Pawel Wargocki
International Centre for Indoor Environment and Energy
DTU SUSTAIN, Technical University of Denmark (DTU)
pawar@dtu.dk

# A general overview of IEA-EBC Annex 78: Supplementing ventilation with gas-phase air cleaning, implementation and energy implications

## Outline

- Introduction IEA-EBC Annex 78
- Concept of supplementing ventilation by gas phase air cleaning
- Testing of gas phase air cleaners
- Energy impacts of using gas phase air cleaning
- Conclusions (with a twist)

## Summary

- Operating Agents
  - Bjarne W. Olesen, Technical University of Denmark
    Pawel Wargocki, Technical University of Denmark
- Time schedule
  - Preparation phase 01-07-2018 to 30-06-2019
  - Working phase 01-07-2019 to 30-06-2023
  - Reporting phase 01-07-2023 to 30-06-2024

## Structure

- Subtask A: Energy benefits using gas phase air cleaning
  - Subtask leader: Alireza Afshari, Denmark
  - Co-leader: Sasan Sadrizadeh , Sweden
- Subtask B: How to partly substitute ventilation by air cleaning
  - Subtask leader: Pawel Wargocki, Denmark
  - Co-leader: Shin-Ichi Tanabe , Japan
- Subtask C: Selection and testing standards for air cleaners
  - Subtask leader: Paolo Tronville, Italy
  - Co-leader: Jinhan Mo, China
- Subtask D: Performance modelling and long-term field validation of gas phase air cleaning technologies
  - Subtask leader: Karel Kabele, Czech
  - Co-leader: Jensen Chang , USA

## Concept (ref. to ASHRAE 62.1 and EN16798)

People Component

Building Component

Breathing Zone Outdoor Airflow

$$V_{bz} = R_pP_z + R_aA_z$$

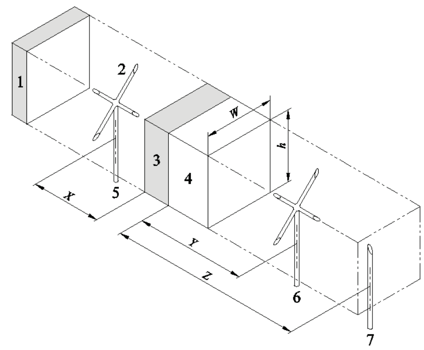
$R_p$: Minimum l/s/Person

$P_z$: Number of People

$A_z$: Building Area

$R_a$: Minimum l/s/m²

# Concept (supplementing ventilation)




**Key**

1 diffusor and $\Delta p$ device
2 sampling points – should be of "fork" type or similar with multiple inlet points to make a compounded sample over the whole cross section
3 GPACD under test
4 GPACD section of test duct
5 upstream sampling point for $T_U$, $RH_U$, $p_U$ and $C_U$ at $X$ mm before the GPACD
6 Downstream sampling point for $T_D$, $RH_D$, $p_D$ and $C_D$ at $Y$ mm after the GPACD
7 $Q$, air flow rate sampling point at $Z$ mm after the GPACD
$W$ internal width of the test duct along the GPACD section, 3+4
$h$ internal height of the test duct along the GPACD section, 3+4

**Figure 1 — Normative section of test stand showing ducting, measurement parameters and sampling points**

ISO 10121-1:2014 "Test method for assessing the performance of gas-phase air cleaning media and devices for general ventilation - Part 1: Gas-phase air cleaning media"

- **Clean Air Delivery Rate (CADR)**
  - **CADR = $\varepsilon_{PAQ} \cdot Q_{AP} \cdot (3,6/V)$**
  - where:
  - $\varepsilon_{clean}$ or $\varepsilon_{PAQ.}$ is the air cleaning efficiency
  - $Q_{AP}$· is the air flow through the air cleaner, l/s;
  - V is the volume of the room, $m^3$.

- **Air Cleaning Efficiency**
  - $\varepsilon_{clean} = 100(C_U - C_D)/C_D$

  where:
  - $\varepsilon_{clean}$ is the air cleaning efficiency
  - $C_U$ is the gas concentration before air cleaner
  - $C_D$ is the gas concentration after air cleaner.

# Methods & standards for testing gas-phase air cleaners

| Standard/Protocol | Methods | Challenge Gaseous | Measured Gaseous | Performance index |
|---|---|---|---|---|
| **Air cleaner, Standardization Administration of China** (GB/T-18801) | Pulldown | Single species gas e.g., | Formaldehyde toluene | CADR |
| **Air cleaner, Standardization Administration of China** (GB/T-18801) | Singlepass | Single species gas e.g., | Formaldehyde toluene | Single-pass efficiency |
| **Reduced Energy Use Through Reduced Indoor Contamination in Residential Buildings, NCEMBT** (NCEMBT 061101), US report | Pulldown | Eight VOCs mixture | $TVOC_{toluene}$ formaldehyde | CADR |
| **Air cleaner, Japanese Standard Association** (JIS C 9615-2007) | Singlepass | $NO_2$, $SO_2$ | $NO_2$, $SO_2$ | Single-pass efficiency |
| **Air cleaners of household and similar use, Japan Electrical Manufacturers Association** (JEM 1467-1995) | Pulldown | Tobacco smoke | Ammonia, acetaldehyde, and acetic acid | Removal rate |
| **Independent air purification devices for tertiary sector and residential applications - Test methods - Intrinsic performances, Association Française De Normalisation** (XP B44-200) | Singlepass | Four VOCs mixture | Acetone, acetaldehyde, heptane, and toluen | Single-pass efficiency, CADR |
| **Test method for assessing the performance of gas-phase air cleaning media and devices for general ventilation** (ISO 29464:2017) | Singlepass | VOCs, acids, bases, and others | VOCs, acids, and bases, and others | Single-pass efficiency |

*Source: Afshari et al. (2022)*

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# Some challenges

- Only a few pollutants examined
- No methods for identifying by-products

## BYPRODUCT GENERATION INCOMPLETE OXIDATION

- Aldehydes → **formaldehyde**, formic acid, CO
- **Alcohols** → aldehydes → acids → shorter carbon chain alcohols and acids →**formaldehyde**, methanol → $CO_2$ and $H_2O$
- Benzene → phenol
- 1-Butanol → butanal (butyraldehyde), butanoic acid, ethanol, acetaldehyde, (propanal (propionaldehyde) and propanol, propanoic acid) → (ethanol, **formaldehyde**) → methanol, **formaldehyde** and formic acid
- Ethanol → methanol, acetaldehyde, **formaldehyde**, acetic acid, formic acid
- Methanol → methyl formate (measured in liquid form only), **formaldehyde**, methylal (formaldehyde dimethyl acetal
- Toluene → benzaldehyde, benzoic acid, cresol, benzyl alcohol, phenol, benzene, formic acid

*Source: Mo et al. (2009)*

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# Assessments of perceived air quality (for building materials' emissions)

INTERNATIONAL STANDARD **ISO 16000-28**

First edition
2012-03-15

**Indoor air —**

Part 28:
**Determination of odour emissions from building products using test chambers**

*Air intérieur —*

*Partie 28: Détermination des émissions d'odeurs des produits de construction au moyen de chambres d'essai*

Test Panel

- Trained
- Untrained

Odour

- Acceptance
- Intensity
- Hedonic tone

**Examples of diffuser and mask used for odour evaluatio**

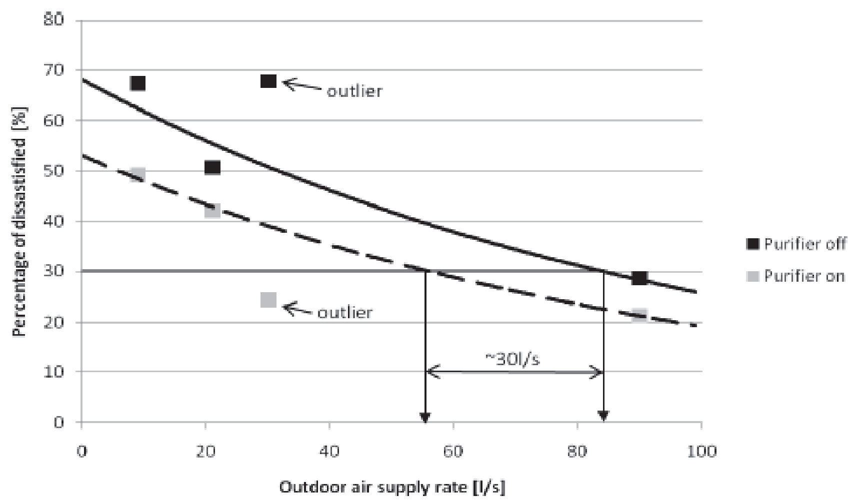
**Figure C.1 — Diffuser**

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

where:

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

# Use of perceived air quality, example

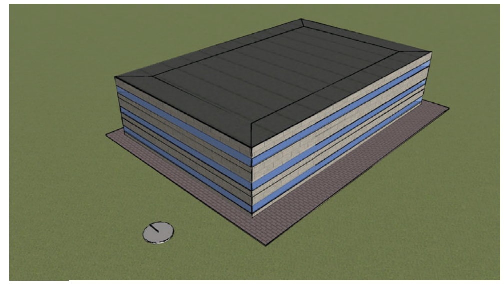



# Energy simulations, example

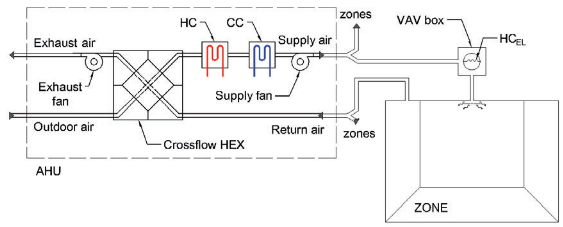
*Source: Bogatsu et al. (2021)*

# Methods - Model

- Middle floor of the DOE medium office building
- Lightweight building, VAV system
  - Tair,supply 12.8 °C
  - VAV box with electrical heating coil



- AHU: air-to-air HEX, heating and cooling coil, fans
- Minimum/Maximum airflow rate 1.4 ACH/2 to 10 ACH
- Airflow rate Method I, EN16798-1:2019




[1]Bogatu, D.I., Kazanci, O.B., and Olesen, B.W. Clean air effectiveness: indicator for assessing the energy use implications of gas-phase air cleaning. Submitted to Energy and Buildings.

[2]Bogatu et al., Resilient cooling and ventilation for buildings and people, PhD Thesis, Technical University of Denmark, 2024



# Methods – Sensitivity analysis

- 5A: cold and humid; 3A warm and humid
- Three arbitrarily chosen CADRs 0%, 30%, 50%
- Two AHU configurations: with or without HEX
- Air cleaner not physically implemented

| Scenario | Climate | Location | HEX | CADR [L/s] | CADR [%] |
|---|---|---|---|---|---|
| CPH | 5A | CPH, DK | Without | 0 | 0 |
| CPH_30 | | | | 536 | 30 |
| CPH_50 | | | | 893 | 50 |
| CPH_HEX | | | With | 0 | 0 |
| CPH_HEX_30 | | | | 536 | 30 |
| CPH_HEX_50 | | | | 893 | 50 |
| TYO | 3A | TYO, JP | Without | 0 | 0 |
| TYO_30 | | | | 536 | 30 |
| TYO_50 | | | | 893 | 50 |
| TYO_HEX | | | With | 0 | 0 |
| TYO_HEX_30 | | | | 536 | 30 |
| TYO_HEX_50 | | | | 893 | 50 |

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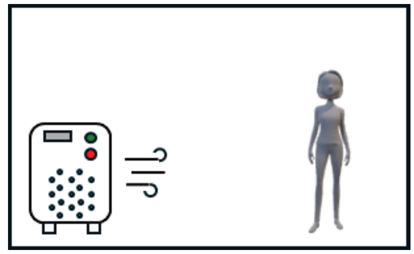
# Methods – Case study

- Energy use of air cleaner vs. energy savings in heating, cooling, and air delivery
- Stand-alone gas-phase air cleaner; operating if:
  - VAV is not in cooling mode
  - During occupancy
- CADR of air cleaner determined experimentally[3]
  - Challenged with both bio-effluents and building emissions
  - Based on PAQ of panel (37 people)



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[3]Based on procedure presented by 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.



# Methods – KPI

- New KPI proposed: clean air effectiveness (CAE):

$$CAE = \frac{CADR}{E_{use}} \quad [L/s\ per\ kWh]$$

- Ratio between the air flow reduction while accounting for the energy used for heating, cooling, and delivering the air

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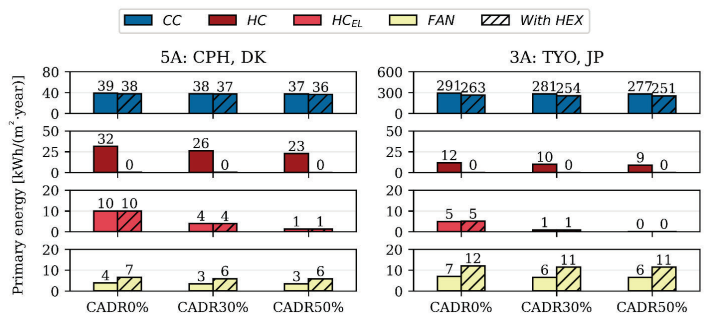
# Results – Energy use

- For 179 L/s (10%) increase in CADR:
  - 5A: 2.3 to 3.9 kWh/m[2]/y energy savings
  - 3A: 3.6 to 4.4 kWh/m[2]/y energy savings
- Energy savings:
  - From heating in cold climates
  - From cooling in warm climates
- Insignificant energy savings from air delivery reduction

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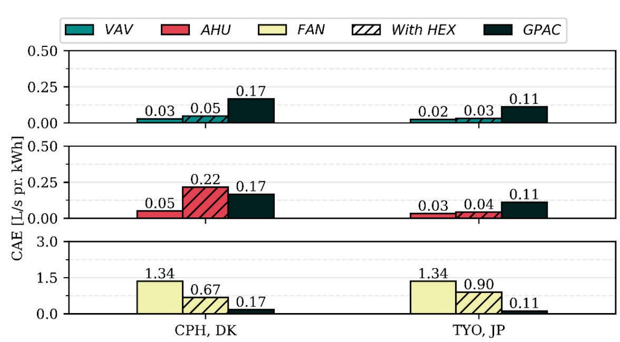
# Results – Case study

- If only fan energy use is considered, the air cleaner is never competitive
- Air cleaner is not competitive in cold climates if demand of each zone is excluded (AHU only) and HEX is included
- Air cleaner is competitive if energy use over entire VAV is taken into account




Scenario CADR 893 L/s (50%)

VAV: entire VAV system; AHU: excluding $HC_{EL}$; Fan: only fan energy use

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## Conclusion

- Air cleaning leads to reductions in heating, cooling, and airflow delivery energy use.
- Air cleaning can lead to energy savings in both cold and warm humid climates.
- Air cleaning may be a competitive energy saving solution even for low outdoor air flow rate reductions, e.g. 20%.
- CAE can be used as a metric of assessing air cleaner efficiency in relation to energy. CAE can be used to select the optimum air cleaner with respect to energy use.
- The CAE offers an equitable comparison only if heating and cooling energy use of the entire HVAC system is included in the evaluation.
- Results suggest a trade-off between the desired air quality and energy savings.



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# Development of a new standard for testing gas-phase air quality performance

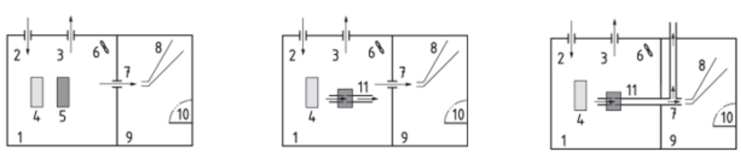
# Proposal of a procedure for testing standard

- Two-stage-testing
- Stage 1: Pass/no pass with respect to the effect on indoor air quality
- Stage 2: Determine clean air delivery rate (CADR) and compare with equivalent ventilation requirements

- Use sensory assessment of air quality by human panel (ultimately chemical measurements)

- No testing of long-term performance

# A new standard for testing air cleaners using sensory evaluations




a) Test room for a standalone air cleaner

b) Test room for a duct air cleaner

c) Test room for a duct air cleaner (single-pass condition)

**Key**

a clearly acceptable
b just acceptable
c just unacceptable
d clearly unacceptable

**Key**

a no odour
b slight odour
c moderate odour
d strong odour
e very strong odour
f overpowering odour

**ISO 16000-44:2023(E)**

First edition

2023-12

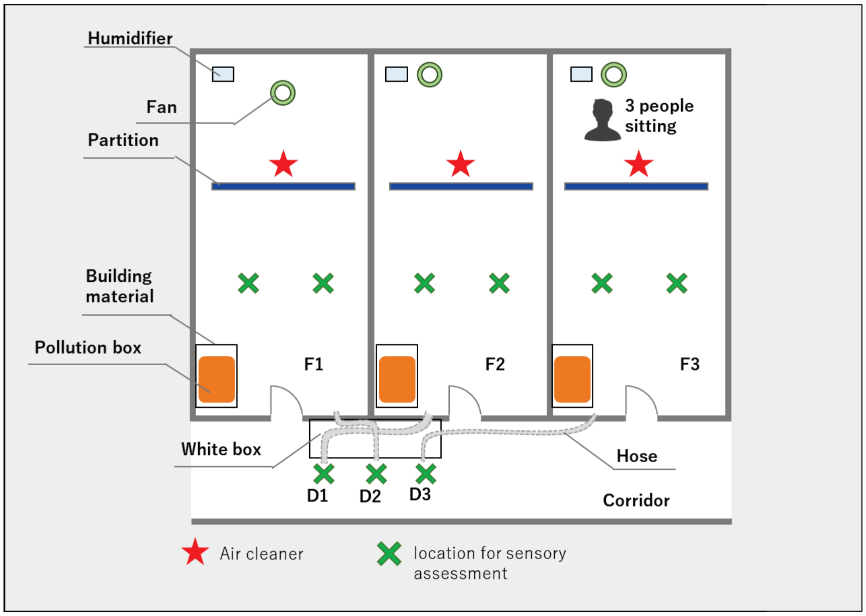
**Indoor air —**

**Part 44:**
**Test method for measuring perceived indoor air quality for use in testing the performance of gas phase air cleaners**

*Air intérieur —*

*Partie 44: Méthode d'essai pour mesurer la qualité de l'air intérieur perçue à utiliser pour tester les performances des épurateurs d'air en phase gazeuse*

# Experimental validation, setup




# Overall protocol

- Portable air cleaners were tested; all operated at close to the maximum capacity
- Air cleaners were challenged with different types of pollutants representing people and building materials
- Conditions under test: ca. 23oC (73oF) and 50%RH
- Up to four levels of ventilation with outdoor air were tested
- Different number of air cleaners were placed in the rooms during testing
- Measurements of air quality were performed with air cleaners idled and in operation

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## Sensory assessments

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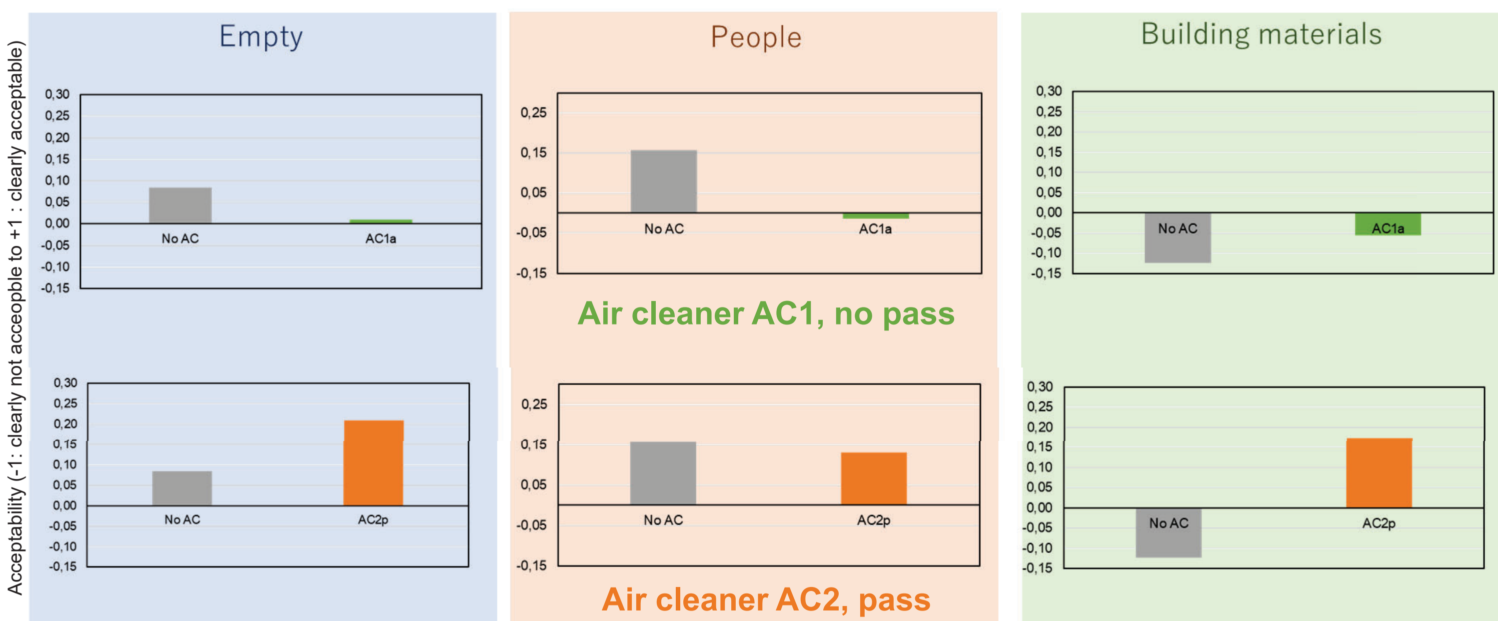
## Stage 1 results, passed/not passed



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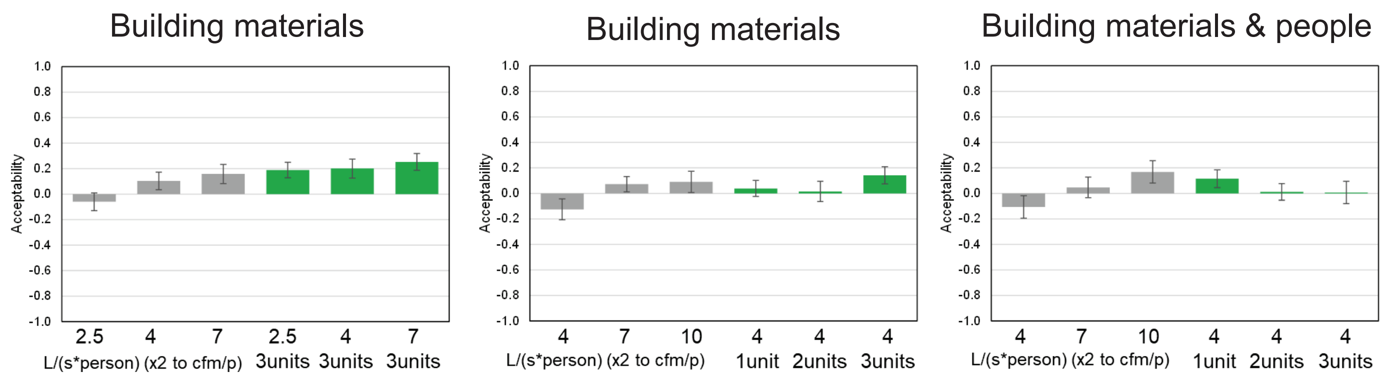
# Stage 2 results

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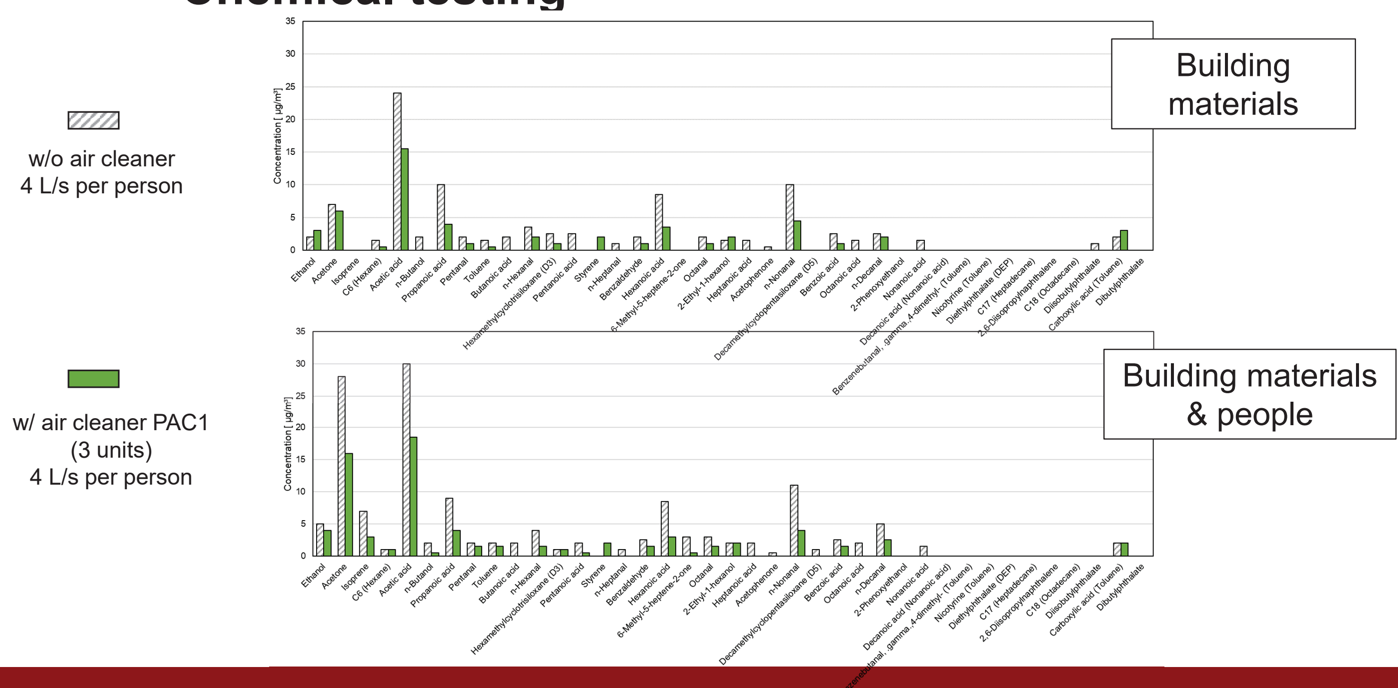
# Chemical testing



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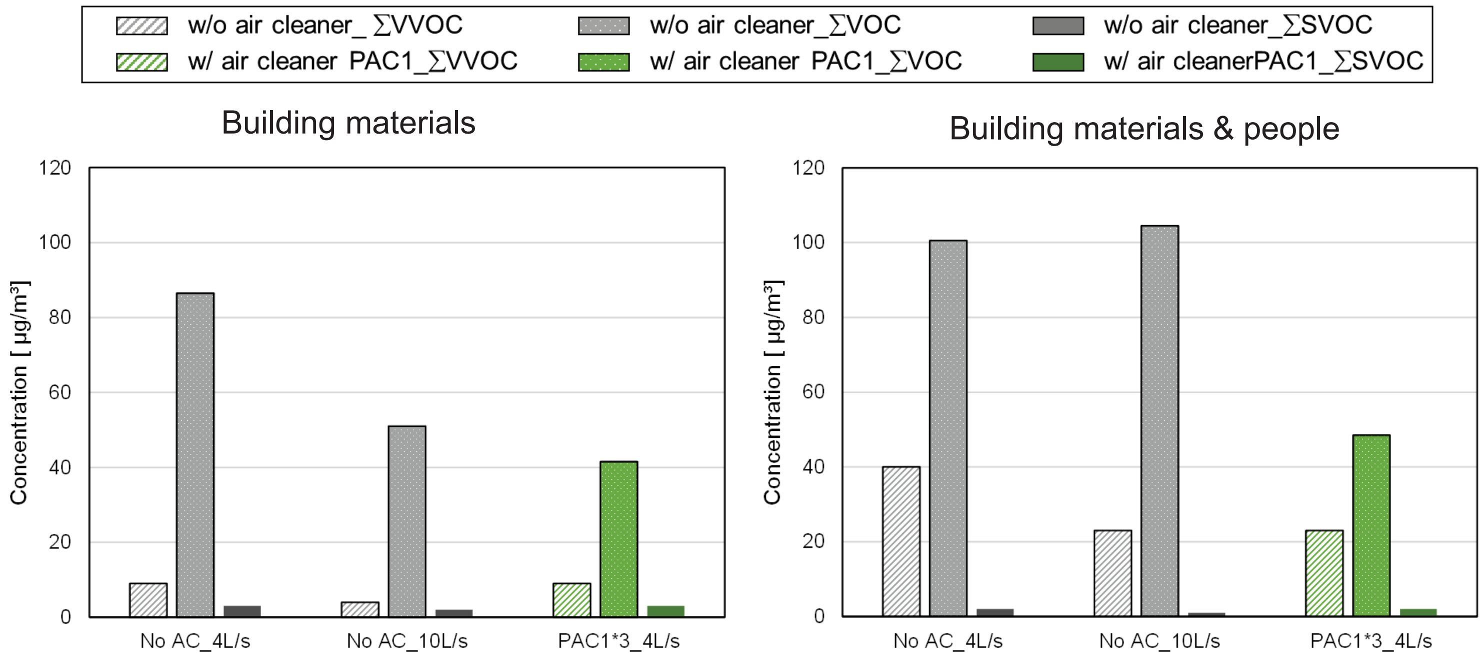
## Chemical analyses, summary

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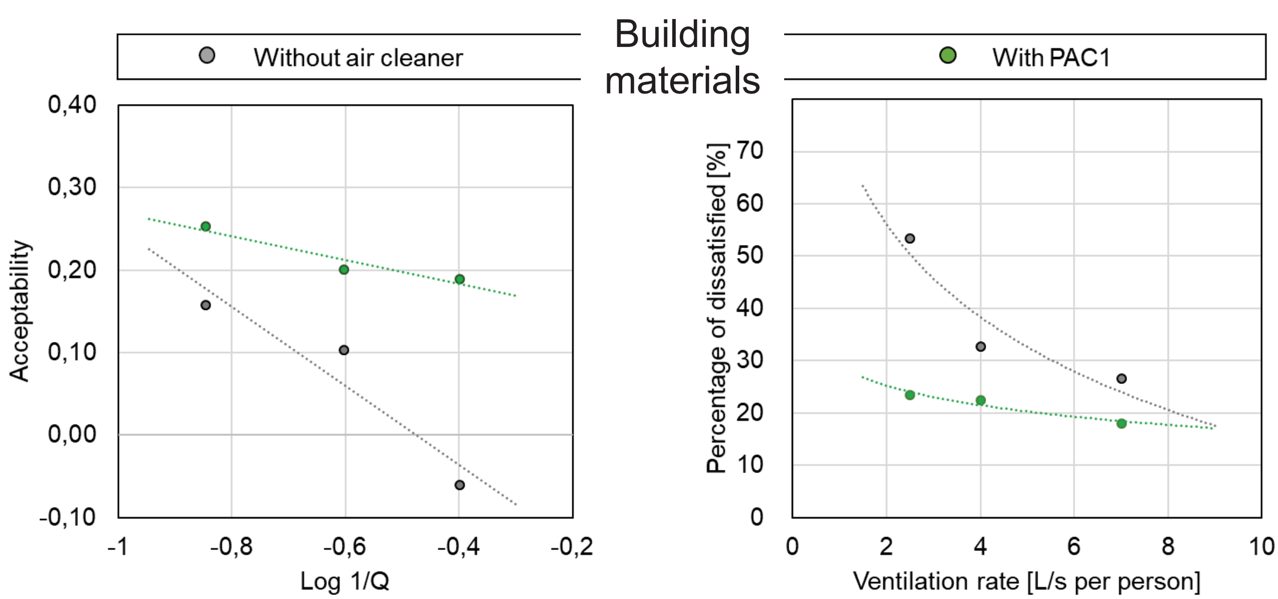
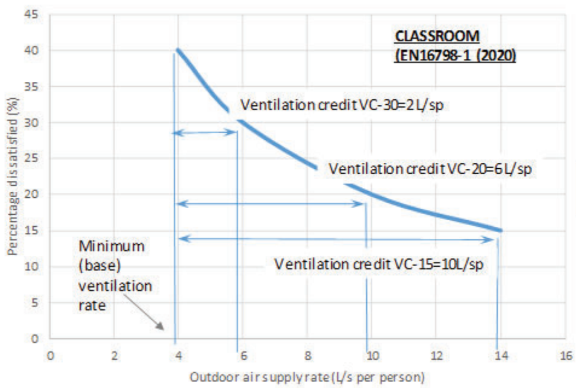
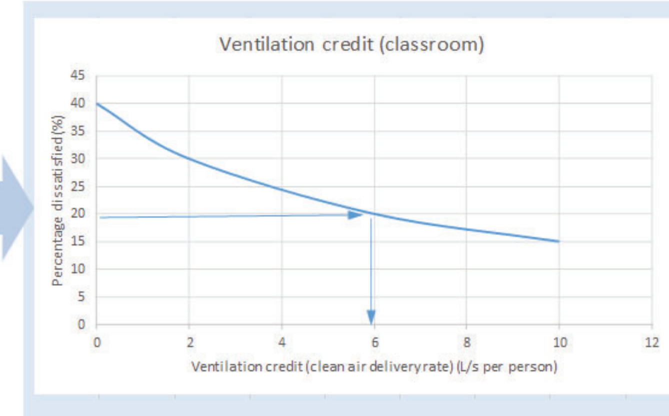
## Estimation of clean air delivery rate (CADR)

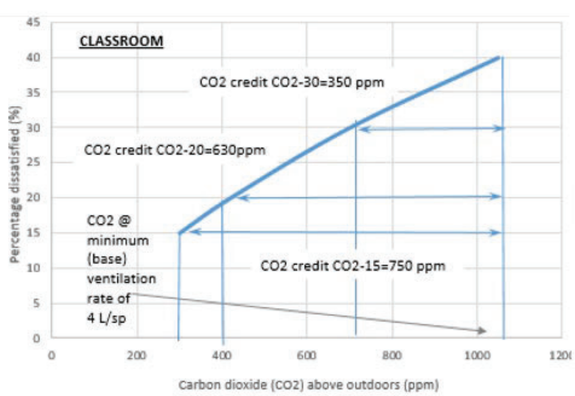


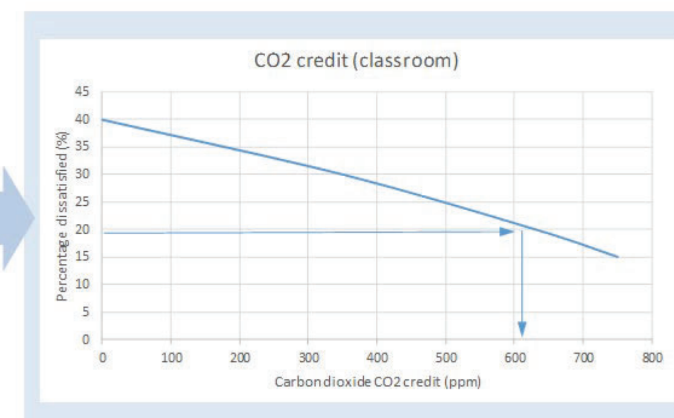
# Ventilation credit or CADR?, new concept




# $CO_2$ credit



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## Conclusions

- 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.
- It must be verified that the reduced ventilation rate is still high enough to dilute individual contaminants.
- Adjusted $CO_2$ criteria must be used to express the indoor air quality and to use for demand-controlled ventilation.



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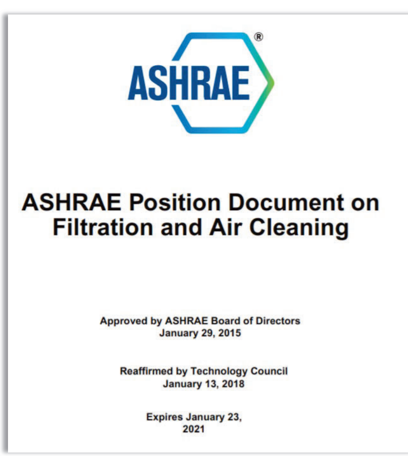
## ASHRAE Position Document on air filtration and cleaning


ASHRAE Position Document on Filtration and Air Cleaning

Approved by ASHRAE Board of Directors January 29, 2015

Reaffirmed by Technology Council January 13, 2018

Expires January 23, 2021

1. **Filtration technologies**, in which particles are removed by at-taching them to the media, often called mechanical or media filters, have been documented to be capable in many cases of reducing particle concentrations substantially, including reductions from levels being above to levels being below the associated regulatory exposure limits for reducing health risk set by recognized cognizant authorities. Modest empirical evidence suggests that mechanical filters will have positive effects on health, especially for reducing adverse allergy or asthma outcomes, but not on acute health symptoms in the gen-eral population, often called sick-building syndrome (SBS) symptoms. Models predict large reductions in morbidity and mortality associated with reduction of indoor exposures to particles from outdoor air, but these health benefits have not been verified empirically.
2. Filtration technologies that generate electrical fields and/or ions, often called **electronic filters**, have been documented to range from relatively ineffective to very effective in reducing particles substantially, including reductions from levels being above to levels being below the associated regulatory exposure limits for reducing health risks set by recognized cognizant authorities. Within this broad characterization of air cleaners, ionizers have been evaluated to either show benefits or no benefits for acute health symptoms. Many electronic air cleaners emit significant ozone and are thus subject to special attention.
3. There are **sorbent air cleaners** that have been documented to re-duce concentrations of harmful gaseous contaminants substantially, including reductions from levels being above to levels being below the associated regulatory exposure limits for reducing health risks set by recognized cognizant authorities. There are very limited data on long-term effectiveness of these air cleaners for indoor air applications with mixtures of contaminants at low concentrations. Minimal empirical data exist on the health effects of using sorbent-based air cleaning technologies.
4. Air cleaners using **photocatalytic oxidation (PCO)** have been documented to remove harmful contaminants to levels being below the associated regulatory exposure limits for reducing health risks set by recognized cognizant authorities. However, there are PCO technologies that are ineffective in reducing concentrations significantly, and there are PCO technologies that have also been shown to generate harmful contaminants during the air cleaning process. No empirical data exist on the health effects of using PCO technologies. Different UV lamps used in many PCO devices can emit significant ozone and are thus subject to special attention.
5. **Ultraviolet germicidal energy (UV-C)** has been documented to inactivate viruses, bacteria, and fungi. Some air cleaning technologies using UV-C disinfection (also termed ultraviolet germicidal irradiation [UVGI]) have been documented in a few studies to show beneficial health effects when upper-room air, ventilation ducts, and evaporator coil surfaces were irradiated with UV-C. There are studies that have failed to detect health benefits. UV-vacuum (UV-V) lamps can emit significant ozone and are thus subject to special attention.
6. **Packaged air cleaners** using multiple filtration and air cleaning technologies are room air appliances intended for residential and small-space application. Their performance is subject to the advantages and disadvantages of the filtration and air cleaning technology incorporated within the devices. Scientific documentation of the health effects of these devices on occupants is sparse and inconclusive. Some of the technologies incorporated into these devices either produce or rely on ozone for application and are thus subject to special attention.
7. Air filtration and cleaning technologies are often regarded as an attractive alternative to ventilation, enabling a reduction of outdoor air ventilation rate. The Indoor Air Quality (IAQ) Procedure of ASHRAE Standard 62.1 allows lower ventilation rates if alternative methods are used to reduce exposures to contaminants of concern, including the use of filtration or air cleaning. Limited data exist documenting the effectiveness of air cleaning, in particular gas-phase air cleaning, as an alternative to ventilation.

pawar@dtu.dk

# Thank you and questions