

ANNEX 5

ANNEX 78

A method for testing gas-phase air cleaners

AIVC Contributed Report 20

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Preface

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international cooperation among the 30 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes (TCPs). The mission of the IEA Energy in Buildings and Communities (IEA EBC) TCP is to support the acceleration of the transformation of the built environment towards more energy efficient and sustainable buildings and communities, by the development and dissemination of knowledge, technologies and processes and other solutions through international collaborative research and open innovation. (Until 2013, the IEA EBC Programme was known as the IEA Energy Conservation in Buildings and Community Systems Programme, ECBCS.).

The high priority research themes in the EBC Strategic Plan 2019-2024 are based on research drivers, national programmes within the EBC participating countries, the Future Buildings Forum (FBF) Think Tank Workshop held in Singapore in October 2017 and a Strategy Planning Workshop held at the EBC Executive Committee Meeting in November 2017. The research themes represent a collective input of the Executive Committee members and Operating Agents to exploit technological and other opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy technologies, systems and processes. Future EBC collaborative research and innovation work should have its focus on these themes.

At the Strategy Planning Workshop in 2017, some 40 research themes were developed. From those 40 themes, 10 themes of special high priority have been extracted, taking into consideration a score that was given to each theme at the workshop. The 10 high priority themes can be separated in two types namely 'Objectives' and 'Means'. These two groups are distinguished for a better understanding of the different themes.

Objectives: The strategic objectives of the EBC TCP are as follows:

- reinforcing the technical and economic basis for refurbishment of existing buildings, including financing, engagement of stakeholders and promotion of co-benefits;
- improvement of planning, construction and management processes to reduce the performance gap between design stage assessments and real-world operation;
- the creation of 'low tech', robust and affordable technologies;
- the further development of energy efficient cooling in hot and humid, or dry climates, avoiding mechanical cooling if possible; the creation of holistic solution sets for district level systems taking into account energy grids, overall performance, business models, engagement of stakeholders, and transport energy system implications.

Means: The strategic objectives of the EBC TCP will be achieved by the means listed below:

- the creation of tools for supporting design and construction through to operations and maintenance, including building energy standards and life cycle analysis (LCA);
- benefitting from 'living labs' to provide experience of and overcome barriers to adoption of energy efficiency measures;
- improving smart control of building services technical installations, including occupant and operator interfaces;
- addressing data issues in buildings, including non-intrusive and secure data collection;
- the development of building information modelling (BIM) as a game changer, from design and construction through to operations and maintenance.

The themes in both groups can be the subject for new Annexes, but what distinguishes them is that the 'objectives' themes are final goals or solutions (or part of) for an energy efficient built environment, while the 'means' themes are instruments or enablers to reach such a goal. These themes are explained in more detail in the EBC Strategic Plan 2019-2024.

The Executive Committee

Overall control of the IEA EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA EBC Implementing Agreement. At the present time, the

following projects have been initiated by the IEA EBC Executive Committee, with completed projects identified by (*) and joint projects with the IEA Solar Heating and Cooling Technology Collaboration Programme by (☼):

- Annex 1: Load Energy Determination of Buildings (*)
- Annex 2: Ekistics and Advanced Community Energy Systems (*)
- Annex 3: Energy Conservation in Residential Buildings (*)
- Annex 4: Glasgow Commercial Building Monitoring (*)
- Annex 5: Air Infiltration and Ventilation Centre
- Annex 6: Energy Systems and Design of Communities (*)
- Annex 7: Local Government Energy Planning (*)
- Annex 8: Inhabitants Behaviour with Regard to Ventilation (*)
- Annex 9: Minimum Ventilation Rates (*)
- Annex 10: Building HVAC System Simulation (*)
- Annex 11: Energy Auditing (*)
- Annex 12: Windows and Fenestration (*)
- Annex 13: Energy Management in Hospitals (*)
- Annex 14: Condensation and Energy (*)
- Annex 15: Energy Efficiency in Schools (*)
- Annex 16: BEMS 1- User Interfaces and System Integration (*)
- Annex 17: BEMS 2- Evaluation and Emulation Techniques (*)
- Annex 18: Demand Controlled Ventilation Systems (*)
- Annex 19: Low Slope Roof Systems (*)
- Annex 20: Air Flow Patterns within Buildings (*)
- Annex 21: Thermal Modelling (*)
- Annex 22: Energy Efficient Communities (*)
- Annex 23: Multi Zone Air Flow Modelling (COMIS) (*)
- Annex 24: Heat, Air and Moisture Transfer in Envelopes (*)
- Annex 25: Real time HVAC Simulation (*)
- Annex 26: Energy Efficient Ventilation of Large Enclosures (*)
- Annex 27: Evaluation and Demonstration of Domestic Ventilation Systems (*)
- Annex 28: Low Energy Cooling Systems (*)
- Annex 29: ☼ Daylight in Buildings (*)
- Annex 30: Bringing Simulation to Application (*)
- Annex 31: Energy-Related Environmental Impact of Buildings (*)
- Annex 32: Integral Building Envelope Performance Assessment (*)
- Annex 33: Advanced Local Energy Planning (*)
- Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
- Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
- Annex 36: Retrofitting of Educational Buildings (*)
- Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
- Annex 38: ☼ Solar Sustainable Housing (*)
- Annex 39: High Performance Insulation Systems (*)
- Annex 40: Building Commissioning to Improve Energy Performance (*)
- Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
- Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
- Annex 43: ☼ Testing and Validation of Building Energy Simulation Tools (*)
- Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
- Annex 45: Energy Efficient Electric Lighting for Buildings (*)
- Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
- Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
- Annex 48: Heat Pumping and Reversible Air Conditioning (*)
- Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
- Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
- Annex 51: Energy Efficient Communities (*)
- Annex 52: ☼ Towards Net Zero Energy Solar Buildings (*)

Annex 53: Total Energy Use in Buildings: Analysis and Evaluation Methods (*)

Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings (*)

Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance and Cost (RAP-RETRO) (*)

Annex 56: Cost Effective Energy and CO₂ Emissions Optimization in Building Renovation (*)

Annex 57: Evaluation of Embodied Energy and CO₂ Equivalent Emissions for Building Construction (*)

Annex 58: Reliable Building Energy Performance Characterisation Based on Full Scale Dynamic Measurements (*)

Annex 59: High Temperature Cooling and Low Temperature Heating in Buildings (*)

Annex 60: New Generation Computational Tools for Building and Community Energy Systems (*)

Annex 61: Business and Technical Concepts for Deep Energy Retrofit of Public Buildings (*)

Annex 62: Ventilative Cooling (*)

Annex 63: Implementation of Energy Strategies in Communities (*)

Annex 64: LowEx Communities - Optimised Performance of Energy Supply Systems with Exergy Principles (*)

Annex 65: Long-Term Performance of Super-Insulating Materials in Building Components and Systems (*)

Annex 66: Definition and Simulation of Occupant Behavior in Buildings (*)

Annex 67: Energy Flexible Buildings (*)

Annex 68: Indoor Air Quality Design and Control in Low Energy Residential Buildings (*)

Annex 69: Strategy and Practice of Adaptive Thermal Comfort in Low Energy Buildings

Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale

Annex 71: Building Energy Performance Assessment Based on In-situ Measurements

Annex 72: Assessing Life Cycle Related Environmental Impacts Caused by Buildings

Annex 73: Towards Net Zero Energy Resilient Public Communities

Annex 74: Competition and Living Lab Platform

Annex 75: Cost-effective Building Renovation at District Level Combining Energy Efficiency and Renewables

Annex 76: ☼ Deep Renovation of Historic Buildings Towards Lowest Possible Energy Demand and CO₂ Emissions

Annex 77: ☼ Integrated Solutions for Daylight and Electric Lighting

Annex 78: Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications

Annex 79: Occupant-Centric Building Design and Operation

Annex 80: Resilient Cooling (*)

Annex 81: Data-Driven Smart Buildings

Annex 82: Energy Flexible Buildings Towards Resilient Low Carbon Energy Systems

Annex 83: Positive Energy Districts

Annex 84: Demand Management of Buildings in Thermal Networks

Annex 85: Indirect Evaporative Cooling

Annex 86: Energy Efficient Indoor Air Quality Management in Residential Buildings

Annex 87: Energy and Indoor Environmental Quality Performance of Personalised Environmental Control Systems

Annex 88: Evaluation and Demonstration of Actual Energy Efficiency of Heat Pump Systems in Buildings

Annex 89: Ways to Implement Net-zero Whole Life Carbon Buildings

Annex 90: EBC Annex 90 / SHC Task 70 Low Carbon, High Comfort Integrated Lighting

Annex 91: Open BIM for Energy Efficient Buildings

Annex 92: Smart Materials for Energy-Efficient Heating, Cooling and IAQ Control in Residential Buildings

Annex 93: Energy Resilience of the Buildings in Remote Cold Regions

Annex 94: Validation and Verification of In-situ Building Energy Performance Measurement Techniques

Annex 95: Human-centric Building Design and Operation for a Changing Climate

Annex 96: Grid Integrated Control of Buildings

Annex 97: Sustainable Cooling in Cities

Working Group – Energy Efficiency in Educational Buildings (*)

Working Group – Indicators of Energy Efficiency in Cold Climate Buildings (*)

Working Group – Annex 36 Extension: The Energy Concept Adviser (*)

Working Group – HVAC Energy Calculation Methodologies for Non-residential Buildings (*)

Working Group – Cities and Communities (*)

Working Group – Building Energy Codes

IEA EBC Annex 78: Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications

The IEA EBC Annex 78 explored the integration of gas-phase air cleaning technologies to supplement traditional ventilation systems, focusing on balancing IAQ and energy efficiency

Ventilation accounts for approximately 20% of the global energy use for providing an acceptable indoor environment. The requirements for ventilation in most standards and guidelines assume acceptable quality of (clean) outdoor air. Worldwide, there is an increasing number of publications related to air cleaning and there is also an increasing sale of gas phase air cleaning products. This puts a demand for verifying the influence of using air cleaning on indoor air quality, comfort, well-being and health. It is thus important to learn whether air cleaning can supplement ventilation with respect to improving air quality i.e. whether it can partly substitute the ventilation rates required by standards. The energy impact of ventilation by using air cleaning as supplement of ventilation needs to be estimated.

IEA-EBC Annex 78 was divided in 4 Subtasks:

- Subtask A: Energy benefits using gas phase air cleaning
- Subtask B: How to partly substitute ventilation by air cleaning
- Subtask C: Selection and testing standards for air cleaners
- Subtask D: Performance modelling and long-term field validation of gas phase air cleaning technologies

IEA EBC Annex 5: Air Infiltration and Ventilation Centre

EBC Annex 5 was first established in 1979 under the name “Air Infiltration Centre” undertaking technical activities and providing information services with the task of minimizing air infiltration energy losses. In 1986, the name was changed to “Air Infiltration and Ventilation Centre” to reflect the importance of the coupling of a good airtightness with appropriate ventilation. Over time, the AIVC has been continuously evolving to respond to emerging concerns, challenges and opportunities. We have now entered the 46th year of the AIVC’s existence and the Centre’s main goal is to provide reference information on ventilation & air infiltration in the built environment with respect to efficient energy use and good Indoor Environmental Quality (IEQ).

In November 2020, the Executive Committee approved the continuation of the AIVC for the period 2022-2026. Peter Wouters and Arnold Janssens are on behalf of INIVE the operating agents for this period.

The AIVC holds a conference each year in September/October in one of the AIVC participating countries. More information can be found here: www.aivc.org/events/conferences

The AIVC organizes 1 to 2 workshops per year. More information can be found here: www.aivc.org/events/workshops

The AIVC organizes a number of webinars per year. More information can be found here: www.aivc.org/events/webinars

The AIVC has formal collaborations with the TightVent platform (<https://tightvent.eu/>), the venticool platform (<https://venticool.eu/>) and the IEQ-GA (<https://ieq-ga.net/>).

Moreover, there is a close interaction with several ventilation related annexes of IEA-EBC. This publication is the result of the collaboration between AIVC and Annex 78.

If you want to be kept informed on the activities of AIVC and related platforms, you can subscribe [here](#).

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1. Introduction

Worldwide, there is an increasing number of publications related to air cleaning and there is also an increasing sale of gas phase air cleaning products. This puts a demand for verifying the influence of using air cleaning on indoor air quality, comfort, well-being and health. It is thus important to learn whether air cleaning can supplement ventilation with respect to improving air quality i.e. whether it can partly substitute the ventilation rates required by standards. This is one of the objective of IEA-EBC Annex 78 “Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications”. Annex 78 also looked at gas phase air cleaning technologies, energy impact of using air cleaners to improve indoor air quality and long term performance of gas phase air cleaners.

International Standards for Ventilation (Indoor Air Quality) like EN16798-1, ISO17772-1 and ASHRAE 62.1 are mainly based on criteria for the Perceived Air Quality (PAQ) combined with a check for individual substances. There is however no testing standard for air cleaners that is based on perceived air quality.

The present report describes a test method for gas phase air cleaners based on PAQ.

2. International standards for indoor air quality and ventilation

The required ventilation rate to provide an acceptable IAQ can be estimated from existing standards like EN16798-1/2, 2019, ISO17772-1/2, 2018 and ASHRAE 62.1, 2019. The concept for estimating the required ventilation rate is to provide an acceptable IAQ according to the following equation.

$$q_{tot} = n \times q_p + A_R \times q_B \quad (1)$$

$$q_{supply} = q_{tot} / e_v \quad (2)$$

Where:

e_v = the ventilation effectiveness

q_{supply} = ventilation rate supplied by the ventilation system

q_{tot} = total ventilation rate for the breathing zone, l/s

n = design value for the number of the persons in the room

q_p = ventilation rate for occupancy per person, l/s, person

A_R = room floor area, m²

q_B = ventilation rate for emissions from building, l/s, m²

The standards include tables with recommended values for the people component and the building component. EN16798-1 and ISO17772-1 operate with four categories of acceptability from 15 to 40 % dissatisfied, while ASHRAE 62.1 operates with an acceptability of less than 20% dissatisfied.

Table 1 shows the recommended levels of ventilation from EN16798-1 and ISO17772-1.

The total recommended ventilation rate will depend on the people’s density in the room and the pollution level of the building.

Table 2 shows an example of the recommended ventilation rate for a 10 m² one-person office for a low-polluting building. The total ventilation rate can be expressed as total l/s, l/(s·person) or l/(s·m²).

Table 1: Design ventilation rates for non-adapted persons for diluting emissions (bio effluents) from people and for buildings for different categories

Indoor Environmental Category	Expected Percentage Dissatisfied (%)	People component (q_p)	Building Component (q_B)		
		Airflow per non-adapted person, l/(s.pers)	Very low polluting building, l/(s m ²)	Low polluting building, l/(s m ²)	Non low polluting building, l/(s m ²)
IEQ _I	15	10	0,5	1,0	2,0
IEQ _{II}	20	7	0,35	0,7	1,4
IEQ _{III}	30	4	0,2	0,4	0,8
IEQ _{IV}	40	2,5	0,15	0,3	0,6

Table 2: Example of design ventilation air flow rates for a single-person office of 10 m² in a low polluting building (non-adapted person)

Indoor Environmental Category	Low- polluting building	Airflow per non-adapted person	Design ventilation air flow rate for the room component		
	l/(s·m ²)	l/(s·person)	l/s	l/(s·person)	l/(s·m ²)
IEQ _I	1,0	10	20	20	2
IEQ _{II}	0,7	7	14	14	1,4
IEQ _{III}	0,4	4	8	8	0,8
IEQ _{IV}	0,3	2,5	5,5	5,5	0,6

The standards also include an analytical method or indoor air quality procedure for calculating the dilution of individual substances according to the mass balance equation below.

The design ventilation rate required to dilute an individual substance is calculated by the formula:

$$Q_h = \frac{G_h}{C_{h,i} - C_{h,o}} \times \frac{1}{\varepsilon_v} \quad (3)$$

Where:

Q_h = the ventilation rate required for dilution, in m³ per second

G_h = the generation rate of the substance, in micrograms per second

$C_{h,i}$ = the guideline value of the substance, in micrograms per m³

$C_{h,o}$ = the concentration of the substance of the supply air, in micrograms per m³

ε_v = the ventilation effectiveness

Air cleaning is mentioned in EN 16798-1 and ISO 17772-1. In the guideline (Part-2) a concept for taking into account gas phase air cleaning is proposed; but the standards do not give directly the possibility for reducing the recommended ventilation or methods for showing the possible improvement in IAQ. ASHRAE 62.1 does allow credit for air cleaning by using the analytical procedure described above. This requires that the cleaning efficiency for individual substances has been tested according to existing test standard for individual substances.

3. Measurement of Perceived Air Quality (PAQ)

The perceived air quality can be measured by evaluation of the air quality by people. Today no electronic sensor is available for measuring PAQ. There is however several standard test methods that are using human testing panels to measure PAQ (ISO 16000-30:2014-Sensory testing of indoor air, ISO 16000-44:2023-Test method for measuring perceived indoor air quality for use in testing the performance of gas phase air cleaners). The following Testing Method describes how PAQ is measured and the Clean Air Delivery Rate (CADR) estimated for a gas phase air cleaner. The CADR can then be partly substituted for the recommended ventilation rate calculated according to EN 16798-1 or ISO 17772-1.

4. Testing Method

4.1. Test Chamber

The method was developed and tested in the field laboratories at the International Centre for Indoor Environment and Energy, Technical University of Denmark (Amada et.al, 2023, 2024). This is just an example on how the test chamber can be used. Other test chambers may also be used. It is however required that the complete test must be in the same test facility.

Figure 1 shows a view from inside and Figure 2 from outside of a test room. The volume of the room is 55.7 m³ (width 2.9 m, length 6.0 m, height 3.2 m). In the test described here three similar rooms were used. The rooms were separated by a well-sealed partition and the air did not move between the rooms. The windows from the rooms faced west and were closed during the experiments. The test room must be ventilated with fresh outdoor air (no recirculation) using a mechanical ventilation system with filtration and heating/cooling. The air supply is installed in the ceiling while the exhaust is located above the door. Each room must be kept at a slight overpressure towards surrounding spaces.

The outdoor air supply rate, temperature, and relative humidity in the rooms must be controlled. The room temperature is kept at 23 °C and Relative Humidity 50%. The testing can be done at other temperatures and humidities; but the same conditions must be kept during the complete testing. Fans were installed in the room to ensure good mixing. Partitions with a height of 1.5 m were placed in each room to hide air cleaners and people sitting inside the rooms so that the panelists performing sensory evaluations could not see them under various exposure scenarios. Other pollution sources (building materials) were placed in the ventilated cabinets called 'pollution boxes'; an inaudible fan installed on the top of each cabinet and operated at a sufficient speed ensured that cabinets were adequately ventilated. The pollution sources and air cleaners could not be seen when performing measurements with panelist entering the room for whole body exposure (see later).

For testing with face exposure, the air from each room was extracted by a small fan through a hose duct to the corridor; this air was presented for sensory evaluations via a diffuser at a flow rate of 1.0 L/s (Figure 2). Three diffusers were installed to extract air from the three test rooms, and the diffusers' arrangement was made so that the panelists performing sensory assessments could not identify which diffuser extracted the air from which room and even whether the air in the diffuser was extracted from the rooms. Two crosses were marked on the floor before the partition to indicate where the sensory evaluations had to be performed upon entering the room.



Figure 1: Test room with partition to hide pollution sources and air cleaners



Figure 2: Outside test room with three diffusers

Another example of a test chamber (Akamatsu et. Al, 2024) is shown in Figure 3. Only one chamber was used in this test. Only emission from people was used as a pollution source. The test chamber was a stainless-steel construction. Exterior of the mid-size stainless-steel chamber (W 1.9 m × D 1.55 m × H 1.9 m, Vol. 5.5 m³).

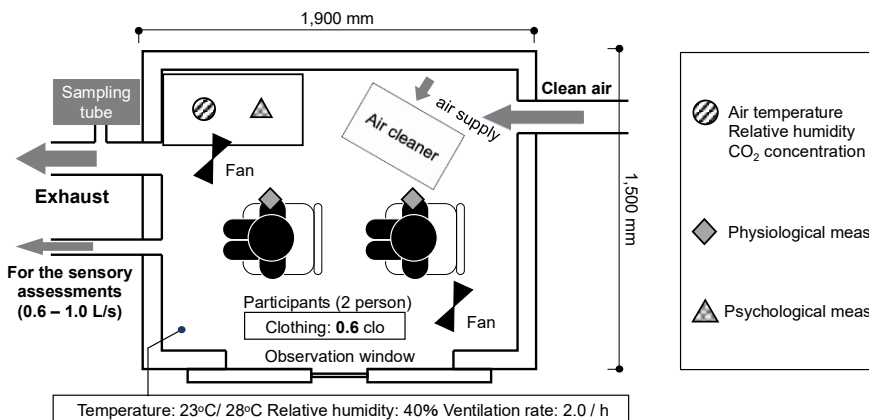


Figure 3: Chamber plan and the measurement locations for the test (Akamatsu et. Al, 2024)

4.2. Test Participants

The following describes the test done by Amada et. al., 2023. The participant performing sensory evaluations, called panelists, and participants serving as sources of human emissions (bio effluents), called occupants, were recruited. About 30 panelists were recruited. The number of panelists will influence the accuracy of the results. All panelists were students. To characterize the sensory abilities of panelists, we calculated a chemical sensitivity scale (CSS, Nordin et. al., 2024) but did not perform any medical examination or tests examining the ability to perceive odours; the average CSS was typical for the general population and suggested no specific sensitivity for the selected panelists.

All recruited participants (panelists and occupants) were requested not to consume alcohol, garlic, or spicy foods in the evening and night before the experimental day and on the day of the experiments. They were also requested not to consume coffee an hour before the experiment and were only allowed to consume water during the experiment. Strong deodorizers or perfumes were prohibited on the day of the experiment. The occupants were instructed to shower in the evening of the day before the experiment using odourless shower gel provided by the experimental team.

It is important and recommended that panelists and occupants have lived in the same country during at least a year before the test.

4.3. Pollution sources

Building materials (5 m² of old carpets and 5 m² of linoleum) placed in “pollution boxes”. The building materials were placed in pollution boxes one week before the experiment.

Humans, three people sitting behind the partition, were used as pollution sources. People entered the rooms two hours before the sensory evaluations began. People were seated quietly during measurements (reading, listening to music, watching lectures, etc.) but walked around the room for the first half an hour after entering the experimental rooms to build-up their emissions so that the steady-state level of bio effluents could be obtained before the sensory assessments commenced.

4.4. Testing Procedure

In the test by Amada at DTU (Amada et.al., 2023) three rooms were used to speed up the experiments (Figure 4). In the example in Figure 4 the room on the left has only building materials as source. The middle room had no source, and the room at the right had both building materials and occupants as pollution sources at the same time. Each room had an air cleaner. The crosses indicate the position of the evaluator of perceived air quality during whole body exposure.

The air cleaners' type had been placed in the rooms and turned on three hours before sensory evaluations commenced; it was turned off 30 min after the sensory measurements were completed. The panelists performed sensory evaluations upon entering the rooms and on the air extracted from the rooms via diffusers. The evaluations were made in rooms without pollution sources, with humans, or building materials, while the air cleaners were in operation or idled.

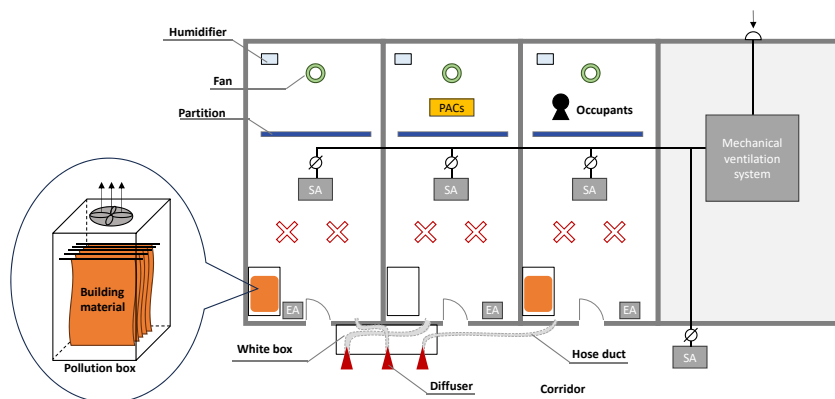


Figure 4: Three test rooms used at DTU (Amada et. al., 2023)

The panelists assessed the acceptability of the air quality and odour intensity using the scales presented in Figure 5. The following sentence preceded the scale for acceptability to create the proper context of assessment: 'Imagine that during your daily life in non-industrial buildings, you were exposed to this air. How do you assess the acceptability of the air quality?'. The acceptability scale is broken to force the panelist to decide between acceptable-unacceptable. During each evaluation, the panelists assessed either acceptability or odour intensity; in each location, the evaluations were thus made twice (one acceptability and one odour intensity), so each panelist made 12 evaluations during one measuring session a day. The order of evaluations was balanced across the panelists.

The panelists were instructed not to discuss their assessments or make facial expressions that could indicate their opinions. They took a 2–3 min break between assessments to avoid sensory fatigue. They sat in a corridor adjacent to the experimental room during this period. The corridor was well-ventilated, where the temperature and relative humidity were measured and similar to the room conditions. The experimenter informed the panelists when and where they should perform the next assessments.

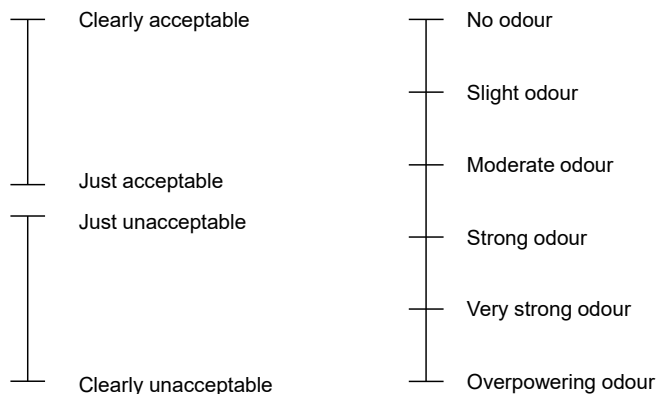


Figure 5: Scales used by participants in the experiment to assess the air quality. Left: Acceptability. Right: Odour intensity

The sensory assessments were conducted upon entering the rooms (termed whole-body exposures) and on the air extracted from the rooms via diffusers to the corridor adjacent to the experimental rooms (termed facial exposure) (Figures 1 and 2); the panelists were not told that the air was extracted from the rooms.

During whole-body exposures, the panelists were instructed to make evaluations by adhering to the following protocol: Two panelists entered the rooms by pushing the door (which closed automatically after they had entered the room), approached the crosses on the floor (about 1.5 m away from the door), inhaled the room air and made immediately a rating on the scale printed on the paper. Then, they immediately left the room to reduce the time they spent inside. Instructions were made not to breathe the air when approaching the cross and to make an assessment after only one inhalation.

During facial exposures, the panelists were instructed to make evaluations by adhering to the following protocol: The panelists approached the diffuser singly, put the face in the center of the diffuser, took one inhalation of the air from the diffuser and made the assessment.

Once they finished either the facial or whole-body assessment, they returned the voting sheet to the box with the front side of the sheet down.

The ratings made on the paper scales were digitized. The scales were coded as follows: clearly acceptable = 1, just acceptable/just unacceptable = 0.001/-0,001, clearly unacceptable = -1, no odour=0, overpowering odour=5. The averages were calculated based on the sensory evaluations made by the panelists.

In Phase 1 the air cleaner is tested at one ventilation rate (2,5 l/s per person, 7,5 l per room with three occupants) with building materials as source and one test with occupants as source. If the effect of the air cleaner was negative i.e. the perceived air quality decreased with the air cleaner on compared to no air cleaner, then the air cleaner is not going to Phase 2 and no CADR is estimated.

In Phase 2 the pollution sources are the same as in Phase 1. The sources are examined separately like in Phase 1 but also together. The room(s) where the measurements is made is ventilated with outdoor air at the rates of 7.5 L/s, 12 L/s, 21 L/s and 30 L/s (i.e. 2,5, 4,0, 7,0 and 10 l/s per person); with three people in the rooms. These ventilation rates corresponded to the rates recommended by the standard EN16798-1. Other procedures and processes were the same as in Phase 1. The ventilation rate was set about 20 hours before sensory evaluations on the following day. Besides

the sensory measurements, chemical measurements were performed with and without air cleaner running at the lowest ventilation rate of 7,5 l/s (see below).

4.5. Chemical measurements

It is recommended to perform some chemical measurements in Phase 2 at the lowest ventilation rate of 7.5 L/s. It is recommended as a minimum to measure VOC's, as indicator for emission from building materials, Ozone to make sure no harmful concentration of Ozone is generated by the air cleaner, and CO2 as indicator for the level of ventilation.

Of course, additional chemicals could be measured (VOC's, SVOC's, Aldehydes) to better understand any chemical reaction taking place.

4.6. Data analysis

The data can be presented in different ways as described below.

4.6.1. Perceived Air Quality (PAQ)

Using sensory assessments of the same exposure in a given environment made by a group of observers (a panel), mean votes of acceptability of air quality are calculated after the ratings made on the paper questionnaire are digitized. The scale is coded as follows: clearly not acceptable=-1, just not acceptable/just acceptable=0, clearly acceptable=1.

Single ratings made by each observer in a group are used for calculating the group mean vote of acceptability characterizing indoor air quality in a given environment:

$$ACC = \frac{\sum_{i=1}^N (ACC_i)}{N} \quad (4)$$

Where:

ACC = mean vote of acceptability of air quality

ACC_i = acceptability vote by the observer

N = number of observers

Using mean acceptability ratings, the percentage dissatisfied with the air quality can be calculated (Gunnarsen and Fanger, 1992):

$$PD = \frac{\exp(-0.18 - 5.28 \cdot ACC)}{1 + \exp(-0.18 - 5.28 \cdot ACC)} \cdot 100 \quad (5)$$

Where:

PD = percentage dissatisfied with the air quality, %

ACC = mean vote of acceptability

Using the percentage dissatisfied, the perceived air quality expressed in decipol, as defined by Fanger (1988), can be calculated:

$$PAQ = 112 [\ln(PD) - 5.98]^{-4} \quad (6)$$

Where:

PAQ = perceived air quality, decipol

PD = percentage dissatisfied with the air quality, %

4.6.2. Estimation of percentage dissatisfied (PD) as a function of odour intensity (OI)

Percentage Dissatisfied can be related to the odour intensity based on the scale in Figure 6.

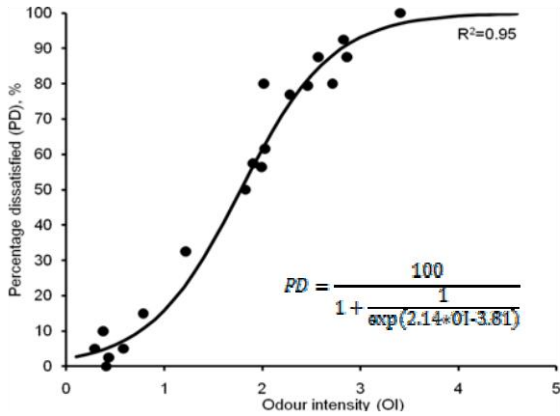


Figure 6: Percentage of dissatisfied with air quality (estimated using assessments of acceptability on dichotomous scales) as a function of odour intensity

4.6.3. Air cleaning efficiency based on Perceived Air Quality

The air cleaning efficiency can be expressed in % as:

$$\varepsilon_{PAQ} = 1 - PAQ_{AP} \times Q_{AP} / (PAQ \times Q_o) \quad (7)$$

Where:

ε_{PAQ} = the air cleaning efficiency for perceived air quality, %

Q_o = the ventilation rate in the test room l/s

Q_{AP} = the air flow through the air cleaner, l/s

PAQ = the perceived air quality without the air cleaner, decipol

PAQ_{AP} = the perceived air quality with the air cleaner, decipol

4.6.4. Comparison of the whole-body and facial sensory evaluations

Figure 7 shows that whole body exposure result in effect on the ratings i.e. higher odour intensity and lower acceptability. The scales are required in ISO 16000-44 for measuring perceived air quality.

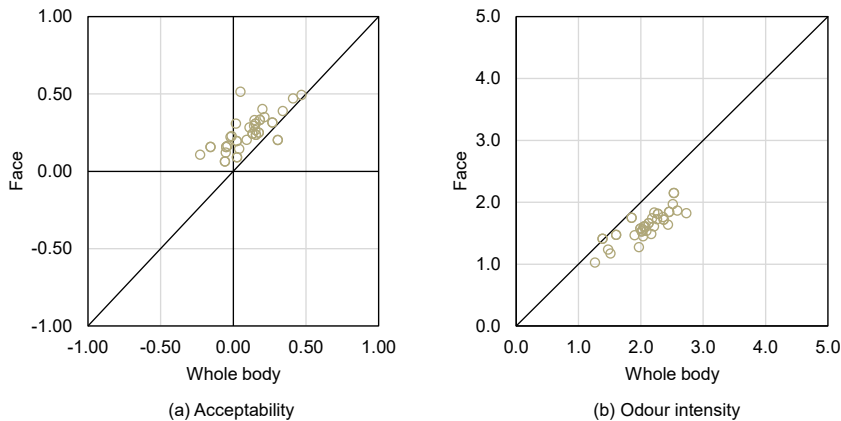


Figure 7: Comparison of the whole-body and facial sensory evaluations

4.6.5. Estimation of the Clean Air Delivery Rate, CADR

The Clean Air Delivery Rate, h^{-1} , based on air cleaning efficiency is calculated as:

$$CADR = \varepsilon_{PAQ} \times Q_{AP} \times (3.6/V) \quad (8)$$

Where:

ε_{PAQ} = the air cleaning efficiency for perceived air quality, %

Q_{AP} = the air flow through the air cleaner, l/s

V = the volume of the room, m^3

The Clean Air Delivery Rate can be found by graphically showing the relation between ventilation rate on Percentage Dissatisfied, PD without and with the air cleaner.

Draw all the measured PD with and without air cleaners on a PD-airflow rate diagram, make a regression for the points without using the air cleaner. This curve will be used as a baseline. CADR is the horizontal distance between the baseline and the points showing PD when using the air cleaners (Figure 8).

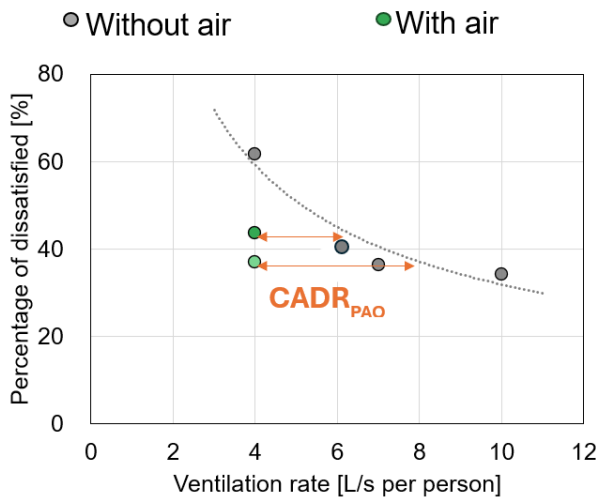


Figure 8: Example on how CADR is determined

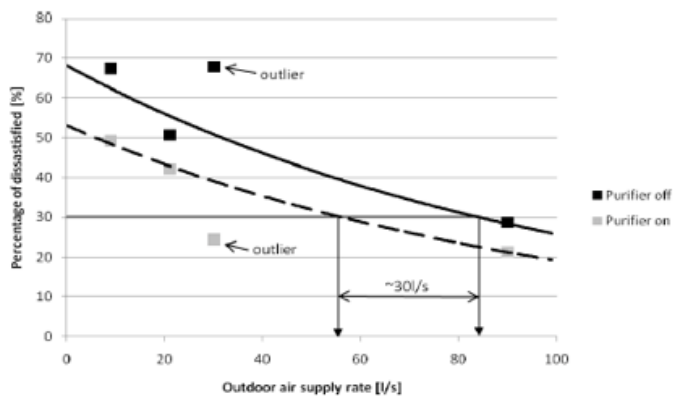


Figure 9: Example on how CADR is determined

Example of test results in Figure 9, where the performance of the tested air cleaner is expressed as Percentage Dissatisfied, PD. For the same PD level the ventilation rate can be reduced with 30 l/s when using an air cleaner.

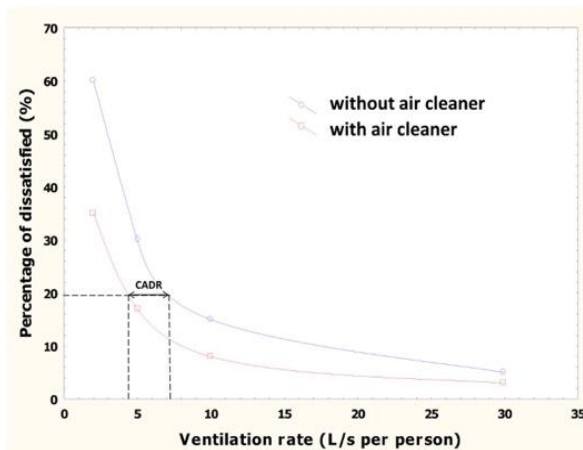


Figure 10: Example on how CADR is determined

Example of test results in Figure 10, where the performance of the tested air cleaner is equivalent to 3 l/s per person of clean air, called the Clean Air Delivery Rate, CADR. (Fang et al., 2011).

5. Summary

The proposed method comprises two phases of testing of air cleaners. The first phase examines whether the air cleaner can improve or reduce air quality (qualitative testing). In contrast, second phase thoroughly examines the air cleaner performance (quantitative testing). The idea behind the proposal is the efficient use of resources: that air cleaners that do not pass Phase 1 should not be tested in Phase 2.

No firm recommendations can be made on whether the sensory evaluations of air quality when testing the performance of air cleaners should be made on the air extracted from the experimental rooms (facial exposures) or upon entering the rooms (whole-body exposures).

Although acceptability and odour intensity ratings were strongly correlated (Figure 9), the overall results of sensory evaluations for individual conditions were not always consistent. For that reason, at this moment, it can be recommended to use both sensory evaluations of odour intensity and acceptability of air quality when testing the performance of air cleaners using sensory methods. They both provide a more complex characterisation of sensory effects.

The relationship between ventilation rates and sensory ratings of acceptability of air quality and odour intensity was non-linear. Consequently, when determining the clean air delivery rate for air cleaners and comparing against the effects obtained by ventilation, it is necessary to perform the tests at different ventilation rates. Examining CADR only at one ventilation rate is insufficient and these results should not be extrapolated to other ventilation rates.

The ISO 16000-44 standard was approved in 2023. It describes a test method for measuring perceived indoor air quality for testing the performance of gas phase air cleaners. The method in the standard is similar to the one examined in the present experiments. The perceived air quality is determined using the acceptability of the air quality and odour intensity. The air assessed by a panel is presented via a sniffing device (facial exposure). If measurement accuracy can be guaranteed, the panel can also enter a chamber directly to assess the air (whole-body exposure). The air change rate of the test chamber is set at 0.50/h (± 0.03 /h) and 2.0/h (± 0.12 /h) in ISO, which is the same as in the present study at 7.5 L/s and 30 L/s. The experimental methods used in this study are generally comparable with those proposed by the standard. Therefore, the methodology described and examined in the present paper supports and validates, to some extent, the approach proposed by ISO 16000-44.

6. Conclusion

A prototype method for testing gas-phase air cleaners using sensory assessment was examined. This study generally followed methodologies proposed by the ISO 16000-44 standard and the results of this study validate and support them. More testing is still necessary before its full application in practice.

The proposed method includes two phases. The results confirmed that Phase 1 effectively eliminates the air cleaners that do not improve air quality. Phase 2 is necessary since it provides detailed information on the actual performance of air cleaners in the form of Clean Air Delivery Rate (CADR). The recommended ventilation rates in ISO 17772-1/2 may then be reduced by the CADR of a gas phase air cleaner.

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