects of the different odorants and to link them to the declared perception of intensity and well-being, and to the chemical composition of the exposure environment.

Results indicate that for very low VOC emissions, and pleasant odorant stimuli, sensory evaluation discriminate between odorant environments for intensity and pleasantness, but no discrimination is highlighted along time of exposure, whereas physiological measures traduce different evolution of responses. Skin blood flow level is linked to the perceived pleasantness of the odorant environment, the electrodermal response is correlated to the relaxation level and heart rate is linked to arousal and relaxation.

INTRODUCTION

Physicochemical and sensory methods for odor analysis show several limitations to evaluate the effect of an odorant on the physiological state of a human subject. For example, physicochemical analysis, although allowing the identification and quantification of many odorants at very low thresholds in air or water may not be as sensitive as human perceptual levels (Lawless & Heymann, 2010). Perception is much more complex and multiparametric as it involves individual variability in age, gender, genetics, experience, emotional state, thresholds, etc., but is also capable of detecting odors at very low thresholds (ppb or below) and often below the detection limits of instrumental analyses (Sáenz-Navajas et al., 2010). In addition, the synergistic effect (whereby one quality is enhanced by the other) between the aromatic components is not considered with chemical analysis only (Ishii et al., 2008).

An alternative approach would be to move up the perception chain and access the subconscious and unintentional process that occur during the olfactory perception of an environment. For example, undetected odors in the environment can alter mood and behavior (Zucco et al., 2009). The direct measurement of the involuntary and subconscious physiological responses provides objective information to supplement the expressed and conscious perception, especially when the differences between the evaluated products are very subtle and difficult to detect (Boucsein & Schaefer, 2008).

The purpose of this study was to investigate the benefits of the addition of physiological data to discriminate the effects of the different odorants, and to link them to the declared perception of intensity and well-being, and to the chemical composition of the exposure environment.

METHODS / CASE STUDY DESCRIPTION

Subjects

Eight subjects, aged from 24 to 56, with a normal BMI, non-smokers, and having a high declared and measured sensitivity to odorant stimuli were selected among a larger representative sample.

Odorants

Two odorant products were evaluated using self-assessment questionnaires and physiological measurements, as well as a neutral environment without odorant emission (E0). The first odorant (E1) was a deodorant with a verbena and lemon scent, the second one (E2) was a deodorant with a lavender scent.

Sensory evaluation

The perceived intensity and its associated well-being were evaluated using two 11-points scales, at several times after starting the odorant emission in the test chamber (1 min, 2 min, 5 min, 10 min and 15 min).

Physiological responses

The physiological responses which were measured were heart rate, skin blood flow, electrodermal response (EDR) and breathing rate.

In this study, the FE132 ECG module was combined with three MLA2503 ECG electrodes (AD Instruments,
Oxford, UK). The black reference electrode was placed on the lateral malleolus of the right ankle, the white electrode below the right collarbone and the red electrode on the last left floating rib.

The system using MLT116F GSR (Galvanic Skin Response) electrodes was used in this study to measure the EDR. These electrodes are bipolar. They were attached to the fingers of the non-dominant hand (Roth et al., 2012) of the subjects with Velcro™ lashes, without an electrolyte between the skin and the sensor. They were connected to the GSR FE116 amplifier (AD Instruments, Oxford, UK). The amplifier supplies a low constant voltage of 22 mV at 75 Hz approved by the electrical safety standard IEC 60601.

The Periflux PF 5010 system (Perimed AB, Sweden) with a fiber optic probe PR407, which enables non-invasive monitoring of blood perfusion in capillaries, arterioles, and venules, was chosen. The measurement is expressed in perfusion unit (PU), which is an arbitrary unit corresponding to the product of the average speed of moving red blood cells and their concentration (Humeau et al., 2007). Recordings were performed on the pulp of the index finger of the non-dominant hand due to the strong vascularization of this area.

The breathing rate was recorded using a respiratory belt MLT 1132 (AD Instruments, Oxford, UK) measuring changes in thoracic or abdominal circumference during respiration. All four physiological signals were recorded with the PowerLab PL35088/35 acquisition system with 8 channels and the data were collected at 1 kHz and analyzed with the Labchart® (AD Instruments, Oxford, UK).

**Test emission chamber**

The experiments took place into a specific test emission chamber of 30 m³, the AIR’IN chamber. This equipment is a realistic emission test chamber characterized by 2,9 m of large x 4,15 of long m x 2,5 m of high, with a stainless-steel inner coating to limit phenomena between gas phase and walls. A ceiling fan ensures the homogenization of pollutants. The air change rate of the chamber was 0.33 hr⁻¹, with controlled temperature and humidity.

The odorants are placed in a 10L glass chamber where a dry and clean air flow of 16 L.min⁻¹ circulates. A valve allows the odor to be injected into the test chamber or removed to the outside. Under our experimental conditions, the mass flux of deodorants E1 and E2, during exposure, is respectively 0.39 mg.L⁻¹ and 1.51 mg.L⁻¹.

The subjects were exposed individually to the three different environments, in the test emission chamber for 15 minutes. Before and during the exposure time, the air in the chamber was sampled on specific adsorbent tube and analyzed with TD/GC/MS system, according to NF ISO 16000-6:2012.

**Experimental procedure**

Subjects were instructed not to eat or drink for at least 1 h prior to the test. They arrived 15 minutes before the beginning of the test and were equipped with the physiological devices during this time. They were at rest, sitting in a comfortable chair. This equipment phase also enabled the subjects to acclimate to the temperature and the general environment of the room, particularly the temperature (maintained constant at 23 ± 1°C).

A sound signal indicated to the subjects that they had to fill in the sensory questionnaire about their environment odor perception for each time of exposure defined before.

**RESULTS & DISCUSSION**

Results obtained from the sensory questionnaires show that there are significant differences between the three odorant environments (Figure 1). E0 was perceived significantly less intense and less pleasant than E1 and E2, E1 was perceived as the most pleasant.

![Figure 1. Mean plots of the intensity scores for E0 (a), E1 (b) and E2 (c) and the pleasantness scores of E0 (d), E1 (e) and E2 (f)](image_url)

Tuckey’s multiple comparisons post-hoc test show that E0 and E2 were not significantly perceived as different in intensity but that E1 was perceived significantly higher in intensity during the whole duration of exposure. No significant effect of the duration of the odorant release is observed on the perceived intensity or the global pleasantness.

Results also indicate significant differences between the odorants for all the physiological responses (Figure 2).

![Figure 2. Physiological responses for E0, E1 and E2](image_url)
The electrodermal response level increases during the exposure for the three odorant environments but in a slower way for E1 than E0 and E2 and is significantly lower after 5 minutes of exposure for E1 (38% lower for E1 compared to E2, p=0.042).

The skin blood flow level decreases for both E0 and E2 during the exposure whereas it increases for E1. The level is significantly higher for E1 on the total duration of exposure (44% higher for E1 compared to E0 and 40% higher for E1 compared to E2, p<0.0001).

Heart rate increases faster at the beginning of the exposure when an odorant is released and decreases more rapidly for E1.

Breathing rate shows no significant differences between the three environments.

Results obtained for emissions of VOC show low values of concentrations measured in the AIR’IN chamber. Emissions are dominated by very volatile organic compounds and terpenes, among them major compounds identified are linalool, D-limonene and citral. As shown on Figure 3, no significative differences are observed for emission of linalool during all experiments. For D-Limonene, concentrations measured for experiments E1 are higher than for experiments E0 and E2. Finally, citral is detected only for experiments E1.

Significant differences were observed in the temporal evolution of the heart rate, electrodermal response and skin blood flow between the different environments. The skin blood flow level is linked to the pleasantness of the odorant environment as it increases during the exposure to a pleasant and intense odor. The electrodermal response is correlated to the relaxation level since its level increases in a slower way when a pleasant and more intense odor is perceived. Heart rate is linked to arousal and relaxation, it increases at the beginning of the exposure when the odor is perceived as intense and pleasant and decreases along the exposure, whereas for less intense and pleasant odors exposure the heart rate level remains more stable during the 10 last minutes of exposure. There is no significant evidence of a direct link between skin blood flow level and emission of major terpenes induced by odorants sources tested.

These experiences underline the relevance of the proposed global perception approach. This method could be deployed for wider ranges of VOC emissions for air fresheners, as well as for other sources impacting on comfort.

ACKNOWLEDGEMENTS

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Achieving a healthy indoor air by using an emissions barrier

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SUMMARY
A new type of emissions barrier was used in premises with indoor air complaints due to moisture driven emissions from the buildings in question. The emissions comprised chlorophenols/chloroanisoles and polycyclic aromatic hydrocarbons (PAH) from treated wood, and volatile organic compounds (VOC), mainly 2-ethylhexanol, from PVC flooring and the glue used to paste the flooring onto a concrete slab. Attaching the barrier at the surfaces from where the emissions were spread (floor, walls, ceiling) resulted in a fresh and odour-free indoor air. We conclude that using an emissions barrier in buildings made unhealthy by moisture is an efficient way of restoring a pleasant and healthy indoor air.

INTRODUCTION
Building moisture typically results in spread of chemical and biological emissions into the indoor air leading to illnesses and symptoms such as asthma, skin and eye irritation, fatigue etc (Mendell et al. 2011, Bornehag et al. 2004). Drying is a necessary first step in remediation because it will stop further moisture-driven reactions with the building materials as well as (continued) mould growth. However, drying is not enough to secure a clean indoor air, since the numerous chemicals that have been formed from water - or moisture – acting on the materials will still remain in the building construction and over time inevitably be emitted into the indoor air. The emissions may be e.g. VOC from paints, glue, insulation materials, chipboards, microorganisms, impregnation and plasticizer chemicals, or toxins from microorganisms such as mould. In the present study we applied a new type of emissions barrier (Markowicz and Larsson 2012, 2015) developed at Lund University Sweden to stop such emissions thereby improving the indoor air quality (IAQ) in buildings with IAQ complaints.

METHODS
This study comprised three buildings with IAQ complaints due to emissions from the building construction. In short, the surfaces from where the emissions were spread (floor, ceiling, walls) were covered with a flexible emissions barrier to prevent them from reaching the indoor air. In the specific barrier used, the cTrap, an adsorption layer functions together with a hydrophilic polymer sheet making the adsorption virtually irreversible (Markowicz and Larsson 2012, 2015). The flexible cTrap cloth was attached at the surfaces using an adhesive tape and/or a staple gun. The indoor air concentrations of the emissions were measured both before and after the cTrap installations by pumping air through an adsorbent followed by thermal or chemical desorption and analysis using gas chromatography-mass spectrometry.

RESULTS
1. We studied the living-room and a bedroom of a wooden summer house built in 1964 with a disturbing "summer cottage smell" indoors which was attributed to chloroanisoles. The building had previously been treated with chlorophenol-containing preservatives which were widely used in the 1960-70s; at moist conditions chlorophenols may be biomethylated to form chloroanisoles having an intense, characteristic mould-like odour. The ceiling, walls and floor in the bedroom (as well as the doorway between the bedroom and the living room), but not in the living-room, were covered with the cTrap cloth. Subsequently, air sampling for chlorophenols/chloroanisoles was carried out simultaneously in both rooms. Tetrachlorophenol, trichloroanisole, and pentachloroanisole were detected in the air of the living-room, but only tetrachlorophenol was found in the bedroom, and in an air concentration 93% lower than in the living room (Table 1). Also, the mouldy odour disappeared in the bedroom following the cTrap installation.
2. A building where a creosote-based tar layer had been attached onto the concrete slab as a moisture barrier was studied. The air concentrations of polycyclic aromatic hydrocarbons (PAH) were 1726 ng/m3 air. There was a disturbing smell inside the building which persisted even after the tar had been removed. Then, the cTrap cloth was installed on a about 75 percent of the wall surface. The smell disappeared and the PAH air concentration decreased to 139 ng/m3, thus corresponding to a reduction of 92% (Table 1).
3. A townhouse was studied where the tenants suffered from itching all over the body when staying at home, symptoms which disappeared when outside the building. A PVC flooring had been glued onto a concrete slab which had become moist through diffusion of water from the ground. The air concentration of 2-ethylhexanol, a compound which is ubiquitous in small concentrations in indoor air but found in increased
concentrations e.g. following hydrolysis of glue and/or phthalates of PVC floorings, was 63 µg/m³ (directional measurement). The cTrap was attached onto the existing flooring, and the itchiness disappeared. 3 months after cTrap had been installed the air concentration was 1.5 µg/m³ (Table 1), a value which persisted in a follow-up study 6 years after the installation - and the residents still reported no symptoms.

Results are summarized in Table 1.

Table 1. Results of cTrap installations

<table>
<thead>
<tr>
<th>Emissions (µg/m³ air)</th>
<th>Without cTrap</th>
<th>With cTrap</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tetrachlorophenol</td>
<td>0.14</td>
<td>0.01</td>
</tr>
<tr>
<td>Chloroanisoles</td>
<td>0.013</td>
<td>n.d.</td>
</tr>
<tr>
<td>PAH</td>
<td>1.726</td>
<td>0.139</td>
</tr>
<tr>
<td>2-ethylhexanol</td>
<td>63</td>
<td>1.5</td>
</tr>
</tbody>
</table>

**DISCUSSION**

Staying in a moist building can cause health problems (Mendell et al. 2011, Bornehag et al. 2004) e.g. in the respiratory tract due to moisture-driven emissions which are spread from the building construction into the indoor air. This study shows that such emissions can be effectively stopped by using an emissions barrier. Laboratory findings (Markowicz and Larsson 2012) as well as several years of experiences in buildings (data not shown), have revealed that by such measure the symptoms and/or unpleasant odour decrease or disappear completely. If any visible mould is observed it should first be removed by chemical or mechanical methods before applying the barrier to ascertain that no remaining mould products, or traces of the aggressive chemicals that might have been used, can escape into the indoor air. The specific device used in the current project, the cTrap (surface emissions trap), is air tight while at the same time allowing moisture to pass through with almost no resistance at all, and will thus not affect the moisture balance of the building [3,4]. After the device has been applied on a floor a surface layer, e.g. a laminate, parquet, or plastic flooring etc, is installed on top of the cTrap cloth. When attached on walls or ceiling the cloth is usually covered with a gypsum board which is then painted or decorated with a wall-paper. We conclude that use of an emissions barrier represents an effective, economic, and eco-friendly way of restoring a healthy indoor air in buildings affected by moisture.

**CONCLUSIONS**

In summary, use of an emissions barrier may provide an efficient, economic, quick, and environment-friendly way of ensuring a healthy indoor air.

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The effect of Relative Humidity on the Emission of Volatile Organic Compounds (VOCs) from Building Materials

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SUMMARY
The effect of relative humidity (RH) on the emission of volatile Organic Compounds (VOCs) from commercially bought building materials has been characterized in this study. This was done by placing each material in the CLIMPAQ at two RHs: 50 and 85% for 28 days each and taking measurements according to the French standard ISO 16000.

A total of about 90 compounds was quantified from the different materials. Among the studied materials, wood wool, which is the only bio-based material, was the most emissive material, especially at high humidity level. Emission rates of Total VOCs (TVOCs) and carbonyls from the four characterized materials were multiplied by about 2 to 10 times upon increasing RH from 50 to 85%. The emissions of most VOCs from wood wool reached their maximum after 3 days at 85%.

KEYWORDS
Building materials, CLIMPAQ, relative humidity, VOC emissions

INTRODUCTION
Volatile Organic Compounds (VOCs) are considered one of the most ubiquitous indoor pollutants. The presence of VOCs in indoor environments can lead to severe health effects (WHO, 2008). Indoor VOCs can originate from multiple indoor or outdoor sources; however, their emission from building and consumer materials is considered one of the most important sources due to the use of different products, such as paints and solvents (Kim et al., 2001).

The emission of VOCs from these materials can be affected by various parameters including the change in temperature, ventilation rates, and relative humidity. It is known to increase with increasing temperature (Kim et al., 2001). Lee and Kim showed that the emission of TVOCs was doubled with a 10 °C increase in temperature (Lee & Kim, 2012). However, the increase in ventilation can lead to a decrease in TVOCs indoor concentrations due to air dilution (Hernandez et al., 2020). The effect of relative humidity on VOC emission is still controversial. Sollinger et al. showed that humidity has a negligible effect on the emission of organic pollutants from floorings (Sollinger et al., 1994) while Wolkoff found that increasing relative humidity has different impacts on the VOCs emitted from five building materials, depending on the characterized compound and the emission source (Wolkoff, 1998). This result was later validated by Fang et al. who found that humidity has a significant impact only on VOCs emitted from waterborne materials, such as floor varnish and wall paint (Fang et al., 1999). Recently, Liang et al. found that humidity has a great influence on the initial emittable concentration of VOCs (Cd) where it increased by about 3 folds upon increasing humidity from 20 to 80% (Liang et al., 2016).

The internal structure of walls in France is typically composed of vapor barrier for damp proofing, thermal and acoustic insulating material, and plasterboard for fire protection and insulation which are potential sources of indoor VOCs. Therefore, VOC emissions from four different materials: vapor barrier, glass and wood wools, and plasterboard have been characterized in this study at two different humidity levels: 50 and 85% to further understand the effect of this latter on VOC indoor emissions.

METHODS
Four materials: vapor barrier, glass and wood wools, and plasterboard were commercially bought from French market. A 51 L glass chamber called CLIMPAQ (Chamber for Laboratory Investigations of Materials, Pollution and Air Quality) has been used in this study as recommended by the European Standard ISO 16000-9 (International Organization of Standardization, 2006). The air exchange rate was equal to 1.2 h⁻¹. Blank measurements were taken before each experiment to check the absence of contamination. Each material was then placed inside this chamber at ambient temperature and relative humidity (RH) of 50%. VOC samples were actively collected after 28 days on DNPH cartridges (2,4-Dinitrophenylhydrazine), placed in series to avoid breakthrough, for trapping the emitted carbonyls and...
on Tenax TA tubes for all the other VOCs according to the European standards ISO 16000-3 and 16000-6, respectively (International Organization of Standardization, 2011a, 2011b). The sampled volume was between 30 and 130 L depending on the material emission. After 28 days, the RH was increased to 85% and sampling occurred after 3, 7, 14, and 28 days following the same procedure.

The collected DNPH cartridges were then eluted by 3mL acetonitrile and analyzed using an HPLC/UV (High Performance Liquid Chromatography coupled to Ultra Violet Detector, Dionex Ultimate 3000, Thermo Scientific U.S.A.) equipped with an Acclaim RSLC Carbonyl column (2.2 μm, 2.1 x 150 mm, Thermo Scientific, U.S.A.). The Tenax TA tubes were analyzed using TD-GC-MS/FID system (Thermal Desorption Gas Chromatography, Clarus 680 - Mass Spectrometry and Flame Ionization Detection, Clarus SQ BT, Perkin Elmer, U.S.A.) with a CP-Sil 5CB column (60m x 0.25mm x 1µm, Agilent U.S.A.). The analytical methods used by (Tobon-Monroy, 2020) were used in this study. Calibrations were run before each HPLC and GC analysis. Carbonyls were quantified using their individual calibration coefficients in HPLC while a calibration of the TD-GC-MS/FID using 10 VOCs occurred. All other VOCs were quantified as toluene equivalent. For a sampled volume equal to 30L the limit of detection (LOD) of the GC method for toluene was equal to 0.003 µg m⁻³ while that for carbonyls in HPLC ranged from 0.2 to 0.5 µg m⁻³, depending on the compound.

RESULTS AND DISCUSSION

VOC emissions from the four studied building materials at the two RH values were characterized in terms of emission rate (ER). A group of about 90 VOCs in total has been quantified from the four materials.

Classification of the materials

The French Ministry of Ecology has issued an obligatory label for classifying building and consumer materials according to their VOCs emission before being placed on the market (Official Journal of the French Republic, 2011). Based on this label, materials can be classified from weakly (A⁺) to highly (C) emissive for 10 VOCs in addition to Total VOCs (TVOCs). Therefore, the obtained emission rates of these compounds from the four characterized building materials at RH = 50% in the CLIMPAQ were transferred into emission rates in a 30 m³ reference test chamber with an air exchange rate of 0.5 h⁻¹ and a wall surface area of 31.4 m² (table 1).

Results showed that VOC emissions from these materials are low and thus these materials can be classified as weakly emissive (A⁺).

Comparison of VOC emissions from wood wool at different sampling days at RH = 85%

The individual ER of almost all the quantified VOCs, from the four characterized materials at the different humidity levels, was less than 1 µg m⁻³ h⁻¹, except from wood wool which is the only bio-based material. Therefore, in order to understand the difference in emissions at 85% RH after 3, 7, 14, and 28 days, VOCs emitted from wood wool with an ER > 1 µg m⁻³ h⁻¹ will be discussed in this part (table 2).

The obtained results show that the highest VOC emissions from wood wool are for aldehydes, ketones, and acetic acid which is coherent with the study of Pohleven et al. (Pohleven et al., 2019). Aldehydes emissions from wood-based materials mainly originate from the oxidative decay of cellulose and lignin while acetic acid comes from the cleavage of acetyl groups of hemicellulose upon exposure to moisture (Sassoli et al., 2017).

The emission rates of these VOCs were multiplied by about 2 to 66 times with a humidity increase from 50 to 85% after 3 days of emission. When the water content in air is high, water molecules enter in competition with VOCs, especially the hydrophilic ones like aldehydes, to occupy the active adsorbent sites on the material surface resulting in higher VOC emission rates at first (Lin et al., 2009). However, most of the aldehyde emissions were measured as maximum after 3 days of emission at 85% RH and then deceased gradually during 28 days. This can be explained by their high affinity to water and by VOC depletion from the material after a prolonged exposure to humidity (Harb et al., 2018). On the other hand, the emission of certain compounds took from 7 to 14 days to reach its maximum. In the case of nonanal, methylglyoxal, and acetic acid, this can be explained by their lower affinity to water, compared to other compounds, where they will take longer time to be displaced by the water molecules. However, for propanone, this can be due to its high solubility in water. In this case the emitted propanone might be soluble again in the water film present on the surface of the material leading to its emission for longer durations.

Table 2. Comparison of VOC emissions (µg m⁻² h⁻¹) from wood wool at two different humidity levels and within days at 85%

<table>
<thead>
<tr>
<th>RH</th>
<th>50%</th>
<th>85%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D+28</td>
<td>D+3</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>5.5</td>
<td>11.4</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>0.7</td>
<td>5.9</td>
</tr>
<tr>
<td>Methyl Vinyl Ketone</td>
<td>1.8</td>
<td>9.7</td>
</tr>
<tr>
<td>Crotonaldehyde</td>
<td>1.2</td>
<td>4.6</td>
</tr>
<tr>
<td>Benzaldehyde</td>
<td>0.07</td>
<td>4.7</td>
</tr>
<tr>
<td>Hexanal</td>
<td>0.8</td>
<td>5.4</td>
</tr>
<tr>
<td>Methylglyoxal</td>
<td>4.6</td>
<td>15.7</td>
</tr>
<tr>
<td>Furfural</td>
<td>4.0</td>
<td>6.5</td>
</tr>
<tr>
<td>Nonanal</td>
<td>1.1</td>
<td>1.4</td>
</tr>
<tr>
<td>Propanone</td>
<td>&lt;LOD</td>
<td>1.6</td>
</tr>
<tr>
<td>Acetic acid</td>
<td>0.8</td>
<td>1.7</td>
</tr>
</tbody>
</table>
Comparison of VOC emissions from the different building materials

Since the emission rates of individual VOCs emitted from the other 3 building materials and quantified by GC were < 1 µg m⁻² h⁻¹; comparison of emissions among materials will be as function of TVOCs and carbonyls (table 2). Based on the results discussed in part b, the effect of RH on VOC emissions from these materials will be characterized by comparing their obtained ERs at 50% - D+28 and 85% - D+ 3 (table 3).

After 28 days at 50% RH, TVOCs ER was the highest from the vapor barrier (25.6 µg m⁻² h⁻¹) followed by the plasterboard (19.2 µg m⁻² h⁻¹), wood wool (7.3 µg m⁻² h⁻¹), and glass wool (1.0 µg m⁻² h⁻¹) while emissions of carbonyls, especially aldehydes, are shown to be the highest from wood wool. This can be due to the chemical composition of wood wool as discussed previously. Similar to the previously explained results for individual VOCs emitted from wood wool, ERs of TVOCs and carbonyls from the other materials increased by about 2 to 10 times when increasing the humidity from 50 to 85%.

CONCLUSION

The effect of relative humidity on VOC emissions from four building materials; glass and wood wools, plasterboard, and vapor barrier was characterized in this study at 50 and 85%. These materials were classified as very weakly emissive (A⁺) based on the French label.

VOC emissions from wood wool, the only bio-based material, were relatively high at both humidity values compared to other materials while emissions from glass wool, mineral-based material, were the lowest.

VOC emission rates from the different building materials increased significantly upon increasing humidity from 50 to 85% due to the competition between water molecules and VOCs for occupying the active sites at the surface of the material. Aldehydes ERs from wood wool reached their maximum after 3 days at 85% RH; however, the maximum emission of certain other compounds was reached after 7 or 14 days due to their lower affinity to water. After that, all VOC emissions decreased gradually during 28 days at 85% RH due to the material exhaustion.

ACKNOWLEDGEMENT

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Table 1. Classification of the four characterized building materials as function of VOC emission rates (µg m⁻² h⁻¹) according to the French Label

<table>
<thead>
<tr>
<th>Compound</th>
<th>Glass Wool</th>
<th>Class</th>
<th>Wood Wool</th>
<th>Class</th>
<th>Plasterboard</th>
<th>Class</th>
<th>Vapor Barrier</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>Formaldehyde</td>
<td>0.3</td>
<td>A+</td>
<td>4.7</td>
<td>A+</td>
<td>0.8</td>
<td>A+</td>
<td>0.3</td>
<td>A+</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>5.4</td>
<td>A+</td>
<td>0.6</td>
<td>A+</td>
<td>0.5</td>
<td>A+</td>
<td>0.1</td>
<td>A+</td>
</tr>
<tr>
<td>Toluene</td>
<td>&lt;LOD</td>
<td>A+</td>
<td>0.2</td>
<td>A+</td>
<td>0.1</td>
<td>A+</td>
<td>0.1</td>
<td>A+</td>
</tr>
<tr>
<td>Tetrachloroethylene</td>
<td>&lt;LOD</td>
<td>A+</td>
<td>&lt;LOD</td>
<td>A+</td>
<td>&lt;LOD</td>
<td>A+</td>
<td>&lt;LOD</td>
<td>A+</td>
</tr>
<tr>
<td>Xylene</td>
<td>&lt;LOD</td>
<td>A+</td>
<td>&lt;LOD</td>
<td>A+</td>
<td>0.04</td>
<td>A+</td>
<td>0.1</td>
<td>A+</td>
</tr>
<tr>
<td>1,2,4-Trimethylbenzene</td>
<td>&lt;LOD</td>
<td>A+</td>
<td>&lt;LOD</td>
<td>A+</td>
<td>0.01</td>
<td>A+</td>
<td>0.02</td>
<td>A+</td>
</tr>
<tr>
<td>1,4-Dichlorobenzene</td>
<td>&lt;LOD</td>
<td>A+</td>
<td>&lt;LOD</td>
<td>A+</td>
<td>&lt;LOD</td>
<td>A+</td>
<td>&lt;LOD</td>
<td>A+</td>
</tr>
<tr>
<td>Ethylbenzene</td>
<td>&lt;LOD</td>
<td>A+</td>
<td>&lt;LOD</td>
<td>A+</td>
<td>&lt;LOD</td>
<td>A+</td>
<td>0.02</td>
<td>A+</td>
</tr>
<tr>
<td>2-Butoxyethanol</td>
<td>&lt;LOD</td>
<td>A+</td>
<td>&lt;LOD</td>
<td>A+</td>
<td>0.04</td>
<td>A+</td>
<td>0.1</td>
<td>A+</td>
</tr>
<tr>
<td>Styrene</td>
<td>&lt;LOD</td>
<td>A+</td>
<td>&lt;LOD</td>
<td>A+</td>
<td>0.01</td>
<td>A+</td>
<td>0.01</td>
<td>A+</td>
</tr>
<tr>
<td>TVOCs</td>
<td>1.4</td>
<td>A+</td>
<td>6.2</td>
<td>A+</td>
<td>14.5</td>
<td>A+</td>
<td>12.3</td>
<td>A+</td>
</tr>
</tbody>
</table>

Table 3. Comparison of TVOC and Carbonyl emissions (µg m⁻² h⁻¹) from the different materials after 28 and 3 days of emission at 50% and 85% RH, respectively

<table>
<thead>
<tr>
<th>Material</th>
<th>Glass Wool</th>
<th>Wood Wool</th>
<th>Plasterboard</th>
<th>Vapor Barrier</th>
</tr>
</thead>
<tbody>
<tr>
<td>RH</td>
<td>50%</td>
<td>85%</td>
<td>50%</td>
<td>85%</td>
</tr>
<tr>
<td>TVOCs</td>
<td>1.0</td>
<td>2.3</td>
<td>7.3</td>
<td>69.8</td>
</tr>
<tr>
<td>Formaldehyde</td>
<td>0.2</td>
<td>0.3</td>
<td>5.5</td>
<td>11.4</td>
</tr>
<tr>
<td>Acetaldehyde</td>
<td>ND*</td>
<td>ND</td>
<td>0.7</td>
<td>5.9</td>
</tr>
<tr>
<td>MVK</td>
<td>&lt;LOD</td>
<td>&lt;LOD</td>
<td>1.8</td>
<td>9.7</td>
</tr>
<tr>
<td>Crotonaldehyde</td>
<td>&lt;LOD</td>
<td>&lt;LOD</td>
<td>1.2</td>
<td>4.5</td>
</tr>
<tr>
<td>Benzaldehyde</td>
<td>&lt;LOD</td>
<td>&lt;LOD</td>
<td>4.7</td>
<td>&lt;LOD</td>
</tr>
<tr>
<td>Hexanal</td>
<td>&lt;LOD</td>
<td>&lt;LOD</td>
<td>0.8</td>
<td>5.4</td>
</tr>
<tr>
<td>Methylglyoxal</td>
<td>&lt;LOD</td>
<td>&lt;LOD</td>
<td>4.6</td>
<td>15.7</td>
</tr>
</tbody>
</table>

*ND: Non-documented value
Further Development of Odour Testing of Building Products – Sample Presentation and Evaluation of Perceived Intensity

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2 German Environment Agency, Dessau-Roßlau, Germany
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SUMMARY
Indoor air quality is affected by the emission of volatile organic compounds (VOC) or the odour from building products. Odours can be measured by applying the standard ISO 16000-28:2020.

In the study presented here proposals for further technical development of the ISO method are presented. The sampling procedure and evaluation method of the perceived intensity are investigated in particular because they have a major influence on reproducibility of measurement results.

INTRODUCTION
The use of low-odour and low-emission building products in construction or renovation projects is a prerequisite of ensuring good indoor air quality. Recognised methods for gathering information on the odour behaviour of building products have been available since 2012 in the form of the international standard ISO 16000-28:2020. This describes laboratory procedures for testing odour emissions from building products using a number of panellists. Applicability of the test methodology has been verified and documented in interlaboratory tests (Brosig et al., 2013; Brosig et al., 2014; Brosig et al., 2015).

The German Environment Agency is currently funding the research project ‘Low-odour and low-emission products for healthy indoor air – development of requirements for the Blue Angel for large-area products relevant to interiors’ (research code: 3717 37 319 0) to further improve the procedure and the evaluation method, and to measure and evaluate as many building products as possible using sensory techniques. The Bundesanstalt für Materialforschung und -prüfung (BAM) and the University of Applied Sciences for Technology and Economics, Berlin (HTW) are conducting sensory tests and determining the emissions of elastic floor coverings and wood products. Proposals for the further technical development of the process are also being investigated within this project.

METHODS
The specimen to be investigated for odour is placed in an emission test chamber according to ISO 16000-28. The emission test chambers and climatic conditions specified in ISO 16000-9:2006 and EN 16516:2020 are the basis of the odour measurement procedure. Odour testing can thus be carried out together with analytical emission tests. The product loading factor, i.e. the size of the test specimen in relation to the emission test chamber volume and the air volumetric flow rate flowing through the chamber, is specified by simulating real room conditions. The product remains in the chamber for a specified period of time depending on the measurement requirements. Then, on the desired measurement day, the exhaust air from the chamber is delivered to individual panellists via a funnel for evaluation.

The perceived intensity $I$ with the unit pi (perceived intensity) can be used as a measurand. This is evaluated with the aid of a comparative scale in order to minimise the influence of the subjective odour sensation on the measurement result. At least 6 different concentrations of the reference odorant, acetone in air, are provided in an ascending order of scale. The lowest perceived intensity, i.e. the odour threshold of acetone, is set at 0 pi, and the highest intensity is set at 15 pi. This covers the range in which the typical intensities of building products lie. The relationship between the set acetone concentration and the perceived intensity is linear over this range (Müller et al., 2017). Panellists who have been trained in a 5-day procedure compare the acetone intensities with the intensity of the sample. The mean value of the sample intensity can be determined from the individual values.

It must be ensured that a sufficient and constant sample-air volumetric flow rate of 0.6 to 1.0 l/s is available to the panellists at the evaluation funnel for them to evaluate the air sample. This prevents ambient air from being sucked in during sensing and mixing with sample air.

If the volumetric flow rate of the sample air is sufficient at the test chamber outlet of the emission
test chamber, a funnel can be attached there for direct evaluation. However, sample containers (bags) for indirect evaluation are used as a standard because the air velocity at the test chamber outlet is not usually high enough in commonly used emission test chambers, or the emission test chamber's external environment does not meet the background odour requirements. The bags are filled with sample air and provided to the panel for evaluation using a presentation system.

STUDY DESCRIPTION

1. Further development of sample presentation

The revision of ISO 16000-28 at the end of last year, specified the use of sample containers as the standard procedure for odour evaluation. Direct evaluation is now only possible for emission test chambers with a volume greater than 4.3 m³. The required minimum air volumetric flow rate of 0.6 l/s at the sample funnel of the test chamber outlet can only be achieved from chambers of this size and a specified air exchange rate of 0.5 per hour. The commonly used emission test chambers with volumes of up to one cubic metre are operated with an air volumetric flow rate of up to 0.14 l/s, which is not sufficient for direct odour evaluation.

Various studies show that the type of sample presentation has an influence on odour measurement result (Müller et al., 2011; Müller et al., 2016; Müller et al., 2017; Schulz et al., 2016), which is why there is a great need to research the presentation of odour samples.

The proposal presented here for further development of sample presentation enables the collection and presentation of sample air in just one step. A sample container, e.g. a bag or a rigid container, is permanently positioned on the emission test chamber's outlet and continuously filled with sample air flowing through it. The filling or flow is only briefly interrupted at the time when a sample is taken by a panellist for the test. The size of the sample container is sufficient to provide enough sample air for evaluation by at least one panellist. Afterwards, it is refilled within a few minutes for the next person to evaluate. Since sampling and presentation are technically connected, the system is called an adapter. The adapter consists of the sample container and the necessary periphery to enable alternating sampling and presentation.

The aim is to shorten the time between sampling and presentation and to avoid transporting the sensitive air samples. The samples can thus be made available for evaluation with little or no changes, which reduces measurement errors. Potential uses are in laboratories where odour evaluation can be carried out in close proximity to the emission test chamber. The same requirements are placed on the sample container as on the sample containers used so far for indirect evaluation. It must be airtight and odourless and the materials used in its construction must not alter the air sample or must at least meet the 80% recovery rate for selected organic compounds specified in Annex C of ISO 16000-28:2020. The adapter must guarantee that the sample air does not mix with ambient air when the sample is presented.

The volume of the sample container must guarantee that sufficient sample air is provided for evaluation by a panellist (minimum volume) and that the time between two individual presentations fits into the measurement sequence (maximum volume). The aim is to be able to use the adapter for emission test chambers ranging from 250 litres in size and a minimum volumetric flow rate of 0.03 l/s.

2. Evaluation of perceived intensity

Before the last revision of the standard in November 2020, a minimum of 8 panellist were specified for testing the perceived intensity, and the accuracy of the evaluation, expressed by the 90% confidence interval, had to be ± 2 pi (ISO 16000-28:2012). Since many measurements failed to achieve the required accuracy, at least 12 to 15 panellists are now recommended to determine the perceived intensity and if the confidence interval requirement cannot be met (ISO 16000-28:2020), it has to be recorded in the test report.

However, the increased panellist number as recommended, increases the measurement effort and costs for the already complex investigation. Even so, it may occur that the measurement fails to reach the confidence interval. Therefore, investigations will be carried out within the framework of this research work aiming to simplify the evaluation of the perceived intensity using the comparative scale.

An odour nuisance is unacceptable according to AgBB if more than 30 % of a non-trained group of panellist evaluate an odour as unacceptable. Based on this and on health aspects, the AgBB sets a perceived intensity of 7 pi after 28 days as a preliminary evaluation criterion (AgBB, 2018). This fact leads to the conclusion in our investigations that a building product is unsuitable for indoor use if more than 30 % of panellists perceive the odour of a sample to be more intense than an acetone concentration of 7 pi offered for comparison. It is ultimately important to know whether a building product has a perceived intensity of ≤ 7 pi or > 7 pi on the 28th day of measurement in order to determine the sensory suitability of building products for indoor use. Knowledge of the exact value as determined by the reference method is not actually necessary.

To investigate this, the panellists are offered an acetone intensity of 7 pi at one of the funnels of the comparison scale in order to determine perceived
intensity. They are asked to indicate whether a sample is perceived as less to equally intense (≤) or of greater intensity (> in comparison. The odour intensity of a sample is thus classified in one of two possible ranges.

This range query simplifies the panellists' task. The investigations should clarify whether the required number of panellists and the extent of tests can be reduced, e.g. whether and to what extent is training necessary.

RESULTS & DISCUSSION

1. Further development of sample presentation

The principle of the adapter has so far been checked in initial analytical tests. 0.43m² of an elastic floor covering (rubber) was placed in a 270 litre emission test chamber operated at an air exchange rate of 1.1 per hour. Three different potential materials for the sample container (glass, Nalophan and Tedlar) were tested in the chamber’s exhaust air over a period of 13 days. Only VOC concentrations were compared in these measurements, odour was not evaluated.

The exhaust air from the emission test chamber was used successively to fill and flow through the various containers with sizes ranging from about 8 to 15 litres. The sample air was evaluated by emission measurements at the chamber and in the sample container after at least two days of flushing. This long purging time was found to be sufficient to largely reduce potential effects such as adsorption and desorption at the container wall and to guarantee that the sample container is filled exclusively with sample air. The minimum flushing time will be determined in the next tests.

Sampling was performed by loading sample air into two Tenax tubes from the chamber and to two Tenax tubes from the respective adapter. 1 and 2 litres sample volumes were taken respectively (double determination) at a sampling rate of 100 ml/min for the Tenax tubes. The substances are determined using thermodesorption and gas chromatography coupled with mass spectrometry measurements (TDS/GC/MS).

The analysis results show that there are almost no differences between the sample air from the chamber and the respective adapter (Table 1).

<table>
<thead>
<tr>
<th>Component (CAS number) – direct determination as per a standard</th>
<th>Glass adapter</th>
<th>Tedlar adapter</th>
</tr>
</thead>
<tbody>
<tr>
<td>Styrene (100-42-5)</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>Cyclohexaneone (108-94-1)</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>Benzothiazole (95-16-9)</td>
<td>75</td>
<td>75</td>
</tr>
<tr>
<td>Phthalamic (88-96-0)</td>
<td>10</td>
<td>11</td>
</tr>
</tbody>
</table>

Table 1: Excerpt from the analysis results of emission measurements at the emission test chamber and glass or Tedlar adapter, respectively

2. Evaluation of perceived intensity

Initial investigations took place in a measurement series on three samples. The products were placed in emission test chambers (CLIMPAQs) for testing, and sensory evaluated on four measurement days (days 3, 7, 14, 28) using the direct method, which resulted in a total of 12 evaluations. Between 9 and 13 trained panellists were available on the various measurement days. When determining the perceived intensity, first the described range query was carried out, but the level of acetone intensity was not made known to the panellists. Subsequently, the same group carried out the test specified by the standard to determine the perceived intensity over the entire comparative scale, where a 90 % confidence interval was achieved by all 12 evaluations. The evaluation of the measurement was carried out according to the 7 pi evaluation value of the AgBB scheme.

The test results in Figure 1 show that the range query in all 12 evaluations led to the same result as the perceived intensity test according to ISO 16000-28:2020. Samples that were perceived as more intense by 30 % of the panellists compared to the 7 pi acetone intensity also achieved values greater than 7 pi in the intensity evaluation according to the standard (red field). The reverse was also true (green field). There were a few panellists who evaluated the sample differently from the majority in the range query for the measuring points that are neither at 0 nor at 100 % on the abscissa. Measuring points in the yellow fields would have passed only one of the two types of test.

Further investigations will aim at expanding the database of the range query. Samples whose evaluation lies in the marginal areas between the fields are of special interest.

CONCLUSIONS

The further development of the sample presentation and evaluation methodology for perceived intensity is of great importance to the evaluation of building products according to the AgBB scheme within the framework of the ISO 16000-28:2020 odour
measurement procedure. The results of both key research topics can contribute to further developing the standard.

The sample presentation system is currently being developed and built and will then be tested in its application. Initial tests show that the composition of sample air is almost unchanged.

Overall, the results should contribute to increasing the acceptance of the evaluation of perceived intensity using ISO 16000-28:2020 and to determining odours from building products more and more precisely according to evaluation criteria that are as objective as possible.

The investigations are planned for the next two years.

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Indoor air 2-ethylhexanol levels in an office building after floor repairs – a follow-up study

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Correspondence: olavi.vaittinen@raksystems.fi

SUMMARY
2-Ethylhexanol is a VOC emitted into the indoor air through hydrolysis of PVC plasticizers and flooring adhesives. It is a strong indicator for material degradation and a subject of some health concern. Elevated indoor air 2-ethylhexanol levels were observed in an office building after renovations indicating a failed flooring installation. After reinstallation, the emissions of the flooring materials were studied using active air sampling and gas chromatography mass spectrometry (GC-MS).

In this study (which is still in progress) indoor air VOC concentrations are measured over one year in four separate rounds. The air samples are collected from at least 12 rooms and the sampling is performed with the same ventilation settings in each round.

During the first three months after floor repairs, the indoor air 2-ethylhexanol levels decreased by about a half or more. The removal rate of 2-ethylhexanol was highest in the rooms having the largest air exchange rates.

INTRODUCTION
2-Ethylhexanol (2-EH) is a pollutant often found in indoor air (Wakayama et al., 2019). It can be emitted by e.g. degradation of phthalate plasticizers such as di-2-ethylhexyl phthalate (DEHP) used in polyvinyl chloride (PVC) floorings. This occurs specifically in alkaline conditions when excess water is present in the concrete slab. Another significant source of 2-EH is 2-ethylhexyl acrylate containing adhesives.

A prominent characteristic of 2-EH is the seasonal fluctuation of its indoor air concentration. The compound is detected at higher concentrations in high-temperature and humid seasons and at markedly lower concentrations during winter. 2-EH can be retained on surfaces and in indoor air for a long time.

It is assumed that indoor air 2-EH is not a serious health hazard as such, and the real danger of flooring degradation comes from exposing occupants to phthalate plasticizers (Castagnoli et al., 2019). However, it is possible that 2-EH may affect human health already at concentrations close to the highest levels occasionally found in indoor air (for current levels in Finnish office spaces see Wallenius et al., 2021). The compound may provoke irritation of the respiratory tract and cause asthma-type symptoms at levels exceeding 175 µg/m³. In any case, the detection of elevated levels of 2-EH in indoor air is a strong indicator of PVC flooring degradation and an indirect proof of occupant exposure to possibly dangerous DEHP levels. 2-EH is also a potential marker for microbial growth in the flooring materials (Nalli et al., 2005).

Some reference values of 2-EH concentrations have internationally been proposed for occupational settings and in general indoor environments. In Finland, the action limit for the indoor concentration of 2-EH determined as toluene equivalent is 10 µg/m³. The action limit is not health-based.

CASE STUDY DESCRIPTION
Abnormally high indoor air levels (up to 25 µg/m³) of 2-ethylhexanol were observed in an office building one year after completed renovations. This happened even though textile floor covering with a non-phthalate plasticizer was used as a flooring material. This suggested a failed flooring installation probably owing to an adhesive releasing high amounts of 2-EH. This was established through meticulous studies of the installed flooring materials and statistical analyses.

After reinstallation, in this study, the emissions of the new flooring materials are investigated using indoor air VOC sampling. The samples are collected with a pump using Tenax TA – Carbograph 5TD adsorption tubes. The samples are collected from the middle of the room and the sampling height is about one meter. The sampling time is about 45 minutes. One sample is taken from each studied room.

The samples are analyzed using thermal desorption gas chromatography mass spectrometry (TD-GC-MS). The analyses are performed by a commercial laboratory and no exact information on the TD-GC-MS analysis procedure is available. The measurement uncertainty of the analysis method is about 30 percent and the quantification limit is about 0.4 µg/m³ for 2-EH.

The air sampling is carried out in four stages: 1) one month, 2) three months, 3) six months and 4) twelve months after the completion of the floor repairs. Samples are collected from across the premises (total area of about 1600 m²) which consist of about 30 separate rooms with varying sizes and air exchange rates. Mechanical ventilation is used in all rooms. The smallest rooms are single-occupancy spaces and the
largest ones are typical open office spaces. At least 12 spaces representing different room types are covered in each round. Rooms with the highest original (prior to the reinstallation of the flooring materials) 2-EH concentrations were preferred in the sampling. One room without repairs (deliberately left as such) and one room with normal 2-EH levels (indicating faultless flooring materials during the original floor installation) were earmarked as reference spaces. All 30 rooms are investigated in one of the rounds. Altogether about 70 indoor samples are collected during the measurement campaign.

In the date of writing of this report, two first rounds of the campaign are fulfilled (one and three months after floor repairs). The measurements were performed in October and December 2020. In the first round, 12 regular rooms and one reference room were investigated. In the second round, the same rooms plus an additional reference room were sampled.

The measurements were performed with standard ventilation settings at a constant indoor air temperature of about 22 °C. The air exchange rates of the investigated rooms varied from 1.9 to 9.6 1/h (these are design values; the reason for the large variation in the air exchange rates is not known – in general, the smallest rooms had the highest air exchange rates). The relative humidity RH was about 49 % and 26 % in October and December 2020, respectively.

Only 2-EH concentrations are addressed in this report.

RESULTS & DISCUSSION

In the first measurement round, the 2-ethylhexanol levels varied between 4 and 16 µg/m³, excluding the reference room. In the second round, the concentrations diminished clearly, and they varied from 1 to 8 µg/m³. Four out of eleven samples exceeded the action limit for the indoor concentration of 2-EH in Finland in the first round. There were no results exceeding the limit in the second round.

The results of the second round are presented in Figure 1 as a function of the air exchange rate. It is obvious from Figure 1 that the 2-EH levels were the lowest in the most ventilated rooms. This occurred although there was originally (prior to the reinstallation) no difference in the quality and emissions of the flooring materials depending on the size or air exchange rate of the room. This demonstrates the importance of ventilation in removing 2-EH after floor repairs. The removal rate can be increased by using maximal available ventilation.

All results obtained up to date are presented graphically in Figure 2. Rooms 3095 and 4018 are the reference spaces. In room 3095, no corrective repairs were performed after the original (failed) flooring installation. Room 4018 represents a space where the faulty adhesive causing elevated 2-EH levels was not applied. The same flooring materials were used in both reference rooms as in the other rooms.

![Figure 1](image1.png)

**Figure 1.** Indoor air 2-EH concentrations three months after floor repairs as a function of air exchange rate. The results of the reference rooms are not presented in this Figure for clarity.

According to the results, the average 2-EH concentration has decreased by about 49 percent in two months between the measurements (Figure 2). It is possible that part of the concentration decrease is due to the reduced indoor air humidity. This is, however, probably not a major effect because the 2-EH levels of the reference room 3095 stayed roughly the same over the same measurement period (21 and 20 µg/m³ in October and December 2020, respectively). The 2-EH levels are expected to decrease further in the coming measurement rounds.

![Figure 2](image2.png)

**Figure 2.** Indoor air 2-EH concentrations at one (red) and three (blue) months after repairs. Rooms 3095 and 4018 are reference rooms where the same flooring materials were used (see text).

The indoor air 2-EH concentrations were measured prior to the repairs in January 2020 by another agent. The 2-EH levels obtained in this study were compared...
to those levels and the results of the comparison are given in Table 1. On average, the 2-EH levels have decreased by about 67 percent as compared to the measurements performed before the flooring reinstallation.

Table 1. Comparison of 2-EH levels before and after renovation.

<table>
<thead>
<tr>
<th>Room</th>
<th>2-EH (µg/m³) 01/2020</th>
<th>2-EH (µg/m³) 12/2020</th>
<th>Decrease (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3097</td>
<td>18</td>
<td>5</td>
<td>72</td>
</tr>
<tr>
<td>30972</td>
<td>15</td>
<td>6</td>
<td>60</td>
</tr>
<tr>
<td>3098</td>
<td>17</td>
<td>6</td>
<td>65</td>
</tr>
<tr>
<td>3099</td>
<td>14</td>
<td>7</td>
<td>50</td>
</tr>
<tr>
<td>30993</td>
<td>19</td>
<td>4</td>
<td>79</td>
</tr>
<tr>
<td>3201</td>
<td>13</td>
<td>2</td>
<td>85</td>
</tr>
<tr>
<td>3210</td>
<td>25</td>
<td>8</td>
<td>68</td>
</tr>
<tr>
<td>3214</td>
<td>16</td>
<td>6</td>
<td>63</td>
</tr>
<tr>
<td>3221</td>
<td>8</td>
<td>2</td>
<td>75</td>
</tr>
<tr>
<td>3231</td>
<td>-</td>
<td>1</td>
<td>-</td>
</tr>
<tr>
<td>3243</td>
<td>7</td>
<td>3</td>
<td>57</td>
</tr>
</tbody>
</table>

Unfortunately, the analyses of the previous samples were performed in another laboratory, and no records of the concurrent ventilation settings were available. The measurement results are therefore possibly not fully comparable. In any case, the measurement conditions should be similar enough as the air exchange rates were the same in both investigations. In Figure 3, the decrease (percentual change) of the 2-EH concentration measured in December 2020 in relation to the concentration measured in January 2020 is presented as a function of air exchange rate of the room. The figure shows that there is a correlation between the air exchange rate of the room and the decrease in 2-EH concentration over time.

Although the data is limited, it is obvious that 2-EH is removed faster from the rooms with the highest air exchange rates. It is therefore expected that the decrease of the 2-EH levels will continue especially in the rooms with the lowest air exchange rates. It is also noteworthy that three months is not enough to remove the excessive 2-EH completely, at least in the rooms with the lowest air exchange rates.

CONCLUSIONS

- Ventilation is essential in removing excess 2-ethylhexanol in indoor air after floor repairs
- Indoor air 2-ethylhexanol levels have decreased on average about 67 percent in three months after floor repairs as compared to the levels obtained prior to the repairs

REFERENCES


Can human CO<sub>2</sub> emission rates staying awake be used staying asleep?

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INTRODUCTION

Indoor air quality (IAQ) has been imposed to negatively affect humans, not only the comfort and work performance staying awake (Wargocki, 1999; Zhang et al., 2017a, b) but also sleep quality during sleep and its consequence on next-day work performance (Strøm-Tejsen et al., 2016; Xu et al., 2020). Therefore, sufficient ventilation needs to be secured and has far-reaching implications for occupants’ health. However, we should note that ventilation ensures good IAQ at the cost of energy consumption. The ventilation rate (VR) should then be determined precisely and reasonably.

Currently, the required VR can be calculated for most buildings using CO<sub>2</sub> concentration under a steady-state (ASHRAE Standard 62.1-2016, 2016). This estimation entails the knowledge of human CER. Persily and De Jonge proposed a new approach to estimate CER based on understanding human metabolism and exercise physiology (Persily and de Jonge, 2017). Previous studies have also shown that increasing temperature from 22°C to 26 °C didn’t significantly influence CER (Bivolarova et al., 2019; Markov et al., 2021). Decreased IAQ significantly reduced CER by ca. 13% (Bakó-Biró et al., 2005). While most of these data are for people staying awake. There is minimal information on CER from sleeping people. Whether the CER from awake people can be used for sleeping people is still unknown, even it is reasonable to speculate that this is not the case as CER is a function of physical activity level (Yang et al., 2020). People’s physical activity level should be lower during sleep than staying awake as humans remain still for on average 7-8 hours during sleep. But this lacks evidence to support it.

The objective of the present study was to experimentally determine the human CER during sleep and compare it with that of humans staying awake.

METHODS

Eleven healthy subjects were recruited (height: 1.67±0.08 m; weight: 60.4±5.4 kg; age: 28.3±4.1 (y); BMI: 21.6±1.4 kg/m<sup>2</sup>). They were asked to sleep for four nights in a specially constructed capsule (net volume: 1.911 m<sup>3</sup>) located in a climatic chamber under three conditions (Table 1). The sleeping capsule was designed to create a confined and well-sealed space with its own ventilation devices. The first night was for adaption to eliminate the potential bias of an unfamiliar sleep environment. Subjects were asked to self-adjust their pajamas until thermal neutral at 23 °C and then wear the same pajamas during the whole experimental period. The physiological reactions and subjective responses were collected. The sleep quality was measured objectively and subjectively. The chemical emissions during sleep were also monitored. Subjects were also asked to complete the cognitive tests before and after sleep to examine the changes in work performance. These results will be presented elsewhere. The CER was estimated using a mass-balance equation (1) after the CO<sub>2</sub> concentration reached steady-state.

\[
CER = \frac{Q \times (C_{in} - C_{out})}{1000}
\]

Where Q: ventilation rate (m<sup>3</sup>/h); \(C_{in}\): mean CO<sub>2</sub> concentration (ppm); \(C_{out}\): ambient mean CO<sub>2</sub> concentration (ppm).

The obtained data were first tested for normality using Shapiro-Wilk’s test. Normally distributed data were subjected to analysis of variance in a repeated measures design. The differences induced by various conditions were tested by post hoc analysis using the Bonferroni test. Non-normally distributed data were analyzed using Friedman’s analysis of variance and the Wilcoxon Signed-Ranks test to examine the effects of conditions on humans. The statistical analysis was done with SPSS 22.0. The significance level was set at P=0.05 (2-tail).

RESULTS & DISCUSSION

The physical parameters describing the sleep environment quality in the capsule are summarized in Table 1. The measured temperature and CO<sub>2</sub> concentration were maintained in the intended levels, and the measured air temperature did not exceed 0.3 °C compared with the designed group. The deviation between the measured CO<sub>2</sub> concentration and the intended CO<sub>2</sub> level was within 30 ppm. The relative humidity was not controlled but still in the comfortable zone (Arundel et al., 1986).
Table 1. Physical measurements in the capsule (Mean±SD) at different conditions.

<table>
<thead>
<tr>
<th>Planned conditions</th>
<th>Measured parameters</th>
<th>CO2 concentration (ppm)</th>
<th>T (°C)</th>
<th>CO2 concentration (ppm)</th>
<th>T (°C)</th>
<th>Relative humidity (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T24P800</td>
<td></td>
<td></td>
<td>24</td>
<td>800</td>
<td>23.7±0.2</td>
<td>771±34</td>
</tr>
<tr>
<td>T24T1700</td>
<td></td>
<td></td>
<td>24</td>
<td>1700</td>
<td>24.0±0.2</td>
<td>1671±121</td>
</tr>
<tr>
<td>T28P800</td>
<td></td>
<td></td>
<td>28</td>
<td>800</td>
<td>28.0±0.2</td>
<td>795±75</td>
</tr>
</tbody>
</table>

Figure 1 dedicates the calculated CER and its variation at three conditions. The measured CER was on average 11.16 L/h per person, ranging from 9.87 to 13.04 L/h per person at the reference condition of T24P800. Compared with reference condition, when decreasing IAQ indicated as increased CO2 concentration from 800 to 1700 ppm, the mean CER reduced slightly to 10.51 L/h per person in the range of 7.14 to 13.80 L/h per person. The mean CER increased slightly (mean:11.43 L/h per person, range: 8.82-14.58 L/h per person) when the temperature increased from 24 °C to 28 °C. However, no significant differences in CER were observed, either increasing temperature or decreased IAQ indicated by increased CO2 concentration. The CER for sleeping people can be thus obtained by averaging the values among three conditions. The CER during sleep is 11.04±1.43 L/h per person.

Two widely adopted equations from the published paper (Persily and de Jonge, 2017) and the standard (ASHRAE Standard 62.1, 2016) to calculate the CER were also used in the present study. The calculated CERS are shown in Fig. 2. The calculated human CERS during sleep are 10.1±1.1 L/h per person and 10.84 L/h per person by equations from Persily and Jonge (2017) and ASHRAE Standard 62.1 (2016), respectively. These CERS are similar to what was observed in the present study.

Figure 2. Comparison of CO2 emission rate from the present study with standard and previous research.

Figure 3 depicts the differences in CER between sleep and awake people. Two different physical activity levels (Lying and light office work) were chosen to compare with. It can be seen that the calculated lowest CER is higher than the CER during sleep. The differences between them increase significantly as increased activity level. Therefore, CER from awake people cannot be used directly in sleeping people. VR is a function of CER, as shown in equation (1). The required VR in bedrooms should be lower than other functional areas in buildings. If the CER from awake people is used for sleeping people, the required VR would be overestimated, resulting in energy waste.

Figure 3. Comparison of CO2 emission rate staying sleep with that of staying awake. The CER is the average value of all reported CER at all office activity levels examined; The physical activity level for lying; Physical activity level for light office work.

Even there are no significant differences in CER at present experimental conditions; we can not conclude that the CER is not affected by increasing temperature or reducing IAQ as the changes in either temperature or IAQ may not enough to evoke the changes in CER. Alternatively, subjects could take off pajamas and/or sleep without quilt to copy with the thermal stress that may exist induced by increasing temperature. Further studies are necessary to explore this.
One limitation in the present study is that only 11 college-age healthy subjects participated in the experiment. Future studies are necessary to validate the current results with more subjects and different populations.

CONCLUSIONS
The measured CO₂ emission rate from sleeping people was 11.04 ± 1.43 L/h per person, which is similar to what estimated by equations in the previous study and standard. Measured CO₂ emission rate did not change when increasing temperature from 24°C to 28 °C and reducing indoor air quality indicated by increasing CO₂ concentration from 700 ppm to 1700 ppm. The measured CO₂ emission rate during sleep is significantly lower compared with that of awake people.

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REFERENCES
Numerical Investigation of Human CO₂ Emission in a Personalized Work Environment

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SUMMARY
Estimation in human CO₂ emission rate by chamber method strongly depends on heterogeneous CO₂ concentration distribution in a chamber. In this study, we conducted a computational fluid dynamics (CFD) simulation reproducing the chamber experiments for CO₂ emission rate. As a result, the difference in CO₂ concentration between exhausted air and inhaled air was confirmed. Thus, the numerical model may have potential to improve physical measurements for CO₂ emission rate.

INTRODUCTION
Carbon dioxide (CO₂) concentration indoors is often used as an indicator of ventilation rate and indoor air quality in occupied buildings. The concentration is a result of outdoor CO₂ level, ventilation rate with outdoor air, CO₂ emission rate from occupants, and mixing of air within a space. To determine ventilation efficiency, it is important to accurately estimate the CO₂ emission rate from occupants. There are mainly two experimental methods for obtaining CO₂ emission rates from humans. One is monitoring CO₂ concentration in an airtight or ventilated chamber where volunteers perform different physical activities; the mass balance equation is subsequently used assuming complete mixing. In the other one, the indirect calorimetry devices such as Douglas bag are used by detecting exhaled CO₂. There is difference in the estimated CO₂ emission rate between these two methods mainly because of the heterogeneous CO₂ concentration distribution in the chamber, especially in the breathing zone.

METHODS
In this study, we developed a Digital Twin model based on CFD technique, which can demonstrate the experiments which were performed in a small climate chamber (Fig. 1) to measure the CO₂ emission rate from occupants and physiological responses on environmental conditions [1]. To fully capture the experimental situation, the Digital Twin model was integrated with a computational simulated person (CSP) reproducing human metabolic heat generation and CO₂ emission under transient breathing cycle. In terms of the thermo-physiological sensible heat generation from human bodies, Fanger’s thermoregulation model was applied to a CSP. For simplicity of this analysis, the simplified boundary condition was used, assuming a nude condition. With respect to the CO₂ emission from human under transient breathing cycle, we set the average CO₂ concentration of 5% in alveoli region because the CO₂ concentration in the alveoli does not change significantly and is well known to be approximately 5%. Although the simplified CO₂ generation model was used in this study, we precisely reproduced the delay time of CO₂ release to indoors during exhalation caused from the respiratory dead space of approximately 200mL. The small chamber was ventilated with outdoor air (temperature: 23°C, CO₂ concentration: 400ppm) from a ceiling plenum. Due to the large size of the air supply area, we set the velocity of the supplied air of 0.005 m/s corresponding to ventilation rate of 0.0053 L/s. A laminar downward piston flow entered the chamber from the whole ceiling. The air was exhausted through an opening located 10cm above the floor. Additionally, two mixing fans were installed near the ceiling in order to ensure the air mixing. In this simulation, the air velocity from the mixing fans toward CSP was assumed 2.0m/s.

RESULTS & DISCUSSIONS
Fig 2 shows the flow patterns and temperature distribution in the periphery of the CSP under steady-state conditions (with metabolic heat generation and without respiration). These flow patterns and temperature distributions were used to setup the initial conditions for the analysis of CO₂ emission from CSP under continuous breathing.
As shown in Fig 3, the non-uniform CO₂ concentration distribution in the chamber was confirmed even when mixing fans were installed. Compared to averaged volume of a space, exhausted air and inhaled air, the differences in CO₂ concentration were seen. The downward flow from the ceiling and air mixing by the fans led to the low concentration of CO₂ in inhaled air compared to the volume averaged concentration in the chamber and monitored concentration in exhaust outlet. On the other hand, the simulation result focusing on the CO₂ concentration in a personalized work environment (PWE) by Wang et al. [2] showed that the inhaled CO₂ concentration was higher than the volume averaged concentration over time, which could be caused by the upward flow toward the ceiling. Thus, the flow field in the breathing zone and locations of outdoor supply inlet and exhaust outlet strongly affect the inhaled CO₂ concentration.

Fig 4 shows two estimated CO₂ emission rates according to the inhaled CO₂ concentration. One was estimated by using the CO₂ concentration at the exhaust outlet as the representative CO₂ concentration in the chamber, which is same to experimental method. The other was estimated by the difference between the inhaled and exhaled CO₂. In an early exposure when the inhaled CO₂ concentration was around 500ppm, the emission rate based on CO₂ at the exhaust outlet was less than at 750ppm because of delayed transportation of exhaled CO₂. In this simulation, the exhaled CO₂ in each breath was almost same because we assumed the constant CO₂ concentration in alveoli and fixed breathing cycle. In contrast, the inhaled CO₂ increased as CO₂ concentration in the chamber was elevated. As a result, both of these estimated CO₂ emission rate decreased as inhaled CO₂ concentration increased. These results were consistent with the experimental studies on this topic [1]. However, the reduction in the CO₂ emission rate was very low compared with the experimental results. Therefore, in order to precisely reproduce the experimental results, we need to consider the physiological effects of inhaled CO₂ on the respiratory system, especially breathing cycle and O₂-CO₂ gas exchange in alveoli region.

CONCLUSIONS
In this study, we developed the Digital Twin model for the measurements of CO₂ emission rate. The flow field in the breathing zone and locations of supply inlet and exhaust outlet is important factors for inhaled CO₂ concentration. The estimated CO₂ emission rate is dependent on the inhaled CO₂ concentration. The Digital Twin model could improve physical measurements leading to the estimation of CO₂ emission rates.

ACKNOWLEDGEMENTS
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REFERENCES
Optimal sensor positioning for monitoring indoor air quality in a simulated office environment

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INTRODUCTION

As people spend most of their time indoors, securing a good indoor air quality (IAQ) has become an important component in buildings for occupants' health. Particularly, P. Wargocki et al. (2000) mentioned poorly ventilated offices with worse indoor air quality contribute to sick building syndrome (SBS) symptoms while decreasing employees' productivity. Moreover, positioning monitoring sensors to accurately estimate indoor environment is crucial for improved control of HVAC system. Given this, it is reasonable to think about how to properly monitor IAQ (where to put sensor and what parameter to measure) to better understand human exposure to air pollutants.

The current practice of monitoring IAQ in buildings, most researchers prefer heights between 1.0 m to 1.2 m in the middle of an occupied zone as a representative location of placing CO2 sensor, which can be compared with a recognized breathing zone height of between 0.75 m to 1.8 m as mentioned in one research by Mahyuddin & Awbi (2012). In addition to the breathing zone of occupant, supply/exhaust air duct and wall can also be the one of most preferred sensor locations in monitoring indoor air pollutants in buildings. Besides CO2 sensor location, there hasn’t been much common practice or guideline in placing other measuring devices such as PM monitors or gas (TVOC, CO, NO2, etc.) monitors.

Alberts (1994) mentioned that human is the source of indoor air pollutants, thus it is necessary to include them from monitoring stage of the building to the control stage of HVAC system. Particularly, contextual variations induced by different indoor air pollutants of occupants and occupancy levels are highly related to the concentration of indoor air pollutants like CO2 and particulate matter as mentioned in a research done by Sahu & Gurjar (2019). Thus it is necessary to estimate occupancy including occupant number and activity as one variable to determine ventilation rates and strategies.

In this study, we aim to better understand spatio-temporal variations of CO2, PM2.5, and PM10 affected by various building-related and occupant-related variables and investigate the optimal sensor placement which can approximate human exposure to studied air pollutants in a simulated office environment. Our study focused on placing sensors in various locations throughout the space and comparing each placement with breathing zone location while simulating diverse conditional variables such as occupant number, office activities (intensity), space types, ventilation types.

METHODS

In this study, we conducted a total of 32 experiment while simulating various office environments in a controlled climate chamber for consecutive five weeks (2020.07.13 - 2020.08.11). Table 1 presents a summary of our experimental design. We introduced different number of human participants (2, 4, 6 and 8) performing typical office activities (a total of 16 activities with certain time duration, Table 2) and four space types (two types of shared offices, meeting room and cafeteria). Each experiment was conducted for 1-hour. Two different mechanical ventilation strategies (mixing and displacement) and air change rates (2.4 – 2.6 and 3.5 – 3.6 h–1) were studied.

Table 1. Experimental Design of controlled experiment

<table>
<thead>
<tr>
<th>Space type</th>
<th>Space size</th>
<th>Occupant No.</th>
<th>Ventilation type</th>
<th>Environmental conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shared office 1</td>
<td>25 m²</td>
<td>2</td>
<td>MV / DW</td>
<td>24.5°C, 50% (ACR 2.4–2.6 h–1)</td>
</tr>
<tr>
<td>Shared office 2</td>
<td></td>
<td>4</td>
<td></td>
<td>24.5°C, 50% (ACR 3.5–3.6 h–1)</td>
</tr>
<tr>
<td>Meeting room</td>
<td></td>
<td>6</td>
<td></td>
<td>24.5°C, 50% (ACR 2.4–2.6 h–1)</td>
</tr>
<tr>
<td>Cafeteria</td>
<td></td>
<td>8</td>
<td></td>
<td>24.5°C, 50% (ACR 2.4–2.6 h–1)</td>
</tr>
</tbody>
</table>

Table 2. Simulated office activities

<table>
<thead>
<tr>
<th>ID</th>
<th>Activity descriptions (time)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Entering (5’)</td>
</tr>
<tr>
<td>2</td>
<td>Leaving (5’)</td>
</tr>
<tr>
<td>3</td>
<td>Sitting and working with laptop (15’)</td>
</tr>
<tr>
<td>4</td>
<td>Stuffing the cabinet with boxes (5’)</td>
</tr>
<tr>
<td>5</td>
<td>Sitting and working with paper (15’)</td>
</tr>
<tr>
<td>6</td>
<td>Walking and operating coffee machine and kettle (5’)</td>
</tr>
<tr>
<td>7</td>
<td>Sitting and talking on phone with drinking tea/coffee (10’)</td>
</tr>
<tr>
<td>8</td>
<td>Walking and watering the plants (5’)</td>
</tr>
</tbody>
</table>
We used 14 sensors for measuring both CO₂ and PM in the climate chamber. 12 HOBO® MX CO₂ Loggers (MX1102) and one LICOR (LI-850) were used for background CO₂ measurement. We also deployed up to 12 optical particle counters (Metone 804, Metone instruments, USA and Metone HHPC 6+, Beckman Coulter, USA) and two high accuracy PM counters (Miniwras 1371, Grimm, Germany) to measure background PM concentrations. TVOC concentration was monitored using gas sensor (Advanced sense pro, Graywolf). All IAQ sensors were calibrated side-by-side in a controlled climate chamber in advance. The IAQ parameters (CO₂ and size-resolved PM) were measured at seven locations (ID 1-7, Table 3) to evaluate optimal sensor positioning. TVOC was measured at 3 different locations (ID 2-3, 6). The details of each sensor placement is shown in Table 3.

For human exposure estimation, one LICOR(LI-805) and one PM counter (Metone 804) were placed near one designated occupant (20cm below from subject’s nose). All data was obtained in 1-min time interval except CO₂ measurement at breathing zone, which was kept in 0.5-second interval. Each experiment continued for 1-hour with different sets of office activities for each space type, which were executed by participants with alarm notifications. The occupant activities were divided into sitting versus non-sitting activity for the analysis. Human exposure to CO₂ is estimated while taking only the minimum CO₂ value during one respiration cycle (3.5 s) from the starting point to minimize the impact of exhalation of the subject. Human exposure to PM was measured at 1-min interval which was able to be compared directly with background PM measurements.

For data analysis, we firstly reported average obtained IAQ data (CO₂, PM₂.₅, PM₁₀, and TVOC) and evaluated the impact of occupant activities on human exposure to CO₂, PM₂.₅ and PM₁₀. Finally, we executed multiple linear regression analysis to investigate optimal IAQ sensor placement which correlates well with breathing zone concentration and can represent the human exposure to studied IAQ parameters.

**RESULTS & DISCUSSION**

In order to ascertain the overall influence of the sensor placement on spatio-temporal variations of indoor air pollutants, the average value of each IAQ parameter obtained during 1-hour experiment were categorized into seven sensor placements (placement ID 1-7) regardless of space type. The average and standard deviation value of CO₂, PM₂.₅, PM₁₀ and TVOC are shown in Table 4. Consistent with previous research by Licina et al. (2017), we found higher average concentrations of CO₂, PMs at breathing zone compare to other background locations. The highest average TVOC concentration was shown in exhaust location followed by center of room and near source location. The second highest PM₂.₅ concentration was shown in Exhaust, while the PM₁₀ concentration was found in descending order of Breathing zone > Near source > CBL > Exhaust. Except the Breathing zone location, the concentration of CO₂ and PMs reached similar average value in all studied sensor locations since we didn’t consider other conditional variables (space types or occupant activities) which can affect the concentration of air pollutants.

**Table 3. Sensor placement (ID and descriptions)**

<table>
<thead>
<tr>
<th>ID</th>
<th>Sensor placement</th>
<th>Description (Height)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Wall</td>
<td>Wall-mounted (1.4 m)</td>
</tr>
<tr>
<td>2</td>
<td>Near Source</td>
<td>30 cm from strong activity or object (1.4m)</td>
</tr>
<tr>
<td>3</td>
<td>Center of room</td>
<td>CO₂ (0.1, 1.1, 1.7 m)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>PMs (1.1, 1.7 m)</td>
</tr>
<tr>
<td>4</td>
<td>CBL (Thermal plume)</td>
<td>One side of the desk near an abdomen of one seated subject</td>
</tr>
<tr>
<td>5</td>
<td>Desk</td>
<td>On each subject’s desk</td>
</tr>
<tr>
<td>6</td>
<td>Exhaust</td>
<td>At exhaust diffuser (2.4m)</td>
</tr>
<tr>
<td>7</td>
<td>Breathing zone</td>
<td>Fixed at 20 cm below from a subject nose using tube and experimental jacket</td>
</tr>
</tbody>
</table>

**Table 4. Data* for obtained CO₂, PM₂.₅, PM₁₀, and TVOC**

<table>
<thead>
<tr>
<th>Placement ID (description)</th>
<th>CO₂ (ppm)</th>
<th>PM₂.₅ (µg/m³)</th>
<th>PM₁₀ (µg/m³)</th>
<th>TVOC (ppb)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 (Wall)</td>
<td>636 (22)</td>
<td>0.3 (0.2)</td>
<td>5.1 (2.8)</td>
<td>-</td>
</tr>
<tr>
<td>2 (Near source)</td>
<td>572 (23)</td>
<td>0.3 (0.2)</td>
<td>7.2 (4.1)</td>
<td>152 (29)</td>
</tr>
<tr>
<td>3 (Center of room)</td>
<td>574 (20)</td>
<td>0.3 (0.1)</td>
<td>4.8 (2.5)</td>
<td>171 (21)</td>
</tr>
<tr>
<td>4 (CBL)</td>
<td>614 (41)</td>
<td>0.3 (0.1)</td>
<td>5.3 (2.8)</td>
<td>-</td>
</tr>
<tr>
<td>5 (Desk)</td>
<td>597 (25)</td>
<td>0.2 (0.1)</td>
<td>3.5 (2.0)</td>
<td>-</td>
</tr>
<tr>
<td>6 (Exhaust)</td>
<td>613 (24)</td>
<td>0.4 (0.2)</td>
<td>4.4 (2.4)</td>
<td>295 (18)</td>
</tr>
<tr>
<td>7 (Breathing zone)</td>
<td>1031 (181)</td>
<td>1.2 (0.9)</td>
<td>19.5 (11.4)</td>
<td>(14.6)</td>
</tr>
</tbody>
</table>

* Arithmetic average (standard deviation)

**Human exposure estimation by office activities**

We investigated the breathing zone concentration of IAQ parameters (CO₂, PM₂.₅, and PM₁₀) categorized by 16 different office activities (ID: 1-16, Table 2). This step was to evaluate if different occupant activity can
impact on human exposure to indoor air pollutants. Figure 1 shows average concentration of each IAQ parameters divided into 16 office activities and categorized as sitting versus non-sitting. Human exposure to PM$_{2.5}$ and PM$_{10}$ showed a big difference between sitting and non-sitting compare to the result of CO$_2$ which can be interpreted as occupant activity intensity is strongly related with PM concentrations. The highest CO$_2$ and PM$_{2.5}$ concentrations were appeared in non-sitting activities while one exception appeared in the activity ID 9, which was "Group talk in sofa with drinking tea/coffee" activity. This can be explained by the material of the sofa (fabric source) and water vapors from hot drinks, which can result in higher PM concentration regardless of low intensity of the activity.

**Figure 1. Human exposure estimation by office activities**

**MLR: Multiple Linear Regression**

To find out the significant correlation between background IAQ measurements and human exposure estimation, we conducted MLR analysis by using the IBM SPSS Statistics for Windows, Version 25.0. Independent variables were the time-series IAQ data obtained from the background placements (placement ID 1 – 6, Table 3) and the dependent variable was the time-series IAQ data obtained at breathing zone location near human subject (placement ID 7). Table 5 represents the description of obtained MLR models composed for each IAQ parameter. The table shows the $r^2$ values of proposed MLR models along with the Pearson correlation (R-value) between measured and unstandardized predicted IAQ values from the proposed MLR model.

**Table 5. Description of MLR models**

<table>
<thead>
<tr>
<th>Space type</th>
<th>CO$_2$ Model ($r^2$)</th>
<th>CO$_2$ Pearson correlation, R-value (Measured vs Predicted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>0.239</td>
<td>0.488**</td>
</tr>
<tr>
<td>Office 1</td>
<td>0.459</td>
<td>0.677**</td>
</tr>
<tr>
<td>Office 2</td>
<td>0.738</td>
<td>0.859**</td>
</tr>
<tr>
<td>Meeting room</td>
<td>0.798</td>
<td>0.893**</td>
</tr>
<tr>
<td>Cafeteria</td>
<td>0.957</td>
<td>0.978**</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Space type</th>
<th>PM$_{2.5}$ Model ($r^2$)</th>
<th>PM$_{2.5}$ Pearson correlation, R-value (Measured vs Predicted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>0.507</td>
<td>0.712**</td>
</tr>
<tr>
<td>Office 1</td>
<td>0.827</td>
<td>0.909**</td>
</tr>
<tr>
<td>Office 2</td>
<td>0.416</td>
<td>0.645**</td>
</tr>
<tr>
<td>Meeting room</td>
<td>0.424</td>
<td>0.651**</td>
</tr>
<tr>
<td>Cafeteria</td>
<td>0.253</td>
<td>0.503**</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Space type</th>
<th>PM$_{10}$ Model ($r^2$)</th>
<th>PM$_{10}$ Pearson correlation, R-value (Measured vs Predicted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total</td>
<td>0.775</td>
<td>0.88**</td>
</tr>
<tr>
<td>Office 1</td>
<td>0.94</td>
<td>0.969**</td>
</tr>
<tr>
<td>Office 2</td>
<td>0.891</td>
<td>0.944**</td>
</tr>
<tr>
<td>Meeting room</td>
<td>0.739</td>
<td>0.86**</td>
</tr>
<tr>
<td>Cafeteria</td>
<td>0.736</td>
<td>0.858**</td>
</tr>
</tbody>
</table>

*Correlation is significant at the 0.01 level (2-tailed)*

In Table 5, the weakest explanatory power ($r^2$) of models was shown in “Total” case for all studied IAQ parameters, which explains space type can influence the outcomes. Pearson correlation (R-value) was obtained by correlating the measured IAQ values at breathing zone location and the predicted values by proposed models. We concluded that estimation of human exposure to CO$_2$ is more accurate if the number of occupant is bigger as Meeting room and Cafeteria space showed higher power, where larger number of subjects was present compare to offices. Moreover, the model power is stronger for PM exposure estimation when there is a high-intensity activity (e.g. stuffing cabinet) with a few number of people which was the case of Office 1. If we compare the given three IAQ parameters, PM$_{10}$ was the most accurate factor to derive a strong statistical model for estimating
breathing zone concentration in all scenarios, where \( r^2 \) values were always over 0.7. Along with estimating breathing zone concentration with incorporated background IAQ measurements, we needed to answer for our fundamental question: "What can the most appropriate sensor placement which can well represent human exposure to indoor air pollutants according to different space types?" To do this, we collected top significant variables where \( r^2 > 0.5 \) (sig. < 0.01) and calculated the percentage of each sensor location account for among all the significant results in all the scenarios (Total case) regardless of space types for each IAQ parameter (\( \text{CO}_2 \), \( \text{PM}_{2.5} \), and \( \text{PM}_{10} \)). The reasonable location for estimating human exposure was exhaust for \( \text{CO}_2 \), which accords with the earlier observation by Pei et al. (2019). The Center of room was prominent sensor placement for \( \text{PM}_{2.5} \) exposure estimation while Near source and CBL location were shown as equally proper placement for \( \text{PM}_{10} \).

**CONCLUSIONS**

- Average \( \text{CO}_2 \), \( \text{PM}_{2.5} \), and \( \text{PM}_{10} \) concentrations at breathing zone were 2 – 5 times higher than the ones from background sensor placements
- Multiple linear regression analysis revealed that estimation of human exposure to \( \text{CO}_2 \) is more accurate when the number of occupant increases while for PMs, the model became powerful when there is a strong occupant activity such as stuffing the cabinet in Office 1
- \( \text{PM}_{10} \) was the most prominent candidate to derive a strong regression model for estimating breathing zone concentration in all space types
- Exhaust (\( \text{CO}_2 \)), The Center of room (\( \text{PM}_{2.5} \)), and Near source and CBL (\( \text{PM}_{10} \)) were appeared as good location candidates for human exposure estimation

The study has some limitations in generalizing of the data obtained because of too varied conditions without completely reaching steady-state condition throughout the experiment. Being limited to investigating human exposure from one subject, it may not include different aspects of human breathing. However, this work offers valuable insights into understanding spatio-temporal variations of indoor air pollutants with considering dynamic office conditions which haven’t been studied much. Moreover, the study will contribute to improving building ventilation control while considering not only building-related but also occupant-related variables on a wider scale.

**ACKNOWLEDGEMENTS**

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 754354.
Experimental investigation of the local air exchange behind an obstacle in laminar flow

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ABSTRACT

This study presents two methods to study the wake area of a round plate (σ=400 mm) in a clean room. First, visualizations were conducted with both, common spot lights and a laser light-section. The air in the wake area behind the plate was made visible by theatre fog. Second, the local air exchange was studied by comparing the mean aerosol concentration below the plate and the decay time for varying velocities of the air supply. The corresponding Reynolds numbers to the varied velocities ranged from 5064 to 8442. The particles’ decay times below the plate decrease with increasing air flow velocity.

INTRODUCTION

Clean rooms with unidirectional airflow and high air change rates (up to 600 1/h) are used in places where the highest demands are made on air quality. Knowledge of the air flow is crucial for maintaining high product and safety standards. An obstacle in the room leads to undesired turbulence, the dwell time in the wake area must thus be minimised.

In this paper, the local air exchange behind a flat plate is studied experimentally, in a clean room with vertical unidirectional airflow. The plate disrupts the air flow, which separates from the plate. Vortices form in the shear region, between the outer laminar vertical flow and the recirculation region behind the plate, leading to an increased pressure drag. Due to instabilities, the vortices break down with increasing flow distance to the obstacle.

The frequency of this instability is dependent on the air flow velocity, as well as the displacement thickness. The displacement thickness is a value similar to the boundary layer thickness. But it characterizes the distance at the break-off point of the plate, to which a solid boundary could be displayed in a frictionless flow, to give the same mass deficit as the boundary layer. The shear layer is the transition zone of two flows in the same direction with different mean velocities.

A method to determine precisely the velocity profile around a plate is Particle image velocimetry (PIV). Particles, introduced to the flow, are captured by a high speed camera. By tracking the individual particles, the velocity of each is evaluated. A detailed experimental study of the influence of the corner shapes on the wake formation in the aftermath of a plate based on PIV was performed by Xu et al. A numerical study was performed by Launay et al. 2019, in which the vortex formation was analysed for rectangular solids (cuboids) and along a transversely flowed plate. The results were compared with PIV measurements and the velocity fields, as well as the vortex formation, were studied for varying length over width ratios. A very detailed numerical study of the vortex formation behind a flat was performed by Narasimhamurthy and Andersson 1994 and Hemmati et al. 2019. The theoretical results of these authors will be discussed with the own visualizations.

In this article, the flow in the wake of a round plate in a clean room with vertical flow is studied experimentally in two sets of experiments. First, fog is inserted underneath a plate and it is visualized by common spotlights and a laser to study the volume of the recirculation zone behind the plate, as well as the shear layer thickness and the vortex build-up. Second, particles are inserted in the flow just above the plate and the particle concentration is measured in the recirculation zone. The decay time is studied for varying supply air velocities, ranging from u = 0.19 to 0.32 m/s. Thus, this study offers a basis for a further examination of the frequency of the vortex formation behind the plate and aims to visually study the vortex structure.

METHODS

Experimental set-up

The test stand consists of a round plate, which was placed in a height of 1710 mm and a horizontal distance of 1760 mm to the wall. The plate is made from a steel sheet, had a diameter of 400 mm, a thickness of 1.5 mm and was fixed by screw nut on a threaded bar. The airflow is vertical in the clean room, which dimensions are 4.8 m x 4.8 m x 2.7 m (length x width x height).

Visualizations

To study the flow in the wake of a round plate, two types of flow visualization were carried out. One visualization was performed with a usual spotlight to qualitatively study the volume of the contaminated air
behind the plate. And another visualization was carried out with a laser light-section, in which the eddy formation is studied, in the border region between the clean air with vertical flow, and the entrained air in the wake of the plate. The laser light was created by a laser (type micro-compact PL.MC525.700-L60 by Pegasus), with 525 nm wavelength and an 60° fan angle, and the images were captures by the camera (type D7500 by Nikon). To calibrate the camera, a sheet of paper with checker-board pattern was used to focus the camera on the laser plane. The air flow was made visible by using a fog generator (type Tiny S Mini by Retrotec). The theatre fog, consisting of a very fine aerosol, was introduced by a short pulse with a volume flow of approx. $8.33 \cdot 10^{-6} \text{ m}^3/\text{s}$. From the images, the shear layer thickness is studied visually.

**Particle concentration**

Besides the visual examination, particle measurements were carried out. Therefore, the same experimental set-up was used and aerosol was inserted in the flow just above the plate. It was generated by an aerosol generator (type ATM 225 by Topas) with a particle generation rate of $1.2 \cdot 10^{13}$ particles/m$^3$. Particles were counted by a laser particle counter (type Solaris 3100E by Lighthouse). The measuring probe was positioned 150 mm below the plate, at a distance on the half radius from the centre (100 mm).

First, the stationary particle concentration was continuously measured over a time period of 1020 s (17 min), in measurement time intervals of 10 s. Then, the aerosol generator was switched off to measure the decay time, which was reached, when the particle concentration fell for the first time below $1/100$ of the stationary concentration. The Reynolds number was calculated based on the air flow velocity $u$, the kinematic viscosity of air, $\nu = 1.53 \cdot 10^{-5} \text{ m}^2/\text{s}$ and the plate diameter $d=400 \text{ mm}$, according to:

$$Re = \frac{u \cdot d}{\nu}. \quad (1)$$

**RESULTS**

**Visualizations**

In Figure 1 and 2 the contaminated air in the wake of the plate is illustrated by fog and different light sources, a spotlight and a laser light. It can clearly be seen that the airflow current detaches at the height of the plate (break-off point) and free shear layers form, between the vertical airflow and the recirculation zone behind the plate, where the fog lingers.

The structure of the vortex formation can be seen from the laser light-section, where the contours are visible. The primary vortices form at the break-off point, or rather the break-off ring along the whole plate. From there, the vortices roll up and grow up, as well as the shear layer thickness, with increasing flow distance.

**Figure 1** – Vortex formation in the aftermath of the plate. The arrow on the left-hand side indicated the height where the fog is inserted.

Due to instabilities, the vortices disintegrate in the further downstream area. Thus, they get more blurred in the lower part of the images.

Furthermore, secondary vortices are created with an opposite direction of rotation. The recirculation flow occurs as follows: In the area just below the plate, the air flows from the middle into the outer area, towards the shear layer. By the induced outer vertical flow, it flows downwards. In the lower area of the image, the air from the shear layer flows to the centre below the plate and rises upwards. This could clearly be seen from the video, shown in the presentation.

It can be seen, that a bright shear layer thickness forms and the vortices begin to roll up from around

**Figure 2** – Visualization with laser light of the wake behind the plate ($=400 \text{ mm}$). The shear layer thickness of 137 mm is marked at the height of 150 mm below the plate.
56 mm below the plate. This is the distance between the plate and the first vortex visible in Figure 2. The area of validity is on the left below the plate, as the focusing of the camera took place in this area.

**Particle concentration**

In Table 1 the results of the measured particle concentrations are displayed for varying inlet air flow velocities of the room. It can be seen, that the mean particle concentration decreases with increasing air flow velocity of approach, from $9.6 \times 10^7$ particles/m$^3$ at a velocity of 0.19 m/s, to $1.4 \times 10^8$ particles/m$^3$ at a velocity of 0.32 m/s. The Reynolds numbers show a turbulent flow regime, according to the classification of flows normal to flat plates, as presented by Narasimhamurthy and Andersson (1994). It can also be seen, that the decay time decreases in a similar way at higher air flow velocities.

In Figure 3, the measurements for stationary concentration measurement below the plate are displayed in violin plots. The white dots indicate the medians, the thick black bars indicate the first and third quartile and the thin black lines represent the rest of the distribution. All particles below and above those thin lines can be considered as outliers. It can be seen, that there is a much wider range of the particle distribution for lower airflow velocities.

Figure 4 shows the decay curves, starting from the stationary concentration reached in the first 1020 s (3-4 min.) of measurement time. It can be seen that for each airflow speed, the purification time is between 160 and 230 s (3-4 min.).

**DISCUSSION**

**Visualizations**

The results show, that based on the laser light-section images, the vortex formation and the shear layer thickness can be analysed very well. The formation of primary and secondary vortices, as well as an increase of the shear layer thickness in the downstream of the plate are in good accordance with a wide range of literature, e.g. Hemmati et al. (2019), Launay et al. (2019), Narasimhamurthy and Andersson (1994). The rolling up of the shear layer was firstly described by Schade and Michalke (1962) who studied single vortices. The vortex formation of this study starts just behind the plate, whereas Narasimhamurthy and Andersson (1994) reported that the shear layer expands to a distance, two times the length of the plate, before the vortices in their simulation start to roll up. This could be due to the fact, that the authors based their simulation on a rectangular plate of infinite length. The overall formation of the secondary vortices corresponds to the velocity fields, studied by Carvalho (1987), even if the author analyzed the wake of plate close to a wall. Basnet and Constantinescu (2017) calculated velocities in the wake of the plate, which were directed in the opposite direction of the main flow velocity and thus support the description of the secondary vortices. Overall, it can be stated, that the method using the laser light-section seems to be effective to study the frequency of the vortex detachment.

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**Particle concentration**

At a higher speed of the surrounding airflow, the particle concentration in the wake of the plate decreases, as well as the decay time. According to Ingham, the volume of the recirculation zone in the flow behind a flat plate increases with increasing Reynolds number. Thus, the measured concentrations could be lower due to a higher dead zone in the wake of the plate. At a higher Reynolds number, the frequency of the vortex formation is increased, which leads to a higher air exchange between the contaminated air below the plate and the fresh air. However, only one measuring position was used in this experiment and the concentration field changes with varying air flow velocities.

**CONCLUSION**

- The Visualization with fog and a spot light offers a good method, to study the overall volume of recirculated air and it’s flow of direction.
- The structure of the vortex formation can be seen

---

**Table 1 – Varying air velocity, the corresponding Reynolds numbers and the resulting mean particle concentrations (≥ 0.3 µm) during stationary measurement, as well as the decay times for each series.**

<table>
<thead>
<tr>
<th>Velocity in m/s</th>
<th>Reynolds number in -</th>
<th>Particles in particles/m$^3$</th>
<th>Decay time in s</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.19</td>
<td>5064</td>
<td>$9.6 \times 10^7$</td>
<td>230</td>
</tr>
<tr>
<td>0.24</td>
<td>6189</td>
<td>$1.2 \times 10^8$</td>
<td>200</td>
</tr>
<tr>
<td>0.28</td>
<td>7316</td>
<td>$1.5 \times 10^8$</td>
<td>180</td>
</tr>
<tr>
<td>0.32</td>
<td>8442</td>
<td>$1.4 \times 10^8$</td>
<td>160</td>
</tr>
</tbody>
</table>
clearly in the laser-light section.

- The particle distribution in the steady-state measurement varies significantly more at lower velocities.
- The decay time decreases with an increasing air flow, due to an increased mass transfer in the shear layer.

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References

REFERENCES


