Feedback from the 44th AIVC-12th TightVent & 10th venticool Conference: Summary of the Smart Ventilation, IAQ & Health presentations

On 9-10 October 2024, the AIVC – TightVent - venticool 2024 joint Conference "Retrofitting the Building Stock: Challenges and Opportunities for Indoor Environmental Quality", 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) and the international platform for ventilative cooling (venticool). The University of Galway, the Maynooth University and the Sustainable Energy Authority Of Ireland (SEAI) were also key organisers. This successful event brought together over 180 participants, including researchers, engineers, architects, policymakers, manufacturers, stakeholders, and international organizations from 26 countries.

The conference programme featured three parallel tracks with approximately 150 presentations across the key themes of Smart Ventilation, Indoor Air Quality (IAQ) and Health, Building & Ductwork Airtightness, and Ventilative and Resilient Cooling. A special session of "90-Second Industry Presentations", was organised to disseminate exclusive information from the event's sponsors to the conference participants, in addition to the conference exhibition.

Additionally, the conference provided a vital forum for discussions on current projects, including the IEA EBC Annex 86, Energy Efficient Indoor Air Quality Management in Residential Buildings & IEA EBC Annex 87, Energy and Indoor Environmental Quality Performance of Personalized Environmental Control Systems.

The "Smart Ventilation, IAQ & Health" track at the conference was organised in 14 sessions, 4 of which were topical sessions with a number of invited presentations:

1. Exploring Challenges and Opportunities in Decarbonizing Buildings through Building Ventilation (Topical Session)
2. Smart ventilation strategies
3. Performance-based IAQ regulations in dwellings: present and future (Topical Session)
4. IAQ in schools
5. IAQ and ventilation
6. IEQ, HVAC and airtightness
7. IAQ assessment
8. Ventilation regulations in various countries
9. The Challenges of Radon and Energy Retrofitting: Unravelling Complexities and Interaction within the Built Environment (Topical Session)
10. Performance evaluation of ventilation systems
11. IAQ in retrofit buildings
12. IAQ monitoring
13. What is new in the EPBD recast 2024 with respect to indoor environmental quality and ventilation? (Topical Session)
14. IEQ-Analysis and assessment methods

This article offers an overview of the main trends, ideas, and insights shared over the two-day conference, focusing particularly on Smart Ventilation, IAQ & Health.

Exploring Challenges and Opportunities in Decarbonizing Buildings through Building Ventilation

The workshop "Exploring Challenges and Opportunities in Decarbonizing Buildings through Building Ventilation" explored the intersection of building ventilation, decarbonization, including resilience, focusing on challenges and opportunities in energy retrofitting, ventilation, and emerging technologies (McGrath, 2024) (McGrath, 2024) (Molina C. , 2024) (Molina C. , 2024). Key discussions highlighted the difference between optimizing energy use and minimizing CO_2 emissions, the role of electrification in improving indoor air quality by eliminating combustion-related contaminants, and the impacts of decarbonization on occupant health and resilience to extreme weather events. Challenges included high costs, maintenance complexities, and social inequities, while opportunities emphasized reducing energy burden, improving public health, promoting workforce development, and enhancing climate resilience. The dialogue underscored the need for innovative technologies, effective occupant engagement, and industry involvement to achieve equitable and sustainable decarbonization outcomes.

IAQ in Schools

Handy & Burridge conducted a study in the framework of the Schools' Air Quality Monitoring for Health and Education (SAMHE) project focusing on evaluating particulate matter ($PM_{2.5}$) levels in classrooms across the UK during the 2023/2024 academic year (2024). Their findings show that classroom $PM_{2.5}$ concentrations are significantly influenced by outdoor $PM_{2.5}$ concentrations with outdoor air being a significant source of $PM_{2.5}$ (Handy, 2024). While long term exposure is predominantly due to "low concentration" days, "outdoor $PM_{2.5}$ events" (short periods of elevated concentrations) strongly correlate with peaks in classroom $PM_{2.5}$ levels and might contribute significantly to the long-term exposure to $PM_{2.5}$ over the academic year (Figure 1). These events, even when occurring during unoccupied times, permeate indoor spaces, indicating school buildings' susceptibility to outdoor pollutants. This study highlights the importance of using data-driven evidence to create guidelines for enhancing indoor air quality and inform future building, and retrofitting, of school buildings. Ventilation is a critical method for removing indoor pollutants from classrooms; however, caution is needed when addressing particulate matter, as outdoor air can be a significant source of PM pollution indoors.

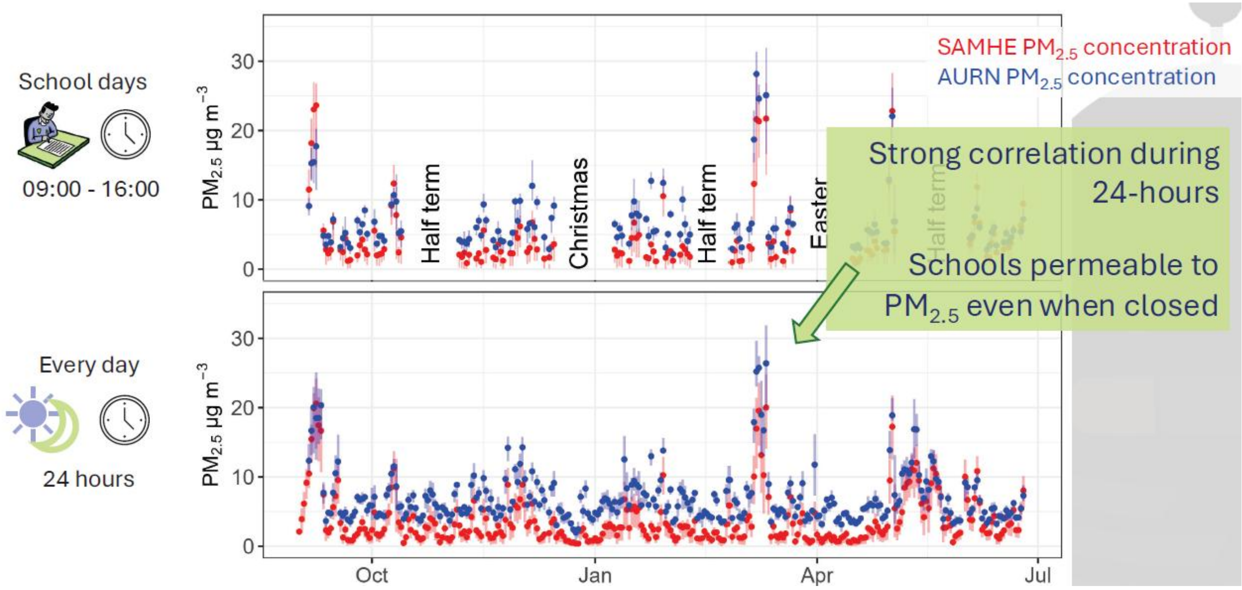

Figure 1: Temporal trends over the year (Handy, 2024)

A study by Beck & Rojas (2024) investigated the use of CO_2 feedback devices, or "traffic lights," to improve indoor air quality (IAQ) in Austrian school classrooms relying on window airing. These devices visually alert occupants when CO_2 concentrations exceed thresholds, prompting better ventilation. A quasi-experimental design monitored CO_2 levels before and after device implementation in selected classrooms, comparing them to control classrooms without devices (but the same awareness level). The analysis of CO_2 levels across various outdoor temperatures indicates that visual feedback devices significantly improve air quality in classrooms at lower ambient temperatures, supporting the validity of CO_2 traffic lights as an intervention. This finding is partially corroborated by comparisons with the control group, which exhibited no improvement in air quality at outdoor temperatures below 9°C in a hypothetical intervention scenario (Figure 2). The study concludes that visual feedback systems effectively reduce CO_2 levels during colder periods but highlights the need for further investigation into long-term impacts, including behavioural adaptations, thermal comfort, and energy consumption. Limitations include potential habituation to the devices and the late timing of the intervention, which complicates interpretation due to seasonal weather and behavioural variations.

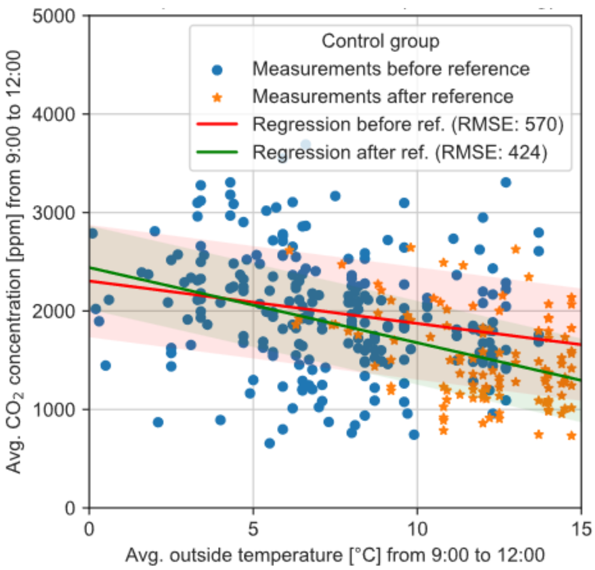

Figure 2: Correlation of outside temperature and inside CO₂ concentrations for classrooms (control group) (Beck, 2024)

Boulic et al. used computational fluid dynamics (CFD) to assess and improve classroom ventilation in three New Zealand cities (Auckland, Wellington, and Dunedin) (2024). Their study focused on evaluating trickle ventilators, with and without exhaust fans, as cost-effective alternatives to mechanical HVAC systems, especially relevant during winter when natural ventilation through window opening is inadequate. Their simulations revealed that while trickle ventilators can achieve acceptable airflow rates during summer in cities like Wellington, their effectiveness diminishes in winter due to reduced airflow and "CO$_2$ pockets" caused by poor air mixing. The study underscores the potential of integrating exhaust fans with trickle ventilators to meet recommended airflow rates year-round (Figure 4) and plans to validate findings through sensor deployment in classrooms.

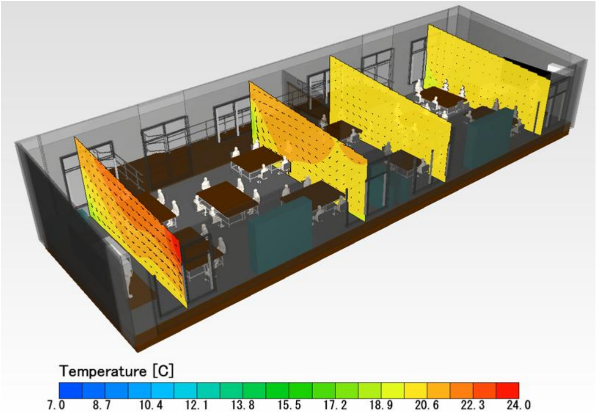

Figure 3: Temperature distribution (left, vertical plan)

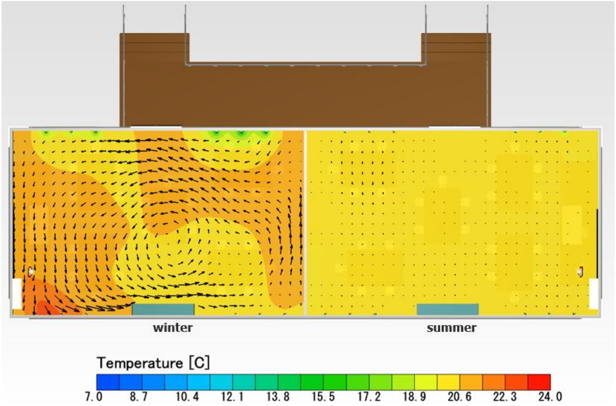

Figure 4: Temperature distribution (right, at 1.5 m from the floor)

Smart Ventilation

De Jonge introduced the Health-Equivalent Energy Efficiency Factor, a new metric designed to evaluate and balance the trade-offs between energy efficiency and health impacts in indoor air quality (IAQ) management systems (2024). Using metrics such as energy use and health impact indicators (expressed in Disability-Adjusted Life Years, DALYs), their study models and compares eight smart ventilation strategies, against predefined reference systems. It finds that using a reference line based on target values for energy efficiency and health impacts, results in greater versatility and wider applicability. The study highlights the importance of aligning IAQ strategies with both health and energy goals and supports adopting this metric in future regulatory frameworks to improve building ventilation systems.

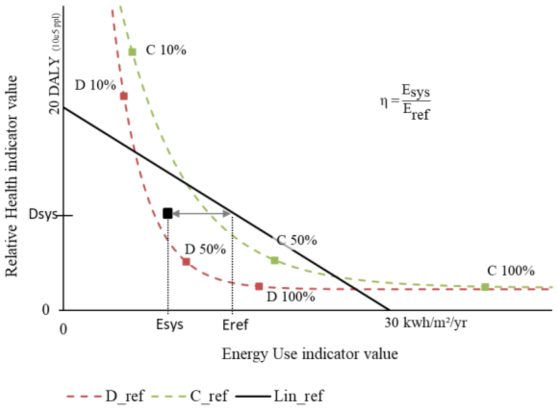

Figure 5: Plot graphically explaining the principle of the health-equivalent energy efficiency factor and the different investigated reference lines. The full line represents a linear reference line based on two target values. The dotted lines represent two reference lines based on simulations of two continuous airflow Belgian standard systems (system C-MEV and system D with heat recovery -MVHR) (De Jonge, 2024)

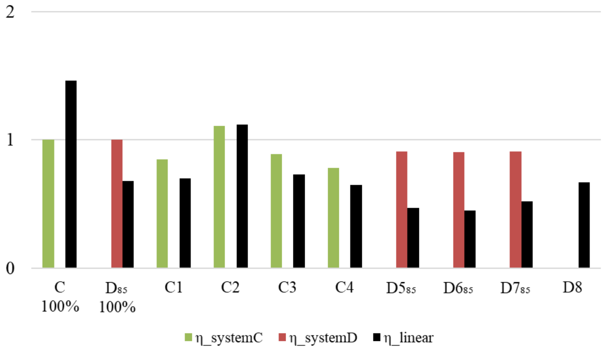

Figure 6: The different available Health-equivalent energy efficiency factors for each smart ventilation system and two reference systems (100%) (De Jonge, 2024)

The SmartAIR French project focuses on adapting the tools developed under Annex 86 (Energy Efficient Indoor Air Quality Management in Residential Buildings) to improve the energy efficiency of IAQ management strategies in operation (Andrade & Guyot, 2024). As part of this ongoing project, Andrade & Guyot, are evaluating the indoor air quality (IAQ) and energy performance of residential smart ventilation strategies in France, Denmark, Belgium, Brazil and Austria. Eight ventilation systems have been selected for simulation. The study involves collecting CO_2 and relative humidity concentration profiles, as well as exposure concentration profiles for various contaminants across all rooms in a standardized dwelling setup; these systems are assessed using various performance indicators such as DALY, cumulative formaldehyde and $PM_{2.5}$ exposures and energy losses. Raissa Andrade presented the methodology for assessing the sensitivity of all these indicators to entry data (Andrade & Guyot, 2024).

A study by Cremers explored the concept of implementing adaptive comfort technology in balanced ventilation systems, both with and without post conditioning (Cremers, 2024). They presented examples from monitored projects demonstrating how indoor temperature setpoints in adaptive temperature control vary in time. The data highlights how the bypass mechanism and postconditioning respond to variations in the temperature setpoints. Together, these components influence the supply air temperature, ultimately ensuring that indoor conditions remain comfortable. For ventilation units without postconditioning, the temperature setpoint influences the frequency of bypass operation (Figure 7) while for ventilation units with postconditioning (Figure 8), the temperature setpoint influences the frequency of bypass operation and the demanded heating use or cooling use.

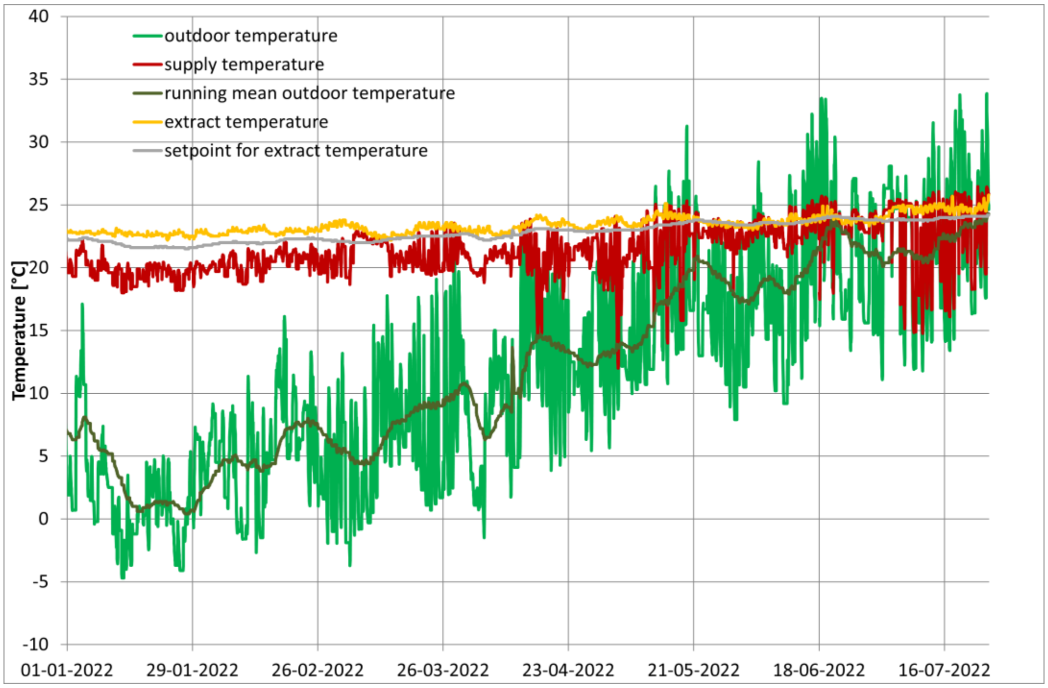

Figure 7: Monitored temperatures for a balanced ventilation system without postconditioning (Cremers, 2024)

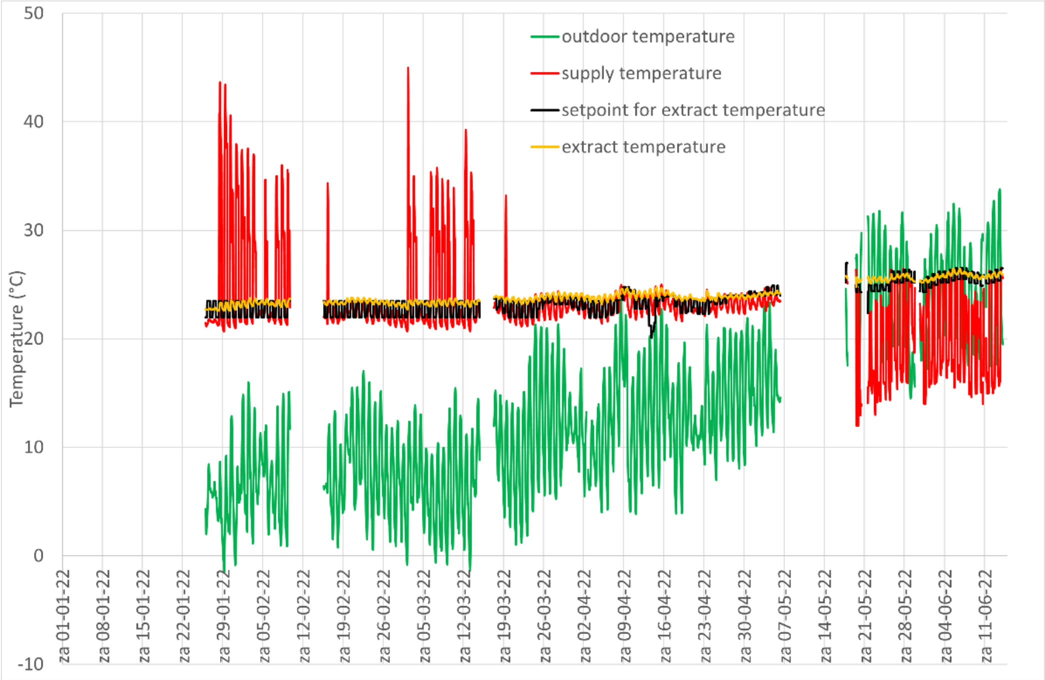

Figure 8: Monitored temperatures for a balanced ventilation system with postconditioning. Gaps in the chart are due to periods during which data transmission had failed (Cremers, 2024)

Performance based regulations (PBR)

Performance-based regulations define required results without specific direction on how those results are to be obtained. The topical session “Performance based IAQ regulations in dwellings: present and future” considered this concept. Guyot and Leprince opened the session with an overview of the development and application of performance-based approaches in research projects since 2016 and their integration into standards and regulations (Guyot & Leprince, 2024). They emphasized the significance of these approaches in addressing indoor air quality (IAQ) and energy efficiency for residential ventilation systems. While prescriptive ventilation rates remain prevalent, smart ventilation systems—designed to optimize airflow based on actual needs—are gaining attention for enhancing IAQ while reducing energy consumption. According to the presenter with the same airflow/air change rate, you can reach different level of IAQ criteria whilst with a lower mean airflow, you can improve the level of IAQ (Guyot & Leprince, 2024).

Linares-Akemparte & Garcia-Ortega (2024) reviewed Spain's performance-based IAQ regulations, focusing on their evolution, application challenges, and future anticipated changes. They detailed the transition from prescriptive to a fully performance-based approach in the Código Técnico de la Edificación (CTE), with CO_2 as the primary IAQ indicator, setting thresholds such as a maximum annual average concentration of 900 ppm and an annual accumulated concentration limit. Furthermore, they listed specific issues identified in CTE’s applications, which primarily relate to the consideration of smart ventilation systems in energy assessment tools and the rise of condensation risk in renovations. Anticipated updates focus on revising the energy performance assessment tool (Herramienta Unificada Lider-Calener - HULC) to reflect more accurate ventilation flow rates and better integrate demand-controlled ventilation systems (Linares-Alemparte, 2024). Additionally, the presenters emphasized the need to move beyond CO_2 as the sole indicator of IAQ and the setting of thresholds levels for additional pollutants. While a major challenge in implementing this change is to establish the correlation between pollutant concentration and its impact on occupant health, research is currently underway to investigate the generation of the most common pollutants in dwellings, their concentration and their impact on occupant health in terms of DALYs.

A presentation by Garcia-Ortega focused on assessing IAQ in existing residential buildings within a performance-based regulatory framework through a predictive model (2024). Traditional ventilation in Spanish dwellings relied on passive stack ventilation- employing the principles of thermal buoyancy and the Venturi effect to remove stale air from wet rooms- which has limitations such as poor performance in low wind or thermal inversion conditions and high thermal losses. Research by the Instituto de Ciencias de la Construcción Eduardo Torroja (CSIC) explores correlations between measurable factors (e.g., season, dwelling’s surface area, permeability, occupancy) and real CO_2 measurement outcomes, bypassing detailed occupant behaviour. Their study leverages easily obtainable parameters like floor area, construction year etc. to develop predictive statistical models for IAQ, avoiding reliance on field measurements. These models aim to inform the development of IAQ regulations, guidelines, and building renovation plans by assessing neighbourhood-level IAQ potential, identifying building typologies prone to IAQ issues, and evaluating how occupant behaviour varies with geography, climate, and socio-economic factors.

Leprince & Poirier presented a methodology for developing performance-based ventilation regulations in France, offering an alternative to the existing prescriptive regulation of 1982 (2024). The proposed framework includes key performance indicators (KPIs) to assess ventilation systems' effectiveness in maintaining indoor air quality (IAQ) concerning health, well-being, and building durability. The KPIs cover parameters like CO_2 concentration, relative humidity, proxy pollutants and air renewal, tailored for simulation and validation rather than on-site measurements. Simulations of typical French ventilation systems were conducted to define threshold values and to check the impact of the various input parameters and target values for the KPIs were defined. They also defined a structured validation process for industrial and project-specific systems. France is set to introduce performance-based regulations for ventilation in dwellings, providing an alternative to prescriptive standards. This approach will foster a more open market for smart ventilation systems, enabling solutions that maintain or enhance indoor air quality (IAQ), minimize energy consumption and embodied energy, and are specifically tailored to the needs of each project (Leprince & Poirier, 2024).

A presentation and study by Poirier looked into the uncertainty of IAQ and energy performance schemes for residential smart ventilation (Poirier, Guyot, & Woloszyn, 2024). Their study quantified the uncertainty of a new recent performance assessment method using RBD-FAST sensitivity analysis to evaluate the variations of impacts of input data such as: the pollutant emissions scenarios - moisture, formaldehyde and particle matter $PM_{2.5}$ -, model input parameters and ventilation strategies (Figure 9). For this sensitivity analysis, five ventilation systems were studied on a French low energy house: 2 with constant airflows, 1 humidity-based exhaust-only smart ventilation and 2 humidity+CO_2 based smart ventilation. The study found that occupant bio-effluent, formaldehyde, and $PM_{2.5}$ emission rates contributed 11% to 87% of the uncertainty in IAQ performance indicators, with $PM_{2.5}$ deposition velocity parameter alone accounting for 50% of the uncertainty in the $PM_{2.5}$ indicator. Moreover, they highlighted the energy benefits of the humidity-based ventilation, with heat losses on average 20% lower than those obtained with equivalent constant airflow ventilation and noted that some smart ventilation strategies offer clear IAQ benefits without significantly increasing energy demand.

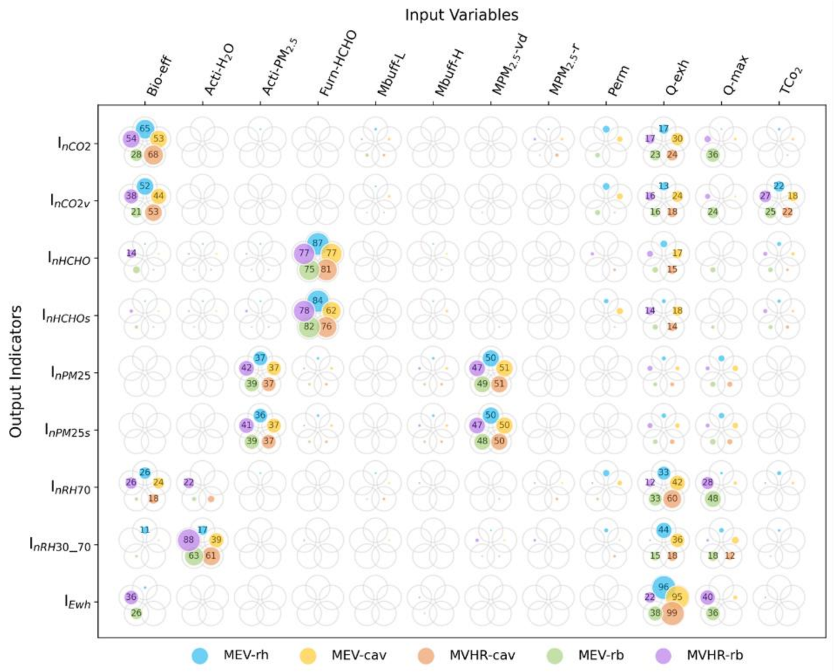

Figure 9: Display of the sensitivity indices calculated for the 5 ventilation strategies

A number of presentations considered harm as a basis for regulation. A paper by Jones et al. (Jones B. , Morantes, Molina, Sherman, & McGrath, 2024) evaluated the protection from chronic harm provided by exposure limit values (ELVs) for indoor air contaminants set by regulatory bodies across member countries of the Air Infiltration and Ventilation Centre (AIVC). Significant variability in the regulated harm levels from ELVs across countries for the same contaminants underscores inconsistencies in public health protection. Their study also introduced the concept of a Regulated Harm Budget (RHB) to quantify the total allowed harm from regulated contaminants implicitly set by a regulatory body and highlighted that the RHBs of most countries exceed harm levels associated with smoking and alcoholism. This signals a need for intervention to mitigate indoor air contaminant harm and reduce it to acceptable levels that are comparable to other regulated risks. Spain's RHB of 2400 DALYs/10^5 person/year for $PM_{2.5}$, NO_2, and formaldehyde is particularly noteworthy (Table 1).

Table 1: Regulated harm budgets for selected contaminants, by country. Highest to lowest median harm. DALYs/105 person/year (Jones B. , Morantes, Molina, Sherman, & McGrath, 2024)

Contaminants	**Country**	**Regulated Harm Budget**	**Geometric Standard Deviation**
HCHO, NO_2, $PM_{2.5}$	Spain	2400	1.3
NO_2, $PM_{2.5}$	China	3600	1.2
	Spain	2400	1.3
	Norway	1500	1.2
HCHO, $PM_{2.5}$	USA	2200	1.2
	Spain	1200	1.2
HCHO, NO_2	Sweden	7300	1.5
	Spain	1100	1.7
	France	570	1.8
	UK	280	1.6

Another presentation and study by Jones et al. showed how a harm budget (an acceptable limit of population harm) might be used to regulate Indoor Air Quality in dwellings at the global north (Jones B. , Morantes, Molina, & Sherman, 2024). They quantified chronic harm from long-term exposure to 45 common indoor air contaminants using DALYs and identified $PM_{2.5}$, $PM_{10\text{-}2.5}$, NO_2, formaldehyde, radon and O_3 as the most harmful contaminants, accounting for over 99% of total harm (Figure 10). By prioritizing these contaminants, the study demonstrated that complying with ASHRAE Standard 62.2 could reduce population harm by approximately 70%, setting an acceptable harm budget of 610 DALYs/10^5 person/year. Harm is shown to be a way of prioritising the contaminants that cause the greatest chronic harm to populations of people, and the harm budget quantitatively establishes acceptable IAQ based on exposure to airborne contaminants in buildings.

Molina et al. used year-long data collection in 15 dwellings in Santiago, Chile, to investigate the relationship between indoor air quality (IAQ) and thermal comfort and the houses' typology (Molina, Jones, Garrido, & Morantes, 2024). Significant variability in particulate matter ($PM_{2.5}$ and PM_{10}) concentrations and thermal comfort was observed. While PM concentrations were below the global representative value, maximum values exceeded the representative maximum. The associated health harm was quantified as 1271 DALYs/10^5 person/year for $PM_{2.5}$ and 683 DALYs/10^5 person/year for PM_{10}. Notably, WHO 2021 annual recommendations were not met, with the daily mean met by 25% of the measured days for $PM_{2.5}$ and 72% for PM_{10}. Acceptable thermal comfort levels were achieved just 56% of the measured time (Figure 11). The study emphasizes the need for a comprehensive regulatory framework that optimizes energy efficiency and prioritizes occupant well-being, providing valuable insights for addressing competing objectives in residential architecture and guiding strategic, impactful interventions.

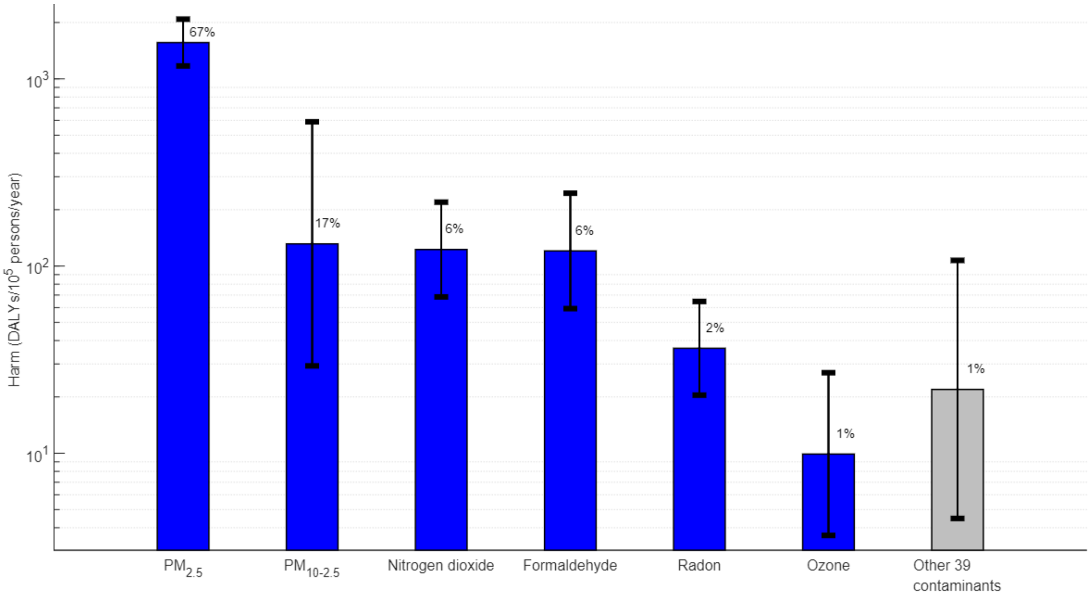

Figure 10: Harm caused by contaminants of concern. Median (bar) & GSD (error bar). Percentage contribution for total harm (Jones B. , Morantes, Molina, & Sherman, 2024)

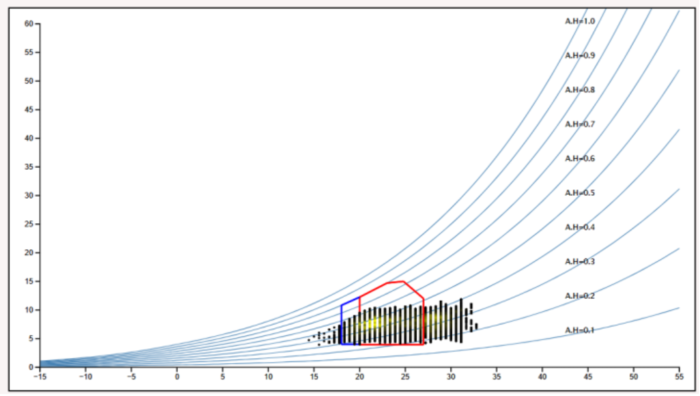

Figure 11: Psychrometric chart for one sensor, showing the data within the thermal comfort zone—red area for summer and blue and red area for winter. Gradients of yellow indicate data saturation (Molina C. , 2024)

IAQ assessment

Kosonen et al. investigated the airborne transmission and infection probability in a six-person meeting room using an overhead perforated duct (OPD) and low-velocity unit (LVU). Using tracer gas (SF6) generated by a thermal breathing manikin to simulate droplet nuclei from an infected individual, the study examines the effects of heat gain, airflow rate, and the infector's location. The average contaminant removal efficiency with OPD was between 0.9 and 1.1 while the infection probability was quite uniform (SD=0.1%), especially at a higher heat gain level (60 W/m^2) (Figure 12). In contrast, LVU displayed significant variability (spatial & temporal) in contaminant removal (0.2–10.1) and infection risk, ranging from 0.3% to 4%, depending on the infector's location, with its best and worst scenarios surpassing OPD performance when properly designed. Locating the infector near the exhaust minimized infection probability with heat gain levels of 38 W/m², highlighting that effective air distribution combined with local exhaust placement is most effective for source removal.

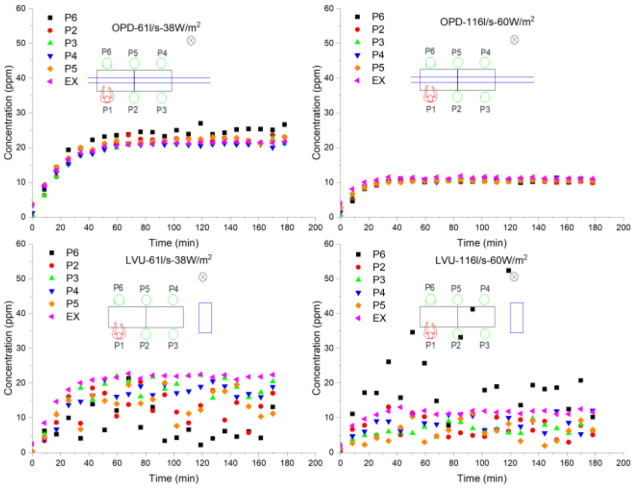

Figure 12: The concentration distribution of tracer gas at different locations when the manikin was at P1 with OPD and LVU with two heat gains of 38 W/m^2 and 60 W/m^2 (Kosonen, Zhao, Kilpeläinen, & Jokisalo, 2024)

A study by Murga et al focused on optimizing airflow rate in displacement-ventilated room to minimize particle inhalation risk and control energy consumption using computational fluid dynamics (CFD), virtual manikins, and a genetic algorithm (Murga, Nakagawa, Bale, & Tsubokura, 2024). The research investigated how building parameters, such as inlet/outlet sizes, inlet/outlet location, and airflow rates, impact airborne viral density and energy use. The optimization process achieved a 50% reduction in particle number when comparing the worst-case scenario (P1) with an optimized solution maintaining the same power consumption (P2). Notably, particles remained at breathing level in non-optimized conditions but were effectively removed after optimization (Figure 13). Then, optimization algorithms can be joined to virtual manikins to improve building design and minimize airborne transmission while managing energy consumption.

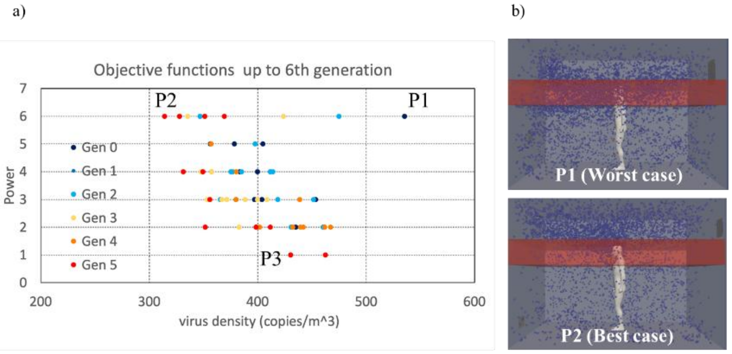

Figure 13: a) Pareto solution and b) Comparison of P1 and P2 (Murga, Nakagawa, Bale, & Tsubokura, 2024)

Shin et al. (2024) assessed airborne cross-infection risk under different discharge angles (-20°, 0°, and +20°) and supply temperatures (18, 25, and 30 °C) of an air-conditioner, with various body orientations (face-to-face, side-by-side, and back-to-back) (Figure 14, Figure 15, Figure 16). They conducted field experiments on particle dispersion in a full-scale test chamber using a manikin-shaped particle generator and detector with simulated particles. Particle transmission trends initially differed depending on body orientations. Cross-infection risk was consistently lower at a discharge angle of -20° and higher at +20° when the supply temperature was 25°C, regardless of orientation. However, the discharge angles linked to increased or reduced cross-infection risks shifted with changes in supply temperature. These findings highlight the significant influence of body orientation on cross-infection risk and underscored the importance of carefully adjusting discharge angles and supply temperatures to mitigate airborne transmission in indoor airflow environments.

Figure 14: Experiment settings in the test chamber - Front-to-front (Shin H. W., Park, Park, & Kang, 2024)

Figure 15: Experiment settings in the test chamber - Side-by-side (Shin H. W., Park, Park, & Kang, 2024)

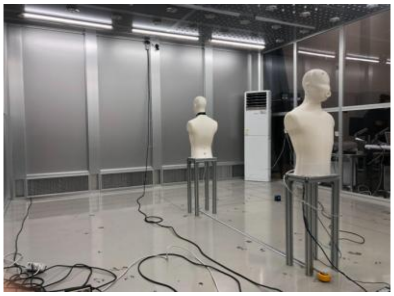

Figure 16: Experiment settings in the test chamber - Back-to-back (Shin H. W., Park, Park, & Kang, 2024)

Paralovo et al. reported on indoor air quality (IAQ) measurements and the presence of SARS-CoV-2 in 11 elderly care homes in Belgium (2024). Over seven days, CO_2, $PM_{2.5}$, temperature, and relative humidity were continuously monitored in selected rooms, while air and surface samples were analyzed for SARS-CoV-2 RNA. They found that particulate matter ($PM_{2,5}$) concentrations in all facilities were most of the time low, meeting indoor guideline values. CO_2 concentrations generally indicated acceptable levels of ventilation, with the lowest concentrations measured in mechanically ventilated facilities. During active COVID-19 outbreaks, all air samples and the majority of surface samples tested positive for SARS-CoV-2. In the absence of a reported on-going local outbreak, positive SARS-CoV-2 samples were found mainly on surfaces. The study highlights the value of assessing viral loads in both air and surface samples as an effective tool for evaluating infection risks in indoor spaces without requiring human sample collection. Expanding such studies to include additional pathogens could provide broader insights into exposure risks for vulnerable populations, such as the elderly, and facilitate the development of more precise prevention strategies. General recommendations for elderly care homes include regular testing of residents and staff (symptomatic or not), isolating positive cases, promoting the use of masks, and enhancing ventilation, particularly in shared spaces, to mitigate the spread of airborne infections.

De Jonge presented a measurement campaign aimed at supporting the implementation of Belgium's 2022 law to improve indoor air quality (IAQ) in public spaces following the COVID-19 pandemic (De Jonge & Janssens, 2024). The campaign involved monitoring CO_2, particulate matter ($PM_{2.5}$ and PM_{10}), temperature, and relative humidity across 11 Belgian public spaces with diverse functions, such as bars, gyms, and restaurants for a duration of at least 7 days in March 2024. The measurements reveal significant variation in IAQ parameters influenced by the building's usage, the presence of specific pollutant sources, and the availability of ventilation systems. Particular sources of particulate matter (PM) can substantially elevate indoor concentrations, often exceeding WHO Air Quality Guidelines for prolonged periods. Bars and restaurants recorded the poorest IAQ metrics, whereas most other locations with mechanical ventilation systems maintained acceptable levels of CO_2 and PM. These findings underscore the challenges in creating a uniform IAQ label suitable for all types of public spaces.

Robitu & Ginestet (2024) performed a study aiming to evaluate the effectiveness of stand-alone air cleaners (ACs) equipped with HEPA filters in reducing airborne particle concentrations within a mechanically ventilated meeting room. The assessment focuses on factors such as the number and type of devices, total airflow rate, their placement within the room, and the flow patterns of the devices. Six commercially available ACs, representative of the French market, were selected for the study, each characterized by unique airflow patterns for both air inlet and outlet. The filtration efficiencies of the ACs are nearly 100%, as expected for HEPA filters. The targeted airflow rates for this study — 80, 200, and 400 m^3/h, corresponding to 1, 2.5, and 5 volume per hour (vol/h), respectively—were achieved. However, the actual airflow rates were found to be 20% to 50% lower than the manufacturers' stated values. Additionally, the sound power levels and operating power of the air cleaners were measured. Numerical 3D simulations (CFD) were conducted to evaluate 66 configurations of ACs within the room. These simulations calculated airflow pattern, air velocity, and particle concentrations over time and at various locations within the breathing zone. The cleaning efficiency, defined as the ratio of particle concentration after 16 minutes of AC operation to the initial concentration, was evaluated. ACs placed in corners behind walls—a common positioning—demonstrated lower performance compared to other locations in the room. Higher airflow rates improved cleaning efficiency, as indicated by a decrease in the C16/C0 ratio. At 5 volumes per hour (vol/h), variations in particle concentrations across the room were weak, but became larger at 2.5 vol/h. Ceiling-type ACs achieved more uniform particle distribution throughout the room. However, most ACs studied produced sound levels exceeding 50 dB(A) at airflow rates above 200 m³/h, potentially causing noise disturbances for occupants.

Oke & Persily (2024) evaluated the accuracy of predicting CO_2 emission rates of building occupants (VCO_2) using two estimation approaches: the ASHRAE Fundamentals Handbook (2021) and the Persily and de Jonge (PdJ) approach (2017). Experimental data from indirect calorimeter chambers involving 50 healthy participants performing activities like cycling, sleeping, and sedentary tasks were compared to predictions made using measured and literature-based inputs. During these activities metabolic parameters such as VCO_2, rate of oxygen consumption (VO_2), basal metabolic rate (BMR), respiratory quotient (RQ), and energy expenditure (EE) were collected. Results indicate that the PdJ method outperforms ASHRAE, with prediction errors of 6% (measured inputs) and 19% (literature inputs), compared to ASHRAE's 28% error. The findings highlight the importance of addressing the challenges in predicting VCO_2 to interpret indoor CO_2 concentrations.

Finneran & Burridge (2024) introduced a robust method for estimating the daily mean per-person ventilation rate ($\bar{Q}_{pp}$) in heterogenous rooms using point measurements of carbon dioxide (CO_2), without requiring assumptions regarding the ventilation provision throughout the day, nor requiring the room to be in a steady state, nor the air within to be well-mixed. Notably, the method facilitates ventilation estimates in operational spaces during normal use, not requiring the room to be unoccupied. Using UK secondary school classrooms as a case study, the study employs Monte Carlo to simulate CO_2 levels and derive a simplified calculation tool based on the CO_2 mass balance equation. The proposed method requires minimal contextual information (CO_2 levels, occupied time fraction, and average per-person CO_2 generation rate), achieving uncertainty reductions from 22% (no contextual data) to 12% with increased contextual data (information of occupants age and room activities, and using multiple CO_2 sensors) (Figure 17). The tool provides a practical means of calculating average per-person ventilation rates from CO_2 data.

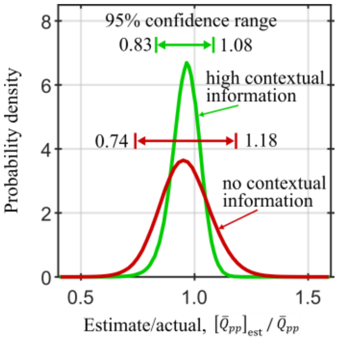

Figure 17: Probability density function for estimated Q¯_pp from the calculation tool/equation compared to the true value, for no and detailed contextual information scenarios

Radon

The topical session on “The Challenges of Radon and Energy Retrofitting: Unravelling Complexities and Interaction within the Built Environment” explored the intricate relationship between radon and the built environment, in the context of ventilation and indoor environmental quality. Pourkiaei et al. used data from 87 Irish homes collected hourly between 2019 and 2021 and, looked at radon entry rates into buildings to identify factors driving the radon flux based on meteorological, environmental, and building characteristics using a statistical approach (Pourkiaei, Byrne, Murphy, & McGrath, 2024). Initial findings reveal considerable variability across the dwellings and within each dwelling, reflected by the wide distribution, highlighting the dynamic process (Figure 18).

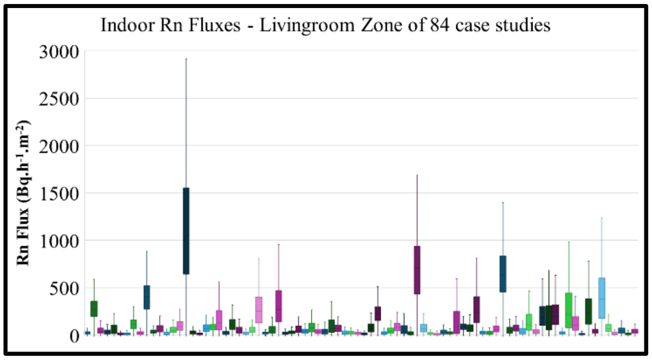

Figure 18: Box plots of radon fluxes distributions of 84 case studies over 18 months (Pourkiaei, Byrne, Murphy, & McGrath, 2024)

Zhou reported on the effects of ventilation approaches on indoor radon concentrations through controlled experiments conducted at the Canadian Centre for Housing Technology focusing on building depressurization & radon ingress, ventilation & indoor radon control (Zhou L. , Li, Gaskin, & Tardif, 2024). The study observed increased indoor radon concentrations during the depressurization testing with the highest levels recorded under lower depressurization caused by clothes dryers, cooker hoods, and bathroom exhausts, operating under typical mechanical exhaust-only ventilation (MEV) conditions. This outcome is likely attributed to increased dilution effects facilitated by enhanced envelope pressure differentials. Balanced mechanical supply and exhaust ventilation (MSEV) was identified as an effective strategy for mitigating radon levels.

Gaskin et al. conducted a field study on the effectiveness of heat recovery ventilation (HRV) systems in reducing moderate indoor radon concentrations in 16 houses in Canada's National Capital Region between 2020 and 2023 (Gaskin J. , Li, Brascoupé, & Zhou, 2024). HRVs were tested under various operational settings—off, periodic, and continuous operation at different fan speeds (high or low). The impact of the HRV system on indoor radon concentrations was assessed across sixteen houses, with an additional analysis comparing the combined operation of the passive depressurization system (PSD) for radon mitigation and the HRV. Results showed that continuous HRV operation achieved an average radon reduction of 40% in houses with forced air furnace heating systems, with reductions ranging from 20% to 56% (Figure 19). The highest reduction effectiveness (80%) was observed in a house with electric baseboard heating and an independently ducted HRV. An overall trend showed greater reduction effectiveness with continuous fan operation compared to periodic operation in houses where more than two HRV settings were evaluated. The presenters concluded that well-designed, properly installed, and regularly maintained HRV systems are effective in reducing moderate indoor radon concentrations. They emphasized that encouraging residents to operate HRV systems continuously can optimize radon reduction.

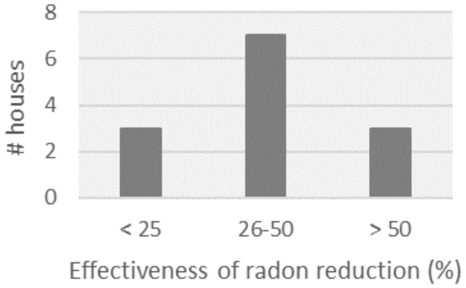

Figure 19: Histogram of HRV effectiveness (Gaskin J. , Li, Brascoupé, & Zhou, 2024)

Dowdall investigated the effectiveness of passive radon sumps, including those fitted with static cowls, as a low-cost method for reducing indoor radon levels in Irish dwellings (2024). A field trial was conducted on six identical houses to measure radon levels under three conditions: with the sump closed, the sump open, and the sump open with a static cowl. Results showed that passive sumps reduced radon levels by 65%, while the addition of a static cowl further increased the reduction to 75%. The percentage of observations exceeding the government's reference level of 200 Bq/m³ dropped from 38% to 0% when both measures were applied. The findings support the inclusion of passive sumps with static cowls as a cost-effective strategy for mitigating radon exposure in new Irish homes.

Table 2: Passive sumps field trail - Results (Dowdall, 2024)

Sump test condition	Average radon level (Bq/m³)	Percentage reduction in radon level	Percentage of daily observations above 200 Bq/m³
Standby sump (closed)	382	-	38
Passive sump (open)	135	65%	9%
Passive sump plus cowl (open)	94	75%	0%

Retrofitting houses

The HAVEN (Health Impact Assessment of Energy Renovations on Irish Domestic Dwellings) research project investigated the health effects and benefits of energy renovations in Irish social housing. Coggins et al. analyzed indoor air quality measurements taken from a sample of Irish social housing properties before and after energy retrofits (Coggins, et al., 2024). The study highlighted that occupant behaviors, such as blocking wall vents and smoking indoors, can adversely affect indoor air quality. As part of the ventilation strategy, it is crucial to engage with tenants to identify the factors driving behaviors that contribute to poor indoor environmental quality. Given the vulnerability of many social housing residents, it is essential to ensure that retrofitting efforts do not compromise indoor air quality.

The RENOVAIR project investigated the impacts of energy renovations on airtightness, ventilation, thermal comfort, and indoor air quality (IAQ) in seventy social housing projects in France. Litvak presented the findings highlighting significant improvements in airtightness (Figure 20), particularly in homes transitioning from natural to humidity-controlled mechanical ventilation (CMV) (Litvak & Handtschoewercker, 2024). Post-renovation ventilation also improved with the installation of mechanical systems. While IAQ generally improved after renovations, temporary increases in VOC emissions were observed due to new building materials, and IAQ returned to pre-renovation levels over time. Thermal comfort varied, and the study recommended prioritizing living rooms for thermal comfort analysis, given their unique occupancy patterns compared to kitchens and bathrooms. The findings underscore the need to explicitly integrate airtightness, ventilation, and IAQ considerations into energy-efficient renovation strategies to ensure occupant health and comfort.

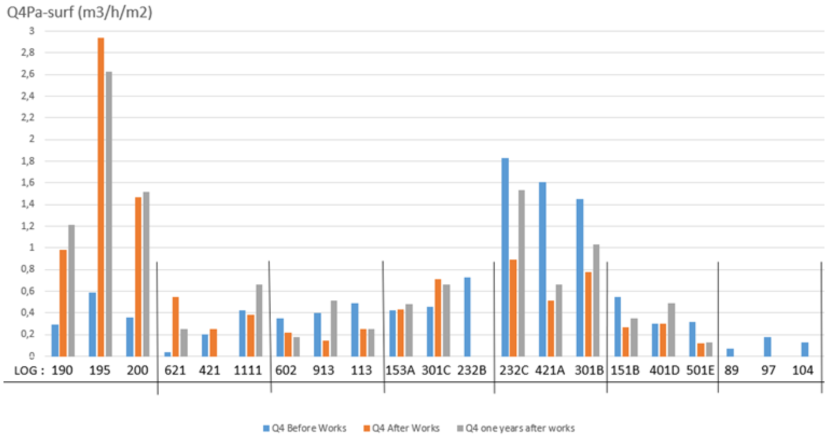

Figure 20: Comparison of air leakage rates (m3/h/m²) "before works"-BW (blue), "after works"-AW (orange) and "one year after works"-1yAW (grey) (Litvak & Handtschoewercker, 2024)

What is new in the EPBD recast 2024 with respect to indoor environmental quality and ventilation?

In the topical session “**What is new in the EPBD recast 2024 with respect to indoor environmental quality and ventilation?**”, Jaap Hogeling (EPB Center) provided an overview of the EPBD recast's overall context (2024). This EPBD recast is an important legislative document as all EU member states have to transpose the requirements into national legislation.

CEN standards can play an important role in the implementation of the EPBD recast.

- The EPBD recast gives increased attention to indoor environmental quality (IEQ) – thermal comfort, acoustics, visual comfort and indoor air quality. One of the requirements is the monitoring of IEQ in non-domestic buildings from May 2026 onwards (article 13.10). Bjarne Olesen (DTU Denmark) presented the activities related to CEN standards on IEQ (2024).
- The EPBD recast also introduces requirements on inspection of ventilation systems in larger non-domestic buildings. Valerie Leprince (CEREMA France) elaborated on the CEN activities in relation to the inspection of ventilation systems (2024).

There are already countries with experiences about inspection of ventilation systems. Maarten De Strycker (BCCA – Belgium) presented the approach for residential buildings in the Flemish region whereby there is a systematic measurement of the air flow rates in new buildings (2024).

In the Netherlands, an overall approach for quality management is developed which also includes ventilation and IAQ related aspects. This was presented by Wouter Borsboom (TNO -Netherlands) (2024)

The implementation of the EPBD recast, particularly concerning IEQ and ventilation system inspections, presents challenges for many member states, whereby CEN standards can play an important role.

Note: *All cited papers will be available on AIVC’s AIRBASE (https://www.aivc.org/resources/collection-publications/aivc-conference-proceedings-presentations) in January 2025*

Disclaimer: *This summary highlights key themes and discussions from the conference, with a particular focus on Smart Ventilation, IAQ, and Health. While it aims to provide a representative overview, not all presentations or papers could be included due to space and scope considerations. The absence of specific contributions does not reflect their significance or value to the event.*

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