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Programme



Air Infiltration and Ventilation Centre

The Concept for Substituting Ventilation by Gas Phase Air Cleaning

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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 (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 CO₂ as a tracer for emission from occupants. However, if air cleaning is used, an equivalent level of air quality will be reached at higher CO₂ concentrations. It is assumed that when ventilation is used for PAQ, the required ventilation will also dilute other contaminants like Radon and VOCs. Today, gas phase air cleaners are tested based on a chemical measurement, which does 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. 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 the potential of gas phase air cleaning to improve indoor air quality by substituting ventilation rates and reduce the energy implication. 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, m²
- q_B ventilation rate for emissions from building, l/s, m²

Ventilation effectiveness is the effectiveness of delivering the air to breathing zone where 1 is for full mixing.

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

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	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 permissible level of the substance based on health or comfort value, 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, and in the guideline Part-2, a concept for taking into account gas phase air cleaning is proposed; but the standards do not directly give the possibility for reducing the recommend 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 air cleaning efficiency for individual contaminants

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} is the air cleaning efficiency for perceived air quality;
- Q_o the ventilation rate without air cleaner, l/s;
- Q_{AP} the ventilation rate with air cleaner, l/s;
- PAQ the perceived air quality without the air cleaner, decipol.
- PAQ_{AP} the perceived air quality without the air cleaner, decipol

The Clean Air Delivery Rate, is calculated as in equation (6):

$$CADR = \varepsilon_{PAQ} \cdot Q_{AP} \quad (6)$$

where:

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

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 m² as shown in equation (7):

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

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 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 shows an example 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 2 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 (Figure 3). 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 is being developed by ISOTC146SC6 especially to be used when testing gas phase air cleaning devices.

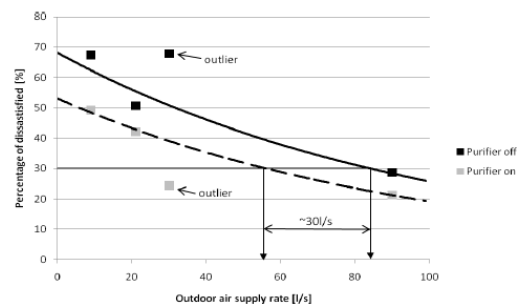


Figure 1 : Example of test results, where the performance of the tested air cleaner is expressed as acceptability. For the same acceptability level, the ventilation rate can be reduced by 30 l/s when using an air cleaner (Fang et al., 2011)

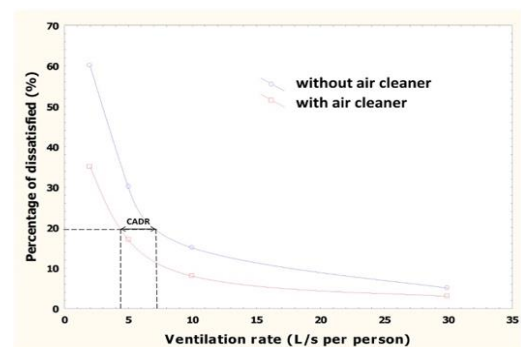


Figure 2 : Example of test results, where the performance of the tested air cleaner is equivalent to 3 l/s per person of clean air, called the Clean Air Delivery Rate, CADR. (Fang et al., 2011)

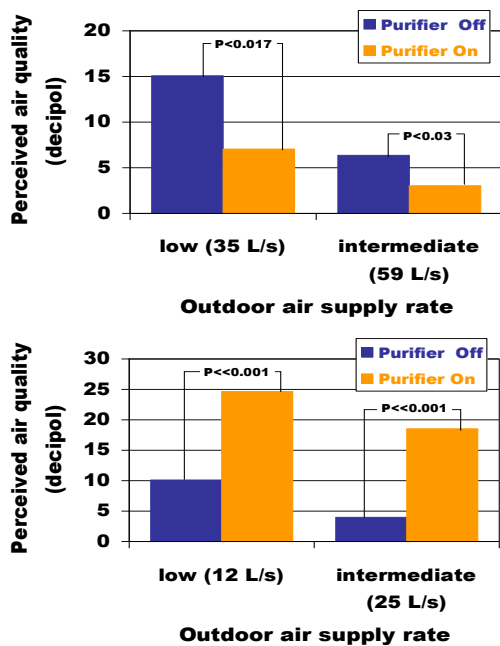


Figure 3: Test results using PAQ with and without human bio effluents as a source (Kolarik and Wargocki, 2010) [Test 1-top: Pollution sources are building materials, PCs and used filters] [Test 2-bottom: Pollution sources are human bio effluent emissions and building materials]

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 CO₂ as air quality indicator

Using gas phase air cleaning raises the question of the relevance of CO₂ as an indicator for IAQ and as a control parameter for Demand Control Ventilation (DCV). In the absence of consistent and strong evidence of negative effects of pure CO₂ on comfort and health below 5,000 ppm (the level that hardly ever is experienced indoors), CO₂ may still be used as a marker of ventilation efficiency in the presence of people. This means that CO₂ can be used as a substitute for ventilation measurements, with higher CO₂ indicating lower ventilation rates and low showing high ventilation rates under the same level of occupancy, Table 3 gives an example of CO₂ values calculated for a single office with and without air cleaning. The air cleaner will supply an equivalent amount of CADR, which means the ventilation rate can be reduced for the same level of indoor air quality. That means with an air cleaner the same air quality is obtained at a higher CO₂ concentration. The considered air cleaner provides the same PAQ with 20% occupants dissatisfied (Category IEQII) with a 30% reduced airflow 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 Δ CO₂ concentration derived from a lower value was marked in bold alongside the resulting values using 4 l/s person in parentheses. From this example it can be seen that the same indoor air quality (category) is obtained at different levels of Δ CO₂ 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: ΔCO_2 levels considering a 30 % reduced ventilation rate due to air cleaners

Space type office	Single	Occupancy [m ² per 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. IEA-EBC Annex 78 is working together with ISOTC142 and ISOTC156WG6 to establish such test methods. Critical issues include establishing a standardized way of using human emissions as a source and a standard way of measuring the perceived air quality.

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 to 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 below from any health limit (5.000-10.000 ppm).

An additional advantage of reducing the ventilation rate is the possible reduction of system noise. The noise from the air cleaning device itself may, however, 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 considers 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 CO₂ criteria must be used to express the indoor air quality and to use for demand-controlled ventilation.

8 Acknowledgments

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