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Operating Agent
and Management
Sint-Pietersnieuwstraat 41,
B-9000 Ghent – Belgium
inive@bbri.be - www.inive.org

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The Concept for Substituting Ventilation by Gas Phase Air Cleaning

Bjarne W. Olesen, DTU, Denmark
Chandra Sekhar, NUS, Singapore
Pawel Wargocki, DTU, Denmark

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 such as 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 and 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.

1 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.

2 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 such as 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:

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

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

where:

- ε_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

		People component, q_p	Building Component, q_B		
Indoor Environmental Category	Expected Percentage Dissatisfied %	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)

Category	Low- polluting building	Airflow per non- adapted person	Design ventilation air flow rate for the room component		
	l/(s·m²)	l/(s.person)	l/s	l/(s.person)	l/(s.m²)
IEQ_I	1,0	10	10	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):

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

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.

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

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):

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

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}, is calculated as in equation (6):

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

where:

$CADR$	the Clean Air Delivery Rate, l/s
Q_{AP}	the air flow through the air cleaner, l/s
V	is 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.

3 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) include 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 & 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 evaluating the perceived air quality. Both human and building emissions were included as a pollution source.

Figure 3 shows 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.

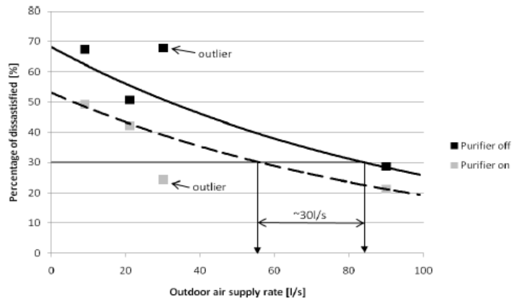


Figure 1 : Example of test results, where the performance of the tested air cleaner is expressed as acceptability. For the same acceptability level, the ventilation rate can be reduced by 30 l/s when using an air cleaner (Fang et al., 2011)

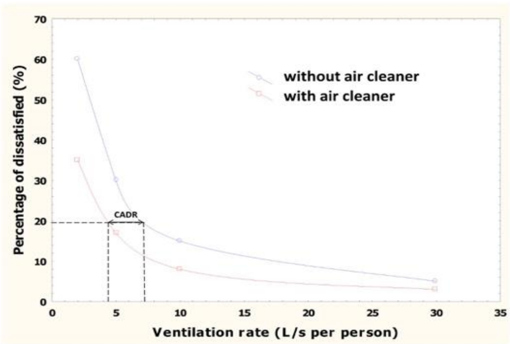
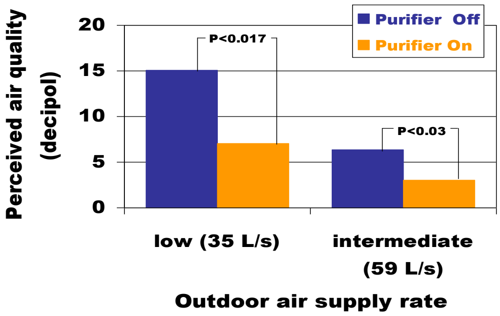


Figure 2 : Example of test results, where the performance of the tested air cleaner is equivalent to 3 l/s per person of clean air, called the Clean Air Delivery Rate, CADR. (Fang et al., 2011)



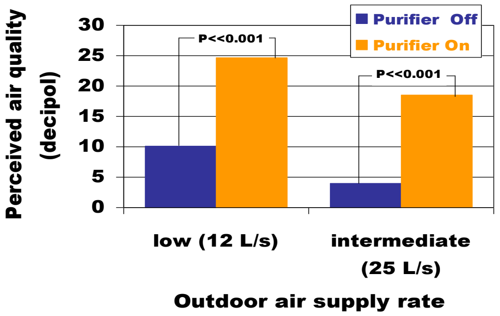


Figure 3: Test results using PAQ with and without human bio effluents as a source (Kolarik and Wargocki, 2010) [Test 1-top: Pollution sources are building materials, PCs and used filters |Test 2-bottom: Pollution sources are human bio effluent emissions and building materials]

4 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 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.

5 Use of CO_2 as air quality indicator

Using gas phase air cleaning raises the question of the relevance of CO2 still being used as an indicator for IAQ and as a control parameter for Demand Control Ventilation (DCV). As CO2 concentrations are inversely proportional to the ventilation rates, the pertinent question is whether the CO2 level in itself will cause comfort/health problems or influence cognitive performance. Table 3 gives an example of CO2 values calculated for a single office with and without air cleaning. The considered air cleaner provides the same PAQ with 20% occupants dissatisfied (Category IEQII) with a 30% reduced air flow rate. See Figure 1.

The categories for ventilation are based on different levels of expected percentage of dissatisfied, IEQI-15%, IEQII-20%, IEQIII-30% and IEQIV-40%. As the standards recommend a minimum of 4 L/s per person, any ΔCO_2 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 ΔCO_2 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.

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

Space type Single office	*Occupancy [m²per 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)

6 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 CO2 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 CO2 on performance may also be a problem even though CO2 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.

7 Conclusions

Gas phase air cleaning technologies are increasingly being 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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9 References

ANSI/ASHRAE Standard 62.1-2019 "Ventilation for Acceptable Indoor Air Quality"

ANSI/ASHRAE Standard 145.2-2016 "Laboratory Test Method for Assessing the Performance of Gas-Phase Air-Cleaning Systems: Air-Cleaning Devices".

B. Nourozi et al., “Heating energy implications of utilizing gas-phase air cleaners in buildings ’ centralized air handling units,” Results in Engineering, vol. 16, no. August, p. 100619, 2022, doi: 10.1016/j.rineng.2022.100619

CEN, EN 16798-1:2019 Energy performance of buildings- Ventilation for buildings – Part 1: Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics, CEN, 2019.

CEN, TR 16798-2:2019 Energy performance of buildings – Ventilation for buildings – Part 2: Interpretation of the requirements in EN 16798-1 – Indoor environmental input parameters for design and assessment of energy performance of buildings addressing indoor air quality, thermal environment, lighting and acoustics, CEN, 2019.

ENE-HVAC, “Energy efficient heat exchangers for HVAC applications.” Accessed: Feb. 01, 2024. [Online]. Available: https://cordis.europa.eu/project/id/314648

IEA EBC, Annex 78 - Supplementing Ventilation with Gas-phase Air Cleaning, Implementation and Energy Implications, Accessed 18-02-2020, https://annex78.iea-ebc.org.

ISO 10121-2:2013 "Test methods for assessing the performance of gas-phase air cleaning media and devices for general ventilation - Part 2: Gas-phase air cleaning devices (GPACD)".

ISO 16000-30:2014 “Indoor Air-Part 30: Sensory Testing of Indoor Air”, 2014

ISO 16000-44:2023 “Indoor Air-Part 44: Test Method for Measuring Perceived Indoor Air Quality for Use in Testing the Performance of Gas Phase Air Cleaners (2023)

ISO 17772-1 2018 Part 1: Indoor Environmental Input Parameters for the Design and Assessment of Energy

Performance in Buildings, ISO, Geneva, 2017.

ISO 17772-2 2018: Part 2: Guideline for Using Indoor Environmental Input Parameters for the Design and Assessment of Energy Performance of Buildings., ISO, Geneva, 2018.

Kolarik and Wargocki: Can a photocatalytic air purifier be used to improve the perceived air quality indoors? Indoor Air 2010;20, 255-262.

Lei Fang, Pawel Wargocki, Adam Targowski, Toshio Tanaka, Kenkichi Kagawa, 2011, Performance of a Non-Thermal Plasma Air Purifier Examined with Sensory Assessments of Air Quality, 12th Int. Conf. on Indoor Air Quality and Climate.

K. Amada, L. Fang, S. VESTH, S. Tanabe, B. W. OLESEN, and P. Wargocki, "A Method for Testing the Gas-Phase Air Cleaners Using Sensory Assessments of Air Quality," Submitted, Under review, doi: 10.2139/SSRN.4701705.

K. Amada, S. Vesth, L. Fang, B.W. Olesen, P. Wargocki, Developing methodology for testing of gas-phase air cleaners based on perceived air quality, in: IAQVEC 2023, 2023.

N. Akamatsu et al., "Effects of a gas-phase air cleaner in removing human bioeffluents and improving perceived air quality," Build Environ, vol. 257, Jun. 2024, doi: 10.1016/j.buildenv.2024.111540.

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