
# Feedback from the 43rd AIVC -11th TightVent & 9th venticool Conference: Summary of the Smart Ventilation, IAQ & Health track

On 4-5 October 2023, the AIVC – TightVent - venticool 2023 joint Conference "Ventilation, IEQ, and Health in Sustainable Buildings", was organised by the International Network on Ventilation and Energy Performance (INIVE) on behalf of the Air Infiltration and Ventilation Centre (AIVC), the Building and Ductwork Airtightness Platform (TightVent Europe), the international platform for ventilative cooling (venticool), and Aalborg University. It was a successful event, which drew just over 200 participants - researchers, engineers & architects, policy makers or regulatory bodies, manufacturers & stakeholders and international organizations from 33 countries.

The conference programme featured three parallel tracks of structured sessions, with around 150 presentations that exploring the main conference themes: Smart Ventilation, Indoor Air Quality (IAQ) and Health, Building & Ductwork Airtightness, and Ventilative Cooling – Resilient Cooling. A special session known as: “90 seconds industry presentations” was specifically organized for the event's sponsors.

Furthermore, the conference served as a major discussion place for ongoing projects, such as the IEA EBC Annex 78 "Supplementing Ventilation with Gas-phase Air Cleaning, Implementation, and Energy Implications", the IEA EBC Annex 80 "Resilient Cooling of Buildings", the IEA EBC Annex 86 "Energy Efficient IAQ Management in Residential Buildings" and the IEA EBC Annex 87 "Energy and Indoor Environmental Quality Performance of Personalized Environmental Control Systems".

In this article, we present the key trends, ideas, considerations, and conclusions that emerged during the two days of the conference, with a primary focus on the topic of Smart ventilation, IAQ and health.

The keynote speech by (Jones, 2023) considered harm from exposure to airborne contaminants using the disability adjusted life year (DALY) metric. $PM_{2.5}$ (~66% of all harm) was found to be the most harmful in homes by an order of magnitude; other important contaminants were $PM_{10\text{-}2.5}$, $NO_2$, $O_3$, and Radon.

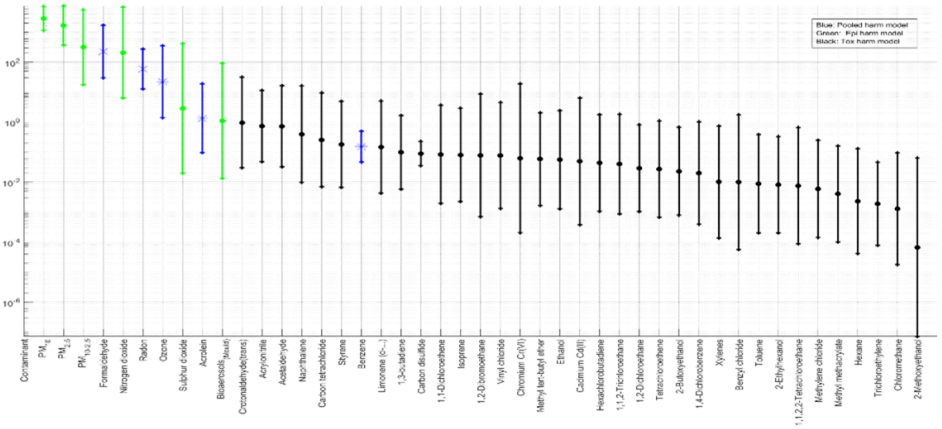


*Figure 1: Total harm (Jones, 2023)*

Oluwatobi Oke (Oke & Persily, 2023) and Carrasco et al. (Carrasco, Molina, & Jones, 2023) investigated uncertainties in $CO_2$ emission rates. Oke concluded that outdoor ventilation rates and metabolic rates have most significant effects on $CO_2$ metric values. Carrasco et al. found that metabolic $CO_2$ emission rates for US and Chilean children for the same activities in school classrooms are broadly similar, and they follow the same age-related trends as body mass differences are insignificant.

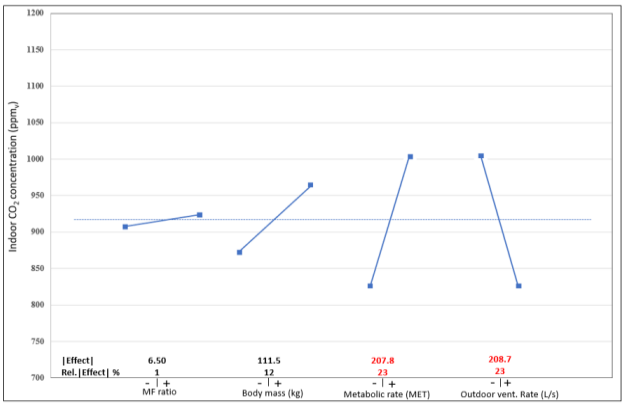


*Figure 2: Main Effects plot for the steady-state CO2 concentration in a classroom comprising students aged 5 to 8 with an adult male teacher (Oke & Persily, 2023)*

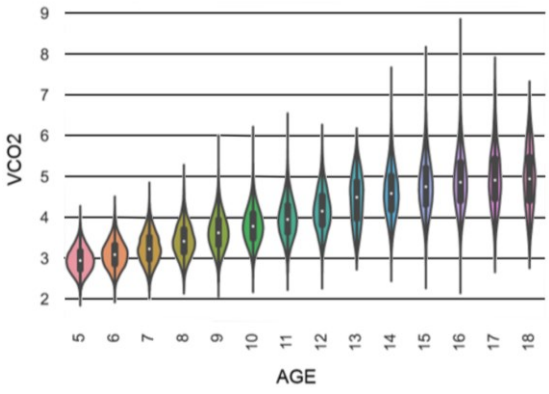


*Figure 3: Distribution of $\dot{V}_{CO2}$ emission by age group (Carrasco, Molina, & Jones, 2023)*

Beck et. al used citizen science approach to explore ventilation performance in Austrian school classrooms (Beck, Rojas, Krois, Goreth, & Hechenberger, 2023). According to their findings, mechanically ventilated spaces had lower $CO_2$ concentrations compared to naturally ventilated ones (i.e., window airing).

Roberts et al. measured $CO_2$ concentrations in 11 public toilets at mass gathering events as part of the UK Government's post-pandemic opening-up programs. Investigation of the maximum $CO_2$ concentrations revealed that at some events there were intermittent periods of high $CO_2$, which indicated poor ventilation relative to the number of occupants (Roberts, et al., 2023). The key recommendations made were to increase ventilation rates or room volume in toilets most frequently visited; to consider audience demographics and consider changing gender toilet allocation; to increase a number of intervals or their length so as to spread occupancy over a longer period; and to consider occupancy patterns when designing the ventilation systems.

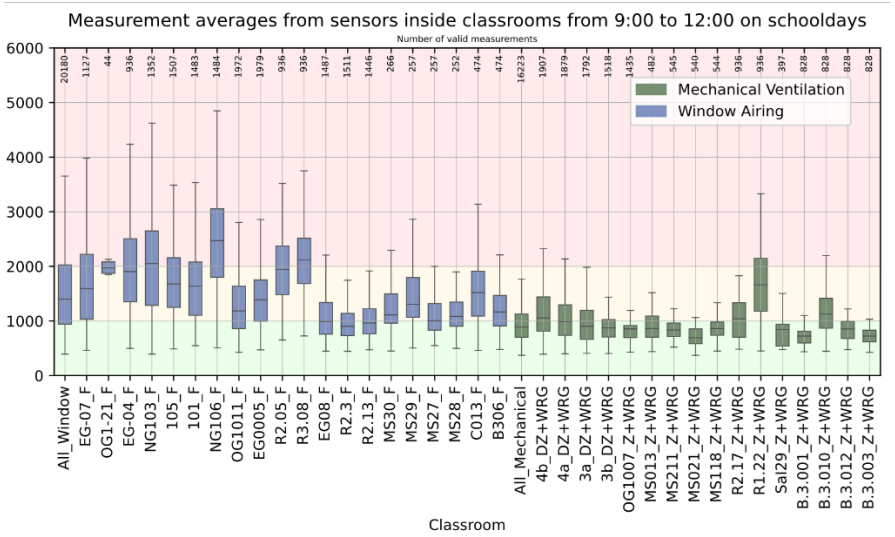


*Figure 4: Boxplots of CO2 concentration measured between 9:00 and 12:00 during schooldays (Beck, Rojas, Krois, Goreth, & Hechenberger, 2023)*

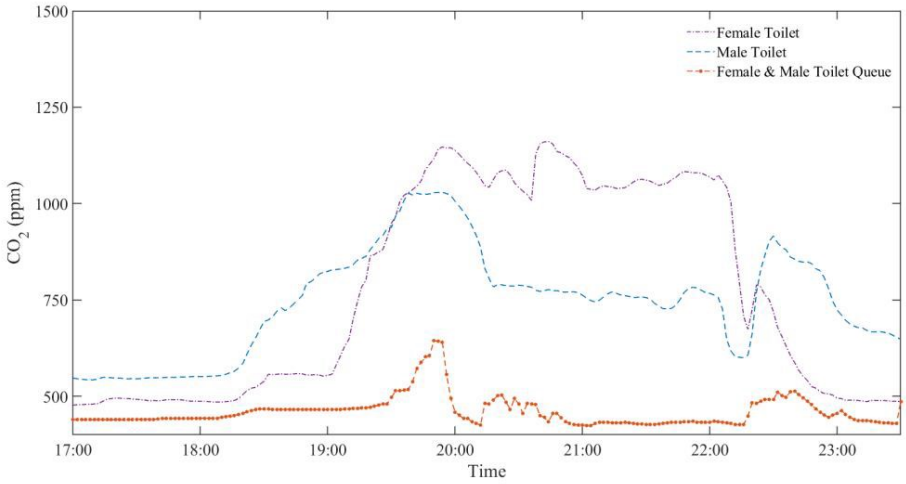


*Figure 5: Measured $CO_2$ concentration time series on Level 1 at the O2 Arena during the music awards event at 18% of usual occupancy capacity (Roberts, et al., 2023)*

Sonia Garcia-Ortega considered the behaviour of occupants of 12 naturally ventilated apartments located in Madrid, Spain and found that the main driver of occupant behaviour in terms of actions that can modify ventilation rates and IAQ (such as window and door operation) seems to be thermal comfort rather than IAQ control (Garcia-Ortega & Linares-Alemparte, 2023).

Kolarik presented the first results of a project aiming to investigate the performance of Metal Oxide Semiconductor (MOS) Volatile Organic Compounds (VOC) sensors in typical residential settings, determine their properties – sensitivity, linearity, hysteresis by comparing their signal with a reference measurement and discuss their suitability for control of residential ventilation (Kolarik, 2023).

There are lots of new requirements of energy use and decarbonisation for buildings (de Mesquita, Casquero-Modrego, Walker, Less, & Singer, 2023) (Burke & Gil, 2023) leading to changes in ventilation requirements. There is a trend towards less prescriptive and more performance-based approaches, which helps us to design ventilation systems that account for several factors including energy and carbon, while allowing innovation.

Speakers in the topical session: “Real performance of (smart) residential ventilation – performance assurance, fault detection, continuous commissioning”, organized by Subtask 4 of the IEA EBC Annex 86: Energy Efficient IAQ Management in residential buildings, shared results and experiences from industry and academia on the real performance of residential ventilation. The session explored how these data stand against existing quality management approaches and inspection protocols for residential ventilation. It tried to identify the crucial issues specific to “smart systems”. The speakers also discussed examples of approaches to ensure reliable operation beyond the commissioning phase.

More specifically, Mélois  presented the methodology and first results of the Performance 2 project aiming to evaluate the durability of Humidity-based Demand Controlled Ventilation (DCV) systems in two multi-family social housing buildings after 15 years of use, and to identify their performances regarding energy consumptions and IAQ depending on the occupants’ “use” (Mélois, et al., 2023).

Pollet provided an overview of Renson’s range of cloud-connected residential ventilation systems, including central and decentral mechanical extract ventilation (MEV), as well as fully mechanical systems with heat recovery (MVHR) (Pollet, Verniers, & Delrue, 2023). These systems incorporate smart control mechanisms that utilize different IAQ sensors ($CO_2$, VOC, RH), to adjust the airflow rate(s) locally or centrally to the detected needs. To obtain valuable insights into real-time performance of connected systems, the central MEV system data in particular has been analysed looking into several characteristics such as the energy consumption, IAQ, maximum ventilation rate, pressure losses, user interaction with the system, etc.

Rojas et al. used data-driven models (i.e., resistance-capacitor network models) to simulate indoor environmental conditions, i.e., temperature and $CO_2$ concentration, for fault detection applications. Their results indicate that indoor temperature anomalies are detected well and that anomalies in $CO_2$-concentration are also detectable with this modelling approach but depend on the available occupancy estimation (or measurement) (Rojas, Jenewein, Prenninger, & Schnitzer, 2023).

Smith & Kolarik utilized “smart ventilation” data (typical data from MVHR units) from 100 apartments in Frederikshavn, Denmark, to assess the supply temperature set-points and airflow balance (Smith & Kolarik, 2023). The results from their study showed that ventilation was poorly balanced in most units; it highlighted relevant issues and future work.

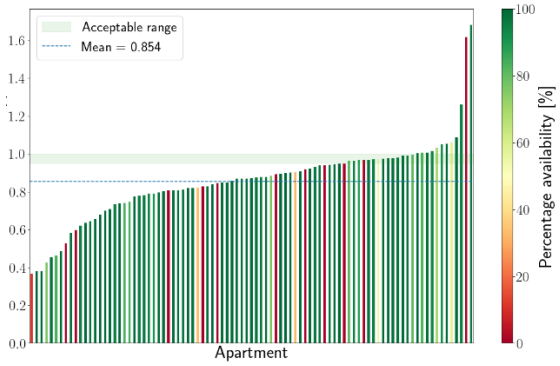


*Figure 6: Flow ratios for 100 ‘smart ventilation’ units (Smith & Kolarik, 2023)*

Cremers highlighted recent technologies (after 2015) in balanced ventilation systems that maintain optimal performance in energy and comfort (Cremers, 2023). These include automated fan speed adjustment during commissioning; balance in mass flow rate rather than volume flow rate; automated fan speed correction (FlowControl); comfort levels instead of values; adaptive comfort technology; modulating bypass technology; season detection; and filter change warning based on time and flow rate.

The discussion time following the presentations raised the question: “Will the technology save us, or do we need to educate the users?”. The answer to that was that we should just make ventilation systems work really well, all of the time, to avoid having to educate users.

Other presenters centred on the topic of smart ventilation, with Poirier presenting a ratings method for smart residential ventilation systems. Poirier provided an overview of the work conducted by the French working group "ESSOC", which was tasked by the French Ministry of Construction with creating a new performance-based regulation for ventilation (Leprince, Poirier, & Guyot, 2023).

The broader theme of Indoor Environmental Quality (IEQ) was explored by many. (Mahdavi & Berger, 2023) looked into the process through which indoor-environmental quality (IEQ) constructs are selected and applied suggesting that there is room for improvement, which would contribute to the formulation of more robust IEQ standards and guidelines. (Tran, et al., 2023) studied the applicability and sensitivity of the TAIL (Thermal, Acoustic, Indoor air, Luminous) rating scheme for schools to conclude that it allows tangible assessment of classroom IEQ and identification of problems requiring improvement.

(Farooq, et al., 2023) conducted a building performance evaluation to investigate health and comfort associated with having a Mechanical Ventilation with Heat Recovery (MVHR) supply vent in bedrooms of low-carbon social housing. (Hajdukiewicz & Loomans, 2023) provided a short-term detailed investigation of a dynamic façade's operation and its impact on IEQ in offices, and occupants' perception of the indoor environment. (Kremer, Rewitz, & Müller, 2023) presented a method to optimise the design of Membrane-based enthalpy exchangers (MEE) that provide a healthy and comfortable indoor air environment with a minimum energy demand.

Multiple papers focussed on ventilation effectiveness. Peter Nielsen investigated airborne transmission of disease in stratified and non-stratified flow to conclude that the use of the stratification effect makes it possible to create a reduced cross-infection risk for long range airborne transmission in some situations, but there is a need for research in system layout to find solutions that will reduce exposure risk in many situations; displacement ventilation may increase short range transmission risk; another possibility is to use mixing ventilation and accept a higher outdoor airflow rate; (Nielsen, Zhang, & Liu, 2023).

Kurnitski et al. analysed a measurement method for ventilation effectiveness, more specifically, for contaminant removal effectiveness with a point source corresponding to infector with tracer gas measurements and infection risk calculations (Kurnitski, Kiil, Mikola, & Võsa, 2023). The results showed that ventilation effectiveness consideration can reduce airflow rates required to mitigate against exposure.

Huijuan Chen et al. evaluated ventilation performance on airborne transmission in buildings, by analysing the effect of different ventilation configurations and flow rates on contaminant removal effectiveness (Chen, Markusson, & Ruud, 2023). Using a high mixing diffuser, they showed ventilation effectiveness generally decreases with particle size and as the height of the ventilation extract is lowered. Considering the location of the infected person could be a measure to reduce transmission.

Melikov explored the past, present and future of mitigation of airborne transmission of respiratory viruses by ventilation (Melikov, 2023). Among his findings, he stressed the need for the development of ventilation solutions that make it possible to remove/disinfect the exhaled air at the location of the occupant before it is mixed with the room air and showed an example of a headset incorporated personal ventilation (i.e. face extractors connected to a wearable filter) proving capable of capturing 80% of exhaled breath.

Kosonen et al. investigated different protection methods (i.e., room air purifier, personal air purifier, face mask, and workstation partition panels) at an office workstation, where the concentration characteristics were studied under mixing ventilation conditions in order to provide insights into the effects of different protection methods for occupational health and safety decision-making for office indoor environments (Kosonen, Lestinen, & Kilpeläinen, 2023). According to their findings partitions don't do reduce aerosol concentration but air cleaners removed aerosols most effectively.

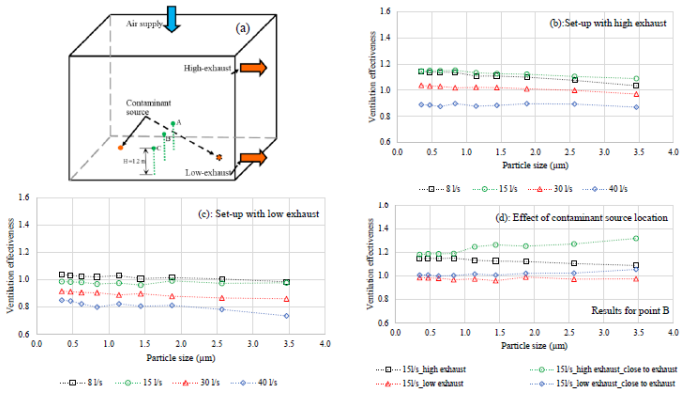


*Figure 7: Measurement set-ups & results (Chen, Markusson, & Ruud, 2023)*

Yoshihara et al. aimed to evaluate the effectiveness of the combination of air conditioning with floor-supply displacement ventilation (FSDV) and a local exhaust hood in a consulting room and its performance as an infection control measure and showed that performance is strongly affected by surrounding airflow (Yoshihara, et al., 2023).

Lastovets et al. performed field measurements and simulations of indoor air quality and building performance in a naturally ventilated hospital building to conclude that natural ventilation alone was insufficient to dilute airborne impurities (Lastovets, Elsayed, Silvonen, Luoto, & Sormunen, 2023). However, a combination of controlled ventilation and air purification reduced infection risk to acceptable probabilities.

The impact and benefits of air cleaning measures was the focus of a presentation and study by Zhou et al. who conducted a controlled intervention study to determine the effectiveness of portable air cleaners (PACs) in reducing indoor air contaminants in 2 schools (Zhou, Shu, Berquist, Gaski, & Nilsson, 2023). Among their key findings was the observation that the outdoor particle sources played the most significant role in deciding the indoor particle concentrations; the presence of exterior walls and windows in a space also affected the indoor particle concentrations.

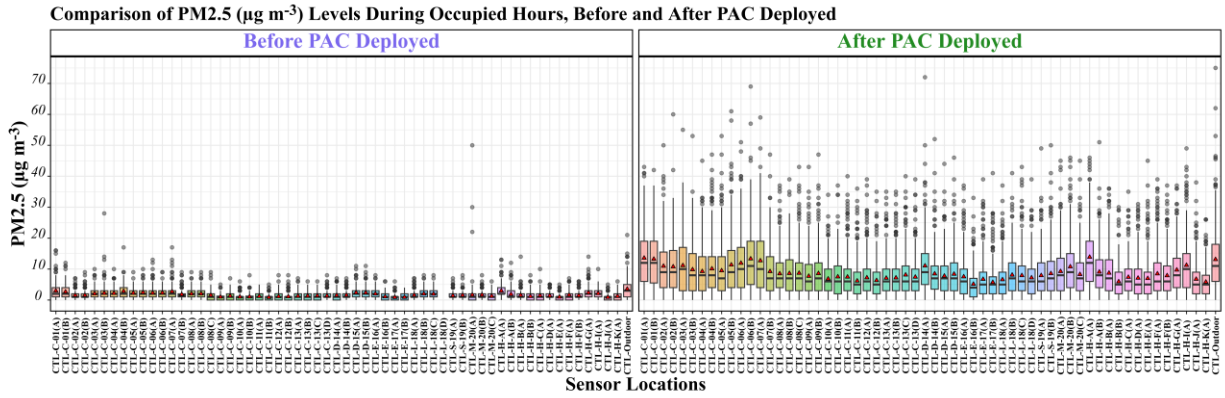


*Figure 8: PM2.5 concentration – control school (Zhou, Shu, Berquist, Gaski, & Nilsson, 2023)*

As $CO_2$ is a perennial topic. Carolanne Vouriot asked us “what can $CO_2$ measurements can tell us about ventilation and infection risk in classrooms?” (Vouriot & Linden, 2023) She analysed the ratio between actual exposure arising from a single infected individual and proxy exposure calculated from point measurements of $CO_2$ and reported that her measured $CO_2$ concentrations were within a factor of 2 to her predictions of exposure to exhaled breath of an infected person; this is dependent on the value of quanta that is used, which can vary by many orders of magnitude.

On the consideration of regulation of environments during a pandemic, Yuguo Li asked why we needed different standards for diseases saying it was due to the different nature of dilution, relationship with exposure/infection and limited transmission rather than conventional contaminants (Li & Jia, 2023). He suggested the use of the dilution air flow rate and not the ventilation air flow rate for infection control. On another question on what suitable criteria for dilution are he mentioned risk assessment, emission rate heterogeneity quantification and technologies.

Wells Riley was mentioned a lot (Kurnitski, Kiil, Mikola, & Võsa, 2023) (Lastovets, Elsayed, Silvonen, Luoto, & Sormunen, 2023) (Li & Jia, 2023) (Yoshihara, et al., 2023), but Benjamin Jones advised caution when using it because many of the parameters required to model infection risk as so uncertain that it is impossible to make good decisions using its predictions (Jones, Iddon, & Sherman, 2023).

Finally, on this subject, ASHRAE's newest standard, 241-2023 Control of Infectious Aerosols, was introduced by Max Sherman (Sherman & Jones, 2023). The US White House commissioned ASHRAE to complete it within the unprecedented development time of 116 days; it was published in July 2023. The standard aims to determine equivalent clean air required by space and system. It helps to determine appropriate technologies and their use and prepare a building readiness plan, among others. It is also a standard to make the building more resilient against infectious aerosols.

During the topical session run by IEA-EBC Annex 78: "Energy Performance of Gas Phase Air Cleaning", Bjarne Olesen gave an overview of the annex explaining that deliverables are the quantification of the performance and testing of technologies and predictive models (Olesen & Wargocki, 2023). Gas-Phase Air Cleaning (GPAC) is a way to reduce the outdoor airflow rate which can lead to a reduction in energy use for preheating/cooling and from transporting the outside air, while maintaining occupants' comfort.

Afshari et al. analysed the feasibility of utilizing advanced air cleaner technology for air purification in a system-based filter (recirculating ventilation system), a room-based filter (local recirculation in each room), a beam-based filter (recirculation in an active chilled beam) (Afshari, Maccarini, & Hultmark, 2023). The results showed that choosing the appropriate air cleaner can significantly impact energy performance and guarantee the improvement of indoor air quality. Integrating a filter in the active chilled beam unit results in notable energy savings.

(Sadrizadeh, 2023) studied the effect of gas-phase air cleaners on building heating demand and explore indoor concentrations of TVOC and $CO_2$ when gas-phase air cleaners are used, and found that integrating gas-phase air cleaner and increasing recirculation rate during peak occupancy hours kept TVOC and $CO_2$ concentrations acceptable.

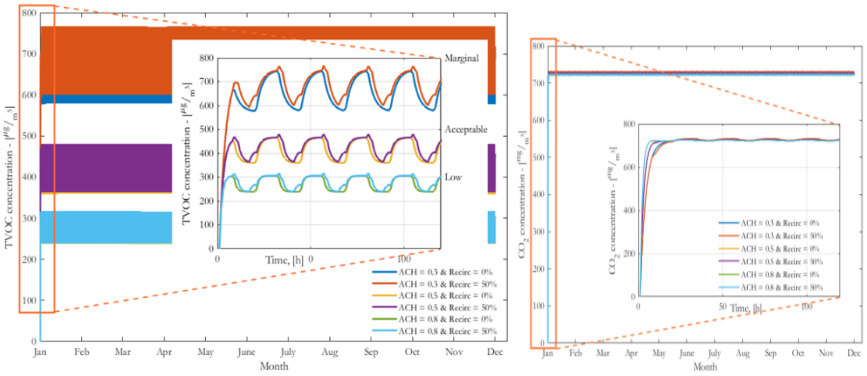


*Figure 9: Impact of recirculation rate on TVOC and CO2 concentration for different ACH values (Bogatu, Kazanci, & Olesen, 2023)*

In the last presentation of the session, Dragos-Ioan Bogatu established a framework and metric for assessing air cleaner efficiency in relation to energy use (Bogatu, Kazanci, & Olesen, 2023). Among their findings, it was reported that the gas-phase air cleaner is more efficient if both bio-effluents and building emissions were present as pollution sources.

There were other presentations on air cleaners, in the context of ASHRAE Standard 241, as well as pathogen risk mitigation (Andersen, Koust, Rasmussen, & Rong, 2023) (Paralovo, et al., 2023) (Koust, Rasmussen, & Stolte, 2023). It appears that there are an increasing number of types of air cleaners and contaminant sensors, but what is needed is more standardisation and performance ratings. Considering this, Hannalore Scheipers reviewed standards describing air cleaner methods and metrics (Scheipers, Janssens, & Laverge, 2023) . This all suggests there is a growing academic interest in these technologies and the ways they can help to achieve acceptable IAQ without using outdoor air.

***Note:*** *All cited papers will be available on AIVC's AIRBASE (https://www.aivc.org/resources/collection-publications/aivc-conference-proceedings-presentations) in March 2024*

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