ISSN 1307-3729

REHVA

Federation of European Heating, Ventilation and Air Conditioning Associations

The REHVA European HVAC Journal

Volume: 60 Issue: 5 October 2023 www.rehva.eu

VENTILATION

School Ventilation

Healthy Dwellings

IAQ issues with AI

ACREX India 2024

15-17 February

IEML, Greater Noida, Delhi NCR

ISHRAE | informa markets

SOUTH ASIA'S LARGEST EXHIBITION ON AIR CONDITIONING, HEATING, VENTILATION AND INTELLIGENT BUILDINGS

POWERING GLOBAL HVAC SUPPLY CHAIN

Visitor Registrations Now Open

The 23rd edition of ACREX India in Delhi, will focus on the rapid growth of the HVAC manufacturing sector in India, showcasing the latest technological advancements and displaying a gamut of HVAC supply chain technologies. ACREX India 2024 will help local and international manufacturers connect with industry captains, government officials, industry stalwarts, end users, and many more, helping them achieve their business objectives.

Key Features

500+ Exhibitors	40000 SqM Gross Exhibition Space	Participation from 40+ Countries	Technical Seminars & Workshops	Interactive Panel Discussions	Insignia Lounge B2B Meeting Area	ACREX Awards of Excellence	ACREX Hall Of Fame	Connect with Govt. and Builder Community

Exhibitor Profile

- Packaged Chillers
- Air Handling & Distribution Products
- Unitary Products (Air Conditioners)
- Fan & Ventilation Products
- Refrigeration Accessories
- Water Distribution
- Water Treatment

and many more...

Visitor Profile

- Contractors (HVAC, Plumbing, Mechanical, Controls)
- Consulting Engineers
- Mechanical Engineers
- Architects
- Wholesalers/Distributors
- Importers/Exporters
- Public Utilities

and many more...

Endorsed By

ASHRAE

Supporting Associations

Domestic Association

IGBC, FSAI, ORATA, ACRA, IIAR, awesome, International Copper Association India

International Association

REHVA, IIF IIR, ISKID

For Sales and Partnership: Rohan Chopra I M: +91 9873201377 I E: rohan.chopra@informa.com

Saiprasad Terde I M: +91 99200 50415 I E: acrex-india@informa.com

For Marketing and Alliances: Jivitesh Wadhwa I M: +91 9833170240 I E: jivitesh.wadhwa@informa.com

www.acrex.in I www.informamarkets.com

The REHVA European HVAC Journal

www.rehva.eu

Volume: 60 Issue: 5 October 2023

SUBSCRIPTIONS AND CHANGES OF ADDRESSES
REHVA OFFICE:
Washington Street 40
1050 Brussels, Belgium
Tel: +32-2-5141171
info@rehva.eu, www.rehva.eu

PUBLISHER
TEKNİK SEKTÖR YAYINCILIĞI A.Ş.
Fikirtepe Mah., Rüzgar Sk. No: 44C
A3 Blok, Kat:11 D:124 Kadıköy/Istanbul, Turkey

Contents

Download the articles from www.rehva.eu -> REHVA Journal

Advertisers

Next issue of REHVA Journal

Instructions for authors are available at www.rehva.eu (> Publications & Resources > Journal Information). Send the manuscripts of articles for the journal to Jaap Hogeling jh@rehva.eu.

Editorial

Did you know that 8th November is the **World Ventil8 Day** (https://www.worldventil8day.com/) which aims to raise awareness of the importance of ventilation? REHVA is one of the initiators who would like to promote the importance of ventilation as a crucial part of enabling health and wellbeing of people indoors.

In this issue of REHVA Journal you can find a few articles concerning ventilation. Two of them are related to the ventilation of schools. As you probably know from your own (professional) experience, in many countries we still have problems with ventilation of school buildings. Very often, there isn't any mechanical ventilation in classrooms, which became a real problem during the COVID-19 pandemic.

Rob McLeod and his colleagues in Austria wrote about their study performed at TU Graz, where they were looking at the relation between the ventilation rate and/or wearing a mask in classrooms and the risk of infection by the SARS-CoV-2 virus.

Another article related to school ventilation is from Piet Jacobs and his colleagues. You can read about their SchoolVent project in Dutch schools where they looked not only at IAQ but also at improved thermal comfort. That is of course, an ideal situation if we can improve both of these IEQ parameters without compromising others (noise, for example).

Two other articles related to ventilation are shortened versions of papers from the Healthy Buildings Europe 2023 conference organized in June in Achen, Germany. If you have been there, you must have noticed that there weren't many ventilation related papers. The conference theme was 'Beyond disciplinary boundaries' and it was really a good mix referring to all IEQ factors and beyond. Many papers were related to the societal challenges which are also adopted by REHVA. You can read two of such papers in this issue.

The Program of Requirements Healthy Dwellings is an example of an initiative to help customers (in this case housing associations) to comprehensively approach building and/or renovation of their houses. The aim is to enable specifying of not only sustainability and energy related requirements but also IEQ requirements specific for dwellings.

The last paper I would like to mention, is written by Mahmoud ELMokadem and his colleagues at RWTH in Aachen, which discusses the combination of IAQ issues with AI (artificial intelligence).

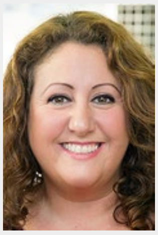
I hope you enjoy reading this issue and if you would like to contribute to the REHVA Journal yourself, please reach out to the main editor. ■

LADA HENSEN CENTNEROVÁ
Guest Editor
REHVA Journal

ARTICLES

Cool and healthy classrooms with SchoolVent ventilation

This article is a summary of the paper 'SchoolVent pilot ventilation system with indirect adiabatic cooling and high efficiency filtering' presented at 2022 in Delft [1]. Part of the text of this paper was used to prepare this article.

PIET JACOBS
TNO, the Netherlands
piet.jacobs@tno.nl

ELIANE KHOURY
VFA Solutions,
the Netherlands

MARIUS KLERK
LUCAM,
the Netherlands

MICHEL VALKEMA
LUCAM,
the Netherlands

Climate change is causing hotter summers. Especially in schools this can cause high indoor temperatures, lower learning performance and during heat waves also the need to close the school. Introducing ventilation systems with (passive) cooling can prevent this and has also the advantage that the windows can be kept closed during the lessons. Closed windows reduce noise disturbance from outside and in combination with fine filters can greatly reduce the indoor fine particulate matter concentration. Using evaporative cooling and electrostatic filtering we demonstrated that this can be done in an energy efficient way, minimizing further climate change.

Keywords: class room, evaporative cooling, electrostatic filtering, $PM_{2.5}$.

Performance requirements

In the Netherlands the so called Dutch Fresh Schools program requirements [2] (PvE frisse scholen) have been set up for the indoor climate in schools. They consist of three classes which are comparable to the energy labelling system. The class C requirements are based on the minimum legal requirements, class B refers to a good indoor climate and class A an excellent climate. See **Table 1** for a summary. All requirements should be met during 95% of the occupied time.

Table 1. *Summary Fresh School program requirements [2].*

	Class C	Class B	Class A
CO_2	1200 ppm	950 ppm	800 ppm
Summer temperature	< 27°C	< 26°C	< 25,5°C
Winter temperature	> 19°C	> 20°C	> 21°C
Filter quality	> F5	> F6	> F7

The goal of this field study was to develop and to demonstrate a school ventilation system that meets the class A specifications of the Dutch Fresh Schools program requirements for CO_2, summer temperature, winter temperature and $PM_{2.5}$.

Pilot test

After successful laboratory tests [2] a pilot has been started on the Montessori Lyceum in Zeist. This school is located at less than 50 m distance from a busy highway. Most classrooms are naturally ventilated. Before installation of the SchoolVent system and before COVID-19 this had led to CO_2 peak concentrations in winter of almost 4000 ppm in January 2019. In summer high temperatures caused the school to close typically 3 days a year. The SchoolVent Air Handling Unit has been installed on the roof and was connected to 5 classrooms, see **Figure 1**. The conditioned air is blown in the classrooms with a T-shaped airsocks.

In principle the system works as a Variable Air Volume (VAV) system. Based on both CO_2 concentration and room temperature, the amount of air per classroom is controlled with valves. To prevent heating and cooling from working against each other, the radiator controls are equipped with servo motors that are also controlled via the SchoolVent system. Monitoring was carried out in the 5 pilot classrooms (N2–N6) and an additional reference classroom (N7) without the SchoolVent system.

Performance during heating season

Figure 2 shows that for a typical school day all classrooms equipped with the SchoolVent system meet the class A requirement of 800 ppm CO_2. In the reference classroom N7 at 8:45 h the CO_2 concentration rises to about 500 ppm and remains constant until 9:45 h. During this time the temperature drops from 19.8 to 18.7°C. Most likely ventilation was achieved by open windows and at 9:45 h the windows were closed because the temperature in the classroom became too low. This results in a temperature rise up to 20.6°C. However, this is at the cost of a high CO_2 concentration of 2339 ppm. This example shows the dilemma between thermal comfort and indoor air quality in naturally ventilated classrooms. The thermal comfort in the reference classroom does not meet the class C requirement.

Performance during summer season

Figure 3 shows the effect of the indirect adiabatic cooling on the supply and room temperature of classroom N6 on a warm day. Around 14:00 h the

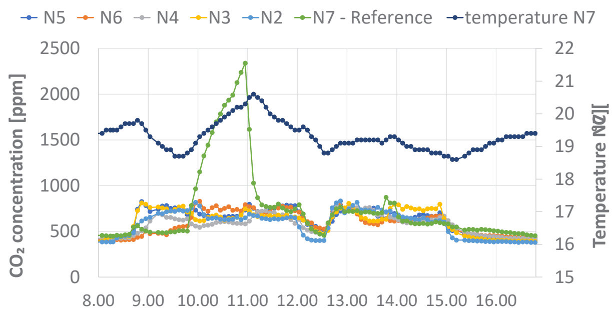


Figure 2. CO_2 concentrations on December 3, 2020 in classrooms N2 – N6 equipped with the SchoolVent system and the reference classroom N7 for which also the room temperature is shown (right axis).

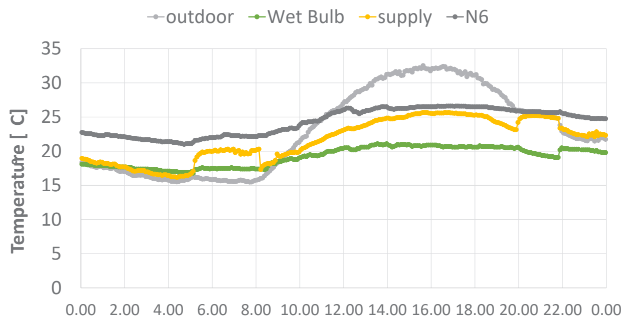


Figure 3. Outdoor, wet bulb, supply and indoor temperature in classroom N6 on September 15th, 2020

Figure 1. SchoolVent air handling unit with insulated ducting.

supply temperature is about 6,5 K lower than the outdoor temperature. The air flow towards classroom N6 amounts then 2000 m³/h. This creates a cooling capacity of 4,4 kW and keeps the indoor temperature at class A level.

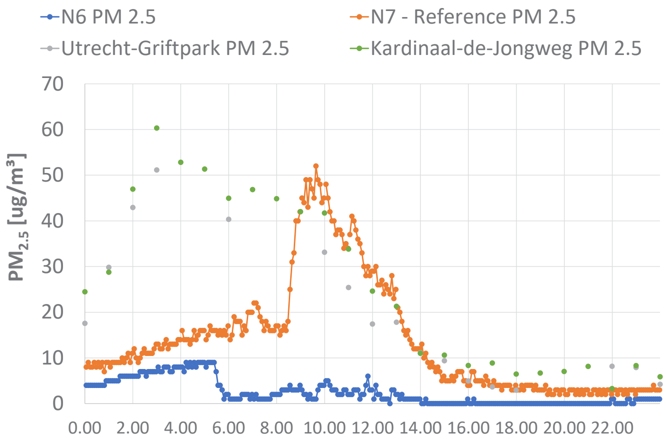


Figure 4. Fine particulate matter in classroom N6 and reference classroom N7 on 23 sept 2020.

Filter performance

The efficiency of the ASPRA filtration system in the Air Handling Unit (AHU) has been determined with two Grimm particle counters (model 11-R and 1.109). One was placed in outdoor air and the other in the AHU downstream the filter section. At a flowrate of 3000 m³/h the minimum efficiency amounted 92% and at 5500 m³/h this dropped to 82%. At 3000 m³/h the EN1822 requirements of an E10 filter (>85%) and almost of an E11 filter (>95%) were met. With regard to $PM_{2.5}$ at this flowrate 94.5% reduction is achieved.

The pilot is executed with a combination of a thin grid as a prefilter and an ASPRA electrostatic filtration system comprising of active charging and electrostatic precipitation section followed by a F7 plate static filter as particle collector. The pressure drop, over this filter combination, amounts 150 – 180 Pa at 10.000 m³/h. By optimizing the pre filter and selecting a plate filter with deeper pockets, we expect that the pressure drop can be lowered to 70 – 100 Pa. For reference, the pressure drop of a typical E10/E11 filter at this flow is about 300 Pa, which leads to much higher fan energy and noise.

An example of the effect of the ASPRA filtration system on the fine particulate matter in the classrooms is shown in **Figure 4**. In classroom N6 at 5:45 hour filtered fresh air is blown in. This reduces the $PM_{2.5}$ concentration. In reference classroom N7 around 8:30 hour the windows are opened. Because of this the indoor $PM_{2.5}$ concentration rises towards the outdoor concentration as measured by two nearby national outdoor air quality measurement stations.

During a three-week monitoring period in classroom N6 equipped with the SchoolVent system the $PM_{2.5}$ concentration was 70 to 96% lower than in the naturally ventilated classroom N7, see **Table 2**. The daily averaged concentration in N7 was comparable with the two nearby outdoor air quality measurement stations.

Table 2. *Daily averaged $PM_{2.5}$ during class time (8.30 – 15.00 h) in classroom N6, N7 and two outdoor air quality measurement stations.*

		$PM_{2.5}$ [ug/m³]		reduction	$PM_{2.5}$ ambient [ug/m³]	Kardinaal
		N6	N7	[%]	Griftpark	de jong weg
week 49	Mon 30 nov.	9.8	44.9	78.1%	45.3	50.3
	Tue 1 dec.	1.3	6.0	77.6%	6.2	6.8
	Wed 2 dec.	3.3	18.9	82.6%	12.8	16.0
	Thu 3 dec.	2.0	10.9	81.3%	13.4	16.7
	vrij 4 dec.	0.1	1.3	96.0%	0.6	6.1
week 50	Mon 7 dec.	1.7	8.0	78.2%	16.0	21.6
	Tue 8 dec.	2.6	11.4	76.9%	18.2	21.9
	Wed 9 dec.	4.8	22.1	78.3%	22.2	28.5
	Thu 10 dec.	3.7	12.4	70.6%	15.2	19.9
	Fri 11 dec.	2.9	9.7	70.4%	13.2	17.2
week 51	Mon 14 dec.	2.1	8.9	76.1%	16.0	21.6
	Tue 15 dec.	2.5	11.3	77.5%	17.5	21.7
	Wed 16 dec.	4.8	22.7	79.0%	21.8	26.9
	Thu 17 dec.	3.7	12.7	70.5%	15.4	20.6
	Fri 18 dec.	2.8	9.5	71.0%	12.7	16.1

Positive feedback

Installation of the SchoolVent system has lowered the energy consumption for heating and improved the indoor climate in an existing school. In the renovated class rooms the air quality and especially the thermal comfort in winter and summer has improved to class A.

The students and teachers have given positive feedback on the system. The automatic temperature and CO_2 control was appreciated. When the temperature rises in the summer, the pilot system is very comfortable because the temperature can be cooled a few degrees. Also the thermal comfort improvement during winter was important as the monitoring period was carried out during the COVID-19 period in which the windows in the other classrooms were opened for sufficient ventilation, which caused much draught and thermal comfort complaints. Some teachers also reported health improvements in the pilot classrooms. This might be caused by the high ventilation and the much lower PM concentration.

The positive feedback has led to the installation of the system in another 14 classrooms during 2021 on the Montessori Lyceum. ■

Acknowledgement

The project was carried out with the Top Sector Energy Subsidy from the Ministry of Economic Affairs. Further the Province Utrecht has contributed by assisting in finding the pilot location and has financially contributed to the installation costs.

References

[1] Piet Jacobs et al 2022 IOP Conf. Ser.: Earth Environ. Sci. https://doi.org/10.1088/1755-1315/1085/1/012025.

[2] PvE frisse scholen: https://www.rvo.nl/onderwerpen/verduurzaming-utiliteitsbouw/maatschappelijk-vastgoed/onderwijsgebouwen-po-en-vo.

Easy upgrade, **significant energy savings**

SCAN ME

Lindab **Ultra BT**™

Demand control system made simple

Ultra BT is an easy and cost-effective way to upgrade your existing ventilation system, room by room. Simply install Lindab's UltraLink regulator in the duct system and Bluetooth sensors on the wall.

Control the ventilation system at a room level (CO2, presence, temperature) and see a huge reduction in ventilation costs and energy consumption. To learn more scan the QR code or visit www.lindab.com

Lindab®

Can ventilation combat airborne infection risks in schools?



ROBERT MCLEOD
FIMechE, CEng, Professor of Building Physics and Sustainable Design, Institute for Building Physics, Services and Construction, TU Graz, Graz, Austria
mcleod@tugraz.at

CHRISTINA HOPFE
FCIBSE, FIBPSA, CEng, Professor of Building Physics, Institute for Building Physics, Services and Construction, TU Graz, Graz, Austria

FATOS POLLOZHANI
DI MSc, University Assistant, Institute for Building Physics, Services and Construction, TU Graz, Graz, Austria

Keywords: hybrid ventilation, natural ventilation, mechanical ventilation, viral transmission, EN 16798-1, ISO 17772-1, ASHRAE standard 241, SARS-CoV-2, pandemic preparedness.

Abstract

The COVID-19 pandemic caught policy makers, government agencies, school management and facility managers largely off-guard, prompting a review of existing ventilation standards in relation to the mitigating of airborne viral diseases. In light of new guidance in ASHRAE standard 241-2023 'Control of Infectious Aerosols' this paper examines the relative airborne viral prophylaxis benefit of seven different ventilation scenarios, involving natural, mechanical and hybrid ventilation systems. The research aims to assess the relative merits of each approach considering current guidance in European Norm (EN 16798-1) and International Standard (ISO 17772-1) in contrast to the increased minimum equivalent clean airflow rates for classrooms in ASHRAE 241.

The results of this analysis show that increased minimum equivalent clean airflow rates have a marked effect on reducing the airborne viral transmission risk. However, even with the best performing ventilation system the risk of at least one individual becoming infected with the SARS-CoV-2 Omicron variant (after an 8 h long exposure period) was 30% (assuming that one infectious individual was present in a classroom of 20 unmasked, immunologically naïve students). By using a combined strategy involving universal FFP2 masking and ventilation the group infection risk level was dramatically reduced to 2–7% (depending on the ventilation type and flowrate) highlighting the importance of layered prophylaxis strategies at times of elevated community transmission.

Introduction

An international review in 2021 by the Global Health Security (GHS) Index [**1**] highlighted the sobering fact, that "all countries remain dangerously unprepared to meet future epidemic and pandemic threats." The GHS Index measures the capacities of 195 countries to prepare for epidemics and pandemics and the average overall GHS country score in 2021 was slightly worse (38.9 out of 100) than in 2019 (40.2 out of 100). Even the "best prepared" countries (USA, Australia, Finland) do not reach the top tier of the GHS Index (i.e. score > 80), indicating that overall pandemic preparedness is "fundamentally weak at all country income levels" (Bell and Nuzzo 2021) (**Figure 1**).

The role of schools in the transmission of the SARS-CoV2 virus has been extensively debated. Despite widespread acceptance of the need to maintain in-classroom teaching (WHO Europe 2021) there is no consensus as to what level of mitigation is needed to do this safely (Lessler et al. 2021).

International building services organisations including REHVA, CIBSE, ASHRAE (amongst others) were quick to provide detailed pandemic ventilation guidance and to continually update that information in the light of emerging knowledge. At a policy and advisory level this work is continuing, for example in July 2023 ASHRAE issued Standard 241, *Control of Infectious Aerosols* (ASHRAE 2023) and has revised many of its existing ventilation standards to reflect emerging scientific findings in relation to the role of ventilation in mitigating the transmission of airborne disease. Pandemic preparedness implies the practical implementation of such changes, typically in a relatively short time scale, and that this requirement is poorly aligned with traditional policy and legislative processes (Caulfield 2013). Moreover, there are financial and resource constraints, wherein for example, retrofitting a single school with an appropriately sized ducted MVHR systems might cost upwards of 10,000 Euros per classroom (Checkatrade 2022). Even ignoring the resource and sustainability implications, rolling out such a strategy at a national scale in every European country would require enormous financial investment [**2**] and could take years to implement. Even if such a strategy were considered feasible and cost-effective in the more affluent countries of the global North (and could be sustained at a 10–20-year replacement interval) it is almost inconceivable that it could be implemented equitably across the global South. Thus existing health inequalities, highlighted by the disproportionate effects of COVID-19 on poorer nations (Oxfam 2022), could be further exacerbated over the longer term by a lack of affordable public health measures to address further waves and even endemicity.

In the light of these challenges, it became apparent that low-cost easy to install (e.g. DIY, Do It Yourself) responses to ventilation and air-cleaning enhancement could play an important role in reducing viral

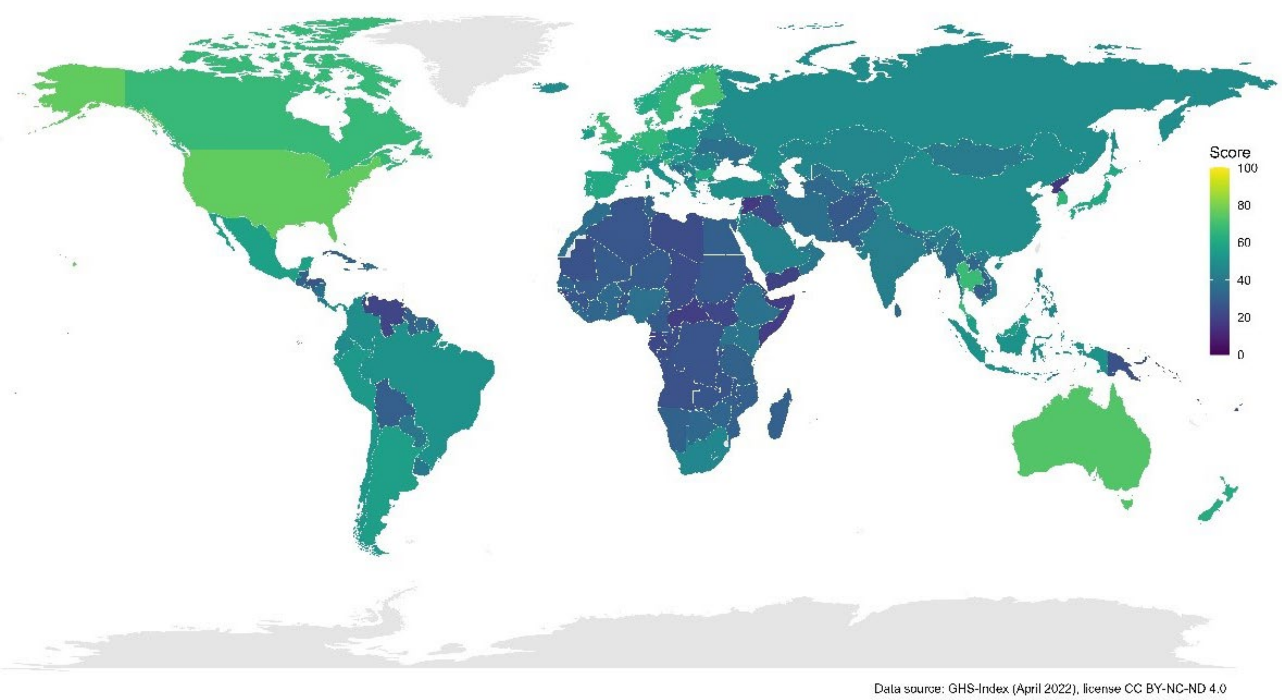


Figure 1. Overall risk ranking according to 2021 Global Health Security Index, which measures the capacities of countries to prepare for epidemics and pandemics (adapted from GHS Index 2021 data).

transmission in schools, in both the short and medium term. One such idea, for a novel hybrid mechanical extract ventilation (MEV) system, was developed by the Max Plank Institute for Chemistry (MPIC) in Mainz Germany (Klimach et al. 2022) (**Figure 2**). This concept was subsequently trialled in several hundred schools in Germany and independently tested by the IBPSC at TU Graz, Austria (Pollozhani et al. 2022) (Eibinger et al. 2022). This study builds on previous work [**3**] by providing a comparative analysis of the airborne infection risk associated with a range of different classroom ventilation strategies whilst also evaluating the additional prophylaxis benefits of using substantially increased ventilation airflow rates, as proposed by ASHRAE 241-2023: Control of Infectious Aerosols (ASHRAE 2023).

Methods

A university seminar room at Graz University of Technology was equipped with a low-cost retrofitted mechanical extract ventilation (MEV) system developed by the Max Planck Institute for Chemistry (MPIC), (Klimach et al. 2022) (Helleis, Klimach, and Pöschl 2023). Adopting the room geometry and using ventilation flow rate data from the experimental setup seven different ventilation scenarios (**Table 1**) were assessed over a one-year period

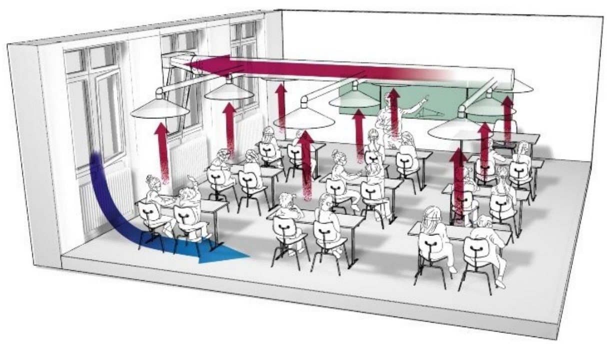


Figure 2. Concept schematic (top, image courtesy MPIC, copyright A. Koppenborg) and final assembly (bottom) of the MPIC-MEV system showing extract hoods, ductwork and extract-fan.

Table 1. *Ventilation scenarios.*

1. Base Case (BC)
The base case (BC) assumed that no purposeful ventilation measures were taken (i.e. all windows and doors remained closed). The purpose of this scenario was to serve as a worst-case comparator for the IAQ and infection risk, and as a best-case scenario for heating energy conservation. It should be noted, that whilst such a scenario is not uncommon in practice, it would not comply with the European standard EN 16798 (CEN 2019) or the international standard ISO 17772-1 for occupied spaces, and is not recommended.
2. Max Planck Institute for Chemistry -Mechanical Extract Ventilation (MPIC-MEV) at 10 ℓ/s.(person)
Scenario 2 examined the MPIC – MEV system installed in the seminar room. The ventilation flow rates were measured directly from the installed system and for 20 occupants were compliant with EN 16798-1:2019 category IEQ_1 (see Pollozhani et al 2023, for further details).
3. Max Planck Institute for Chemistry -Mechanical Extract Ventilation (MPIC-MEV) at 20 ℓ/s.(person)
Scenario 3 examined the MPIC – MEV system installed in the seminar room under the theoretical consideration of increased airflow rates of 20 ℓ/s.(person) in accordance with the recommendation for classrooms in ASHRAE Standard 241
4. Air Handling Unit – Heat Recovery Ventilation (AHU-HRV) at 10 ℓ/s.(person)
Scenario 4 investigated the use of a conventional decentralised air handling unit (AHU) with heat recovery (HR). An AHU with a nominal air flow rate of 0.2 m^3/s (i.e. 720 m^3/h, at a nominal external pressure of 200 Pa) was chosen for the simulation as this corresponded closely to the air flow rates measured on the MPIC-MEV system in scenario 2. This flow rates equates to 10 ℓ/s.(person) to match scenario 2 and comply with EN 16798-1:2019 category IEQ_1. During warmer periods the HR system operated in bypass mode. Thus, when the outside air temperature exceeded 16 °C the extract air was discharged through the bypass (avoiding the heat exchanger) to mitigate overheating (McLeod and Swainson 2017) (Mourkos et al. 2020).
5. Air Handling Unit – Heat Recovery Ventilation (AHU-HRV) at 20 ℓ/s.(person)
Scenario 5 examined the AHU-HR system under the theoretical consideration of increased airflow rates of 20 ℓ/s.(person) in accordance with the recommendation for classrooms in ASHRAE Standard 241
6. Natural Ventilation – Tilted windows (NV-T)
Scenario 4 examined the ventilation of the seminar room by the means of tilted windows. For this case, it was assumed that all five windows of the room were continuously tilted (with a maximum opening depth of 0.18 m, providing a total window opening area of 0.5 m^2 per window, calculated according to Mourkos et al. (2020) during occupied periods (i.e., from 8 a.m. till 12 p.m. and from 1 p.m. till 5 p.m.). This scenario was designed to reflect the background ventilation which would occur through the use of constantly tilted windows without necessitating continual occupant intervention.
7. Natural Ventilation – Purge ventilation (NV-P)
Scenario 5 investigated purge ventilation patterns using fully opened windows. This strategy was advocated by the German environmental agency (German: Umweltbundesamt, (UBA)) at the outbreak of the pandemic. UBA recommended that classrooms should be purge ventilated at regular intervals, using wide-open windows instead of tilted windows (UBA 2021). In this scenario it was defined that all five windows of the seminar room were fully opened every 20 minutes for a duration of 4 minutes during the months of October through to April. In May and June, when the average daily temperatures were around 17- 20 °C, the windows were opened for an extended period, of 15 minutes, every 20 minutes to compensate for the reduced air- pressure differentials between the inside and outside air masses at this time.

using the IDA ICE dynamic simulation software (EQUA 2023). Based on the room occupancy and ventilation rates an analytical model based on a method developed by Lelieveld et al. (2020) was then used to predict the corresponding seasonal risk of infection with the SARS-CoV-2 original Omicron variant. Although the original Omicron variant is no longer the prevalent strain of the SARS-CoV-2 virus the results of this analysis are still useful from the perspective of making comparative risk assessments. Moreover, the viral transmission parameters (**Table 2**) can be readily modified to accommodate emerging variants or viruses.

Scenarios

Seven scenarios were considered in this study, as described in **Table 1**, to provide a comparative analysis between the MPIC-MEV system and common natural and mechanical alternatives.

Experimental setup

The seminar room chosen for this study is typical of many naturally ventilated university teaching rooms, designed for approximately 30 occupants. The room is occupied from 8 a.m. to 5 p.m. daily, during term-time, for a variety of purposes including lectures, workshops, and exams. This means that the room occupancy varies over the course of a day and according to academic cycles. Since occupant density is known to be a significant factor in predicting infection risk (Clayson et al. 2022) a range of typical occupancy levels (n=10, 20 and 30) were investigated in this study.

Table 2. *Parameters used in the analytical infection risk model (after Lelieveld et al. (2020)).*

Parameters	Value	Unit	Notes
Virus			
Virus lifetime - t_{virus}	1.7	h	e-folding time in aerosol (Lelieveld et al. 2020) (van Doremalen et al. 2020)
Viral load - c_v	9.00E+08	cop/ml	for original Omicron variant (MPIC 2021)
Infective dose - D_{50}	154	RNA copies	for original Omicron variant (MPIC 2021)
Inf. risk prob. for single virus part. - P_{RNA}	0.00449	1/RNA copies	$P_{RNA} = 1 - e$^(ln(0.5)/D_{50}) (Lelieveld et al. 2020)
Aerosol			
Wet aerosol diameter - *da*	5	µm	(Lelieveld et al. 2020), (MPIC 2021)
Particle emission breathing - *pe, b*	0.06	No./cm^3	(MPIC 2021)
Particle emission speaking - *pe, s*	0.6	No./cm^3	(MPIC 2021)
Speaking/ breathing ratio	10	%	(MPIC 2021)
Resulting particle emission - *pe, t*	0.11	No./cm^3	$pe,t = pe,s \cdot 0{,}1 + (1-0{,}1)\, pe,b$
Infected person			
Mask factor (exhalation) - $f_{mask,e}$	0.2	[-]	with filter efficiency of 80% (1=no mask) (MPIC 2021)
Mask factor (inhalation) - $f_{mask,in}$	0.3	[-]	with filter efficiency of 70% (1=no mask) (MPIC 2021)
Lung deposition factor - f_{lung}	0.5	[-]	(Lelieveld et al. 2020), (MPIC 2021)
Breathing rate - $q_{b,e}$	10	ℓ/min	(Lelieveld et al. 2020), (MPIC 2021)
Effective breathing rate - $q_{b,eff}$	5	ℓ/min	$q_{b,eff} = q_{b,e} \cdot f_{mask,in} \cdot f_{lung}$
RNA conc. exhaled breath - $CRNA_{,b}$	6.72	RNA/l	$CRNA_{,b} = \pi/6 \cdot da^3 \cdot c_v 10\text{-}12 \cdot pe,t \cdot 10^3$
Emission factor - E	4029	No./h	$E = CRNA_{,b} \cdot q_{b,e} \cdot f_{mask,e}$

Figure 3 shows the floor plan of the seminar room with the MPIC-MEV system overlaid. The room is located on the first floor of a five-storey high university building which was constructed in 1994. The room measured 6.5 by 8.1 m with a height of 3.05 m which (minus three vertical columns) results in a net internal volume of 147.3 m³. The exterior wall faces southwest, with five openable (tilt and turn) windows measuring 0.9 by 1.8 m providing a window-to-wall ratio of 33% (8.1 m² of 24.7 m² interior wall). The windows were equipped with external fixed-angle louvers, which shade approximately half of the windows' solar aperture.

Two hydronic wall mounted radiators (measuring 1.4 m by 0.5 m each) with an estimated combined design output of 4,700 W) provide heat to the room during the colder months. The seminar room is illuminated by 16 compact fluorescent lamps with an electric power consumption of 25 W each (400 W in total, with an estimated 30% convective heat fraction). In addition, a ceiling mounted projector with a power consumption of 150 W is installed in the room. Resulting in a maximum total internal heat gain of 550 W for lights and equipment. Occupant sensible

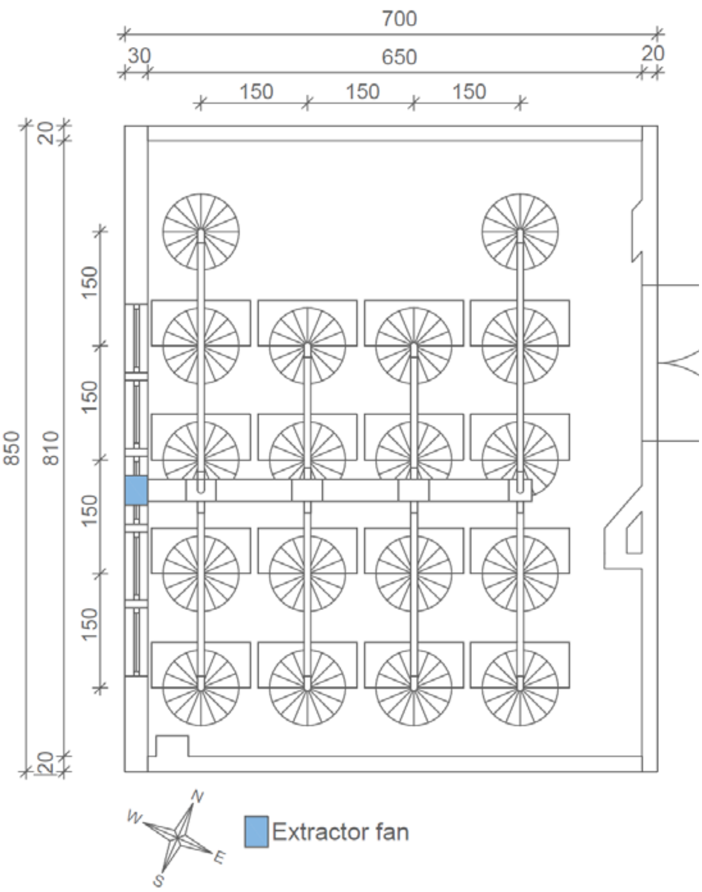


Figure 3. Floor plan of the seminar room showing the layout of the MPIC-MEV system.

and latent heat gains were assumed at 126 W/person at an average metabolic equivalent task (MET) rate of 1.2 (ISO 2005). The thermal specifications of the construction assemblies were sourced from an energy certificate issued in 2012. An average infiltration rate of 0.2 h^{-1} was derived using human-generated CO_2 concentration decays in the space, based on the approach described by Persily (1997) and Cui et al. (2015).

In order to establish the in-situ performance of the non-commercial MPIC-MEV system, a fully functioning system was installed in the seminar room using materials widely available from building merchants, at a total cost of around 500 Euros (for more information about the ventilation system see (Klimach et al. 2021) (Helleis, Klimach, and Pöschl 2022)). The system is designed to extract stale room-air close to the ceiling and supply fresh air nearer to the floor level, through a tilted window (**Figure 2**). In the context of SARS-CoV-2, CFD studies have demonstrated that properly designed displacement ventilation provides an effective means of mitigating long-range transmission (Bhagat and Linden 2020) (Bhagat et al. 2020). Osman et al. (2023) also showed displacement systems are capable of reducing the range of horizontal droplet transfer from coughing episodes. Experimental evidence from the MPIC shows that the addition of extract hoods can further improve the removal of respiratory aerosols by about 30–50% (Helleis, Klimach, and Pöschl 2023).

A summary of the system parameters and operational schedules used the IDA ICE simulations can be seen in **Table 3**.

Based on the transient ventilation rates and design occupancy assumptions the infection risk, which is the main focus of this study, was analytically assessed based on a method developed by Lelieveld et al. (2020) using the parameters and value set out in **Table 2**.

For the original Omicron variant of the SARS-CoV-2 virus, 154 inhaled RNA copies were expected to correspond to an infectious dose (D_{50}), the mean number of vial copies that would cause an infection in 50% of susceptible subjects [15]. The individual infection risk $R_i(t)$ for each susceptible individual is calculated with the following formula (Eq.1) depending on the number of inhaled virus particles $n_v(t)$ and the probability P_{RNA} that a single virus particle causes an infection:

$$R_i(t) = \left[1 - (1 - P_{RNA})^{n_v(t)}\right] \cdot 100 \qquad \text{(Eq.1)}$$

Whilst the risk of a single individual from a group of individuals becoming infected is expressed as a function of the number of susceptible people in the room according to Eq. 2.

$$R(t) = \left[1-(1-P_{RNA})^{(n_v(t)\cdot n)}\right]\cdot 100 \quad \text{(Eq. 2)}$$

Where,

$R_i(t)$ is the individual infection risk for each person [%],

$R(t)$ is the probability of a single person getting infected from a group of susceptible people [%],

n is the number of susceptible (i.e. non-infected) individuals in the room,

$n_v(t)$ is the number of virus particles inhaled per person,

and P_{RNA} is the probability that a single virus particle causes an infection.

The time-dependent airborne virus particle concentration ($c_v(t)$) in the experimental room (under the assumption of one infectious person being present for the duration of time (t)) and the resulting quantity of inhaled virus particles per occupant ($n_v(t)$) were determined for all five scenarios on sample days at different outside boundary temperatures according to the respective air exchange rates resulting from the dynamic simulation with the following formulas:

$$c_v(t) = \frac{E}{V\cdot\lambda}\cdot\left(1-e^{-\lambda * t}\right) + c_{v0}\cdot e^{-\lambda * t} \quad \text{(Eq. 3)}$$

$$n_v(t) = n_{v0} + q_{b,eff}\cdot\frac{E}{V\cdot\lambda}\cdot t\cdot\left(1-\frac{1-e^{-\lambda * t}}{\lambda\cdot t}\right) + c_{v0}\cdot q_{b,eff}\cdot\frac{\left(1-e^{-\lambda * t}\right)}{\lambda} \quad \text{(Eq. 4)}$$

Where,

$c_v(t)$is the concentration of infectious particles (virions) in the indoor air [No./m^3] at time (t),

n_{vo} is the number of viral particles already inhaled by a person [No.],

c_{vo} is the existing viral concentration in the room air [No./m^3] at the start of the classes (t = 0),

$q_{b,eff}$ is the effective breathing rate [ℓ/min] (as described in table 2),

E is the Emission factor [No./h] or rate at which viral copies are released (as described in **Table 2**)

Note, to account for the "hood effect" (η_{hood}) in the MPIC-MEV system the emission factor is modified as follows, $E_{MPIC} = E\cdot(1-\eta_{hood})$

Table 3. *List of scenarios and simulation parameters.*

Parameters	1. BC	2. MPIC-MEV (10)	3. MPIC-MEV (20)	4. AHU-HRV (10)	5. AHU-HRV (20)	6. NV-T	7. NV-P
Air flow [ℓ/s(m^2)]	0.17 [a]	4.45 [b]	9.9	4.45 [b]	9.9	variable [c]	variable [c]
Occupancy schedule [d e]	8 am – 12 pm, 1 pm – 5 pm						
Fan, window, equipt. schedule	8 am – 12 pm, 1 pm – 5 pm						
AHU set-back schedule [f]	-	-	-	7 - 8 am 12 - 1 pm	7 - 8 am 12 - 1 pm	-	-
Number of open windows [g]	-	1 tilted	1 tilted	-	-	5 tilted	5 fully open
HX thermal efficiency [%]	-	-		81	81	-	-
Active internal heat gains			100% of internal gains due to occupants, equipment, light				
Temp. setpoint [°C]			20 °C (2 °C P-band for proportional temperature control)				

a = Value achieved solely by infiltration (which is not considered purposeful ventilation)
b = Occupancy dependent ventilation control strategies used in scenarios 2 and 3
c = 'Variable' because values were determined by IDA ICE tool for transient external/ internal boundary conditions
d = Metabolic rate of 126 W (sensible and latent heat, at 1.2 met and 70 W/m^2) acc. to ISO 7730:2005 [69]
e = Weekends and holidays (acc. to Austrian university curriculum, i.e. Feb., Jul., Aug., Sept.) lecture free
f = Set-back rate of one volumetric air change within two hours prior to occupancy (0.5 h-1) acc. to EN 167981:2019
g = Total free opening area of 0.5 m^2 per tilted window and 1.8 m^2 per fully open window.
h = The power consumption of 47W at 2.90 ℓ/s(m^2) and 71W at 4.45 ℓ/s(m^2) was measured on the installed system.

Results and analysis – comparative infection risk assessment

The risk of infection by the original Omicron variant of the SARS-CoV-2 virus, under the seven different ventilation scenarios (**Table 1**), was analysed for 20 occupants on the coldest (12th January) and warmest (30th June) design days to examine the influence of seasonal temperature variations on the natural and hybrid ventilation scenarios. **Figure 4** shows the virus-containing respiratory aerosol concentration in the room air across the day $c(t)$ (left) and the resulting group infection risk as a function of the exposure duration (right). The latter is the combined probability that at least one susceptible person from any of the group members (of n=20 people) will become infected. For the hybrid (MPIC-MEV) and mechanical (AHU) systems the results for airflow rates of 10 ℓ/s.(person) in accordance with EN16798-1:2019 (solid line, **Figure 4**) and 20 ℓ/s.(person) as recommended by ASHRAE Standard 241 (dashed lines, **Figure 4**) are shown. Note that the model assumes that the room is unoccupied and unventilated for one hour during the lunch period (12:00-13:00 h) (grey bar, Figure 4) and that the same occupants re-enter the room after lunch.

Note that, due to the significantly higher viral concentration in the base case (scenario 1) it is depicted on a secondary x-axis with a different scaling (**Figure 4**, left), therefore, the slope of the base case appears disproportionally low compared to the other scenarios. It can be seen that by providing a constant air exchange rate in the hybrid and mechanical scenarios (orange and blue lines, **Figure 4**, left) a state of equilibrium is reached in the virus particle concentration present in the room. Conversely, as might be expected, varying air exchange rates, as seen in the purge-vent scenario (pale grey line, **Figure 4**, left), resulted in fluctuating viral particle counts.

As might be expected, the results (**Table 4**) show the highest risk of infection occurs in scenario 1 as there is no active ventilation. Under this scenario (assuming an immunologically naïve population) based on an occupancy of 20 persons, there is a probability of 100% that at least one person in the room would get infected during the 8-hour exposure period. If all people present in the room were to wear an FFP2 masks, this value could be reduced to 27%. Scenario 2 resulted in a risk of 47% without masking and 4% with masking that one out of the 20 people

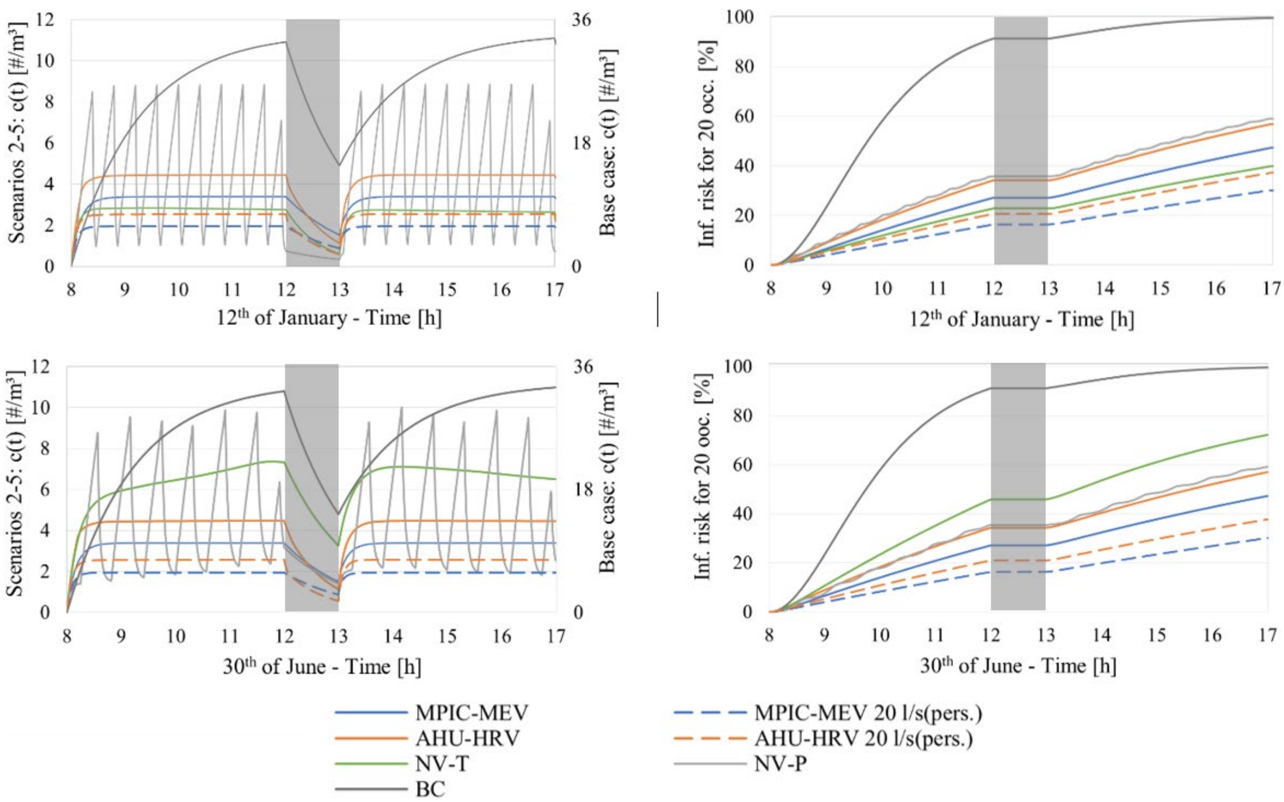


Figure 4. Virus concentration [No./m³] (left) and the probability of at least one person becoming infected [%] as a function of time (right) for 20 unmasked occupants on the coldest day (12th of January) and the warmest day (30th of June) of the year. Grey bars indicate the lunch break period (12:00-13:00 h) where the ventilation systems are turned off and the room is unoccupied. [Double column fitted]

present in the room would become infected after a duration of 8 hours for both the best-case (cold outdoor temperatures) and worst-case (warm outdoor temperatures). Despite the same air exchange rates as for scenario 2, scenario 4 displayed a slightly higher risk of one amongst the 20 occupants becoming infected, with 57% without masking and 5% with masking. This difference between scenarios 2 and 4 can be attributed to the reduced room aerosol emission intensity achieved by the distributed (i.e. localised) extraction of potentially infectious aerosols using the MPIC-MEV system extract hoods.

In contrast the infection risk under the naturally ventilated scenarios showed a stronger dependence on the outdoor air temperatures. Due to the relatively high air exchange rates with continually tilted windows in cold weather (on12th of January) scenario 6 resulted in a lower risk (42% without masks and 3% with masks) cf. scenario 7 (purge ventilation) (59% without masks and 5% with masks). This finding is attributed to the 20-minute phases (between purges) in which the room was not ventilated at all, during which the concentration of virus-containing particles sharply increased to relatively high values (≈10 particles per m^3 of room air, see **Figure 4**). In contrast, with warmer external air temperatures in summer, higher risk values were found with tilted windows (72% without masking and 7% with masking) due to the lower air exchange rate. Under the same conditions the use of purge venting resulted in a lower risk (59% without masking and 5% with masking), although it should be noted that the duration of the purge phase opening time was extended from 4 minutes to 15 minutes (every 20 minutes) in the summer months (**Table 3**). This finding highlights the importance of adjusting purge duration intervals in accordance with outside air temperatures or room CO_2 concentration.

By using larger fans and increasing the mechanical ventilation flow rate from 10 to 20 ℓ/s.(person), in line with ASHRAE Standard 241, the infection risks were further reduced for the MPIC-MEV system (scenario3) (to 30% without masking and 2% with masking) and for the AHU-HRV system (scenario 5) (to 37% without masking and 3% with masking). The additional benefit achieved by the MPIC system can be attributed to the use of hoods above the occupants.

Table 4. *Infection risk probability [%] results for any one individual in a group of 20 people (with and without universal FFP2 masking) after 8 hours of exposure on the coldest day (12th of January, left) and the warmest day (30th of June, right) of the academic year.*

Scenarios	Cold day risk (12th January) [%]		Warm day risk (30th June) [%]	
	Without masks	With masks	Without masks	With masks
1. BC	100	27	100	27
2. MPIC-MEV 10 ℓ/s(p)	47	4	47	4
3. MPIC-MEV 20 ℓ/s(p)	30	2	30	2
4. AHU-HRV 10 ℓ/s(p)	57	5	57	5
5. AHU-HRV 20 ℓ/s(p)	37	3	38	3
6. NV-T	42	3	72	7
7. NV-P	59	5	59	5

Conclusion and limitations

The findings of this study have shown that the infectious virus particle load suspended in room air, and the resultant infection risk are closely dependent on the ventilation rate. During the colder months natural ventilation using tilted windows and the use of the Max Plank Institute for Chemistry Mechanical Extract Ventilation (MPIC-MEV) system (at a flow rate of 10 ℓ/s.(person) both provided a risk reduction of more than 50% relative to the base case scenario (which assumed no purposeful ventilation in the room). During the warmer months extended purge ventilation cycles had a greater effect than tilt ventilation, however only the MPIC-MEV system was able to reduce the (unmasked) transmission risk by over 50% year-round.

When the mechanical ventilation flow rates were increased from 10 to 20 ℓ/s.(person), in accordance with recommendations for classrooms in ASHRAE Standard 24-2023, a significant reduction in the infection risk was observed (with a 17% improvement in the MPIC-MEV system and a 20% improvement in the AHU-MVHR system). Accordingly, the lowest overall risk of one individual becoming infected after an 8 h exposure period was 30% in the case of the MPIC-MEV system, operating at 20 ℓ/s.(person), and the highest risk was 72% on a warm day using tilted windows.

Applying universal FFP2 masking in the base case scenario (in the absence of any purposeful ventilation over an 8 h period) reduced the risk of infection from 100% to 27%. These benefits are further amplified when ventilation was used in conjunction with masking. Notably using the MPIC-MEV system (at 20 ℓ/s.(person) in conjunction with FFP2 masking reduced the risk of any individual becoming infected (after an 8 h exposure period, in a room with one infectious individual) to 2%.

It should be noted that the infection model used here assumes complete mixing of the room air, and therefore the displacement effect was not incorporated in the infection risk model of the mechanical systems. The benefits of using hoods above the occupants to capture viral aerosols were incorporated in the model (for the MPIC-MEV system) using a conservative figure of 30% (based on secondary evidence). Further research is needed to quantify the additional benefits of using displacement ventilation and hood capture in combination, which are likely to be influenced by seasonal changes in the supply air temperature and a number of other factors.

In practical terms these findings highlight the benefit of using higher ventilation flow rates as well as the use of multiple prophylaxis measures, in combination, when community transmission rates are high. Since few existing ventilation systems will be capable of delivering the equivalent clean airflow rates in ASHRAE Standard 241-2023, ways of providing additional clean air capacity (e.g. via filtration units) without creating a significant energy burden and/or exacerbating thermal or acoustic discomfort need to be carefully considered. ■

Endnotes

[1] The Global Health Security Index is an assessment which benchmarks health security and related capabilities, across six categories and 37 indicators, for 195 countries The GHS Index was developed in partnership by the Nuclear Threat Initiative (NTI) and the Johns Hopkins Center for Health Security at the Bloomberg School of Public Health, working with Economist Impact.

[2] Where most schools are naturally ventilated, even in a relatively small European country such as Austria (with approximately 52,000 classrooms) would entail an investment of around 0.5 Billion Euros.

[3] Readers seeking to understand the multiple dimensions of this issue (i.e. including consideration of indoor air quality, thermal comfort, heating, and operational energy aspects) are referred to Pollozhani et al. (2023).

References

Please find the complete list of references in the html-version at https://www.rehva.eu/rehva-journal

Proposed modifications and guidelines for implementation of Article 11a 'Indoor environmental quality' in EPBD draft

REHVA, Nordic Ventilation group and Eurovent launch a common proposal on how to implement Indoor Environmental Quality (IEQ) requirements introduced by EPBD under revision. These new provisions added by the European Commission's and European Parliament's initiative, represent an important step forward to assure healthy and comfortable IEQ in buildings.

Read more

REHVA Federation of European Heating, Ventilation and Air Conditioning Associations

EUROVENT EUROPEAN INDUSTRY ASSOCIATION

NVG NORDIC VENTILATION GROUP Scientific collaboration

Program of Requirements Healthy Dwellings




MARCEL G.L.C. LOOMANS
Department of the Built Environment, Eindhoven University of Technology, Eindhoven, The Netherlands
m.g.l.c.loomans@tue.nl

LADA HENSEN-CENTNEROVÁ
Department of the Built Environment, Eindhoven University of Technology, Eindhoven, The Netherlands

TIM BEUKER
bba binnenmilieu, The Hague, The Netherlands

PIET JACOBS
TNO, Delft, The Netherlands

Programs of Requirements (PoRs) help clients express what they want for a new or renovated building. In the Netherlands, PoRs have been developed for offices and schools with a focus on healthy indoor environments. They are well accepted and applied in Dutch practice. The PoR for healthy dwellings is an addition to support the creation of healthy dwellings. This article provides information about the considerations and details of this PoR.

Keywords: Indoor Environmental quality, health, comfort, practice, user influence, performance requirements, verification.

Introduction

In the Netherlands, Programs of Requirements (PoRs) have been developed for offices and schools [latest versions: PoR 'Healthy Offices' (Binnenklimaattechniek, 2023) and PoR 'Fresh Schools' RVO, 2021)]. The requirements in these PoRs focus on indoor environmental quality (IEQ) and aim to achieve healthy working and learning environments. All four main physical aspects of IEQ are addressed: indoor air quality, thermal, visual and acoustic comfort. The indoor environment addresses more aspects (see e.g. Loomans et al., 2011), but the focus is mainly on the physical parameters. The PoRs distinguish between classes. The lowest class, class C, corresponds approximately to the requirements of the Dutch Building Decree (as far as requirements have been set in this decree). Class B are requirements that assume a better IEQ, and class A is meant for occupants with more needs in terms of IEQ, e.g. due to health issues.

The PoRs for offices and schools have been available for almost more than a decade and are currently well used in Dutch practice for setting indoor environmental quality requirements. This is based on the number of downloads of these PoRs and the feedback from practice. It is an easy way for clients to communicate their wishes regarding IEQ. Validation of the requirements in the actual building is part of the process.

Given the success described above, and the fact that people spend a large part of their lives in their dwellings, a new initiative was started to develop a PoR related to IEQ in dwellings. This PoR was coined: "Healthy Dwellings".

This article provides information on the key assumptions used to develop the PoR Healthy Dwellings. Some examples of the PoR are given. The complete PoR is available free of charge (in Dutch; Binnenklimaattechniek, 2022). Note that this is also the case for the Healthy Offices and Fresh Schools PoRs.

Development considerations

The development of the PoR Healthy Dwellings was based on a combination of literature, guidelines and standards, knowledge from the PoRs for offices and schools, and feedback from two rounds of consultation with a focus group.

A number of assumptions were made in developing the PoR Healthy Dwellings. These assumptions formed the basis for how the PoR was ultimately presented:

- We assumed a close match with the IEQ indicators covering the four physical aspects of IEQ included in the PoR Healthy Offices and Fresh Schools. We have reviewed the literature to discuss the potential of adding other, dwelling specific, indicators and the health risk they may cause.

- All requirements have been formulated as performance-based as possible. This was done to avoid that new (innovative) solutions could not be considered. In fact, we hope that the PoR will stimulate innovation. In some cases, e.g. for Class A, the requirements have been formulated in such a way that we implicitly do not allow the use of certain known solutions.

- Similar to the other PoRs, we assume three classes, A, B and C. Class C largely corresponds to the quality level currently required by the Dutch Building Decree for new dwellings (Bouwbesluit, 2012). Class B requirements aim for a higher level of health and comfort. Class A provides a further improvement compared to class B. It is specifically aimed at a more sensitive target group, such as residents with respiratory diseases or a weakened immune system. A specific class can be targeted for each indicator. This should be decided by the customer. We have not yet ranked the indicators by health risk. This may be implemented in future versions.

- A dwelling contains different rooms (spaces) with clearly defined functions; e.g. bedroom compared to living room. In the PoR, we have differentiated the requirements for individual rooms for some indicators. Considering the fact that nowadays people work more often from their homes and bedrooms became offices during the day, we assumed a combined function bedroom and study room. Again, these requirements (class) can be set differently for each room.

- This version of the PoR focuses mainly on physical indicators, e.g. temperature, concentrations. When considering health, mental and social health could be considered in addition to physiological health. With a few exceptions, we have not yet explicitly included such IEQ indicators. An example in the current version is the indicator 'view to the outside'. Implicitly, of course, physical parameters can also affect mental and social health.

- An important final assumption is that we wanted to refrain from requirements that depend on user behavior, furnishings and use of the dwellings. This means that in the requirements we aimed at conditions that would result in a more robust dwelling when aiming for a higher class. This is reflected in the provision of a larger range within which the home should be able to be controlled. This is particularly visible in the thermal indicators. This is in contrast to the other PoRs mentioned. For air quality requirements, for example, we assume stricter values for a higher class with the perspective of additional contamination due to user behavior. We call this approach "action freedom".

Two examples of the requirements

Some (translated) examples for the PoR Healthy Dwellings are shown in **Figure 1** and **Figure 2**. They show some requirements for air quality and thermal comfort. Note that this is only a selection of the indicators for which requirements are set. The full list includes 28 indicators, some of which relate to more than one performance requirement. Often the indicator requirements are accompanied by a short explanation (explanatory notes) to clarify what is meant. ▶

AIR QUALITY	Class C - SUFFICIENT
CO_2 concentration & Air change rate	• The CO_2-concentration in residence rooms remains during use at maximum **+ 750 ppm** above the outdoor concentration.
	• Assuming a normal, average metabolism (1.2 to 1.4 met) and a CO_2 production of maximum 0.005 ℓ/s per person it can be assumed that the Class C requirement is fulfilled if **25 m^3/h per person** fresh outdoor air is supplied.
	• For the different rooms, the following numbers of people should be taken into account: - master bedroom: 2; - bedroom: 1; - living room: number of bedrooms + 1, with a minimum of 4 people
	Explanatory notes:
	• The Class C requirement for fresh air supply corresponds to the statutory minimum requirement as stipulated in the 2012 Building Code (new construction requirement: minimum 7 ℓ/s/room = 25 m^3/h/room).
	• The amount of air flow must be determined in accordance with the provisions of the NEN 1087 standard. Always use a zero-pressure compensated air flow meter for flow measurements.
	• Although CO_2 sensors per room are not mandatory until Class A, application is recommended even as early as Class B and C because they provide great insight and can lead to awareness.
	• If the local, instantaneous CO_2 concentration is unknown: assume an outdoor concentration of 450 ppm. Here it is taken into account that especially in inner city environments the CO_2 concentration is often elevated.
	• It is assumed that the air in the occupied rooms is supplied and exhausted in such a way that a good flushing of the room is guaranteed; the ventilation efficiency (ratio between the quantity of ventilation air reaching the breathing zone and the total quantity of air introduced) is preferably at least 0.8 (see e.g. ASHRAE 62.1 for the ventilation efficiency of various ventilation concepts).
Humidity Living room, Kitchen, Bed room, Transfer room, Bathroom	• No requirements for the residence areas • Effective (automatic) control is provided that brings the humidity below 70% RH within two hours of using the bathroom.
Fungi Living room, Kitchen, Bed room, Transfer room	• There should be no visible mould on the walls or ceilings in the residence areas.
Volatile Organic Compounds	• The formaldehyde (HCOH) concentration is a **maximum of 60 micrograms/m^3**.
	• The total volatile organic compounds, or TVOC, concentration is a **maximum of 200 micrograms/m^3**.
CO & NO_2	• The carbon monoxide (CO) concentration **does not exceed 10 milligrams/m^3**.
	• If a central heating boiler is present, a CO detector should be present in that room. If one does not normally enter that room, the advice is to place the CO detector so that the alarm can be better heard.
	• The nitrogen dioxide (NO_2) concentration **does not exceed 40 ug/m^3** on an annual average.
Particulate Matter	• The annual average $PM_{2.5}$ (particulate matter) concentration is a **maximum of 10 micrograms/m^3**.
	• Additional requirement regarding the particulate matter penetration through the façade and ventilation system (filter section): the $PM_{2.5}$ (fine dust) concentration inside is maximum the outside concentration (hourly average indoor/outdoor ratio = 1).
	Explanatory notes:
	• The mentioned upper limit for particulate matter concentration applies with normally switched on facilities (e.g., ventilation and heating).
	• The premise is to avoid open flames indoors: no smoking, moderate use of candles and no fireplace, and to use cooking extractor with exhaust to the outside when cooking.

Figure 1. Description of the requirements for the CO_2 concentration and

Class B – GOOD extra as compared to class C	Class A -VERY GOOD extra as compared to class B
• The CO_2-concentration in residence rooms remains during use at maximum **+ 450 ppm** above the outdoor concentration.	• The CO_2-concentration in residence rooms remains during use at maximum **+ 300 ppm** above the outdoor concentration.
• Assuming a normal, average metabolism (1.2 to 1.4 met) and a CO_2 production of maximum 0.005 ℓ/s per person it can be assumed that the Class B requirement is fulfilled if **40 m³/h per person** fresh outdoor air is supplied.	• Assuming a normal, average metabolism (1.2 to 1.4 met) and a CO_2 production of maximum 0.005 ℓ/s per person it can be assumed that the Class A requirement is fulfilled if **60 m³/h per person** fresh outdoor air is supplied.
‹	«
	• Residence rooms are equipped with a CO_2 monitor from which the instantaneous CO_2 value can be read.
	• In order to relieve the residents, the ventilation for each room should be able to be controlled automatically based on CO_2 measurement.
Explanatory notes:	**Explanatory notes:**
‹	«
‹	«
‹	«
‹	«
‹	«
‹ ‹	«
‹	«
• The formaldehyde (HCOH) concentration is a **maximum of 30 micrograms/m³**.	«
‹	«
‹	«
‹	«
• The nitrogen dioxide (NO_2) concentration **does not exceed 20 ug/m³** on an annual average.	• The nitrogen dioxide (NO_2) concentration **does not exceed 10 ug/m³** on an annual average.
• The annual average $PM_{2.5}$ (particulate matter) concentration is a **maximum of 7.5 micrograms/m³**.	• The annual average $PM_{2.5}$ (particulate matter) concentration is a **maximum of 5 micrograms/m³**.
• Additional requirement regarding the particulate matter penetration through the façade and ventilation system (filter section): the $PM_{2.5}$ (fine dust) concentration inside is maximum the outside concentration (hourly average indoor/outdoor ratio = 0.5)	• Additional requirement regarding the particulate matter penetration through the façade and ventilation system (filter section): the $PM_{2.5}$ (fine dust) concentration inside is maximum the outside concentration (hourly average indoor/outdoor ratio = 0.25)
Explanatory notes:	**Explanatory notes:**
‹	«
‹	«

a selection of other IAQ indicators as part of the Air Quality requirements.

CLIMATE	Class C - SUFFICIENT
Comfort Winter **Living room, Kitchen**	
	• The operative temperature can be set manually between 16–23 °C.
	• The desired end temperature can be controlled within a bandwidth of ± 1 K.
	• The above requirement regarding manual re-adjustment of temperature can be influenced with sufficient "speed": temperature effect at least 1 °C per hour after adjustment.
Bedroom/Study room	• The operative temperature can be set manually between 16–22 °C.
	• The desired end temperature can be controlled within a bandwidth of ± 1 K.
	• The above requirement regarding manual re-adjustment of temperature can be influenced with sufficient "speed": temperature effect at least 2 °C per hour after adjustment.
Bathroom	• The operative temperature can be set manually between 16–24 °C.
	• The desired end temperature can be controlled within a bandwidth of ± 1 K.
	• The above requirement regarding manual re-adjustment of temperature can be influenced with sufficient "speed": temperature effect at least 2 °C per hour after adjustment.
	Explanatory notes:
	• The winter comfort requirements are based on allowing occupants to raise the temperature in winter to the desired temperature. The system should be designed to achieve the above requirements. This allows the user to choose his/her own setting within the range at all times.
	• The operative temperature refers (approximately) to the average of the air temperature and the average radiation temperature. In practice, the air temperature can be used unless a solution is chosen that specifically includes radiation.
	• The operative temperature is determined in accordance with the provisions in NEN-EN-ISO 7726 and NEN-EN-ISO 7730.
	• The above indoor temperature requirements apply unless the daily average outdoor temperature is lower than –5 °C.,Daily average outdoor temperature' here means (daily maximum + daily minimum) / 2.
	• For lowering the temperature in winter, it may be assumed that residents use windows that can be opened.

Figure 2. Description of the requirements for the temperature

	Class B – GOOD extra as compared to class C	Class A -VERY GOOD extra as compared to class B
	• The operative temperature can be set manually between **16–24 °C**.	• The operative temperature can be set manually between **16–24 °C**.
	• The desired end temperature can be controlled within a bandwidth of **± 0.5 K**.	«
	‹	«
	• In all residence areas, the temperature is measured and visibly fed back to the users.	«
	• The operative temperature can be set manually between **16–22 °C**.	• The operative temperature can be set manually between **16–24 °C**.
	• The desired end temperature can be controlled within a bandwidth of **± 0.5 K.**	«
	‹	«
	• In all residence areas, the temperature is measured and visibly fed back to the users.	«
	• The operative temperature can be set manually between 16–26 °C.	• The operative temperature can be set manually between **16–28 °C**.
	• The desired end temperature can be controlled within a bandwidth of ± 0.5 K.	«
	‹	«
	• In all residence areas, the temperature is measured and visibly fed back to the users.	«
	Explanatory notes:	**Explanatory notes:**
	‹	«
	‹	«
	‹	«
	‹	«
	• These requirements assume a separate temperature control of the rooms	«
	• The above temperatures can be achieved regardless of the type of room and whether the temperature is adjusted up or down. For temperature reduction, the possibility of opening a window is not assumed.	«

during winter as an example of one of the thermal climate requirements.

Verification

Defining requirements is part of the Program of Requirements and focuses on design. Whether the requirements are met in practice is an essential part of the PoR. A general requirement is that the requirements should be met for 95% of the occupancy time of the specific room. The occupancy time is defined for individual rooms.

The PoR Healthy Dwellings assumes three levels of verification to determine whether a dwelling meets the specified requirements:

1. *Low level verification at handover*. In order to limit the cost of verification, it is recommended that only the most important performance requirements are measured at handover, or that it is verified that the dwelling has been built in accordance with the design with respect to the aspects addressed in the PoR. Inexpensive measuring equipment such as temperature loggers and Class II noise meters can be used for these measurements. It is not possible (nor necessary) to verify all performance requirements. Some requirements require more extensive measurements.
2. *Long-term monitoring with sensors*. Because short-term measurements are less useful for some indicators, such as temperature, a relatively simple sensor network is required to monitor and verify the long-term performance of the home. This sensor network can be an integral part of the home, or it can be installed temporarily. Currently, not only temperature, but also CO_2 and $PM_{2.5}$ concentrations can be measured with reasonable accuracy using low-cost sensors. Therefore, these indicators could also be included in long-term monitoring.
3. *Detailed measurements in response to complaints*. Some of the indicators require relatively complex measurements. It is recommended that the performance requirements for these indicators be verified only at the time of complaints. An example of such an indicator is draft.

Concluding considerations

The developed PoR Healthy Dwellings aims to support the development of dwellings that have health as a starting point and aim for (much) better indoor conditions than would be required based on the Dutch Building Decree. Ultimately, we hope that this will improve the health of the occupants and serve the public good. The PoR is closely aligned with existing PoRs for offices and schools. These PoRs are accepted and well known in the Netherlands. They are applied regularly. This means that it has become an accepted means of setting indoor environmental quality requirements for such buildings. Given this status and the desired alignment, we hope that the PoR Healthy Dwellings will be more readily adopted than other guidelines and schemes that are available, such as TAIL (Wargocki et al. 2021), BREEAM (BREEAM, n.d.) and Well Building (Int. Well Building Institute, n.d.). Although individual dwelling owners may use the PoR Healthy Dwellings to set IEQ requirements, we aim for housing corporations to be the early adopters who want to build or renovate a group of dwellings (new or refurbished) with a particular (health) class based on the PoR. Ultimately, we hope that higher class IEQ will also be recognized in the selling price or mortgage rates. We expect that this will support the application, as it can be directly translated into financial incentives to strive for a healthy living environment, similar to energy (NVM, 2022).

We see that the development of the PoR is not yet complete, but is still evolving. While there is room to extend the PoR to indicators that would serve a broader definition of health, i.e. mental health, or a need to rank the individual indicators in terms of health impact, we see an urgent need to develop the verification part. This process will begin with an assessment of existing dwellings to understand what procedure might work best and whether we can assess existing dwellings according to the defined classes. Once a complete, feasible and working verification procedure is in place, we plan to review the requirements on a regular basis to bring them in line with the latest available knowledge on IEQ requirements. ■

Acknowledgements

The development of the PoR Healthy Dwellings was initiated and financially supported by Binnenklimaat Nederland. We thank all members of the focus group for their active participation and input.

This article is a summary of the paper 'Program of Requirements Healthy Dwellings' presented at Healthy Buildings Europe 2023 in Aachen (Loomans et al. 2023). Part of the text of this paper was used to prepare this article. DeepL Write was used to improve sentences where deemed necessary.

References

Please find the complete list of references in the html-version at https://www.rehva.eu/rehva-journal


systemair
Green Ventilation
Making sustainability an easy choice
The well-being of our planet tomorrow depends on choosing sustainable solutions today.
Systemair's Green Ventilation product label is designed to guide you. To qualify, the products must meet clearly defined criteria for energy efficiency, indoor air quality, safety, global warming potential, and more.
Scan this code to see how this will benefit your projects!
systemair.com/greenventilation

Information: This paper is based on the publication "Using artificial intelligence (AI) in electronic nose system (E-Nose) development for air quality detection in shopping centres" presented at the 18th Healthy Buildings Europe Conference 2023, Aachen, Germany.

Using artificial intelligence to develop a VOC multi-gas sensor system for detecting air quality in shopping centres





MAHMOUD ELMOKADEM **SAMY LOUCA** **ALI ABDELRAHMAN** **KAI REWITZ** **DIRK MÜLLER**

Institute for Energy Efficient Buildings and Indoor Climate (EBC), E.ON Energy Research Center, RWTH Aachen University, Aachen, Germany.

Abstract: With the increasing awareness concerning indoor air quality (IAQ) and energy efficiency, the development of IAQ sensor systems is becoming more relevant, for example to enable demand-controlled ventilation (DCV). Currently, DCV in most indoor environments is based on CO_2 concentration, which is a good indicator for human emissions. For shopping centres (SC), DCV rarely considers volatile organic compound (VOC) emissions from materials, which could significantly affect customer health and consumer experience. VOC multi-gas sensor systems (VOC MGSS) can help to detect and interpret these gases. Due to the high number of sensors and influencing factors such as temperature, relative humidity or type of odour, choosing the best model approach for evaluating IAQ is not trivial. Therefore, we compare linear regression with support vector regression, artificial neural networks and random forest models for the calibration of a VOC-MGSS to predict perceived intensity (PI) for six different SC products. Subjective test data from a trained subject panel and objective test data from the VOC-MGSS are used to train the different model types for the overall dataset and product-specific (PS) datasets.

Keywords: Indoor air quality, total volatile organic compounds, artificial intelligence, E-Nose, linear regression, support vector regression, artificial neural networks, random forest regression

1. Introduction

Several studies show the impact of indoor air quality (IAQ) among others on human health, occupant well-being, comfort and productivity and consequently the need for efficient ventilation strategies [1]. One way of achieving high IAQ with low energy requirements is to use demand-controlled ventilation (DCV). Currently, DCV is mostly based on CO_2 concentration, which is a good indicator of human emissions. However, in SC releasing potentially hazardous VOC from seemingly harmless sources is proven to cause high potential risk to human health, causing sick-building syndrome (SBS) or building-related illnesses [2]. Thus, identification of VOC-inducing products and correlation to subjective evaluation data are essential for a healthy and comfortable environment in SC.

Compared to expensive and complex to use gas chromatography-mass spectrometry, VOC-MGSS are cheap and convenient testing methods to detect VOCs in indoor environments [3, 4]. For such VOC-MGSS, different sensor types can be used. An often-used sensor type is the metal oxide semiconductor (MOx) sensor. Among other benefits being high sensitivity to low gas concentrations, long service life and a low price, MOx sensors are potentially suitable for use in DCV systems. Examples of VOC-MGSS with MOx sensors are available for research use, such as KAMINA from the Karlsruher Institute of Technology (KIT) [5] and for commercial use, such as i-Pen, PEN2, and PEN3 from Airsense Analytics [3] to assess air quality in indoor areas.

Since most of these devices have data from more than one sensor, implementing an artificial intelligence framework can be used to correlate the output of all sensors with target variables, for example to distinguish between different odours or to predict perceived intensities. Earlier research combines artificial intelligence methods and VOC-MGSS technology successfully. Soh et al applied artificial neural networks (ANNs) for herbs recognition [7]. The accuracy of the model reaches 90% in the best case. Wang et al. used a random forest (RF) model for the concentration prediction of binary mixed gases, with the model having an R^2 score of 0.98 [8].

For the assessment of SC air quality, we already developed an VOC-MGSS mainly based on MOx sensors [6]. Different SC product types were tested with the VOC-MGSS and a trained subject panel to evaluate the PI. This testing aimed to find a correlation between objective and subjective data. In this previous work, only one sensor within the VOC-MGSS system was investigated and linear regression analysis was used [6]. For improved analysis, our goal is to investigate different AI frameworks for this application and find the most sufficient model that will enable the VOC-MGSS system to apply all its sensors when calculating the PI.

Table 1. *Sensors and detectable gases within VOC-MGSS system.*

Sensor	Detectable gases
MQ-2	Hydrogen, methane, propane, i-butane, LPG , alcohol, smoke
MQ-3	Alcohol, ethanol, smoke
MQ-7	Carbon monoxide
MQ-9	Carbon monoxide, flammable gasses
MQ-135	Ammonia, nitrogen oxide, alcohol, benzene, smoke, carbon dioxide
HCHO	Benzene, toluene, alcohol, formaldehyde gas, hydrogen
BME680	Industrial sensor for TVOCs

2. Methods

2.1 Objective and Subjective tests

The preceding study was conducted in the Air Quality Laboratory of the EBC. The SC product groups were divided into six categories: books, shoes, clothing, coffee and two perfume variants (100% and 40% diluted). These were filled into so-called emission chambers, shown in **Figure 1**. The chambers are connected to an HVAC system to ensure constant temperature and humidity. Inside each chamber beside the product, the VOC-MGSS was positioned to detect the VOC emissions from the products. A more detailed description can be found in [6].

The essential component within the developed VOC-MGSS system is a MOx sensor array of the MQ sensor series, which can detect a range of VOCs. The MQ sensors were manually pre-calibrated by adjustment of the potentiometer and post-calibrated to temperature and humidity with respect to the log curves available in the datasheets. All applied sensors in this system are outlined in **Table 1**. The VOC-MGSS prototype, including optimized housing, can be seen in **Figure 2**.

Figure 1. Emission chambers in the Air Quality Laboratory at EBC.

Figure 2. VOC-MGSS prototype of EBC, RWTH Aachen University.

For subjective evaluation of the emission intensity from the SC products, a trained panel consisting of 17 participants aided with an acetone test stand was used according to DIN ISO 16000-28. The conducted tests ran with a comparative acetone scale ranging from 0 to 28 PI.

The tests were carried out in respect with variations in temperature (20, 23, 27 °C), relative humidity (30, 50 %) and the air change rate (1, 1.7, 2.05, 3.15, 4.1, 5.1 h^{-1}). In total, 36 evaluations per product and test subject were recorded and stored in a dataset.

2.2 AI Model development procedure

To find a suitable model to predict the perceived intensity depending on the sensor data, different AI models were created and assessed on the MATLAB Regression Learner App. This GUI allows for training, validation, and tuning of models. In our context, sensor signals in **Table 1** are categorized as input data, also called predictors, while the corresponding perceived intensity is the known response. External factors are excluded from predictor selection as an ideal sensor calibration is assumed.

Despite all model types operating differently, the developing approach for each model type is similar, which can be mainly divided into a training and testing process. The model developing procedure for the AI models (AI MDP) is shown in **Figure 3**.

2.2.1 Dataset pre-processing

After a random permutation of the dataset it is separated into training and testing datasets by using 80/20 split [12]. The following step is setting specific model parameters and training of the model with the training dataset. Cross-validation values are calculated to determine the training success[13]. Finally, the trained models are tested to evaluate their performance. To investigate if a product specific (PS) model development leads to improvements in the predictions of the different model types, AI MDP is applied for overall data and each product separately. This leads to six additional product specific models for each model type.

2.2.2 AI model setup

AI models significantly differ in behaviour, algorithmic concept and general bias/variance relevance for different model types in traditional AI problem-solving, machine learning, and deep learning applications [14]. For this, four model types were tested to evaluate their suitability, see **Figure 3**.

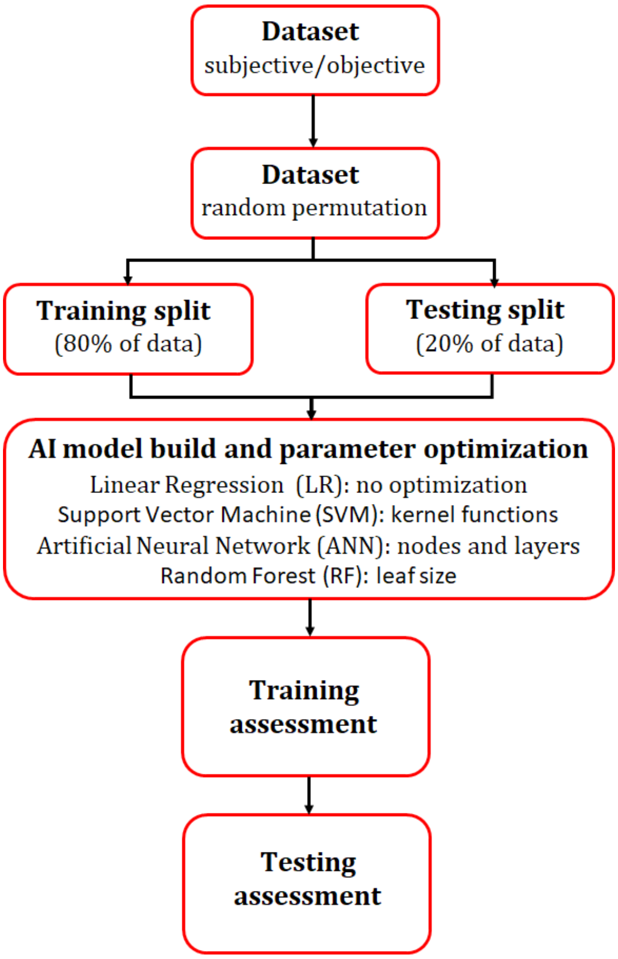


Figure 3. AI model development procedure (AI MDP).

Linear regression finds the best parameter fitting for a regression function with the determination of RMSE. Despite its simplicity, it is subject to underfitting and is affected by outliers [15].

$$y = \beta_0 + \beta_1 x_1 + \cdots + \beta_n x_n \quad (1)$$

Equation (1) shows the applied linear regression function. In this study, y is the predicted perceived intensity, β_n are the fitted coefficients and x_n are the predictors.

Support vector machine (SVM) regression involves the addition of support vectors and kernel functions to estimate a target function within a set constraint (ε) and eliminate outliers (ϑ) from its analysis. The kernel functions can include higher polynomials in finding an optimal hyperplane. In our case, linear and quadratic models are considered. However, the disadvantage is in optimizing the constraint (ε), which can cause a high error tolerance [16]. **Figure 4** visualizes the regression process of a support vector machine with MQ-2 sensor data from this study.

As our system includes multiple MQ sensors more complex models in ANN can run those through numbered sets of layers and nodes[17]. In this study, two network configurations of one layer and 25 nodes and two layers with ten nodes each are used. The main advantage of ANNs is in detecting all possible interaction between predictors. Despite this, ANNs can easily over-fit, and require great computational resources [18, 19]. **Figure 5** visualizes an example of an ANN with sensor signals as inputs, the PI prediction as its output.

Encompassing the same idea with a different execution is random forest (RF) algorithms. Here, the general aim is within constructing a number of decision trees for training [20]. These trees operate with leaves representing data values and applying binary thinking. The leaf size (LS) is related to the number of observations considered in each data split. Thus, RF models with small (4) and large (36) LS were applied in our case. The benefits of RF models are their robustness against outliers. In contrast to this, they are affected by small changes in data [15]. An example of a random forest model is seen in **Figure 6**.

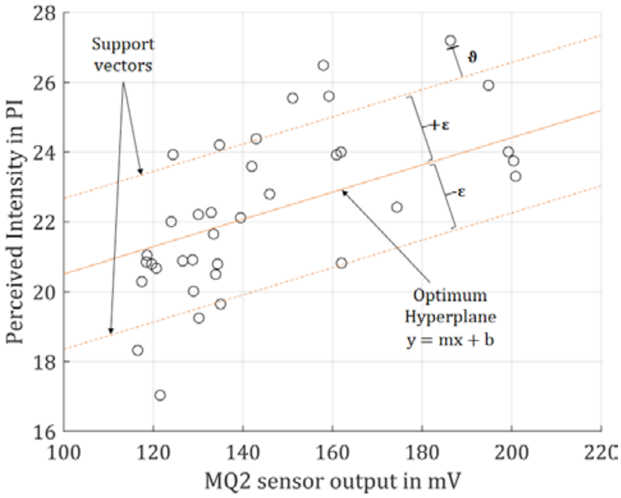


Figure 4. Sample prediction of perceived intensity using support vector regression with MQ-2 sensor output.

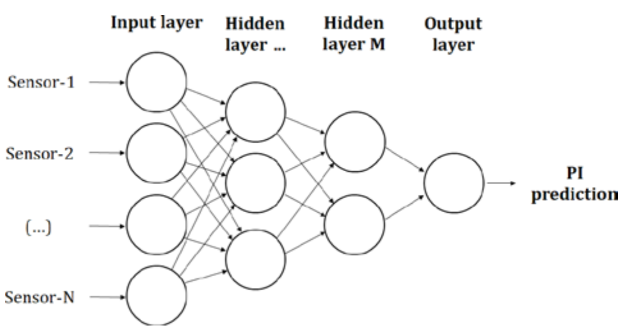


Figure 5. Simplified artificial neural network (ANN) structure in application with VOC-MGSS input & output data.

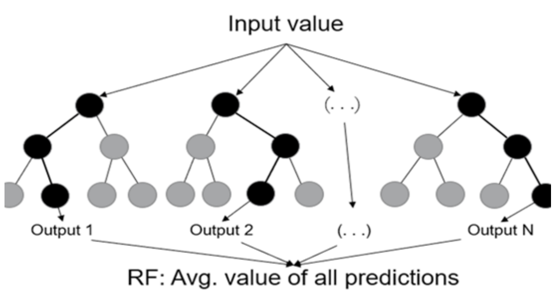


Figure 6. Simplified visualization of random forest algorithms.

2.2.3 Model testing

To build models that accurately predict the PI from objective data, evaluation of the suitability of each model to the dataset is required. RMSE shows how much the model predictions deviate from the subjective test data. [21]. Equation (2) shows the definition for the RMSE. In this study, y_i is PI of the subject test, $m_i(AI)$ is the prediction of each model and n represents the number of data values.

$$\text{RMSE (AI)} = \sqrt{\frac{1}{n} \cdot \sum_{i=1}^{n} (m_i(AI) - y_i)^2} \qquad (2)$$

3. Results

3.1 Training and testing of the overall model

Table 2 presents the RMSE for training and testing for the whole dataset. **Figure 7** shows no major differences in the distribution of the data between the subjective test (red boxplot) and LR, ANN, RF and Quadratic SVM models (grey boxplot), only a small difference is observed for Linear SVM. **Table 2** shows the best performance for the RF model with a leaf size of 4 and 36, achieving testing RMSE of 0.07 and 0.75 PI respectively. The ANN models (1x25 and 2x10) also show a good performance, achieving testing RMSE of 0.85 and 0.86 PI.

Table 2. *Resulting training and testing RMSE for the overall models.*

AI model	RMSE in PI Training	RMSE in PI Testing
Linear Regression	2.15	2.12
Linear SVM regression	2.14	2.15
Quadratic SVM regression	1.24	1.84
ANN (2x10)	2.48	0.86
ANN (1x25)	1.01	0.85
RF (leaf size: 4)	0.10	0.07
RF (leaf size: 36)	0.80	0.75

3.2 Testing of the product specific models

Figure 8 shows the RMSE for the overall models (red bars) and the RMSE for each PS model (grey bar). The best performance of the PS models has RF-LS 4 scored a maximum RMSE of 0.09 PI, which is close to the RMSE of 0.07 PI for the overall model. Increasing the LS to 36 results in an increased maximum RMSE of 0.8 PI for the PS models. The second ranking is for the ANN models (2x10 and 1x25) achieving a maximum RMSE of 0.33 PI and 0.43 PI. These are lower than the RMSE of 0.86 PI and 0.85 PI for the overall models.

Figure 8 shows that for LR, SVM, and ANN the PS RMSE values are smaller than overall RMSE values.

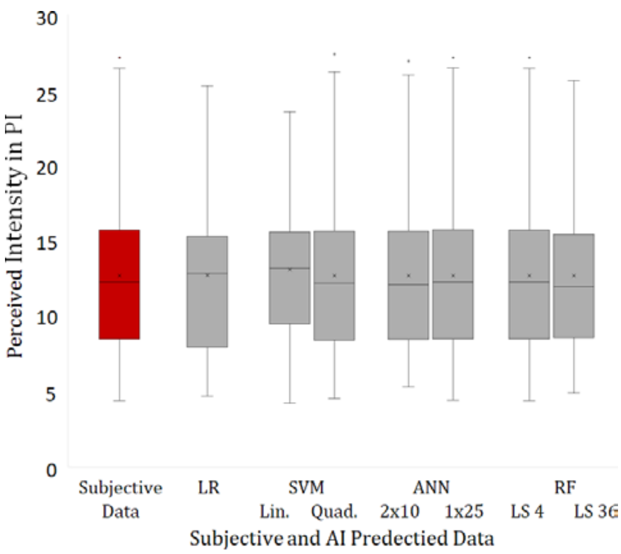


Figure 7. Distribution of subjective test data and prediction of the overall models.

For RF models the RMSE of overall model and PS models are more similar. The results indicate that the PS models should be used for their respective stores in the SC to predict PI rather than the overall model.

4. Conclusion

The results show the potential of VOC sensors for IAQ assessment in SC. Subjective and objective tests were conducted to validate the application of this technology with SC products. The use of AI models enables a correlation between the VOC-MGSS sensor signals and subjective values. To achieve this, an analysis of five AI models is conducted. The models were trained and tested with both overall and PS datasets. For model evaluation, RMSE metrics were applied. The best performance shows RF-approach-LS 4, achieving for the overall and SP dataset 0.07 PI and max. 0.09 PI. However, there may be an overfitting for this model [20]. For all model types except RF models, the results show a decreased RSME for product specific models compared to the overall models. The ANN models (2x10) and (1x25) achieved RMSE of 0.86 and 0.85 PI. This makes them also applicable for this dataset. Overall, further analyses with more subjective and objective data, especially validation data from field tests, are needed to bring such VOC-MGSS system into practice use. Moreover, a correlation of PI and acceptance, is needed for implementing these models in DCV concepts. ■

Acknowledgements

Grateful acknowledgment is made for financial support by the Federal Ministry for Economic Affairs and Climate Action (BMWK) regarding the project "Optimization of modularly planned shopping centres supported by energy data", promotional reference 03ET1502.

References

Please find the complete list of references in the html-version at https://www.rehva.eu/rehva-journal

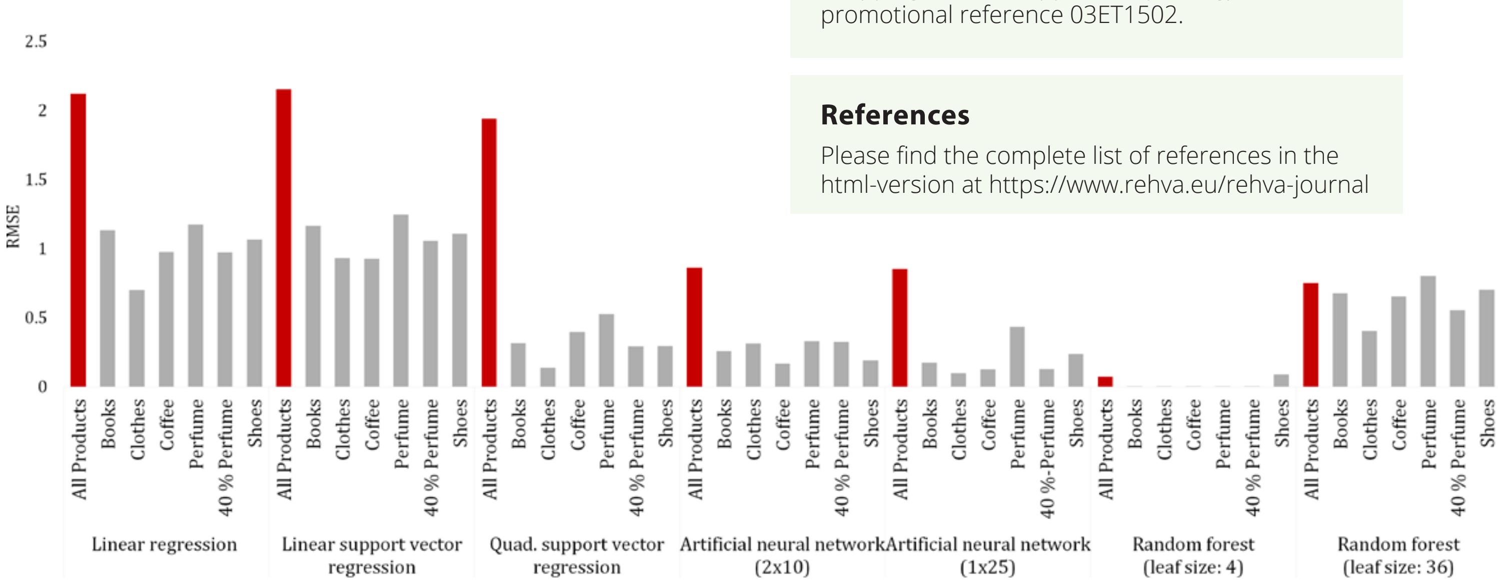


Figure 8. Comparison of the RMSE in PI for the overall and product specific models for testing.

6th Edition

REFCOLD® INDIA

12 – 14 OCTOBER 2023
Chennai Trade Centre, Chennai

ISHRAE® | informa markets

DISCOVER TECHNOLOGIES DRIVING EXCELLENCE IN SUSTAINABLE REFRIGERATION

SOUTH ASIA'S PREMIER REFRIGERATION & COLD-CHAIN EXHIBITION

PRESERVE THROUGH INNOVATION FOR A BETTER FUTURE

The refrigeration industry faces the urgent challenge of reducing its environmental impact in an era where sustainability is paramount. REFCOLD India is set to showcase innovative solutions like Low-GWP Refrigerants, Energy-Efficient Systems, Cold Chain Optimization, Waste Heat Recovery & Internet of Things (IoT) Integrations that not only reduce environmental impact but also propel economic expansion.

KEY FEATURES

- 200+ Number of Exhibitors
- Spread Across 10000 SqM Gross Space
- B2B Networking Area - to ensure the right buyers connect to the right seller
- Hackathon Zone-To create a platform to highlight innovations in the industry
- Conferences & Workshops
- REFCOLD India Awards Night

EXHIBITOR PROFILE

- Cold Storage Equipment's
- Retail Refrigeration Equipment's
- Food & Beverage Refrigeration Equipment's
- Medical Refrigeration Equipment's
- Mobile Refrigeration Equipment's
- Process Chilling Equipment's
- Cold Chain Equipment's

And many more...

KEY PARTNERS

Awards Partner: COPELAND
Diamond Partner: RINAC INDIA LIMITED
Gold Partner: Tecumseh
Techwall Partner: frascold
Cold Storage Equipment Partner: BLUE STAR
Cold Chain Partner: DAIKIN
Green Technology Showcase Partner: Danfoss
Silver Partner: KEHEMS TECHNOLOGIES
Automation Partner: YASKAWA
Bronze Partner: SIGNATURE, ebmpapst
Copper Partner: MEHTA TUBES LIMITED, MEXFLOW
Lunch Partner: ALP AEROFLEX, testo, SANT VALVES
Shuttle Partners: K-FLEX, NADI
Venue Arrangement Partner: GRUNDFOS
Hackathon Partner: Luftek

ENDORSED BY

NCCD

SUPPORTING ASSOCIATIONS

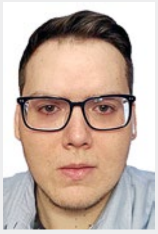
International: IIF IIR, IOR ior.org.uk, ISKID, REHVA
Domestic: ACRA, iiar

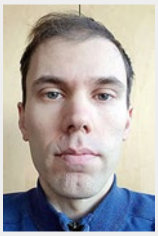
For Marketing and Alliances:
Jivitesh Wadhwa | M: +91 9833170240 | E: jivitesh.wadhwa@informa.com

Scan for Visitor Registration

www.refcold.in

Ventilation ductwork resistance to microbial growth under humid and cold conditions





ILIA KRAVCHENKO
Doctoral candidate
Aalto University
ilia.kravchenko@aalto.fi

RISTO KOSONEN
Professor
Aalto University

SIMO KILPELÄINEN
D.Sc., laboratory manager
Aalto University

SAMI LESTINEN
D.Sc.
Aalto University and A- Insinöörit

PERTTI PASANEN
Professor
University of Kuopio

Two different night-time ventilation strategies for public buildings were examined: continuous and intermittent ventilation. The systems operated for 4 months under humid and cold conditions with microbial media released inside the ductwork. Contact and air samples showed the extinction of colonies by the end of the experiment regardless of the chosen night-time ventilation strategy. This indicated that the risk of microbiological growth in the ductwork is low.

Keywords: ventilation microbial pollution; ductwork mould growth; night-time ventilation; public buildings; air quality

High energy efficiency and indoor air standards

The demand for improved ventilation systems is essential to ensure clean and healthy indoor air. However, these systems can encounter such challenges as microbial pollution during their operation. To guarantee adequate Indoor Air Quality (IAQ) within the European Union, guidelines like EN 15251 and EN 16798-1 have been established, offering criteria for indoor environmental quality and building energy efficiency, which have been incorporated into the building codes of member countries (Ahola et al., 2019). Although, building's ventilation system still may encounter operational challenges over the building's lifespan.

One of the challenges is microbial growth resulting from dust accumulation, water condensation, and related factors, which may occur while is not operating or when airflow is presented (Pasanen et al., 1993). Polluted ventilation systems may emit microbial colonies into the indoor air, potentially leading to mold allergies and fungal diseases (Al-Doory and Domson, 1984; Sakamoto et al., 1996). Hence, it is crucial to comprehend the risk of bacterial and fungal contamination within various segments of the ventilation system.

In Finland, public buildings constitute approximately 30% of the country's total employment infrastructure. These buildings may be vulnerable to contamination within their ventilation ductwork as buildings remain unoccupied for more than 50% of the time, prompting the consideration of strategies to mitigate contamination risks. One approach involves halting ventilation during unoccupied periods potentially fostering fungal and bacterial growth. Another option is to maintain a minimum airflow rate continuously, although this may lead to unnecessary energy consumption during unoccupied periods.

The investigation aimed to explore how intermittent and continuous ventilation strategies during unoccupied periods could influence the risk of microbial growth in the ductwork. The study utilized a mock-up consisting of two separate ductwork systems, simulating intermittent and continuous ventilation strategies. Over four months, the same moisture and temperature conditions were maintained in both ductworks and microbial growth was monitored through wiping and air sampling techniques.

Ventilation ductwork measurement setup

The ventilation ductwork setup was constructed using the commonly employed circular galvanized steel ducts, each with a diameter of 250 mm. The fan operated in both ducts for 12 hours daily, maintaining their nominal airflow rate. During the simulated unoccupied period, the fan in duct 1 was deactivated- see **Fig. 1**. Conversely, in duct two fans ran at a reduced supply airflow rate. Continuous monitoring of microbial growth was conducted within the experimental ductwork, characterized by air conditions of 70–90% relative humidity and air temperatures ranging from 11–14°C, including temperature measurements on the duct surfaces.

Air temperature, relative humidity, and dew point within the duct were monitored at 15-minute intervals, see **Fig. 1**. Specifically, air temperature and humidity were recorded at two locations within duct 0: one before the damper and the other after duct 1. In ducts 1 and 2, air temperature, relative humidity, and dew point measurements were taken at the sample hatch and downstream in duct 2, following the hatch. Surface temperatures inside both ducts 1 and 2 were also measured near the sample hatch, with surface temperature monitoring occurring in the middle of the insulation-covered sampling zone. The reference indoor air temperature, humidity, and dew point were measured on the exterior surface of duct 0. Airflow within ducts 1 and 2 was quantified using a rotary vane anemometer.

To replicate the natural dry deposition of fungal spores, an FSSST aerosol generator was used to generate spores. This approach ensured a more uniform distribution of aerosolized contaminants throughout the duct system, providing a more representative evaluation of the risks associated with microbial growth within ventilation systems. *P. brevicompactum* was chosen to represent common fungi, as it can thrive in conditions where moisture is present (Kravchenko et al., 2023).

Throughout the testing period, wipe and air samples were collected at the beginning, monthly, and at the end of the experiment, see **Table 1**.

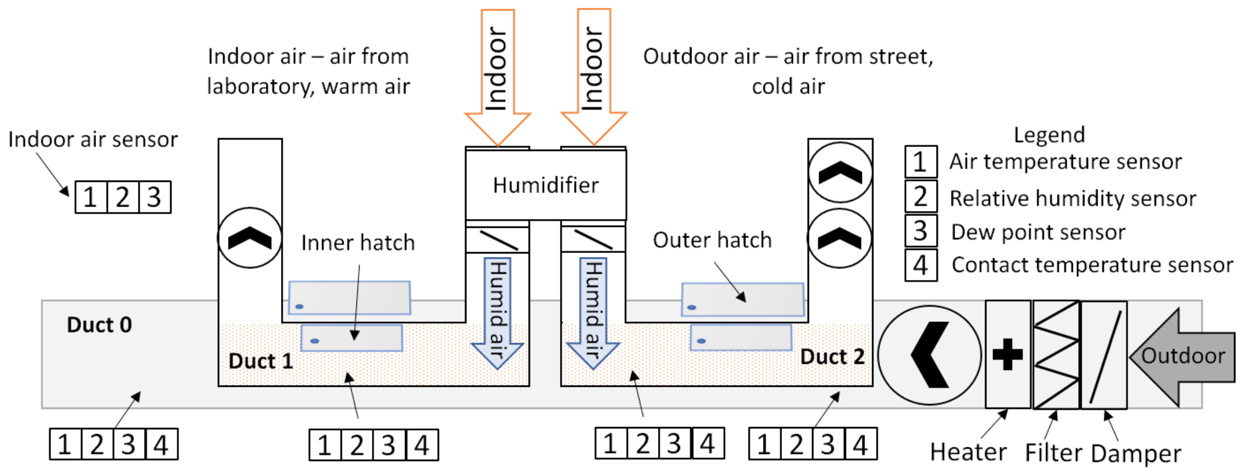


Figure 1. Schematic representation of the ductwork setup and measurement equipment.

Table 1. *Sampling schedule and methods.*

Sampling	Method	11.17.2020	12.18.2020	01.18.2021	02.15.2021	03.10.2021
Contact, Fungal	Petri film	•	•	•	•	•
Air, Fungal	Anderson collector	•				•
Air, Bacterial	Anderson collector	•				•

To monitor microbial concentrations in the supply and exhaust air in case of microbial proliferation within the duct area, air samples were obtained using an Andersen impactor (Andersen, 1958), as shown in **Fig. 2**. The microbial analysis, including microbial counts in swab and air samples, adhered to standard operating procedures followed by the Indoor Air and Occupational Health research group at the University of Eastern Finland ("Research group of Indoor Environment and Occupational Health").

Ductwork long-term pollution with intermittent and continuous ventilation

In accordance with the findings, the levels of fungal spores within the ventilation duct exhibited a decline throughout the observed period, as illustrated in **Fig. 3**. Overall, the fungal spore counts remained quite low. The results indicate that in both test scenarios, no colonies of fungi developed on the surface of the ventilation duct. Notably, in the case of continuous ventilation, the viability of fungal spores decreased at a slightly higher rate compared to intermittent ventilation.

Ductwork air samples are presented in **Fig. 4** where the results of air samples obtained at the beginning (12.11.2020) and the end (10.3.2021) of the observation period, with samples collected from both ends of the ducts. Continuous ventilation consistently exhibited lower Colony-Forming Unit (CFU) counts in all instances, indicating a greater ability to withstand the transfer of bacterial colonies.

Interestingly, the pattern of fungal Colony-Forming Units (CFU) was initially different, with colonies primarily located at the end of the duct for continuous ventilation and at the beginning of the duct for intermittent ventilation, as depicted in **Fig 5**.

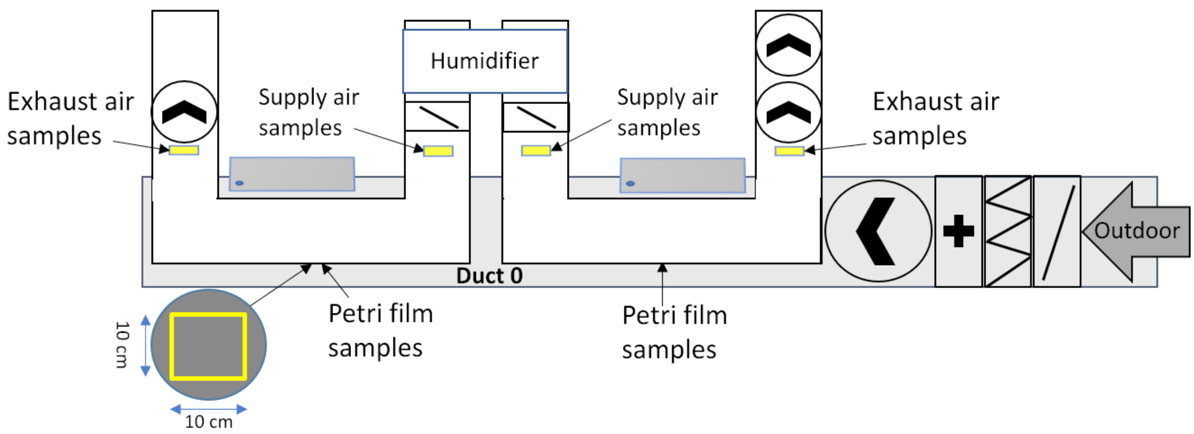


Figure 2. Schematic representation of the ductwork sampling setup and placement.

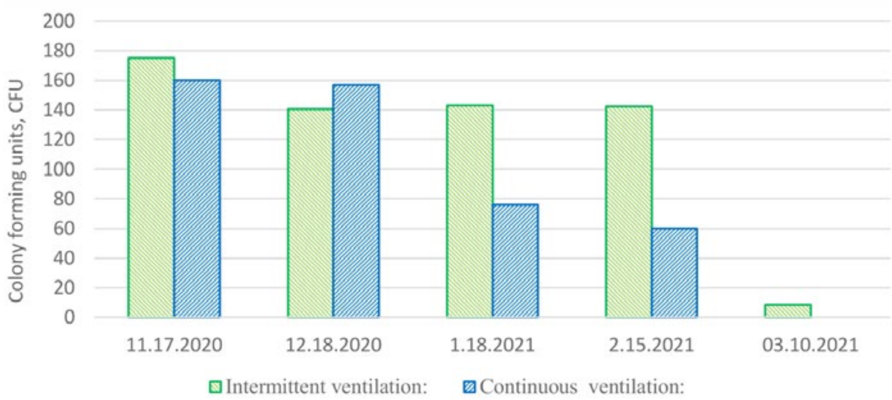


Figure 3. The changes in fungal spore counts within the ventilation duct, comparing intermittent and continuous night-time ventilation

Overall, the air samples corroborate the findings of Petri film, indicating that the number of CFUs within the ventilation duct did not increase significantly with either intermittent or continuous ventilation operation. While the initial theory suggesting that ventilation initiation might create a pressure wave capable of distributing spores was not directly confirmed, there is a subtle difference in CFU levels presented. Based on the results from the air samples, it can be concluded that there was no observable growth within the ventilation ducts.

Conclusions

Both intermittent and continuous ventilation strategies have demonstrated their effectiveness in minimizing bacterial and fungal contamination. However, continuous ventilation exhibited a slightly superior performance in resisting colony growth. The experiment suggests that the likelihood of long-term bacterial and fungal colony growth on the walls of air ducts is improbable. Moreover, the consistently low colony counts in the air throughout the study period indicate that the transfer of colonies from the air ducts to other components of the ventilation system is also unlikely. These results can serve as a foundation for selecting the most suitable ventilation strategies for public buildings, ensuring the maintenance of a healthy indoor air environment. ■

References

Please find the complete list of references in the html-version at https://www.rehva.eu/rehva-journal

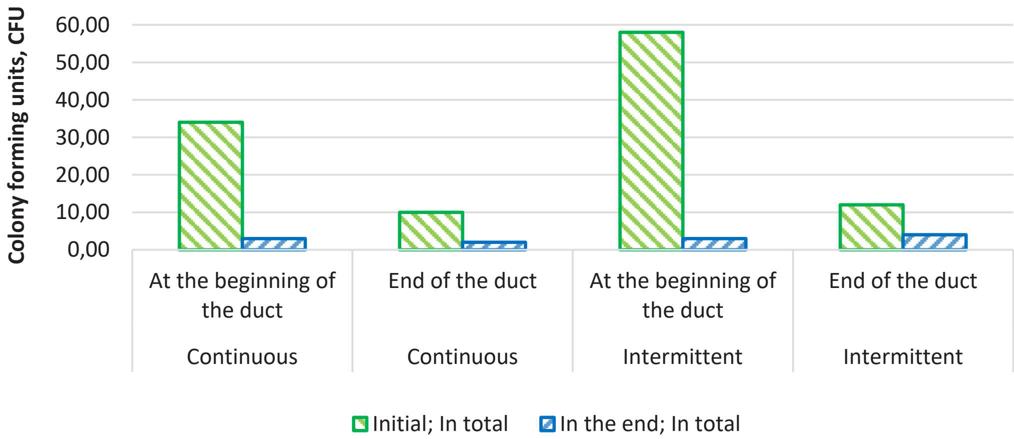


Figure 4. Air samples of bacterial colony-forming units within the ventilation ducts, comparing intermittent and continuous ventilation in the beginning of experiment and at the end.

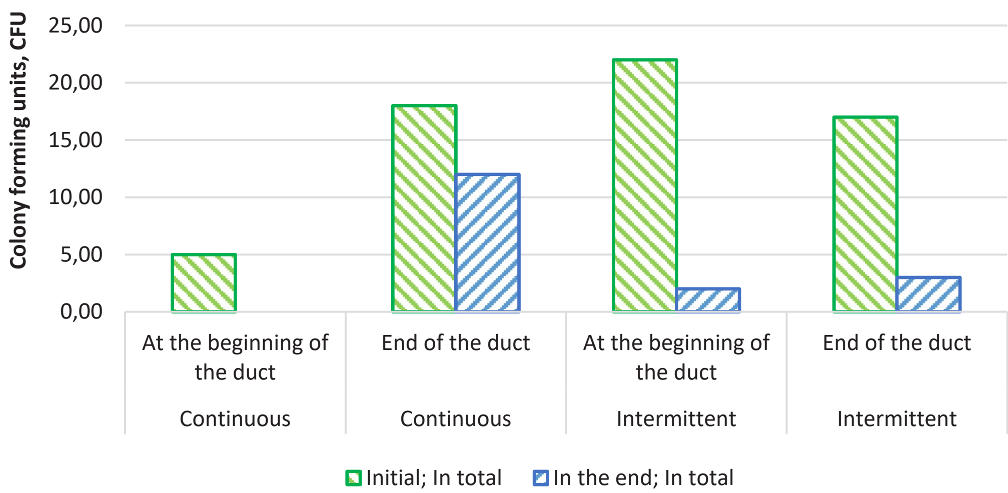


Figure 5. Air samples of ventilation duct fungi colony-forming units within the ventilation ducts, comparing intermittent and continuous ventilation in the beginning of experiment and at the end.

A new generation of natural refrigerant units

20÷200 kW

chiller, heat pump, multifunctional and freecooling units,
air and water source

Doing the right thing has no value, but we know its worth. For us, this was the result to aim for, because it means having given and received in equal measure. To take care of Nature, through Nature. This choice is part of a story that has only just begun.

This is a new generation of natural refrigerant propane units.

MISSION ZERO EMISSION

Discover more
about Swegon's
Mission Zero Emission.

Swegon

Precision Ventilation in Open Plan offices – A study of Variable Jet Interaction between Active Chilled Beams





ALIREZA AFSHARI GÖRAN HULTMARK HAIDER LATIF ALESSANDRO MACCARINI SAMIRA RAHNAMA

Department of the Built Environment (BUILD), Aalborg University Copenhagen, Denmark

Abstract: The objective of this study is to utilize a conventional Active Chilled Beam (ACB) equipped with JetCones, enabling a versatile air pattern in various directions and airflow distributions spanning 360 degrees. This approach aims to attain individualized thermal comfort while upholding a stable room temperature. Multiple ACBs are employed to establish adjustable air velocity zones, thereby ensuring occupants with varying thermal comfort requirements experience acceptable levels of comfort. By implementing Precision Ventilation and slightly elevated cooling setpoint temperatures, energy use is decreased by 15%. This comprehensive approach not only improves individual comfort but also enhances energy efficiency in open-plan offices.

1. Introduction

Optimal thermal comfort significantly impacts the well-being and productivity of office occupants [1, 2]. In open-plan offices, the need for individualized control over environmental factors, such as air velocity and temperature, is frequently emphasized [3, 4].

Thermal comfort results from the interplay of personal and environmental factors. Personal factors include variables like metabolic rates (such as muscle mass, diet, health, age, gender, and activity) as well as clothing insulation, while environmental factors encompass air speed, air temperature, radiant temperature, and humidity [5]. Environmental factors wield substantial influence over personal factors, ultimately determining the comfort or discomfort experienced by office occupants [6]. Following the ISO 7730 Standard, a seated office occupant typically sustains a metabolic rate (MET) of 1.2 MET [7], yet this metric can fluctuate based on personal factors [8, 9].

Conventional mixing ventilation systems fall short of achieving personalized thermal comfort, as uniform conditions fail to satisfy individual requirements. This holds true even for traditional ACB systems lacking JetCones, as they mix cold supply air with warmer room air to achieve thermal consistency [10]. Precision Ventilation builds upon the foundation of a conventional mixing ventilation system. However, it innovatively introduces adjustable air patterns in various directions, thereby crafting an environment of personalized thermal comfort.

In contrast, over the past two decades, traditional personalized ventilation systems have been employed within office settings to establish micro-climates around workstations. These systems utilize various Air Terminal Devices to control airflow rates, directions, and temperatures, resulting in localized thermal comfort conditions and substantial energy conservation [11-13]. Some studies have even utilized more than five Air Terminal Devices around a single workstation to ensure precise localized thermal comfort [14, 15]. By elevating the cooling setpoint temperature of the room to as high as 30°C, traditional personalized ventilation systems have exhibited remarkable energy savings, reaching up to 60% [16-18]. While these systems indeed offer significant energy benefits, their implementation necessitates the incorporation of multiple dimensionally modified Air Terminal Devices to establish micro-climates around office workstations [19].

To address the complexity associated with multiple Air Terminal Devices, a modified ventilation strategy is required, one that can establish micro-climate zones without necessitating alterations to the existing office layout. Precision Ventilation [20, 21] emerges as a technique tailored to meet the specific thermal comfort needs of occupants in open-plan offices. This method entails the strategic positioning of high or low-velocity supply jets, effectively creating distinct air velocity zones within the communal office area. Through the integration of JetCones in ACBs, airflow regulation becomes feasible, enabling personalized airflow distribution in alignment with the relevant metabolic rates for each designated zone [22].

Thermal Comfort

Air velocity is one of the most crucial controllable parameters that influence the convective heat transfer between the human body and the surrounding environment [23, 24]. Among building designers, the energy demand perspective has changed and has resulted in an increase in the temperature setpoint to certain degrees [25]. This has left users to increase the room air velocities to compensate for warm room temperatures. This shift of negative discomfort caused by draught to the positive benefits of achieving acceptable thermal comfort by raising air velocities in warm indoor climates has been achieved in various studies as shown in **Table 1**.

As per the EN ISO 7730 Standard [32], a connection exists between air velocities and elevated air temperatures to attain a satisfactory comfort level for occupants, see **Figure 1**.

2. Methodology

The experiments involved ACBs equipped with JetCones, designed to effectively manage airflow in various directions through the use of adjustable regulators, as illustrated in **Figure 2**. The inherent JetCone functionality integrated into the ACBs offers a versatile means of altering supply airflow patterns. The adjustment regulators are marked with numbers ranging from 0 to 9. Each ACB's JetCones can be managed using four adjustment regulators, with the highest airflow achieved when JetCones are positioned at 9 and the lowest airflow at 0, see **Figure 3**. This Precision Ventilation is attained by maintaining a consistent total airflow from the system, all the while creating zones of varying air velocity through the adjustment of JetCones. These JetCones can be fine-tuned either manually or continuously through actuators, rendering Precision Ventilation a fully operational Demand Controlled Ventilation (DCV) System.

Experiments were carried out utilizing varying quantities of ACBs to define distinct air velocity zones tailored to the specific metabolic requirements of occupants. The air temperature emitted by the ACB is cooler by 3.5°C compared to the ambient room temperature, indicative of a heat load approximately around 25 W/m².

Table 1. *Studies with elevated air temperatures and air velocities.*

References	Air velocity limit	Room temperature limit
[26]	1 m/s	29°C
[27]	1 m/s	28°C
[12]	1.4 m/s	29°C
[28-30]	1 – 1.5 m/s	Up to 31°C
[31]	1.6 m/s	31°C

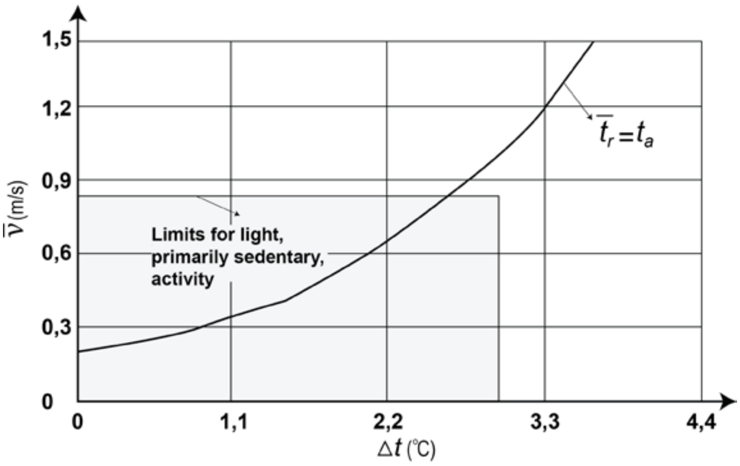


Figure 1. Air velocities required for a temperature rise above 26°C. [7, 32]

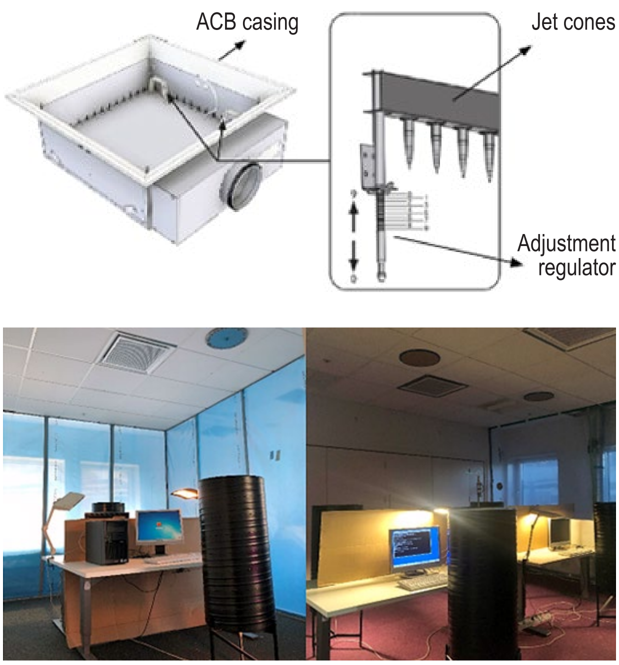


Figure 2. Experimental setup.

The test room's geometry was replicated in SolidWorks 2020 software, mirroring the exact dimensions of the real setup, as depicted in **Figure 4**. The simulated ACB geometry took on a circular form and was partitioned into 16 segments, resulting in radial airflow emanating from the ACB. The air velocities at 16 specific points on the ACB inlets, measured through experimentation, were applied as inlet air velocities for the radial ACB configuration, as illustrated in **Figure 4**. To ensure greater accuracy in dealing with mixed conventional airflows and enhance robustness, the RNG k-ε turbulence model was selected for the numerical simulations, following a successful grid independence test [33].

3. Results

Colliding Jets

In Precision Ventilation, colliding jets are harnessed to establish distinct air velocity zones within open-plan offices, eliminating the necessity for partitions between individual workstations. When these jets collide, a downstream airflow is generated, which is subsequently employed to induce varying air speeds across different regions within the room. The intensity of the jet and the temperature of the supplied air contribute to a stronger downward airflow, resulting in elevated vertical air velocities.

Colliding jets with air velocities of 0.8 m/s and 0.6 m/s, respectively, are directed towards zones with metabolic rates of 1.6 MET and 1.4 MET. These colliding jets established different air velocity zones for different metabolic rate occupants to keep PMV-PPD values within acceptable limits [32].

Variable Air Velocity Zones

Air velocities in the occupied zone were measured at 0.1 m and 1.1 m from the floor. **Figure 5** shows the formation of air velocity zones suitable for occupants with different metabolic rates. The results illustrate four cases as an example of the studied Precision Ventilation technology.

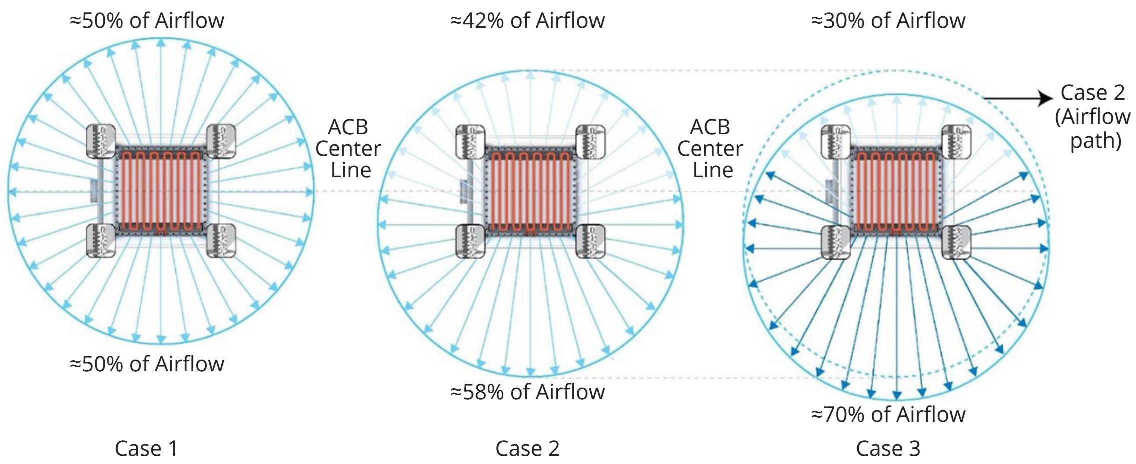


Figure 3. Air pattern out of the ACB.

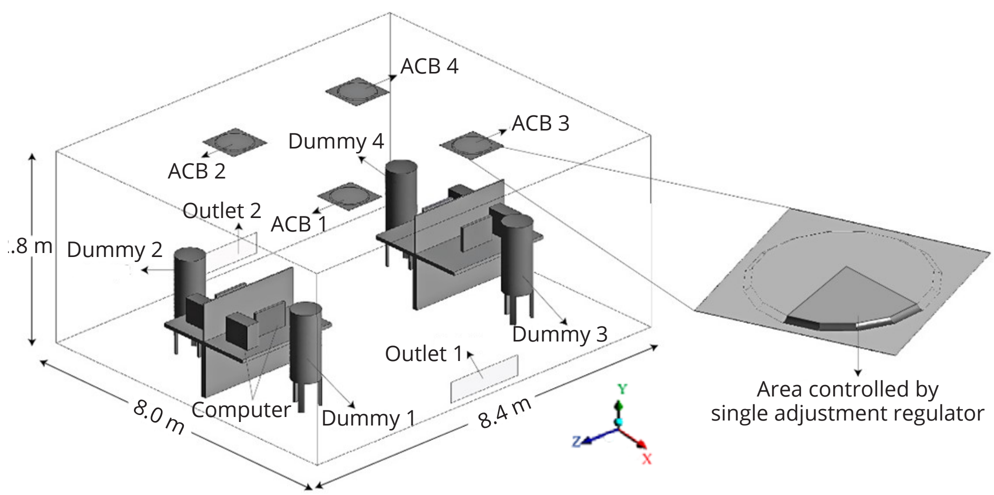
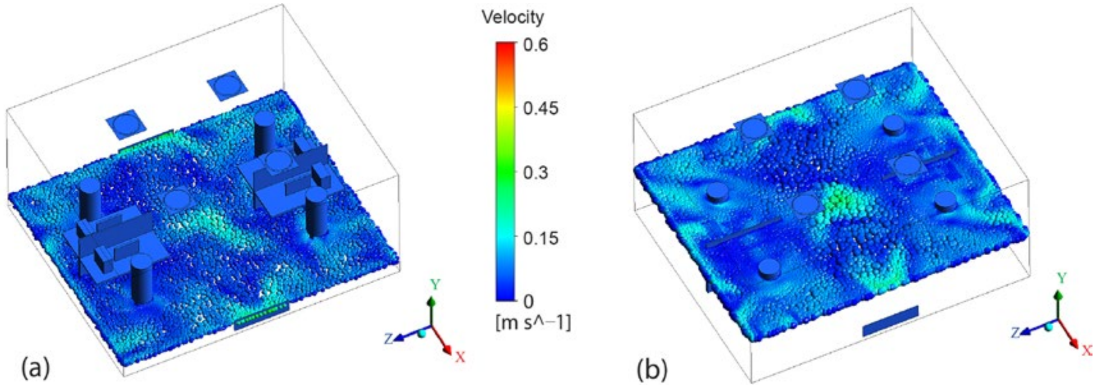
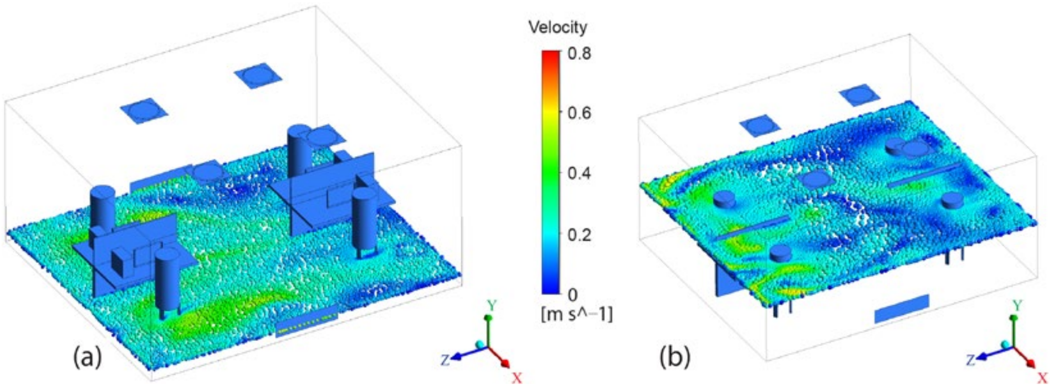


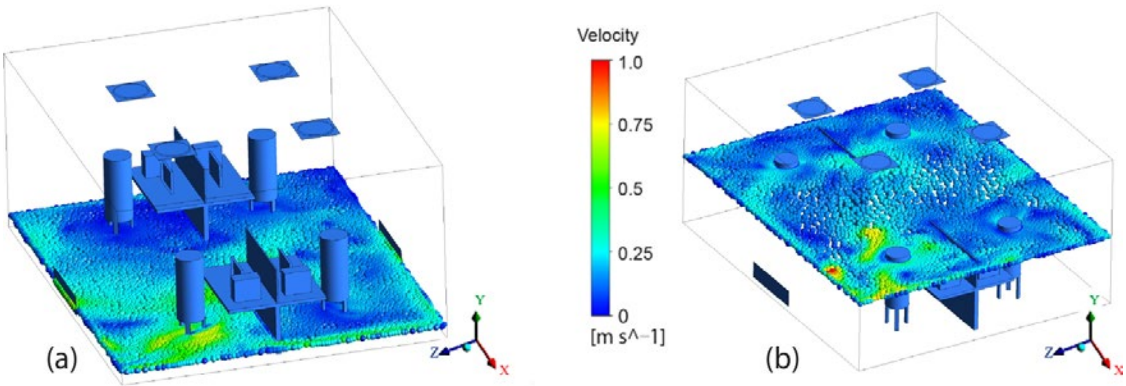
Figure 4. CFD Geometry.



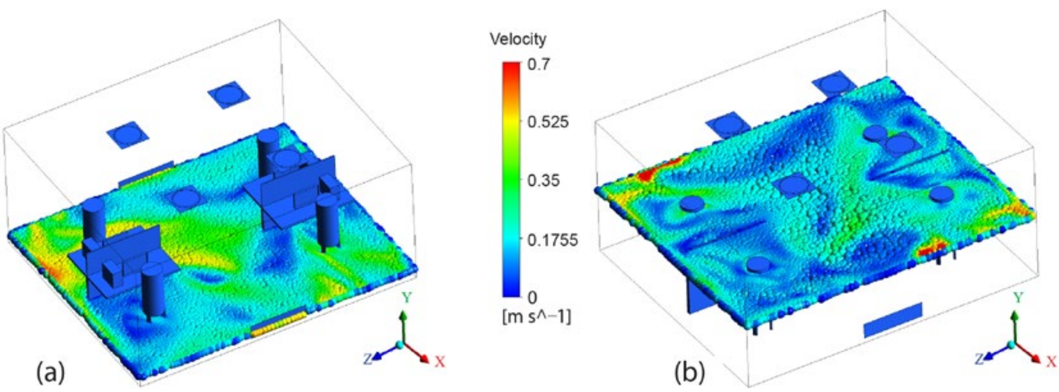
Case 1: Conventional mixing ventilation with uniform air velocity distribution (0.15 m/s).



Case 2: Air velocity distribution (0.45 m/s) for two 1.4 MET occupants in Z-direction and air velocity distribution (0.15 m/s) for two 1.2 MET occupants in the other direction.



Case 3: Air velocity distribution (0.65 m/s) for a single 1.6 MET occupant in the ZX-direction and air velocity distribution (0.15 m/s) for three 1.2 MET occupants in the other directions.



Case 4: Air velocity distribution (0.65 m/s) for a single 1.6 MET occupant in the Z (-X)-direction, air velocity distribution (0.45 m/s) for a single 1.4 MET occupant in X (-Z)-direction and air velocity distribution (0.15 m/s) for two 1.2 MET in the other directions.

Figure 5. Variable air velocity Case 1, Case 2, Case 3, and Case 4. a=0.51 m above floor, b=1.1 m above floor.

Energy Savings

By using precision ventilation during the cooling period, the annual energy savings from heating and cooling were 15% and this was achieved by raising the cooling setpoint by 2°C.

4. Conclusions

The following conclusions can be drawn from the above experimental and simulation study:

1. Precision ventilation can be based on a conventional mixed ventilation system using ACBs.
2. Precision ventilation can act as a new potential ventilation strategy to make the office environment more comfortable and productive for all office occupants.
3. JetCones instead of conventional nozzles brings a novelty in the application of ACBs, which simultaneously achieved low, medium and high-level air velocity zones in a shared office space.
4. The variation in local air velocities with respect to occupants' metabolic rate and room air temperature significantly improved their thermal comfort.
5. Even the occupants with normal metabolic rates, seated together with occupants with higher metabolic rates that were seated in higher air velocity zones remained unaffected and were satisfied.
6. The annual energy savings of 15% were achieved by raising the cooling setpoint by 2°C. ■

References

Please find the complete list of references in the html-version at https://www.rehva.eu/rehva-journal

ARTICLES

Interaction of thermal plumes from a patient wound with mixing and laminar airflow at different room temperatures in two operating rooms at St. Olav's hospital

TOMÁŠ FEČER
PhD, Department of Energy and Process Engineering, Norwegian University of Science and Technology, Trondheim, Norway Marina

ASUERO VON MUNTHE AF MORGENSTIERNE
M.Sc, Department of Energy and Process Engineering, Norwegian University of Science and Technology

YANG BI
PhD student, Department of Energy and Process Engineering, Norwegian University of Science and Technology

HANS MARTIN MATHISEN
PhD, Professor, Department of Energy and Process Engineering, Norwegian University of Science and Technology

TROND THORGEIR HARSEM
MSc, Responsible Research & Development for HVAC, Norconsult

LIV-INGER STENSTAD
MSc, Radiographer and R&D coordinator, St. Olavs Hospital

GUANGYU CAO
Dr. (Sc.), Professor, Department of Energy and Process Engineering, Norwegian University of Science and Technology, Trondheim, Norway
guangyu.cao@ntnu.no

Abstract: This study investigated the interaction of the thermal plumes (TP) of the patient´s wound with two different room temperatures, 21°C and 23°C in two operating rooms with mixing (MV) and laminar airflow (LAF)at St. Olav's hospital. The indoor environment parameters such as temperature, air velocity, and turbulence intensity were measured for the investigation of the thermal plume (TP) over the patient's wound with an interrogation area of 100 cm (height) × 60 cm (width). The higher turbulence intensity appeared along the vertical direction with mixing ventilation. In the case of laminar airflow, the high turbulence intensity zone is located in the horizontal direction around the patient's wound which indicates suppression of the buoyancy effect by the downward laminar airflow.

Keywords: Thermal plume, ventilation, operating rooms, air velocity

Introduction

Clean air in operation rooms (ORs) prevents surgical site infections (SSI) [1], which refer to infection at the skin, tissue, or organ level within 30 to 90 days of surgery [2]. Air currents and human movement in the surgical room can relocate the squames and bacteria-carrying particles (BCPs) towards the sterilised area [3], [4]. Studies have demonstrated that BCPs can be also spread around the surgical area due to thermal plumes and contaminate the surgical site [9]. Interaction between the skin of the human body and surrounding air creates a temperature gradient where the convective boundary layer (CBL) around the surfaces of the human body releases a thermal plume (TP) [5][6]. Therefore, thermal plumes (TP) are an energy exchange between the body and its surroundings, causing the air to rise slowly and transporting pollutants with less density than the supply air [7]. The thermal plume (TR) and the convective boundary layer (CBL) of the human body are studied through both numerical and experimental approaches without, and with a breathing manikin in small occupied spaces [5][6][9][9][10], isolation room [4], operating room with mixing, laminar airflow ventilation and their combination [7][11]. The interest to intervene in a significant way to understand the TP and CBL is obvious. Among those studies, there are three main aspects that influence the buoyancy effect of TP and CBL – the different temperatures between the skin and surrounding air, the body position of the manikin, and the velocity of air over the body.

Therefore, understanding the thermal plumes and interaction between different airflows is critical to recognising the airflow pattern in a room and thus the risk of SSI [12]. This study aims to quantify and characterise the impact of two different room temperatures, 21°C and 23°C, on the thermal plume around the patient wound in two different rooms of St. Olav's hospital with mixing (MV) and laminar airflow (LAF).

Experimental set-up

Measurement of temperature, air velocity and turbulence intensity is executed in two operating rooms, MV and LAF with two different room temperatures, 21°C and 23°C, respectively. The operating room with mixing ventilation and 20 ACH has an area of 59.1 m² and a height of 2.9 m while the laminar operating room with 61 ACH has a total area of 56.1 m², of which 11 m² is the rectangular LAF zone, with a room height of 3.08 m.

A female humanoid thermal manikin is 1.7 m tall and located at an operating bed to simulate a patient under stomach surgery. The manikin is covered by the surgical blanket and at the surgical site is cut into the shape of a 20 cm square. The surface temperature of the patient's wound is in the range of 33.5 to 34.5°C measured by the image of the thermal detector Bosch PTD 1 and infrared camera Flir one - iOS.

The sides of the surgical blanket is taped to the manikin as seen in **Figure 2**. The interrogation area of 100cm (height) x 60cm (width) around the wound is measured by seven anemometers SensoAnemo 5100 LSF, 8.5 cm apart, in levels 5, 10, 25, 50, and 100 cm over the wound. Each level is measured for five minutes. Boundary conditions of measurement cases are introduced in the **Table 1**.

Table 1. *Measuring cases.*

Case No.	Type of ventilation [-]	Room temperature [°C]	Supply temperature [°C]	ACH
Case (a)	MV	21	18.9	20
Case (b)	MV	23	23.3	20
Case (c)	LAF	21	21.2	61
Case (d)	LAF	23	22.8	61

Figure 1. In the left, image of the mixing ventilation operating room at St. Olav. In the right, Image of the Laminar airflow operating room at St. Olav Hospital.

Results

Velocity field

Figure 3 represents the velocity results of four scenarios, where cases, (a) and (b), refer to MV and cases (c) and (d) represent LAF. The thermal plume for the case (a), has the highest velocity at 10 cm above the wound. The thermal plume's velocity decreases with increasing distance from the wound and mixes with the

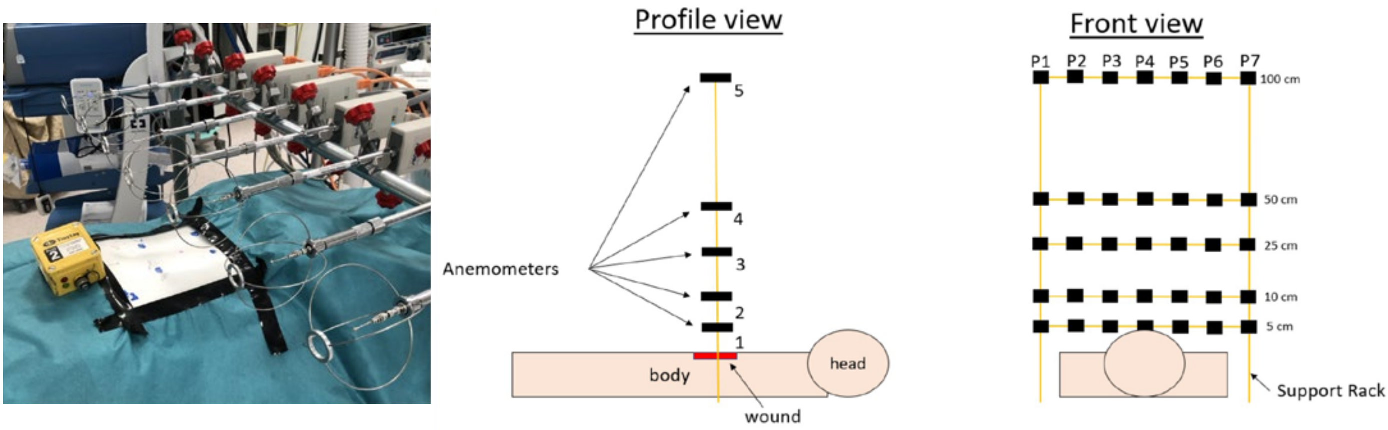


Figure 2. In the left, illustration of anemometers measurement and size of surgical wound. In the right, scheme of measuring points.

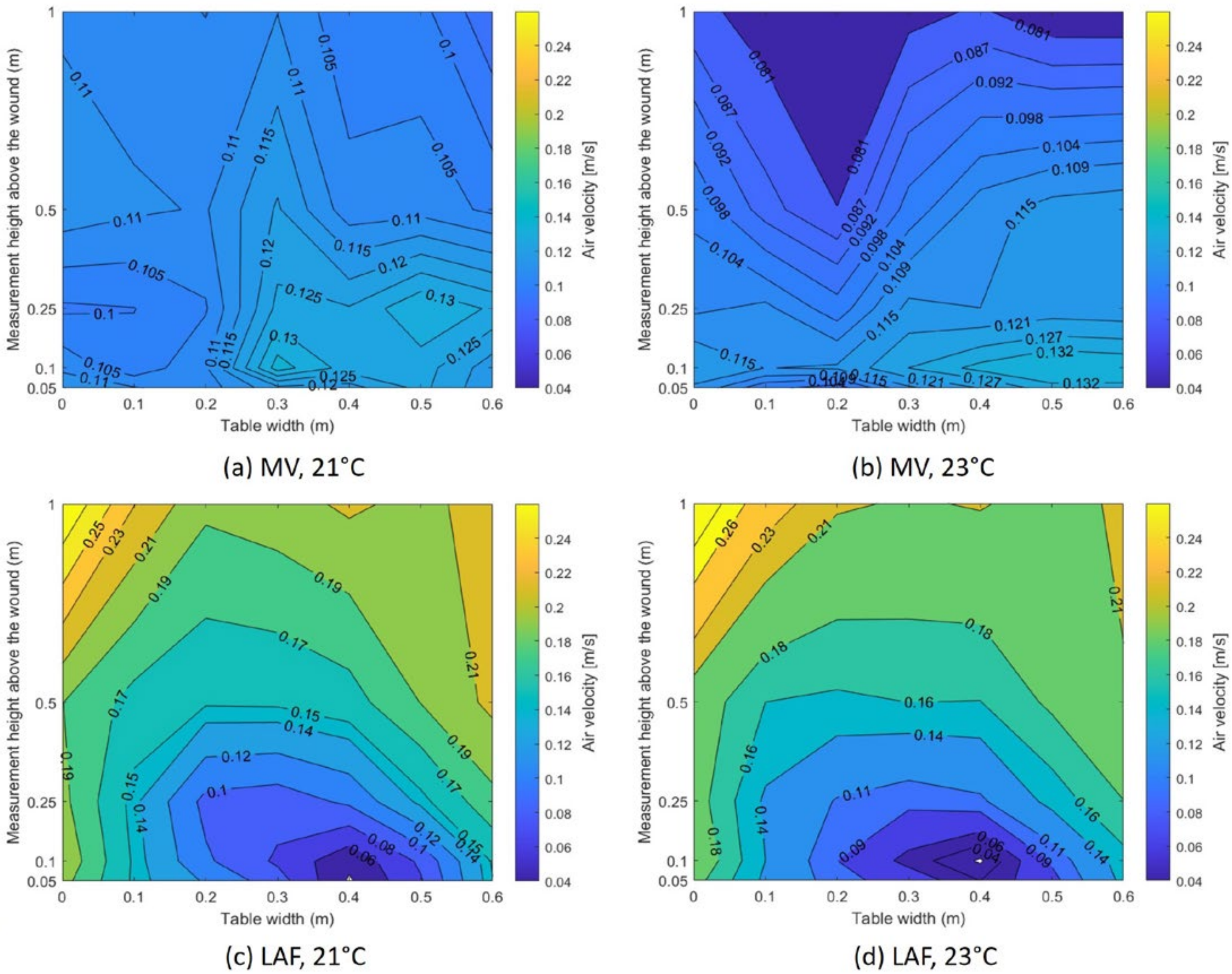


Figure 3. Velocity profile of the patient´s thermal plume of mixing ventilation (a), (b) and laminar airflow (c) and (d).

room air, which is caused by the gradual weakening of the buoyancy effect, respectively. For the case (b) the velocity is lower in the vertical direction than the horizontal direction, which is also proven by temperature stratification in **Figure 5**. In case (c) a higher velocity gradient occurs within 50 cm over the patient's wound than in case (d), which is caused by higher interaction of thermal plume by LAF. In the case (d), due to the lower temperature difference and density difference between laminar airflow and thermal plume, their interaction is observed closer to the wound.

Turbulence intensity and temperature field

Turbulent intensity and temperature are also observed for all four scenarios, case (a), (b), (c) and (d) which are shown in **Figure 4** and **Figure 5**, respectively. Due to higher room temperature in this case (b) by 2°C, **Figure 4** shows that a weaker buoyancy effect occurs, and the thermal plume expands in a horizontal direction. In both LAF cases (c) and (d), laminar airflow is dominated against the buoyancy effect of the thermal plume, respectively. In **Figure 4**, the maximum values of turbulence intensity are observed in the LAF of 40% of cases (c) (d), which are very close to the patient's wound. However, cases of MV (a) and (b) indicate an overall higher gradient of turbulence intensity in the horizontal and vertical directions. In case (a) on both sides is occurs locations with TI up to 23% cause a rising thermal plume, which is possibly observed in the centre of the temperature field. In case (b) is observed area in the vertical direction on the left side and in the upper part of TI up to 30%. This is caused by the expansion of the thermal plume in the horizontal direction and low velocities over the thermal plume which is also observed by stratification on the temperature field. As is mentioned in the previous chapter, case (c) has higher TI above and around the surgical wound than case (d) due to the higher interaction of the thermal plume with LAF.

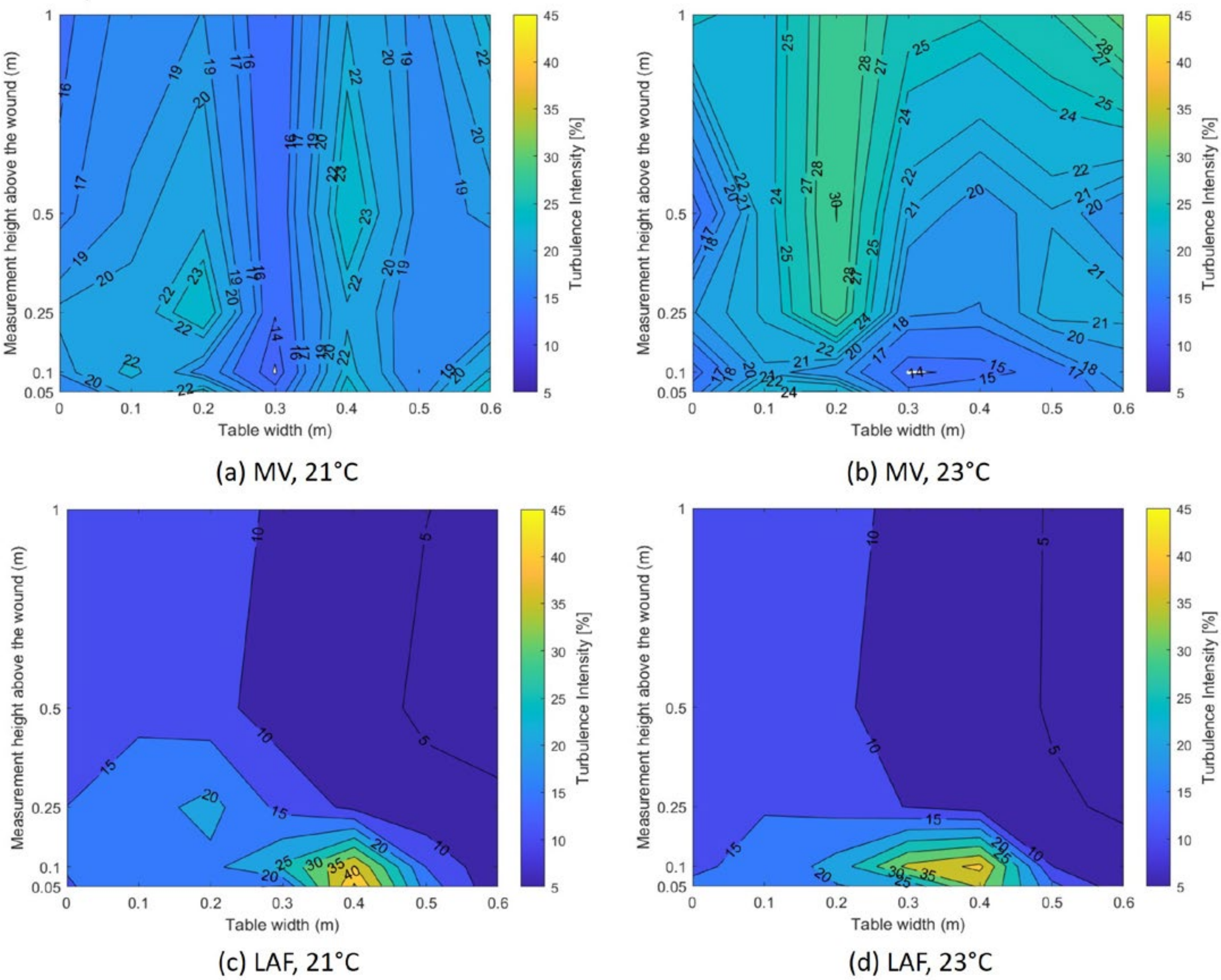


Figure 4. Turbulence intensity profile of the patient´s thermal plume of mixing ventilation (a), (b) and laminar airflow (c) and (d).

Conclusion

This study shows an experimental investigation of the interaction of thermal plumes with mixing and laminar airflow over a patient´s wound at two room temperatures, 21°C and 23°C. By comparing the results of air velocity, temperature, and turbulence intensity of four cases for MV (a), (b) and for LAF (c), (d), the conclusions are summarised as follows:

a) In the cases with a room temperature of 23°C, (b) and (d) observed the expansion of the thermal plume in the horizontal direction, while with a room temperature of 21°C thermal plume directly expanded in the vertical direction.
b) In the case of laminar airflow, a higher room temperature, 23°C, indicates lower turbulence intensity over the patient's wound and surroundings.
c) In the case of mixing ventilation, a lower temperature, 21°C, indicates lower turbulence intensity over the patient's wound and surroundings.
d) Laminar airflow has higher turbulence intensity within 25 cm over the wound than mixing ventilation, while the turbulence intensity with mixing ventilation varies in both vertical and horizontal directions. ■

References

Please find the complete list of references in the html-version at https://www.rehva.eu/rehva-journal

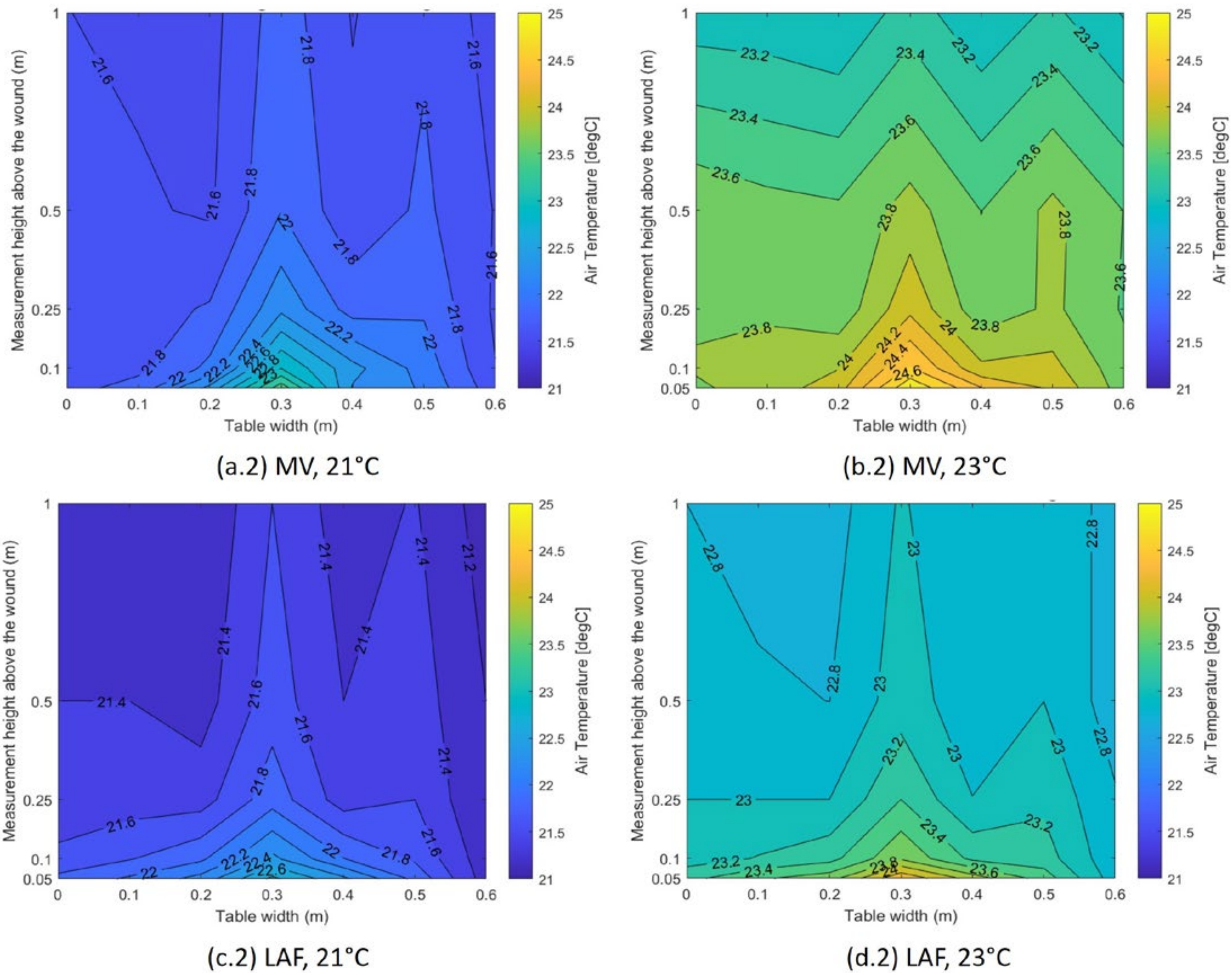


Figure 5. Temperature profile of the patient´s thermal plume of mixing ventilation (a), (b) and laminar airflow (c) and (d).

Synergy in HVAC systems: Exploring Challenges and Opportunities in Dynamic Control Communication

Interview of Dr. **Darius Žižys**, Controls Manager (Residential Air Handling Units), Systemair, discusses the trends related to the interoperability of control systems, and how manufacturers are navigating shifts in customer demand, technology, legislation and cybersecurity in an increasingly connected world.

DARIUS ŽIŽYS
PhD, Product Manager (RAHU controls), Systemair, Lithuania

Contact email: hannah.uy@systemair.com

The importance of interoperability

HVAC systems are pivotal in ensuring building inhabitants' comfort, health and well-being. While the ability of HVAC technologies to regulate mostly air quality, but also temperature and humidity varies based on several factors. The effectiveness of HVAC also greatly depends on the controls that manage and optimise their operation.

Executive Summary

This article covers:

- Exploring complexities and potentials of dynamic control systems in HVAC.
- Adaptation to changing demands, technology, regulations, and cybersecurity.
- Interoperability's pivotal role in HVAC effectiveness.
- Legislative push for interoperability, exemplified by the European Commission's code of conduct.
- Interoperability benefits, including energy optimisation during peak periods.
- Challenges: component shortages, high R&D costs, and cybersecurity concerns.
- Customer hesitance impacting investment in advanced systems.
- The vital importance of proper installations for optimal performance.
- Growing customer awareness driven by IAQ and smart home trends.
- Increasing demand for better controls in the HVAC industry's future.

Sharing a Systemair perspective on this topic is Dr. Darius Žižys, Controls Manager (Residential Air Handling Units), Systemair. "At Systemair, we spend much time analysing the needs and requirements of different markets, hence our products are dynamic and alive. They are constantly changing, and this especially applies to our controls. The current focus in residential applications is serviceability and interoperability of devices - how freely devices can talk to other devices and be integrated into larger systems."

The need for interoperability is becoming a critical issue for manufacturers, says Žižys, pointing out that this is driven by the increasing popularity of Smart Home systems, which are becoming simpler and more accessible for regular residential users. Building management systems (BMS) and the need for device-to-device communication also play a significant role in controls development decision making. "This is also relayed to legislation as interoperability is becoming more of a requirement."

Currently, Žižys adds, legislation regarding controls is not yet comprehensive. "The European Commission's Directorate General of the Environment and Joint Research Centre (JRC) are currently working on a Code of Conduct for Energy Smart Appliances (ESA), which will be voluntary for manufacturers to sign," he explains. "By signing the CoC manufacturer confirms that the energy-related devices produced will be inter-operable with devices of other signatories, the Building Energy Manager (BEM) and the power grid. This will enable the stakeholders to exchange information about current and forecasted energy usage of devices within the household, energy availability and prices from the grid, thus optimising energy usage within the household in the most efficient way. CoC for ESA is part of an even bigger legislative effort to optimise energy usage by the EU, but this only illustrates the trend".

Žižys remarks that this is especially critical against the backdrop of the energy crisis across Europe and high prices of fuel: "This is how the EU is trying to optimise energy use and production, and make it more efficient so consumption is more distributed and predictable, we should consume the energy when there is a surplus of it, and train the device to consume less during low availability and high energy price points."

The need for such functionalities, says Žižys, will only increase in the next 5-10 years. "In my opinion, while this is not a pressing requirement currently, as manufacturers are doing this voluntarily, strengthening the interoperability between devices and the energy grid will become mandatory in time."

From supply chain to cybersecurity: Tackling the critical issues

While the need to innovate controls to address this demand is clear among manufacturers, adapting to this trend can be a challenge. One of the issues that manufacturers have had to deal with recently is a component shortage. "Everyone had an issue with component shortage for about one and a half years," Žižys explains. "We are slowly coming out of it, but the problem is that controllers are rather monolithic. Components such as the Micro Controller Units (MCU), chips that provide complete intelligence and other semiconductor-based components were a real struggle to source. If you cannot source that, you would need to look for alternatives, and based on design and selected architecture, there are limited options. We, like other manufacturers, spent a lot of resources to redesign firmware and hardware to house new components."

Admittedly, says Žižys, there are workarounds through brokers. However, the price could go from € 2 to € 100. "This is why our focus now is on flexibility," he adds. "We investigate using more generic hardware platforms with decoupled software/hardware architectures that would add a great deal of flexibility in times of need. We generally work on being more adaptive regardless of component supply situations by being less dependent on the hardware."

Žižys points out that there is also a heavy cost associated with investing in R&D for changes or improvements in controls. "It can be a struggle as each functional or other change in controls comes with not only significant hardware and/or software development costs but also certification and other direct or indirect costs. Some changes are driven by market requirements, and these are easier to absorb since usually these changes simply help to sell more production by providing unique selling points. On the other hand – some changes are driven by legislative changes and do not necessarily provide obvious added value to the product as seen by the end customer. Such topics cause big debates in trade associations such as Eurovent and EVIA, with many manufacturers fighting against regulations." Žižys says there is always a compromise about what a legislator would like to do and what the manufacturer would like to do, and this is the value of associations and ensuring manufacturers' opinions are well reflected.

Another evolving issue in this space is cybersecurity and data protection laws. "Interoperability is nice, but it's important to remember the other side of the coin, protection of both machine and user personal data, security of the IT and other infrastructure is becoming more and more regulated, that, along with systems becoming more and more complex adds additional administrative and maintenance burden on manufacturers such as Systemair", he says, underlining the importance of adhering to data and cybersecurity regulations and that navigating this is critical going forward.

A customer perspective

In addition to the challenges manufacturers face in developing controls, there can also be reluctance among customers who are unsure if they are willing to invest in the higher cost associated with systems with better controls. "Within the European market, the Energy Related Product (ERP) label is present, denoted by categories like Class A, B, or lower," Žižys states. "These categories are tied to regulations outlining the criteria for achieving each class, including the necessary performance and, most importantly for my line of work, control factor that qualify a product for an "A" or "D" class. For example, a system with zonal CO_2 control can better respond to the changing IAQ conditions in certain building zones by adjusting ventilation rates and, as a result, minimising energy consumption and building energy losses related to ventilation. It greatly benefits customers, but it's not always the easiest to encourage customers to invest in better controls and additional materials required to achieve such functionality. Such functionality is typically only adopted once it is no longer possible to achieve requirements related to total building energy performance classes without adopting such solutions.

As a result, customers are forced to choose more expensive devices with better ERP class to contribute to achieving required building energy performance class."

In markets where requirements for newly built or renovated buildings are not that strict, there is less willingness to select a better control platform.

A shift in customer awareness

Despite the above, Žižys remains optimistic. He believes that the pandemic became a catalyst for greater awareness, as, in some markets, requirements were set for commercial applications to have CO_2 sensors to monitor IAQ.

Additionally, Žižys says there is a growing demand among technologically forward adults who see their homes as a complete system where each device should be able to communicate with each other to achieve the best possible performance. He says that when the smart home platform becomes more affordable, simpler to deploy and more accessible in general, offering systems that can provide connectivity through a cloud API or platforms like Alexa, IFTTT, or Google Home has gained traction and interest. "These interoperability requirements become important, not just because of legislation, but also because end users are becoming more self-aware." As awareness of the importance of ventilation grows, Žižys holds that this will also drive greater investment in better controls. ■

Exhibitions, Conferences and Seminars

Please send information of your event to Ms Marie Joannes mj@rehva.eu

November 2023		
13-14 November 2023	REHVA Brussels Summit 2023 (rehva.eu)	Brussels, Belgium
December 2023		
6-8 December 2023	54th International HVAC&R Congress and Exhibition (kgh-kongres.rs)	Belgrade, Serbia
March 2024		
12-15 March 2024	MCE 2024 (mcexpocomfort.it)	Milan, Italy
April 2024		
22-25 April 2024	Roomvent 2024 (invitepeople.com)	Stockholm, Sweden
May 2024		
15-17 May 2024	REHVA Annual metting 2024 (rehva.eu)	Istanbul, Turkey
June 2024		
9-11 June 2024	BuildSim Nordic 2024 (buildsimnordic2024.ibpsa-nordic.org)	Espoo, Finland
June 2025		
4-6 June 2025	CLIMA 2025 (climaworldcongress.org)	Milano, Italy

REHVA President participation to the AICVF 38th Congress

REHVA President, **Catalin Lungu** participated to the AICVF 38th Congress. He gave an insight of his knowledge during a conference on "*Les choix énergétiques*".

Frank Hovorka, the former REHVA president, also joined the Congress as he is now AICVF President.

It is in Nice, France, that many professionals gathered to discuss one of the biggest challenges of our profession: How to reinvent buildings and reach carbon neutrality?

This essential topic has been debated through multiple conferences, where experts expressed their concerns and opinions on the subject. How to intertwine renovations with new constructions? How to let go of the habit to use fossils energies in our installations? How to replace them?

The goal was to research in within collective knowledge of engineers, to try and respond to these challenges. ■

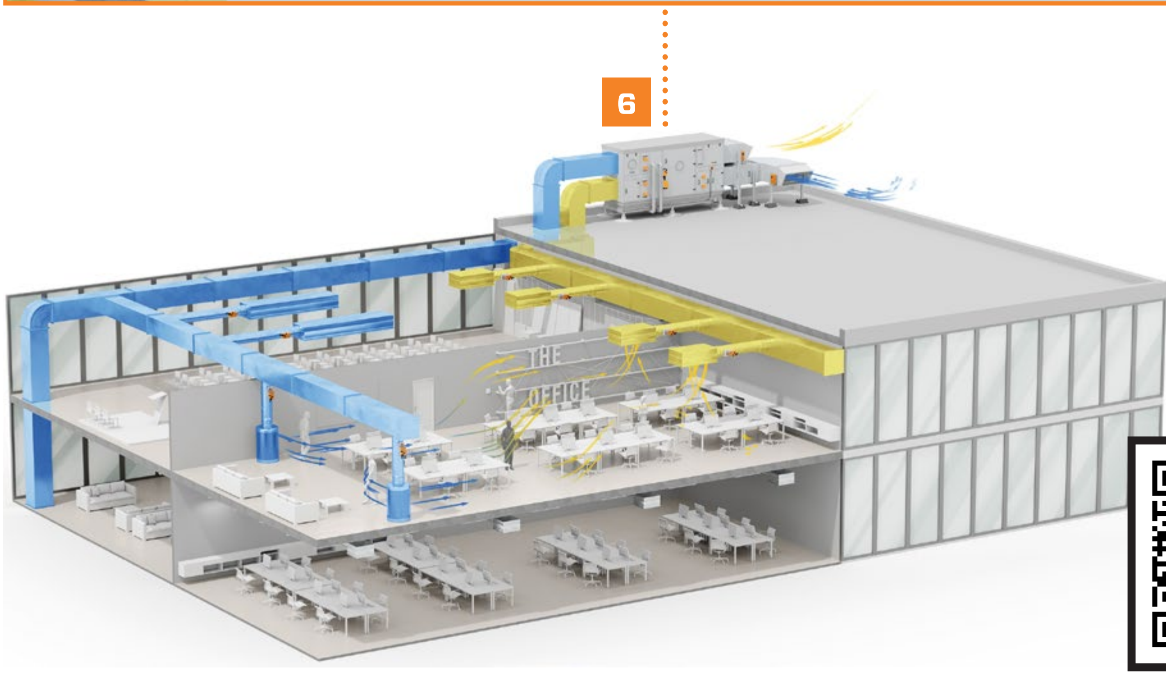
CATALIN LUNGU
REHVA President

FRANK HOVORKA
Former REHVA President

The Seven Essentials of Healthy Indoor Air

6. Effective filtration

To prevent contaminants from entering indoor spaces through supply air ducts, filters must be integrated into the air handling unit. In systems where part of the extract air is mixed back into the supply air, suitable filters must be used to prevent contamination from infectious microbes. To ensure that monitoring of these filters is effective, pressure sensors and dynamic airflow measurement can be used. If the contamination of the filter increases, the pressure drop across the filter also increases. By simultaneously measuring the volumetric flow through the filter, a relatively accurate statement can be made as to whether and when the filter needs to be replaced.



Learn more about Belimo's 7 essentials of healthy indoor air:
https://www.belimo.com/ch/en_GB/indoor-air-quality/7-essentials-iaq

Scan the QR code

REHVA
Federation of European Heating, Ventilation and Air Conditioning Associations

MEMBERS

ATIC vzw–asbl – Belgium
www.atic.be

BAOVK – Bulgaria
www.baovk.bg

STP – Czech Republic
www.stpcr.cz

DANVAK – Denmark
www.danvak.dk

EKVU – Estonia
www.ekvy.ee

FINVAC – Finland
www.finvac.org

AICVF – France
www.aicvf.org

VDI–e.V. – Germany
www.vdi.de

ÉTÉ – Hungary
www.eptud.org

MMK – Hungary
www.mmk.hu

AiCARR – Italy
www.aicarr.org

AHGWTEL/LATVAC – Latvia
www.lsgutis.lv

LITES – Lithuania
www.listia.lt

AIIRM – Republic of Moldova
www.aiirm.md

TVVL – The Netherlands
www.tvvl.nl

NEMITEK – Norway
www.nemitek.no

PZITS – Poland
www.pzits.pl

ORDEM DOS ENGENHEIROS – Portugal
www.ordemengenheiros.pt

AFCR – Romania
www.criofrig.ro

AGFR – Romania
www.agfro.ro

AIIR – Romania
www.aiiro.ro

KGH c/o SMEITS – Serbia
www.smeits.rs

SSTP – Slovakia
www.sstp.sk

ATECYR – Spain
www.atecyr.org

SWEDVAC – Sweden
www.energi-miljo.se

DIE PLANER – Switzerland
www.die-planer.ch

TTMD – Turkey
www.ttmd.org.tr

CIBSE – United Kingdom
www.cibse.org

Network of 26 European HVAC Associations joining 120 000 professionals

REHVA Office: Rue Washington 40, 1050 Brussels - Belgium • Tel: + 32 2 514 11 71 - info@rehva.eu - www.rehva.eu

REHVA

Federation of European Heating, Ventilation and Air Conditioning Associations

SUPPORTERS

Leaders in Building Services

Daikin Europe – Belgium www.daikin.eu	EPEE – Belgium www.epeeglobal.org	EVIA – Belgium www.evia.eu	Velux – Denmark www.velux.com	Granlund – Finland www.granlund.fi
Halton – Finland www.halton.com	Uponor – Finland www.uponor.com	Eurovent Certita Certification – France www.eurovent-certification.com	LG Electronics – France www.lgeaircon.com	Saint-Gobain – France www.saint-gobain.com
Viega – Germany www.viega.com	Aermec – Italy www.aermec.com	Evapco Europe – Italy www.evapco.eu	Rhoss – Italy www.rhoss.com	Royal Haskoning DHV – The Netherlands www.royalhaskoningdhv.com
SMAY – Poland www.smay.eu	E.E.B.C. – Romania www.eebc.ro	Dosetimpex – Romania www.dosetimpex.ro	Testo – Romania www.testo.com	Camfil – Sweden www.camfil.com
Fläkt Group – Sweden www.flaktgroup.com	Lindab – Sweden www.lindab.com	Swegon – Sweden www.swegon.com	Systemair – Sweden www.systemair.com	Belimo Automation – Switzerland www.belimo.com
Arçelik – Turkey www.arcelikglobal.com	Friterm Termik Cihazlar Sanayi ve Ticaret – Turkey www.friterm.com			

REHVA ASSOCIATE ORGANISATIONS:

ISIB – Turkey www.isib.org.tr	ECI – Belgium copperalliance.org	OAER – Romania www.oaer.ro

rehva.eu
info@rehva.eu

REHVA
Federation of European Heating, Ventilation and Air Conditioning Associations