ANNEX **78**

EBC
Energy in Building and Communities Programme

The Concept for Substituting Ventilation by Gas Phase Air Cleaning

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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 CO_2 Emissions Optimization in Building Renovation (*)
Annex 57: Evaluation of Embodied Energy and CO_2 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 CO_2 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

Table of content

1. Summary 2
2. Introduction 3
3. Concept of supplementing ventilation by gas phase air cleaning 4
3.1. Measuring air cleaning efficiency for individual contaminants 5
3.2. Measuring the Clean Air Delivery Rate and air cleaning efficiency based on Perceived Air Quality 5
4. Testing of gas phase air cleaners 7
5. Energy impacts of using gas phase air cleaning 9
6. Use of CO_2 as air quality indicator 10
7. Discussion 11
8. Conclusions 11
9. Acknowledgments 12
10. References 13

1. Summary

Worldwide, there is an increasing number of publications related to air cleaning and sales 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.

International standards for ventilation and Indoor Air Quality like EN16798-1, ISO17772-1 and ASHRAE 62.1 are often based on criteria for the Perceived Air Quality (PAQ), sometimes expressed as levels of CO_2 as a tracer for emission from occupants. However, if air cleaning is used, an equivalent level of air quality will be reached at higher CO_2 concentrations. It is assumed that when ventilation is used for PAQ, the required ventilation will also dilute other contaminants like Radon, VOCs. The decreased ventilation rate when using air cleaning may not be sufficient.

Today, gas phase air cleaners are tested based on a chemical measurement (ISO 10121-2:2013) and ASHRAE (145.2-2016), which do not account for the influence on PAQ and human bio effluents as a source of pollution.

This report will discuss and evaluate the pros and cons by partly substituting required ventilation by gas phase air cleaning.

2. Introduction

Ventilation accounts for approximately 20% of the global energy use for providing an acceptable indoor environment. (B. Nourozi-2022, ENE-.HVAC-2024). 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.

In many locations in the world, the outdoor air quality is so bad that it is better to avoid ventilation. In such cases, the alternative to use outdoor air for ventilation is to substitute it with air cleaning so that an acceptable indoor air quality (IAQ) can be maintained. Even when outdoor air is of a good quality, the use of air cleaning to substitute ventilation air could reduce the rate of outdoor air supplied indoors and thereby energy for heating/cooling the ventilation air and for transporting the air (fan energy) can be saved. Since it is expected that air cleaning may in parallel improve the IAQ and reduce energy use for ventilation, it should be considered as a very interesting technology that can be used in the future. There is however a need for better evaluation of its potential to improve indoor air quality (and substitute ventilation rates) and the energy implication of using gas phase air cleaning. There is also a need to develop standard test methods for evaluating the performance of air cleaning devices.

3. Concept of supplementing ventilation by gas phase air cleaning

To evaluate the potential for supplementing ventilation with gas phase air cleaning it is first important to take a look at international standards dealing with requirements to indoor air quality.

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, 2019, ISO17772-1, 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:

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

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

Where:

$e_v =$ the ventilation effectiveness

$q_{supply} =$ ventilation rate supplied by the ventilation system, l/s

$q_{tot} =$ 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, m^2

$q_B =$ ventilation rate for emissions from building, $l/s.m^2$

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 density in the room and the pollution level of the building.

Table 2 shows an example of the recommended ventilation rate for a 10 m^2 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.m^2).

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 m^2 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 equation (3):

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

Where:

Q_h = the ventilation rate required for dilution, in m^3 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 m^3

$c_{h,o}$ = the concentration of the substance of the supply air, in micrograms per m^3

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 (see below).

3.1. Measuring air cleaning efficiency for individual contaminants

For testing gas phase air cleaning, known gases are used to simulate pollution (i.e. toluene, acetone, etc. to simulate VOCs).

The pollutant concentration is measured before and after the air cleaner. The air cleaning efficiency, in %, is calculated for each of the tested pollutants as in equation (4):

$$\varepsilon_{clean} = 100\ (C_U - C_D)/C_D \quad (4)$$

Where:

ε_{clean} = the air cleaning efficiency

C_U = the gas concentration upstream air cleaner, ppm

C_D = the gas concentration downstream air cleaner, ppm

3.2. Measuring the Clean Air Delivery Rate and air cleaning efficiency based on Perceived Air Quality

The criteria for the ventilation rates in the standards are mainly based on perceived air quality PAQ, which is measured by a human test panel. It is, therefore, also important to be able to test the air cleaning efficiency in relation to the perceived air quality. The air cleaning efficiency can be expressed in % as in equation (5):

$$\varepsilon_{PAQ} = Q_o/Q_{AP} \times (PAQ/PAQ_{AP} - 1) \times 100 \qquad (5)$$

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

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

$$CADR = \varepsilon_{PAQ} \times Q_{AP} \times (3.6/V) \qquad (6)$$

Where:

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

V = the volume of the room, m^3

If the air cleaner has been tested based on chemical measurements according to equation (4) it should then be allowed to reduce the pollution contribution due to the building part in equation (1) with a factor based on the measured air cleaning efficiency and expressed in l/s per m^2 as shown in equation 7:

$$q_{B,clean} = \varepsilon_{clean} \cdot q_B \qquad (7)$$

Similarly, if the air cleaner has been tested based on *PAQ* with a combination of people and building as source, the total ventilation, q_{tot} can be reduced with the clean air delivery rate or air cleaning efficiency.

4. Testing of gas phase air cleaners

There is an increasing development of methods and products for particle and gas phase air cleaning including both particle or adsorption filters and air cleaners using a chemical reaction to remove certain gasses and pollutants (PCO-Photo Catalytic Oxidization, Ionization, UV technology, etc.).

ISO (ISO 10121-2:2013) and ASHRAE (145.2-2016) have standard test methods which measure the air cleaning efficiency or the equivalent amount of outdoor air called Clean Air Delivery Rate, CADR.

Better test methods for air cleaners are required, because at present the test is usually based on chemical measurements and the resulting effect on odour or perceived air quality is not considered. It is also very important to specify which kind of "pollutants" should be used when testing.

Figure 1 and Figure 2 show examples of a test using perceived air quality. The perceived air quality was measured using a test panel entering the test room and immediately evaluated the perceived air quality. Both human and building emissions were included as a pollution source.

Figure 3 show test results using perceived air quality with an air cleaner exposed to different pollution sources. With building materials, the air cleaner improves the perceived air quality; but with human bio effluents, the air cleaner makes the perceived air quality worse. This shows the importance of using perceived air quality as a test measure and also to use human bio effluents as a source.

There are standards for measuring perceived air quality (ISO 16000-30) and a new standard ISO 16000-44 has been developed by ISOTC146SC6 especially to be used when testing gas phase air cleaning devices.

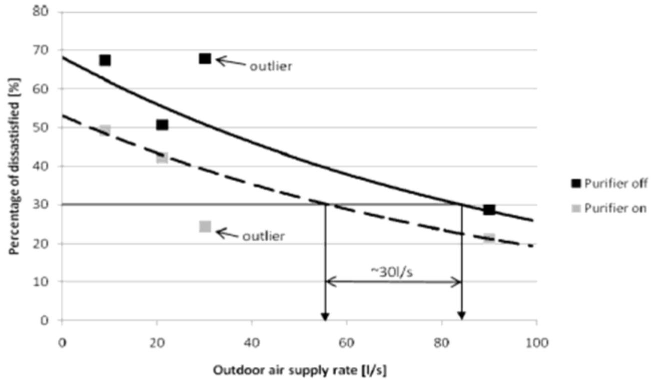

Figure 1: Example of test results, where the performance of the tested air cleaner is expressed as acceptability. For the same acceptability level the ventilation rate can be reduced with 30 l/s when using an air cleaner (Fang et al., 2011)

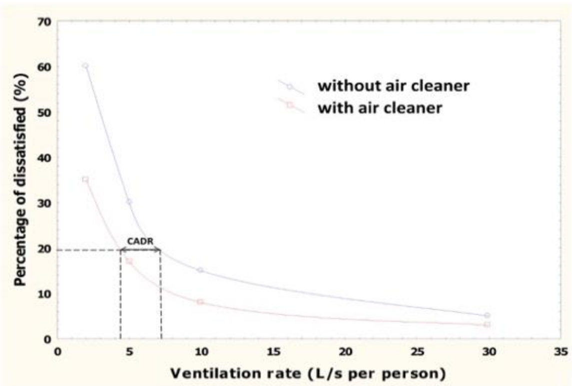

Figure 2: Example of test results, where the performance of the tested air cleaner is equivalent to 3 l/s per person of clean air, called the Clean Air Delivery Rate, CADR. (Fang et al., 2011)

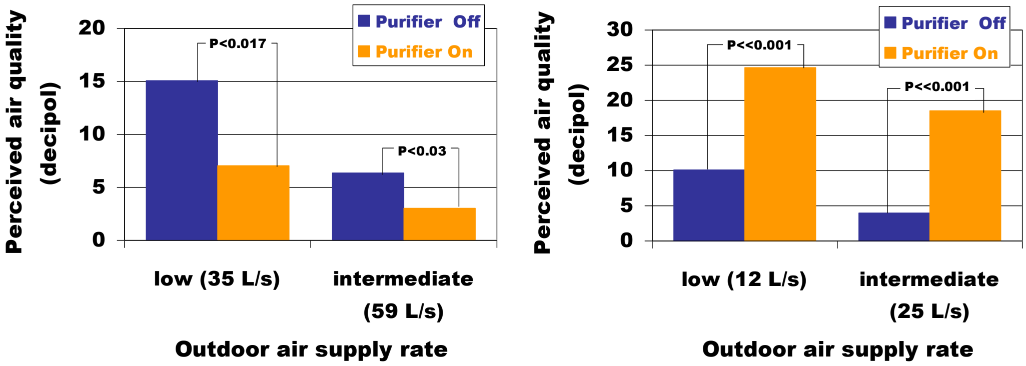

Figure 3: Test results using PAQ with and without human bio effluents as a source (Kolarik and Wargocki, 2010) [Test 1-left: Pollution sources are building materials, PCs and used filters |Test 2-right: Pollution sources are human bio effluent emissions and building materials]

5. Energy impacts of using gas phase air cleaning

In the case of unacceptable outdoor air quality, it is clear that air cleaning is the only solution to improve IAQ. Another argument for gas phase air cleaning is the potential reduction of the energy use for pre-heating/cooling of the outdoor supply air. This energy impact depends on the position of the air cleaner device (as part of the ventilation system, stand-alone device), if a heat recovery unit is installed, and outdoor climatic conditions. Furthermore, there may be a decrease in the fan energy for the ventilation system; but fan energy for the air cleaning device must be added. Does the air cleaning device installed in the ventilation system lead to an increased pressure drop and, thereby, additional fan energy? A reduced amount of outdoor air will reduce energy use for humidification and de-humidification. In colder climates in winter, the need for humidification will be less with a reduced amount of cold, dry air entering a building. In some cases, it may, however, result in too high indoor humidity levels in residential buildings. In warm, humid climates a reduction of outdoor air will lower the energy needed for dehumidification.

Under some climatic conditions, when outdoor air temperatures are below the desired indoor temperature, the ventilation can provide free cooling especially during night-time. With a reduced airflow, when using air cleaning, this benefit will be decreased.

6. Use of CO_2 as air quality indicator

Using gas phase air cleaning raises the question of the relevance of CO_2 still being used as an indicator for IAQ and as a control parameter for Demand Control Ventilation (DCV). As CO_2 concentrations are inversely proportional to the ventilation rates, the pertinent question is whether the CO_2 level in itself will cause comfort/health problems or influence cognitive performance. Table 3 gives an example of CO_2 values calculated for a single office with and without air cleaning. The considered air cleaner provides the same PAQ with 20% occupants dissatisfied (Category IEQ_{II}) with a 30% reduced air flow rate. See Figure 1.

Table 3: ΔCO2 levels considering a 30 % reduced ventilation rate due to air cleaners

Space type Single office	Occupancy [m^2per person]	Category	Derived from equation (1), q_{tot}	
			Very low-polluting building	*Low-polluting building*
			Indoor CO_2 level above outdoor level *ΔCO_2 [ppm]*	
Without air cleaner	10	IEQ_I	370	278
		IEQ_{II}	529	397
		IEQ_{III}	926	694
		IEQ_{IV}	**1389** (1010)	**1010** (794)
With air cleaner	10	IEQ_I	529	397
		IEQ_{II}	756	567
		IEQ_{III}	**1323** (1029)	**992** (817)
		IEQ_{IV}	**1984** (1100)	**1443** (911)

The categories for ventilation are based on different levels of expected percentage of dissatisfied, IEQ_I-15%, IEQ_{II}-20%, IEQ_{III}-30% and IEQ_{IV}-40%. As the standards recommend a minimum of 4 L/s per person, any ΔCO2 concentration derived from a lower value was marked in bold alongside the resulting values using 4 l/s person in parentheses. It is clear from this example that the same indoor air quality (category) is obtained at different levels of ΔCO2 concentrations.

In the standards, it is assumed that ventilation for an acceptable perceived air quality will, in most cases, also be high enough to dilute concentration of individual contaminants below recommended levels of concern. However, when using air cleaning and reducing the amount of ventilation, this may not always be the case. On the other hand, depending on the air cleaning technology, several individual contaminants may or will be broken down.

7. Discussion

The concept presented in this paper requires new testing standards for air cleaning devices that consider human emissions (bio effluents) as a pollution source and require the measurement of perceived air quality as a testing criterion.

Critical issues include establishing a standardized way of human emission as a source and a standard way of measuring the perceived air quality. IEA-EBC Annex 78 has worked together with Technical Committee ISO/TC 146, Air quality, Subcommittee SC 6, Indoor air to develop standard ISO 16000-44 for measuring perceived air quality, when testing air cleaners.

Based on that ISOTC142WG8 Gas-phase air cleaning devices is developing a test method for testing gas phase air cleaning devices. This method is based on the two publications (K. Amada et.al & A. Akamatsu et.al) on testing gas phase air cleaners.

As a part of the emission of the building component of indoor pollution sources, it will be possible with existing testing standards ISO 10121-2:2013 and ASHRAE 145.2-2016 to test and calculate the CADR. This can then be used to reduce the building component when calculating the required ventilation. In spaces with a low occupant density like individual offices or often open plan offices, the building component is of significant importance. While in high density occupancy like schools, auditoriums etc. the influence of the building component is minor compared to the people component. The test according to these standards, however do not account for any bi-products that may occur when human bio effluents are affected by the air cleaner. This will depend on the gas phase air cleaning technology.

Instead of calculating a possible reduction in ventilation rate with air cleaning we can instead express the performance of air cleaning by a possible increase in indoor air quality level according to EN16798-1 or ISO17772-1.

If gas phase air cleaning is used, the air flow rate will be lowered for the same air quality level. The DCV set point for CO_2 must be adapted as a higher one as acceptable for the same level of air quality. Depending on the efficiency or clean air delivery rate (CADR) of the air cleaner, the direct effect of CO_2 on performance may also be a problem even though CO_2 concentrations will still be far from any health limit (5.000-10.000 ppm).

An additional advantage of reducing the ventilation rate is the possible reduction of noise from the system. The noise from the air cleaning device itself may counteract that effect.

8. Conclusions

Gas phase air cleaning technologies are increasingly used to improve the indoor air quality.

A concept for substituting part of the required ventilation with gas phase air cleaning technology has been presented

There is a need for new testing standards that consider perceived air quality and human emissions as a source.

The energy impact of using gas phase air cleaning must be studied further. By reducing the ventilation rate energy use can be reduced for:

- pre-heating or pre-cooling of outside supply air
- humidifying or de-humidifying
- fan energy for air transport

Energy use may be increased due to:

- Additional fan energy for stand-alone air cleaners
- Additional fan energy due to increased pressure drop over the device
- Reduced potential for cooling by outside air

It must be verified that the reduced ventilation rate is still high enough to dilute individual contaminants.

Different CO_2 criteria must be used to express the indoor air quality and to use for demand-controlled ventilation.

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