The Present and Future Role of Gas-Phase Air Cleaning as an Alternative to Increased Ventilation in Office Buildings

The Present and Future Role of Gas-Phase Air Cleaning as an Alternative to Increased Ventilation in Office Buildings

Alireza Afshari & 21-02-2025

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Background

- Increasing global focus on energy efficiency and sustainability in buildings
- Climate change driving demand for resilient HVAC solutions
- Growing health concerns highlight importance of indoor air quality (IAQ)
- Need for innovative approaches integrating energy performance and air cleaning

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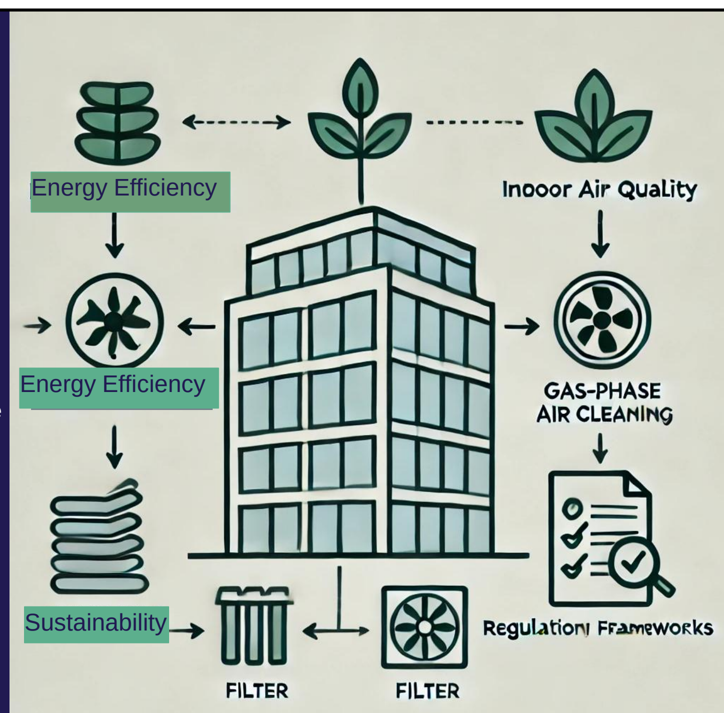

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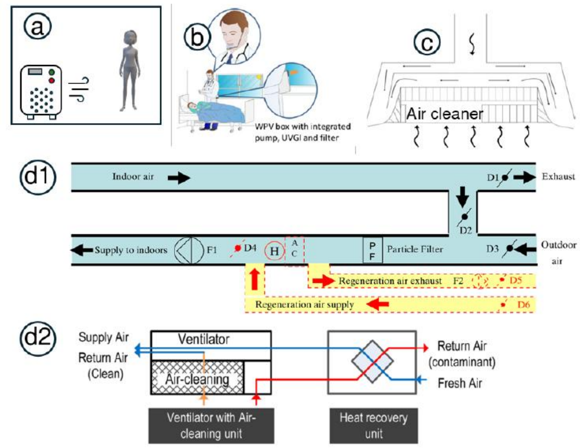
System Configurations – How Air Cleaners Are Used in Buildings

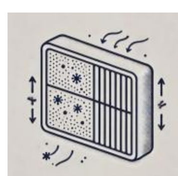
- **Stand-Alone Units:**
  Portable air cleaners placed in rooms to clean the air around people.
- **Personal Ventilation Systems:**
  Small air cleaning units that deliver clean air directly to a person's breathing zone.
- **Beam-Based Systems (Chilled Beams):**
  Air cleaners built into cooling beams that clean the air while providing cooling.
- **Primary Air Supply:**
  Air cleaners placed at the main air supply point to clean outdoor air before it enters the building.

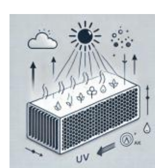


Air cleaning implementation:
a) Stand-alone unit,
b) Personalized environmental control systems (PECS),
c) Beam based,
d) Primary air supply

Key Technologies

- **Activated Carbon Filters:** Absorb gases and odors, effective for VOCs.
- **Photocatalytic Oxidation (PCO):** Uses UV light and a catalyst to break down pollutants.
- **Air Ion Generators:** Release ions to neutralize particles and gases.
- **UV-Based Air Purification:** Kills viruses and bacteria.
- **Hybrid Systems:** Combine multiple technologies for better performance.





Key Findings from Annex 78

- Gas-phase air cleaning technologies can reduce heating energy demand while maintaining IAQ
- Recirculation rates of 20%, 40%, and 60% in offices with HRV systems led to 8%, 16%, and 24% heating energy savings (Nourozi et al., 2022)
- Residential buildings with HRV showed minimal impact from air cleaning; without HRV, 3% savings per 20% recirculation increase
- Air cleaners integrated into active chilled beams yielded primary energy savings of 26% (Afshari et al., 2023)
- Energy savings observed across different climates, e.g., Copenhagen (9 kWh/m²/year) and Tokyo (5 kWh/m²/year) (Bogatu et al., 2024)

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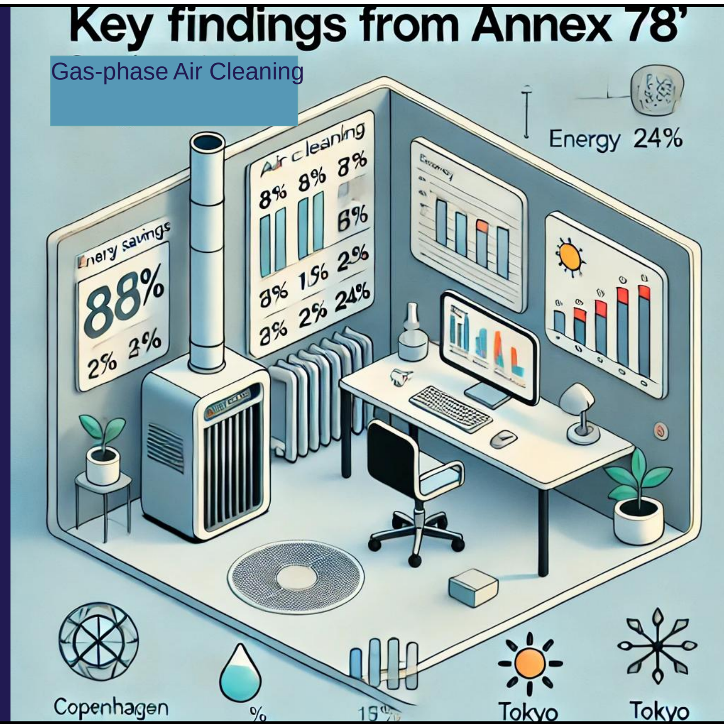

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Technology Readiness Assessment

- Preliminary assessment conducted in Annex 78 and 87
- Technology shows potential in different climates (e.g., Sweden, Tokyo)
- CADR/kWh metric emphasized for evaluation

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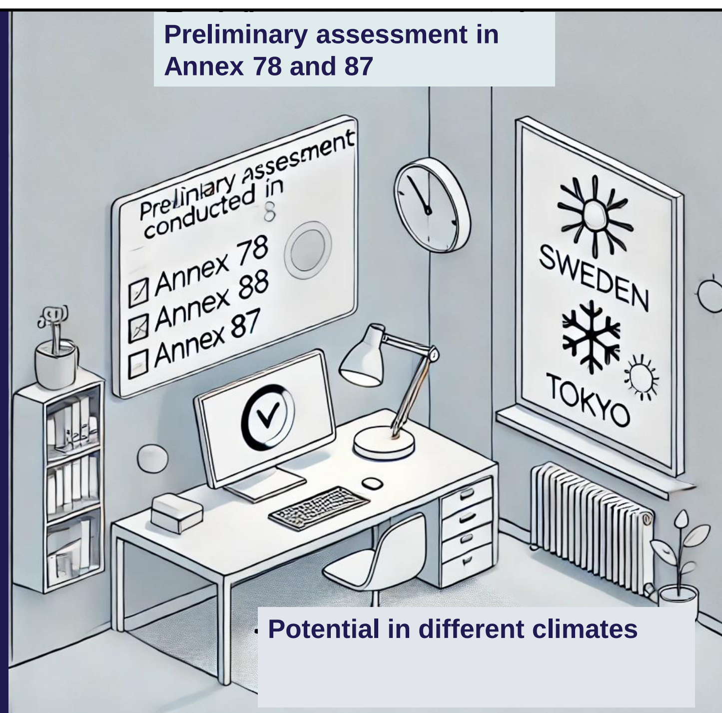

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Problem

- Balancing energy efficiency and indoor air quality (IAQ) in buildings
- Increased urgency due to climate change, heat waves, wildfires, and pandemics
- Traditional ventilation systems lead to high energy consumption

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Approach

- Integrating advanced gas-phase air cleaning technologies:
  - Activated carbon filters
  - Photocatalytic oxidation
  - Air ion generators
- Combining with mechanical filtration
- Reducing outdoor air intake while ensuring pollutant removal

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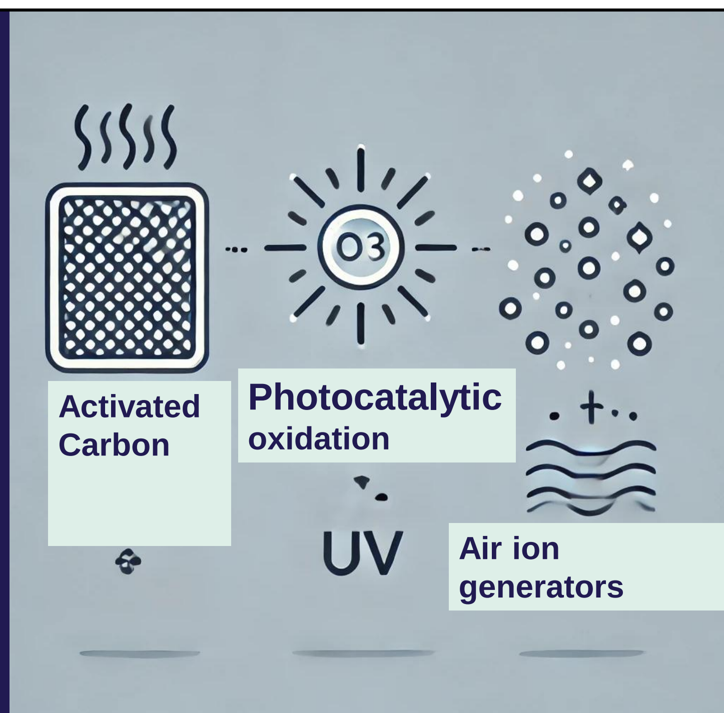

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Objectives

- Develop a standardized framework for selecting and applying gas-phase air cleaning technologies
- Optimize energy performance across building types and climates
- Define selection criteria for air cleaning and filtration systems
- Standardize performance metrics (e.g., CADR/kWh)
- Evaluate energy-saving potential during overheating and climate events
- Conduct field evaluations and real-world case studies
- Support regulatory frameworks

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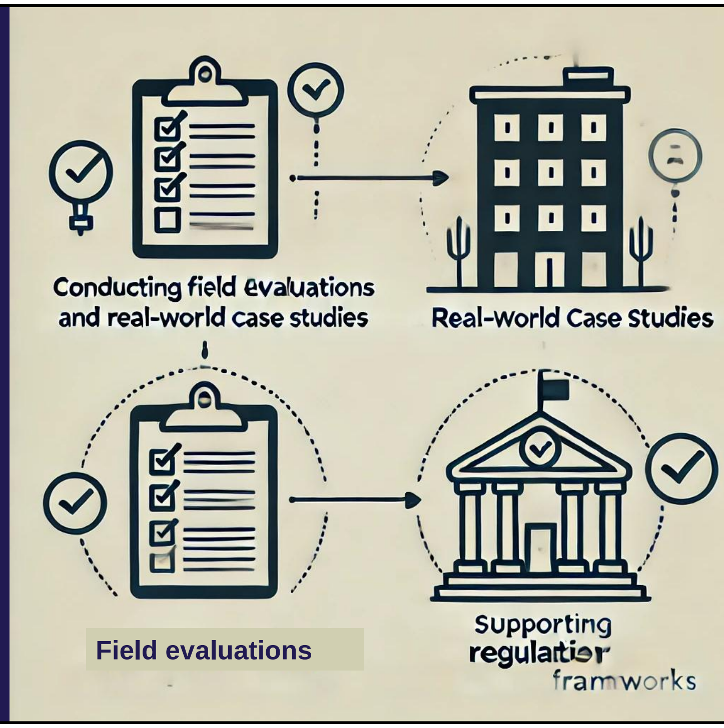

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Scope

- Focus on office and residential buildings
- Two key scenarios:
  - Buildings with heat recovery systems
  - Buildings without heat recovery systems
- Field evaluations to validate real-world performance

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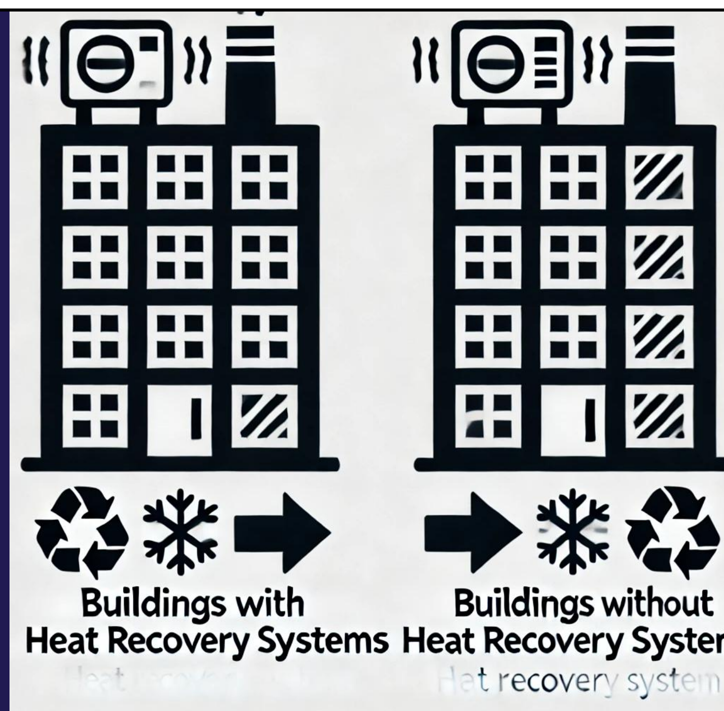

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New Annex

- Shift towards energy efficiency improvements
- Investigating cooling energy recovery and high recirculation rates
- Combining air cleaning and filtration as an integrated strategy

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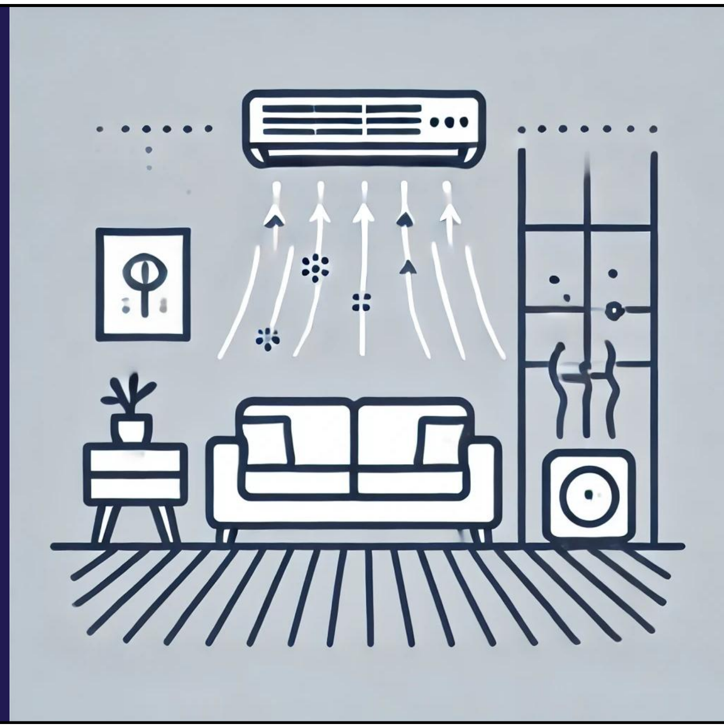

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Field and Simulation Studies

- Conduct field evaluations and case studies
- Test protocols and energy savings assessments
- Develop adaptive control strategies for dynamic response

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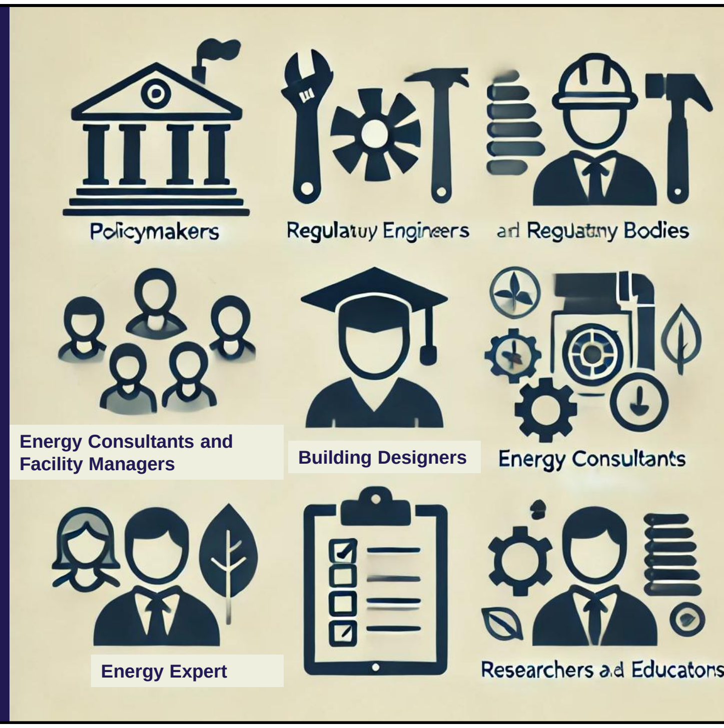
Target Audience

- Policymakers and regulatory bodies
- HVAC engineers and building designers
- Energy consultants and facility managers
- Sustainability experts
- Researchers and educators



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Relation to EBC Strategic Plan

- Supports EBC Strategic Plan 2024-2029
- Step change and disruptive impact:
  - Integration of air cleaning into HVAC for energy reduction
  - CADR/kWh as a performance benchmark
  - Holistic approach to lifecycle and environmental impact

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Required Expertise

- Advanced gas-phase air cleaning technologies
- Lifecycle assessment experts
- Regulatory framework analysts
- Data analytics and AI professionals
- Cross-disciplinary integration experts

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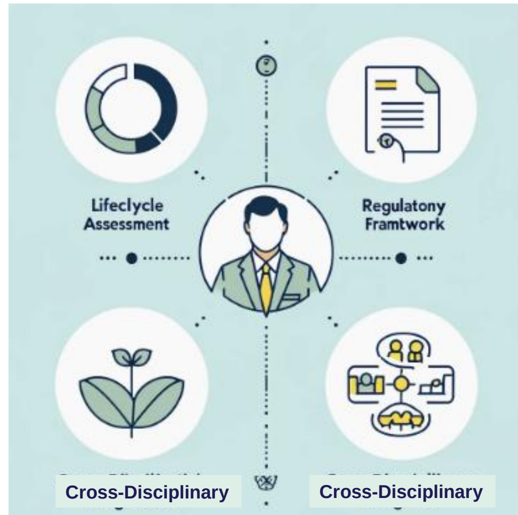

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Collaborating Organizations

- Technical universities (e.g., AAU, DTU, KTH)
- Industry partners (HVAC manufacturers, technology developers)
- Government agencies and policymakers
- NGOs and sustainability certification bodies

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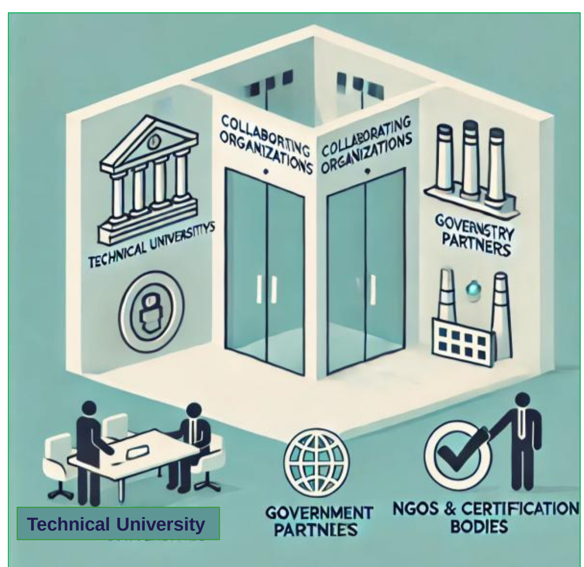

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Energy implication of using gas-phase air cleaners in residential & office buildings

Sasan Sadrizadeh

Nourozi, B., Holmberg, S., Duwig, C., Afshari, A., Wargocki, P., Olesen, B., & Sadrizadeh, S. (2022). Heating energy implications of utilizing gas-phase air cleaners in buildings' centralized air handling units. *Results in Engineering*, *16*, 100619.

Introduction and background

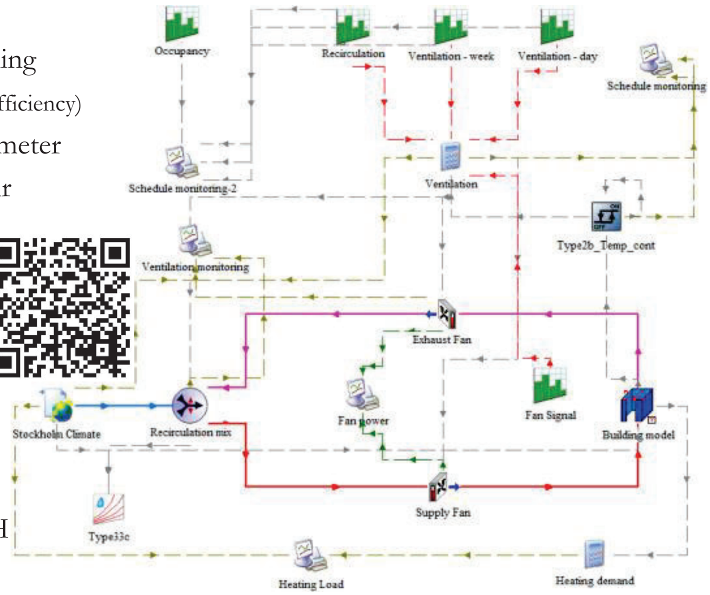
- **Ventilation** systems are important for maintaining a **healthy and comfortable indoor** environment.
- In cold climates, ventilation systems contribute to **approximately 30% of building heat losses**.
- **Indoor emissions** and **outdoor pollutants** affect **indoor air quality** and need to be controlled.
- **Gas-phase air cleaning** as an extension of ventilation can help maintain acceptable indoor air quality while reducing **energy use**.

Investigated parameters

- **Heating demand** of a ventilated building
- Indoor **TVOC level** (with 60% capturing efficiency)
- Indoor **CO_2 level** as a monitoring parameter
- Possibility of **air recirculation** when air cleaner is integrated.

Simulation case

- Newly constructed or renovated buildings
- Older buildings without heat recovery ventilation
- Residential and office cases with various ACH

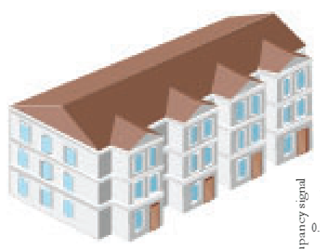


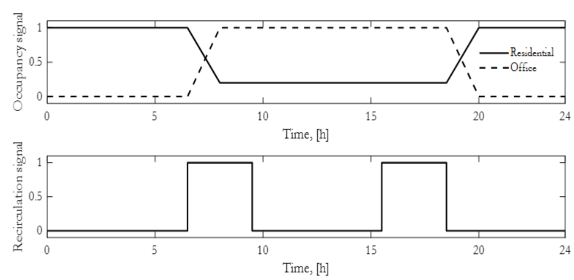
Energy simulation using TRNSYS

Simulation cases study in Stockholm climate equipped with centralized air handling unit (2000 $m^2_{vent.\ area}$)

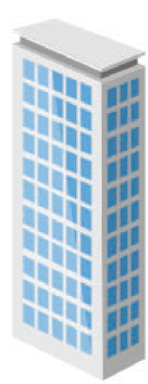
EBC Energy in Buildings and Communities Programme

- **Residential building**
  - 0.45 ACH
  - Occupancy schedule





- **Office building**
  - 2.1 ACH
  - Occupancy schedule
  - Ventilation schedule



Air pollutant	TVOC			CO_2	
Source	Outdoor	Occupants	Interior furnishing	Outdoor	Occupants
Value	$\mu gr.m^{-3}$	$mgr.h^{-1}.person^{-1}$	$\mu gr.m^{-3}h^{-1}$	$mgr.m^{-3}$	$gr.h^{-1}.person^{-1}$
	110	6.3	120	720	120

Indoor and outdoor emission rates

Location	Reference	TVOC concentration $\mu g.m^{-3}$
Europe	Report EUR 14449 EN. 1992	Comfort range < 300 Multifactorial exposure range < 3000 Discomfort range < 25000 Toxic range > 25000
Finland	Finnish Society of IAQ and Climate. 2000	Individual indoor climate < 200 Good indoor climate < 300 Satisfactory indoor climate < 600
Germany	Federal Environment Agency of Germany	Hygienically safe < 1000 Hygienically noticeable < 3000 Hygienically alarming < 10000 Hygienically unacceptable > 1000
Germany	Seifert B.	300

Guideline values for indoor TVOC concentration

Residential building (0.45 ACH)

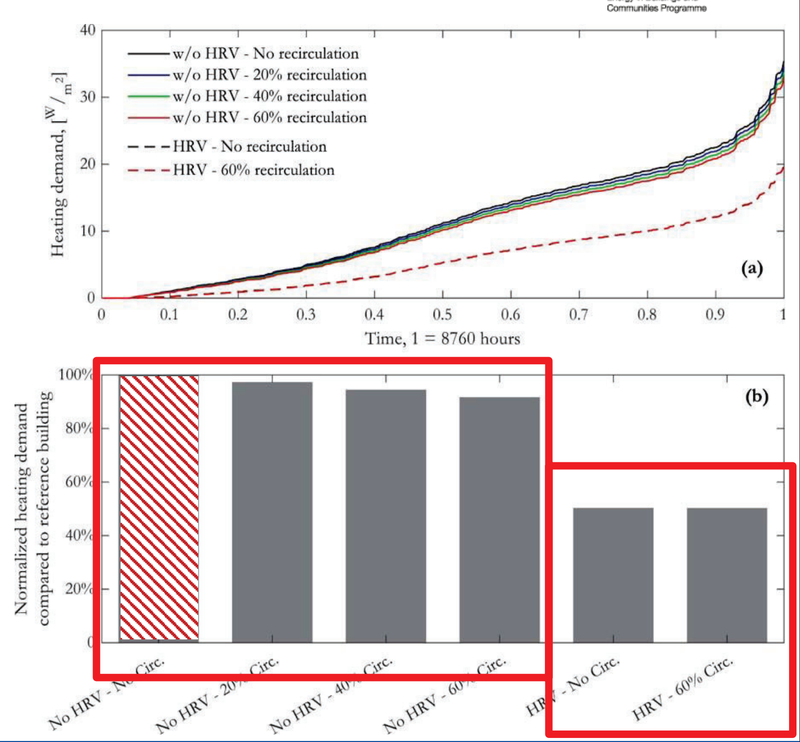
EBC Energy in Buildings and Communities Programme

Ventilation <u>with</u> heat recovery:

- **The recirculation** effect on **heating demand** is <u>negligible</u>!
- Air cleaner implementation **might not be** that effective!

Ventilation <u>without</u> heat recovery:

- **The recirculation** effect on **heating demand** is <u>small</u>!
- Air cleaner implementation **might reduce** building heating demand!



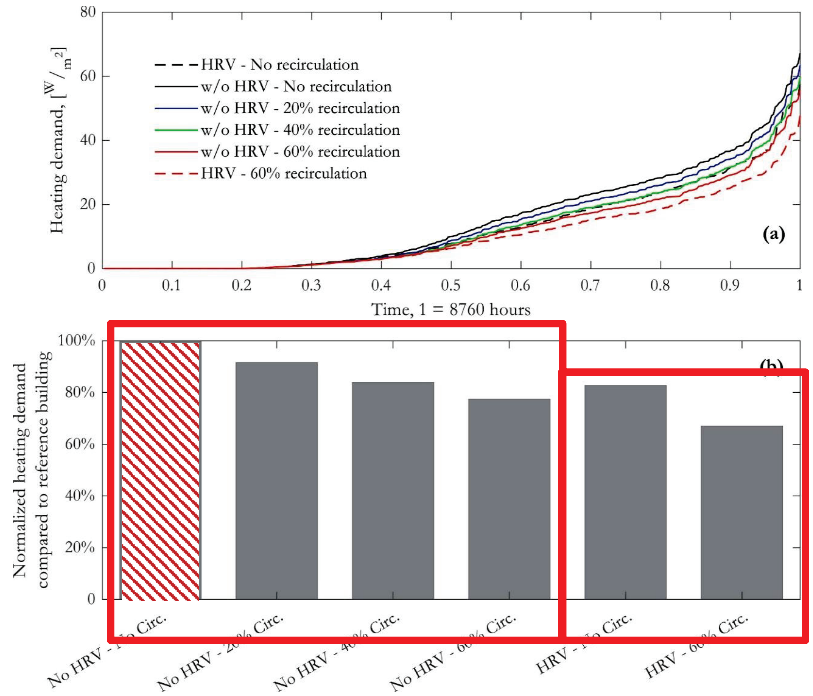
HRV: Heat Recovery Ventilation

Office building (2.1 ACH)

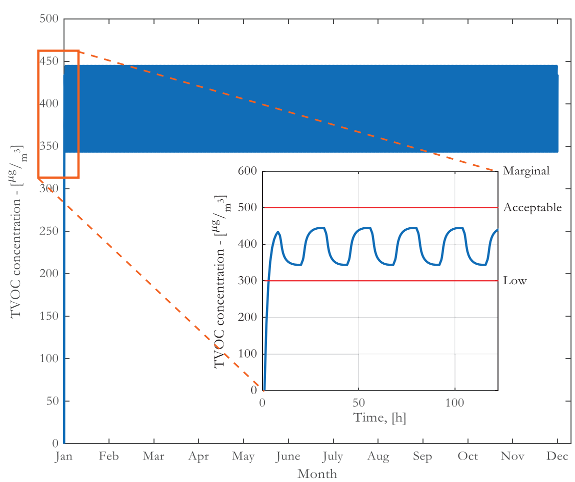
Ventilation with heat recovery:

- **The recirculation** effect on **heating demand** is **notable** compared to the residential buildings!
- This is the case for both **with and without** heat recovery!
- Air cleaner implementation **is effective**!

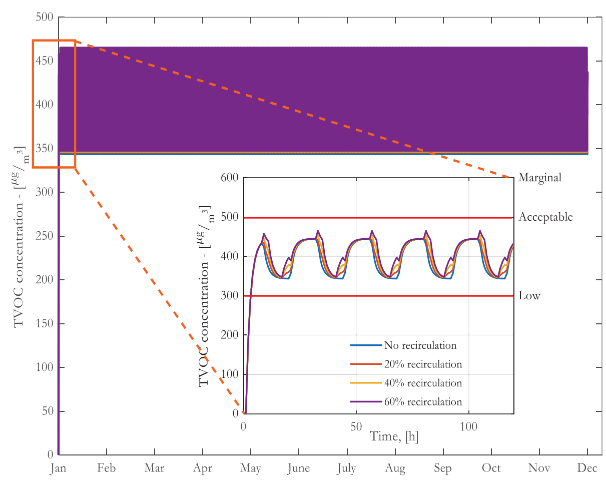
Thus ACH is an important parameter that needs to be considered.



Residential building: Impact of **air recirculation** on TVOC concentration (<500 μg/m³)



Without air recirculation

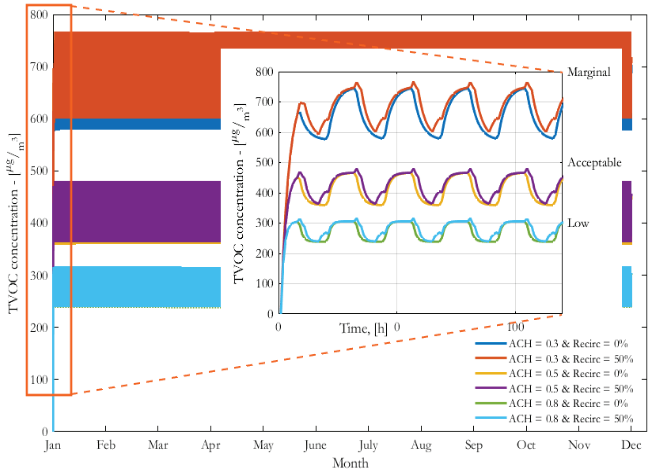


With air recirculation (and air cleaner)

TVOC concentration is within the acceptable range

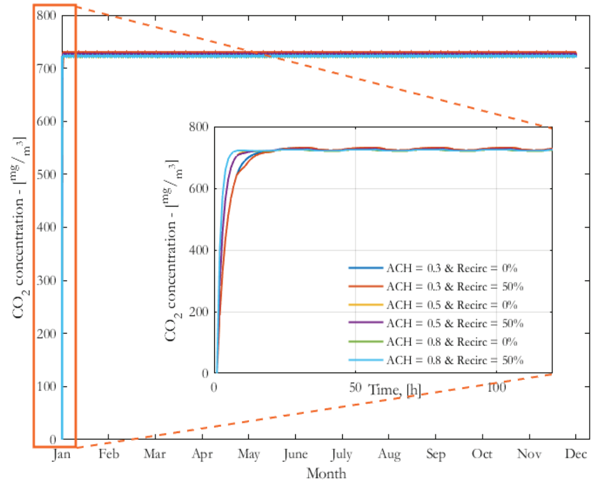
Recirculation does not result in increased TVOC level

Residential building: Impact of air recirculation and ACH on TVOC & CO_2 concentration



TVOC concentration with 0 and 50% air recirculation

- High ACH (>0.5) maintains TVOC concentration within an acceptable range, regardless of recirculation level
- Thus, adding air cleaner and recirculation is beneficial to reduce building heating demand



Co$_2$ concentration with 0 and 50% air recirculation

Recirculation % and ACH do not changes CO_2 level since the main CO_2 source is the outdoor air.

Conclusion:

- This study examines the effect of **gas-phase air cleaners** on **building heating demand**.
- The study also explores indoor **concentrations of TVOC and CO_2** when gas-phase air cleaners are used.
- Different parameters were also discussed, such as **ACH**, **air recirculation**, **ventilation**, and **occupancy schedule** on indoor **TVOC** and **CO_2** levels.
- Increasing recirculation rate **reduced heating demand** in the office building more than in residential.
- 60% recirculation rate reduced heating demand by **9%** in **residential** and **24%** in the **office building**.
- Integrating gas-phase air cleaner and increasing recirculation rate during rush hours of mornings and evenings kept TVOC and CO_2 concentrations acceptable.
- Indoor CO_2 concentration value was affected less than TVOC's by increasing the recirculation rate.
- Higher ACH minimizes the impact of recirculation rate on TVOC and CO_2 levels.

Thank you!

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Gas phase air cleaning effects on ventilation energy use and indicators for energy performance

Concept for calculation of design ventilation rate
Method 1

People Component

Building Component

Breathing Zone
Outdoor Airflow

$$V_{bz} = R_p P_z + R_a A_z$$

R_p: Minimum l/s/Person
P_z: Number of People
R_a: Minimum l/s/m²
A_z: Building Area

Total ventilation rate

$$q_{tot} = n \cdot q_p + A_R \cdot q_B$$

$$q_{supply} = q_{tot} / \varepsilon_v$$

- Where
- ε_v = the ventilation effectiveness (EN13779)
- q_{supply} = ventilation rate supplied by the ventilation system
- q_{tot}= total ventilation rate for the breathing zone, l/s
- n = design value for the number of the persons in the room,
- q_p = ventilation rate for occupancy per person, l/s, pers
- A_R= room floor area, m^2
- q_B = ventilation rate for emissions from building, l/s,m^2

3

DTU

PAQ & CADR

4

CONCEPT OF SUPPLEMENTING VENTILATION BY GAS PHASE AIR CLEANING.

- **Clean Air Delivery Rate (CADR)**
  - **CADR = $\varepsilon_{PAQ} \cdot Q_{AP} \cdot (3,6/V)$**
  - where:
  - ε_{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**
  - $\varepsilon_{clean} = 100(C_U - C_D)/C_D$

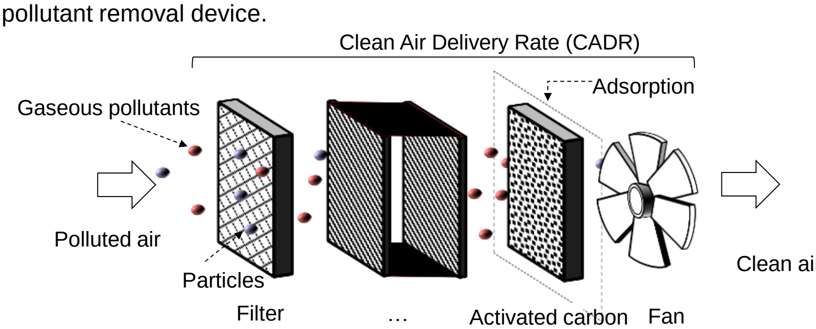
  where:
  - ε_{clean} is the air cleaning efficiency
  - C_U is the gas concentration before air cleaner
  - C_D is the gas concentration after air cleaner.
- **Higher Air Quality Category**

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

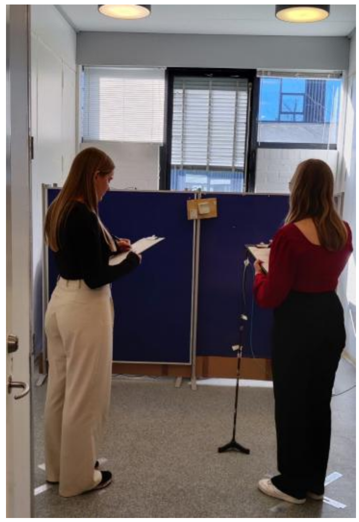
- where:
- ε_{PAQ} is the air cleaning efficiency for perceived air quality;
- Q_o is the ventilation rate without air cleaner, l/s;
- Q_{AP} is the ventilation rate with air cleaner, l/s;
- PAQ is the perceived air quality without the air cleaner, decipol;
- PAQ_{AP} is the perceived air quality without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

Gas-phase air cleaning

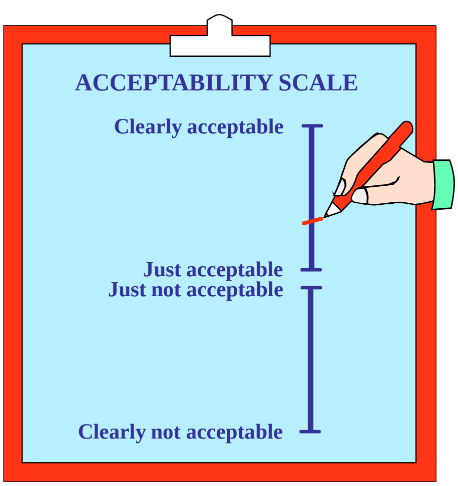
- Removes gaseous pollutants (e.g. benzene, toluene, xylene) & odour.
- Installed centrally or as stand-alone units.
- Consist of filters and a gaseous pollutant removal device.
- Characterized by a CADR

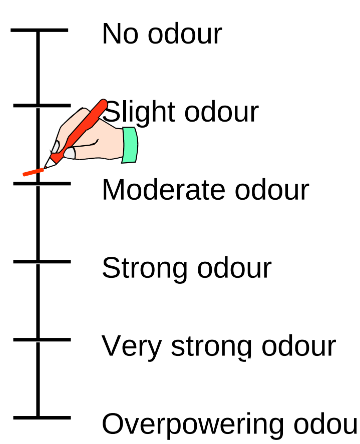


Sensory panel



Primary measurements





PAQ & CADR - Methods

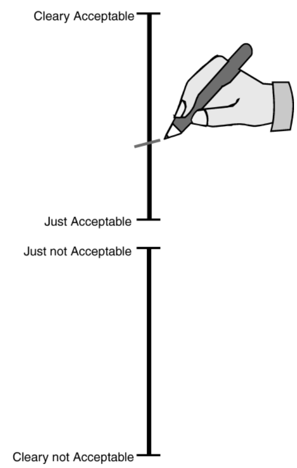
- Perceived air quality (PAQ)

$$PD = \frac{\exp(-0.18-5.28\cdot\overline{ACC})}{1+\exp(-0.18-5.28\cdot\overline{ACC})}\cdot 100\ \ [\%]$$

- CADR

$$CADR = \frac{q-q_{GPAC}}{q}\cdot 100\ \ [\%]$$

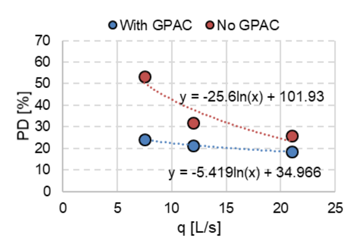
where q and q_{GPAC} are for the same PD with or without GPAC



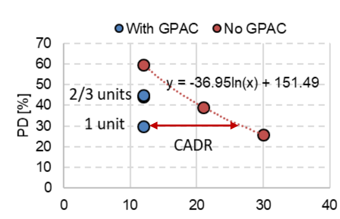
Wargocki, Pawel; 2004. "Sensory Pollution Sources in Buildings." 14(Suppl 7):82–91. doi: https://doi.org/10.1111/j.1600-0668.2004.00277.x

PAQ & CADR - Results

- With GPAC, dissatisfaction rate **reduced** for the same outdoor air flow rate
- With GPAC, outdoor air flow rate can be **reduced** for the same PD
- Increasing n_{GPAC} did not improve PAQ
- CADR:
  a) 50% (12 L/s)
  b) 30% (9 L/s)



a) building emissions only



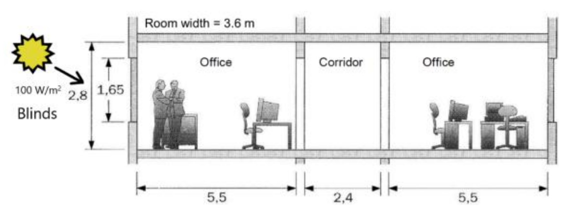
b) bio-effluents and building emissions

Energy use

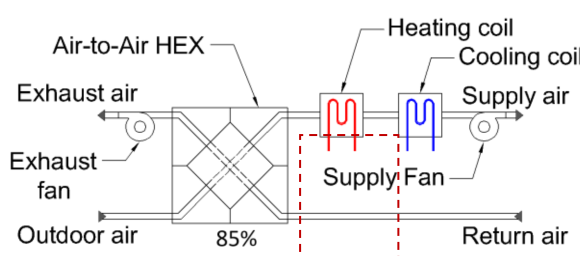
Methods - Energy

Simulation

- Copenhagen, DK
- $T_{OP,SP}$ 20 to 26 °C
- Ventilation: CAV
- Scenarios
  - with and without HEX
  - 2x pollution levels VLP and LP



Source: Olesen and Dossi, 2004



Bogatu et al. "Gas-Phase Air Cleaning Effects on Ventilation Energy Use and the Implications of CO2 Concentration as an IAQ Indicator for Ventilation Control.", Proceedings of Building Simulation 2021, 2021.

Clean Air Efficiency (CAE)

Methods - CAE

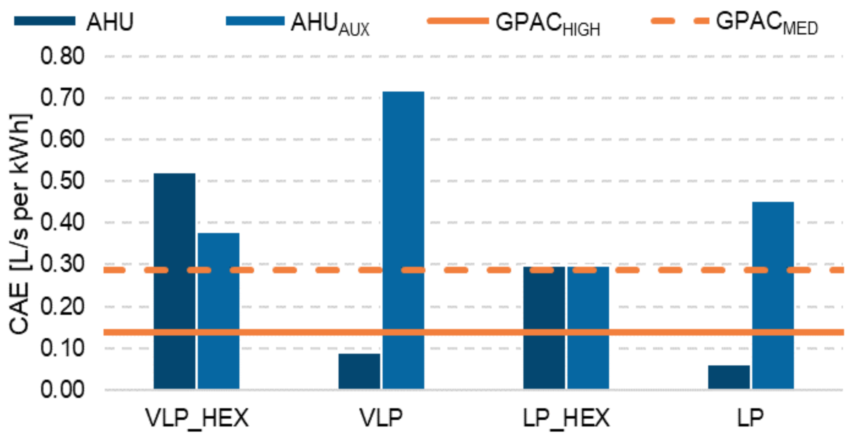
Indicator for comparing the efficiency of the AHU and stand-alone air cleaner

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

Amount of air, **CADR in L/s**, and energy use for **heating, cooling, and AUX** or **GPAC**

Results - CAE

- If the GPAC is compared only to AHU_{AUX}, the GPAC is never efficient
- If a HEX is included the GPAC is not efficient
- Higher savings can be achieved if GPAC can be operated at a setting lower than HIGH (22 W)



a) bio-effluents and building emissions, CADR of 9 L/s

Bogatu et al. "Gas-Phase Air Cleaning Effects on Ventilation Energy Use and the Implications of CO2 Concentration as an IAQ Indicator for Ventilation Control.", Proceedings of Building Simulation 2021, 2021.

Conclusions

- CAE can be used to compare different solutions for providing clean air into the space.
- In Copenhagen, DK (high heating load), GPAC was competitive only if the AHU was not equipped with a HEX.
- GPAC more efficient when it removed both bio-effluents and building emissions.
- GPAC can be used to either improve IAQ or reduce air flow rate