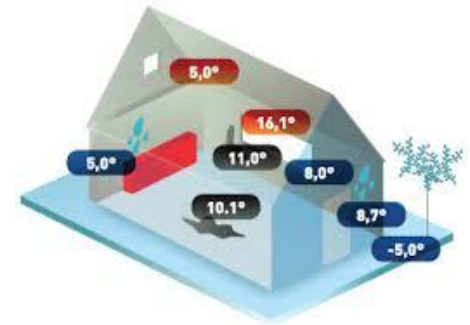
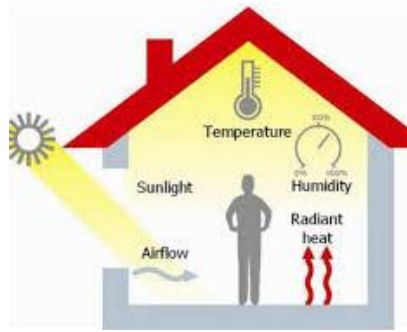


# CIVIL 212

# Indoor Climate

Fall 2025



## IAQ controls (Ventilation #2)

20 November, 2025



Human-Oriented Built Environment Lab

Website: [hobel.epfl.ch](http://hobel.epfl.ch)

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# EPFL

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Environmental Engineering

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# Any problems with the homework?

- As per ASHRAE 62.1, calculate the minimum needed ventilation rate for 60 m<sup>2</sup> classroom that is occupied by 55 students.

**Solution:**  $V_{bz} = q_p P_z + q_b A_z = 3.8 \times 55 + 0.3 \times 60 = 227 \text{ l/s} = 817 \text{ m}^3/\text{h}$

**TABLE 6.2.2.1 Minimum Ventilation Rates in Breathing Zone**

(This table is not valid in isolation; it must be used in conjunction with the accompanying notes.)

Occupancy Category	People Outdoor Air Rate $R_p$		Area Outdoor Air Rate $R_a$		Notes	Default Values			Air Class
	cfm/person	L/s-person	cfm/ft <sup>2</sup>	L/s-m <sup>2</sup>		Occupant Density (see Note 4)	Combined Outdoor Air Rate (see Note 5)		
						#/1000 ft <sup>2</sup> or #/100 m <sup>2</sup>	cfm/person	L/s-person	
Lecture classroom	7.5	3.8	0.06	0.3		65	8	4.3	1

# Any problems with the homework?

---

- In a room, there are 85 students. They are working on exam questions with each of them generating 23 liters/hour of metabolic carbon dioxide. In order to comply with building standard, carbon dioxide limit must be set to 1000 ppm. Assuming that outdoor carbon dioxide levels are 380 ppm, estimate the required ventilation rate in m<sup>3</sup>/h by means of the steady state mass balance model. Assume that the room is well-mixed, ventilation rate is constant, ventilation effectiveness is equal to 1, and that indoor and outdoor carbon dioxide levels are constant.

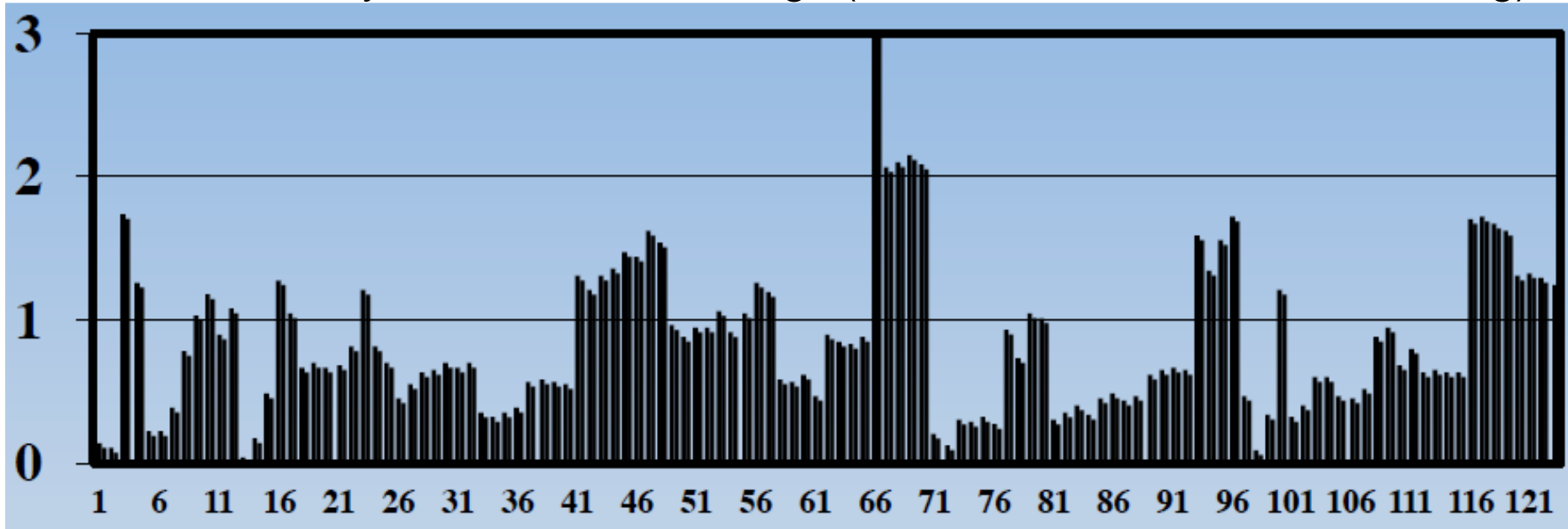
**Solution:**

$$\begin{aligned} Q &= E / (C_{in} - C_{out}) \cdot \varepsilon_v = \\ &= (85 \cdot 23 \text{ l/h}) / (1000 - 380) \cdot 10^{-6} \cdot 1 = \\ &= 3'153'225 \text{ l/h} = 3'153 \text{ m}^3/\text{h} \end{aligned}$$

# Air-exchange rates: design vs operation

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EPA BASE study of 100 office buildings (4 measurements in each building)



**Ratio of Measured/Design minimum outdoor air supply by system**

**What are the key issues?**

# Today's objectives...

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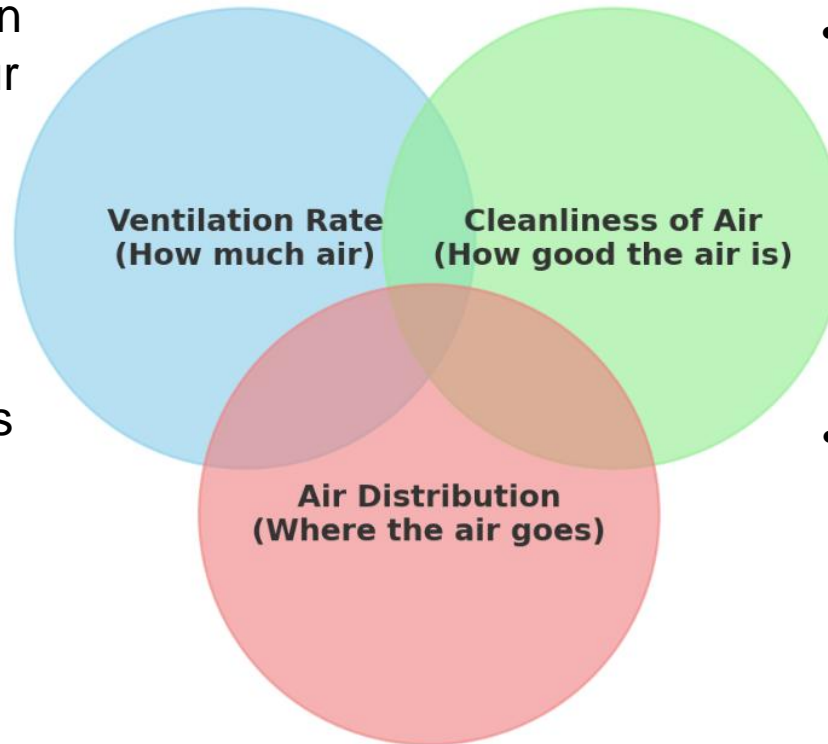
## Controls:

- Room air distribution (Ventilation effectiveness)
- Filtration & air cleaning
- Exercise
- Remaining schedule & course summary

# Last time - Ventilation

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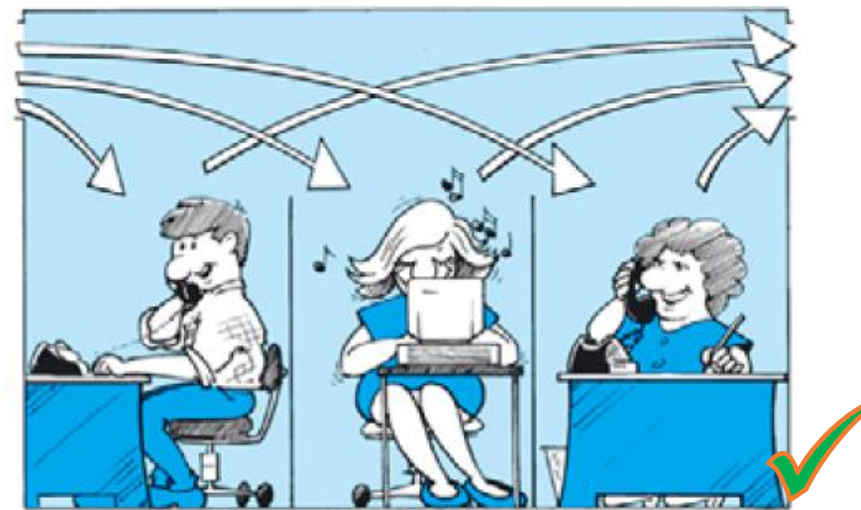
- Usually expressed in air changes per hour (ACH), L/s per person, or L/s per floor area.
- Determines the dilution of indoor-generated pollutants and the supply of oxygen.



- Depends on outdoor air quality, filtration efficiency, and removal of contaminants (particles, ozone, VOCs, etc.) before entering the occupied space.
- Includes considerations for recirculated air treatment (filters, UV, etc.).

- How air is supplied and removed within the space.
- Determines ventilation effectiveness and exposure (e.g., mixing vs. displacement, stratification, short-circuiting).
- Captured by metrics like air distribution effectiveness or ventilation effectiveness (as in ASHRAE, EN standards).

# Air distribution is important, but out of scope!

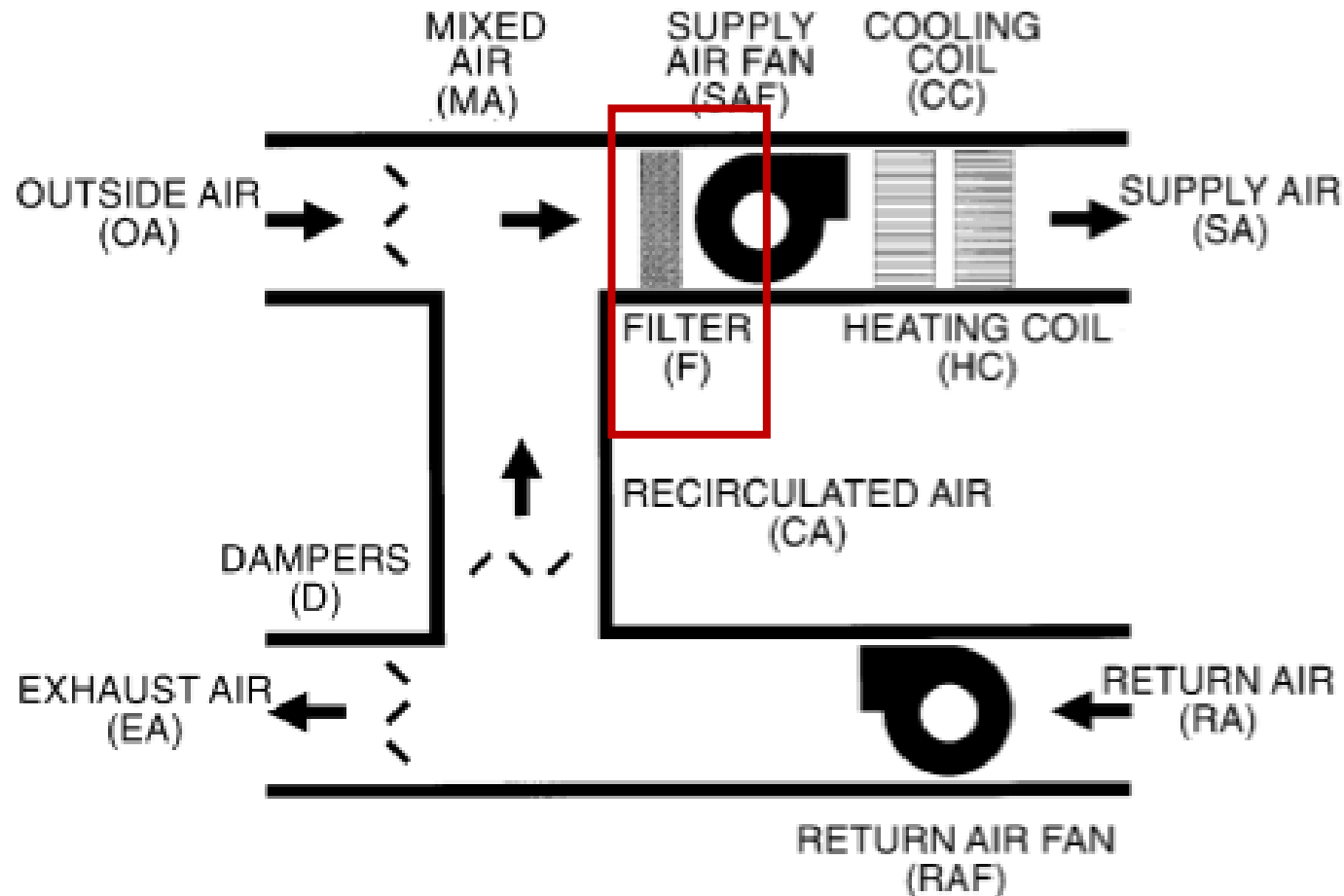


- Room air distribution (ventilation effectiveness) determines **inhaled** air quality
- **Less ventilation** air is needed when it is efficiently distributed

# Filtration / Air cleaning

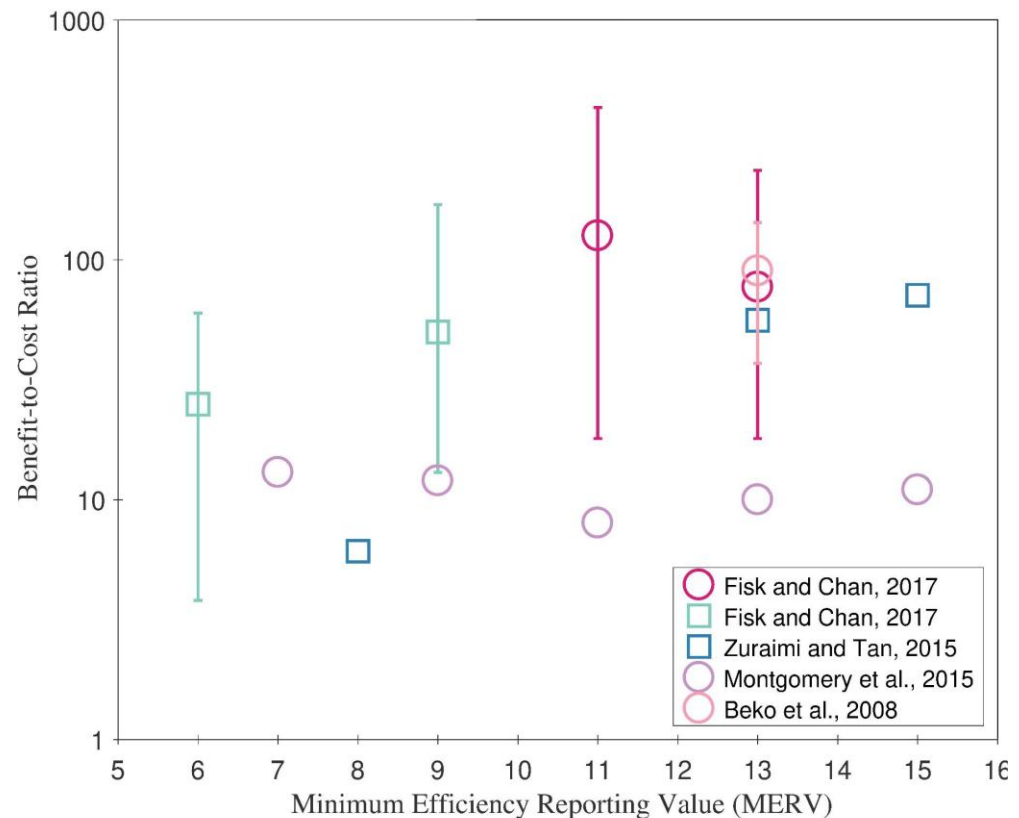
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- This is a typical commercial HVAC system:



# What is the purpose of a filter?

- To protect human health?
- To protect equipment?
  - Both
  - Clear benefit to cost ratio

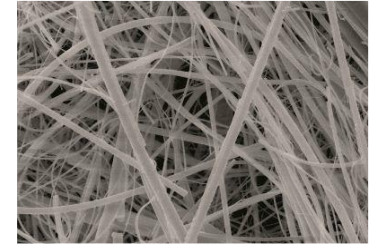


# What can we filter out in our building

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- **Particles**

- Fibrous filters
- Electrostatic precipitators
- Every forced (mechanical) HVAC system will have some kind of particle filter



- **Gases (out of scope)**

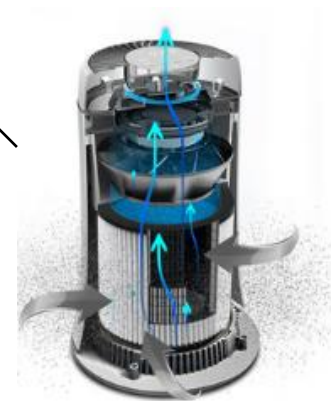
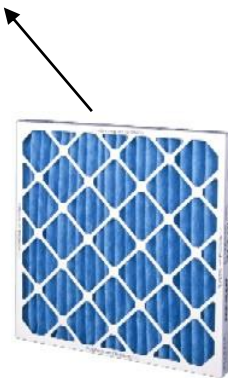
- Activated carbon
  - Relies on adsorption of VOCs/other gases to high surface area carbon
- Very few buildings have gas-phase filtration



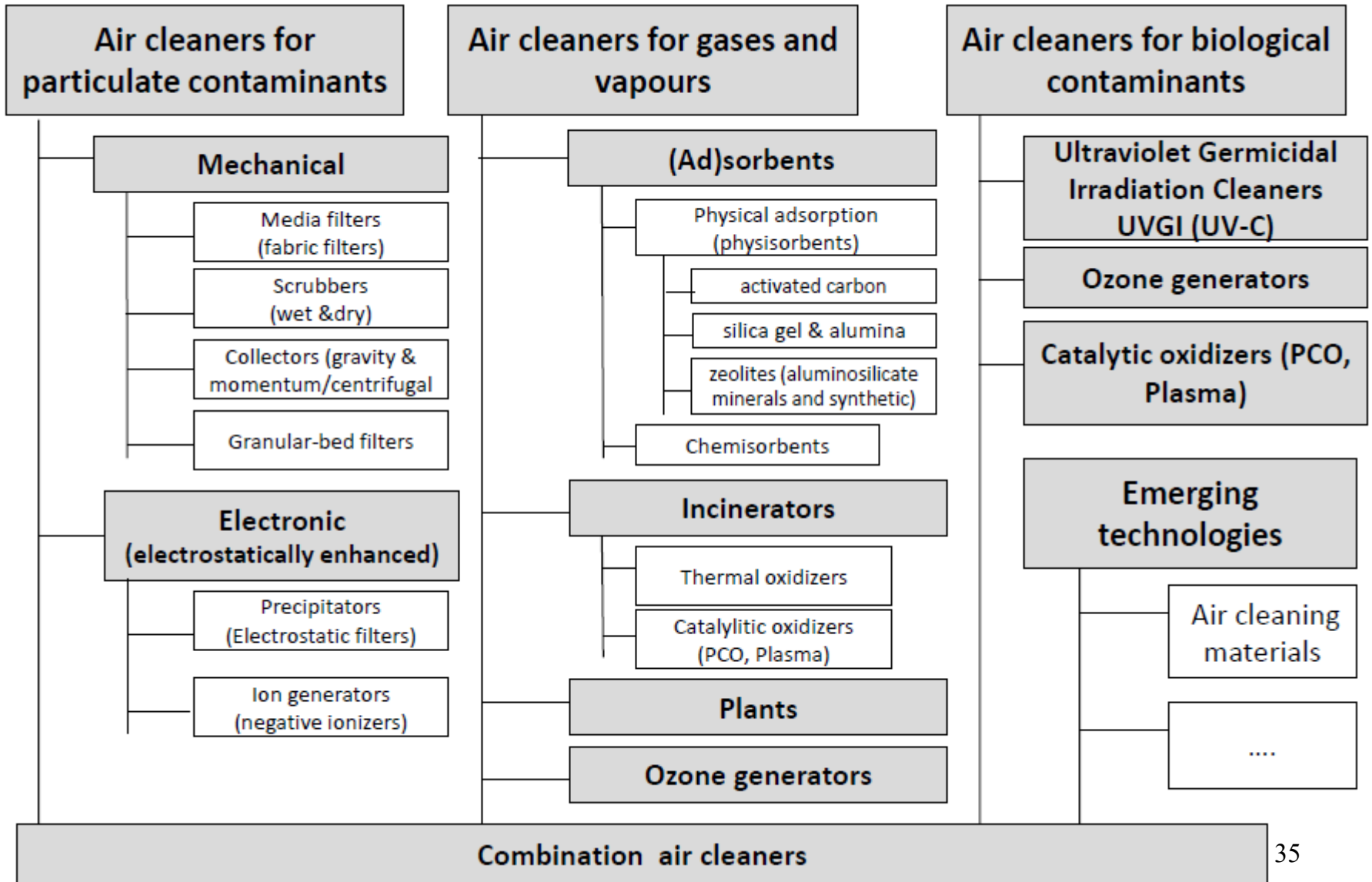
# Classification of air cleaning devices

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- **By pollutants removed:** particle air pollution, gaseous air pollution, biological pollutants: microbes and bacteria, combination of the above
- **By principle of operation:** passive and active
- **By means of principle:** collect, remove/destroy and transform
- **By construction:** in-duct and portable

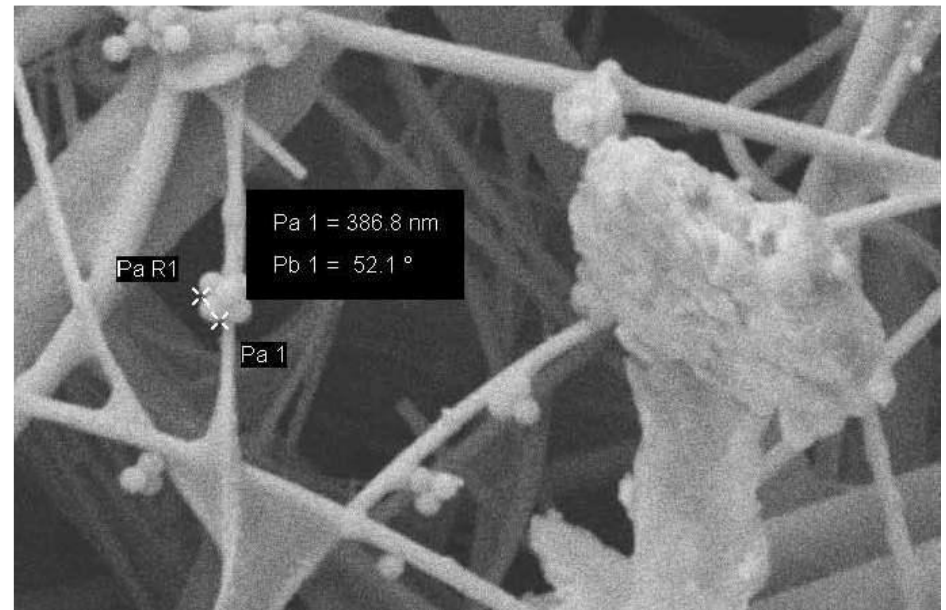
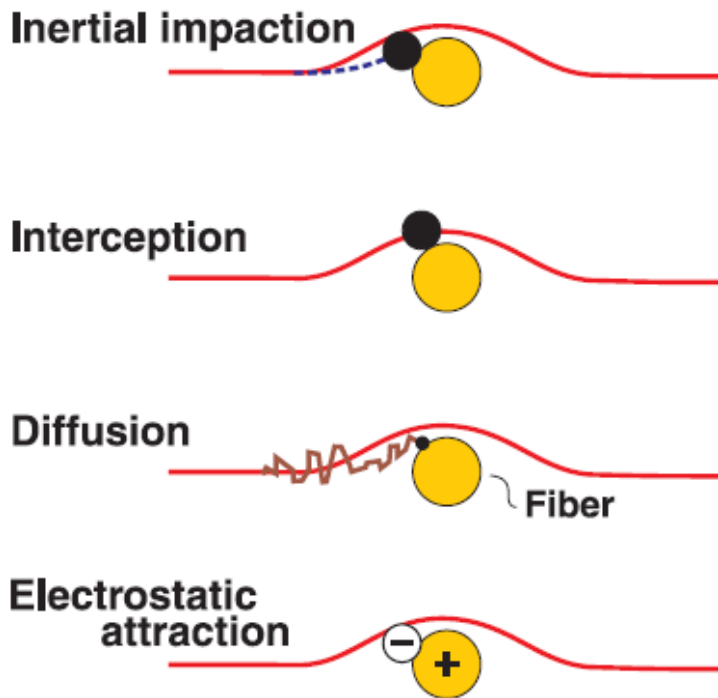


# Classification of air cleaning devices



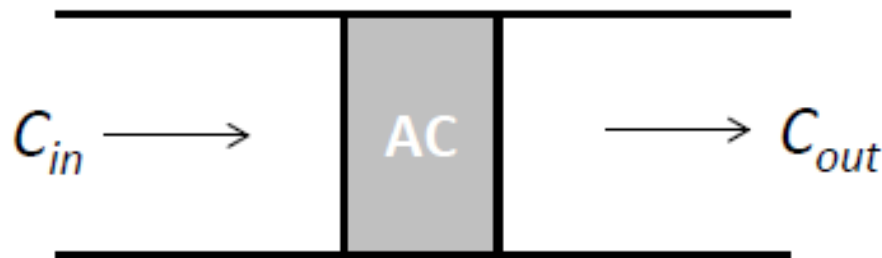
# Fibrous filtration (for particles)

- Particle removal occurs through a combination of forces:
  - Gravitational settling, Brownian diffusion, impaction, electrostatic forces, thermophoretic forces



# Performance indicator: Single-pass efficiency ( $\eta$ )

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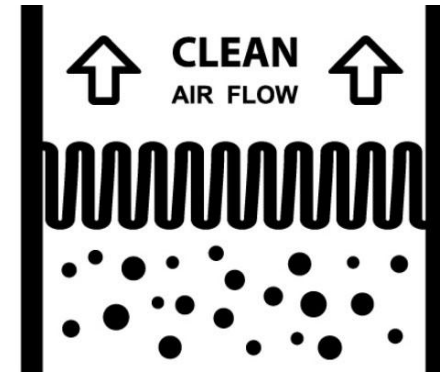
$$\eta = \frac{C_{in} - C_{out}}{C_{in}} \cdot 100 [\%]$$

- Fraction of pollutants removed as it passes through the device ( $C_{in}$ : concentration at the inlet;  $C_{out}$ : concentration at the outlet)
- Maximum conversion is 100% indicating that contaminant(s) have been removed completely
- It can be used to estimate the outlet concentration of a pollutant downstream the air cleaner

# Performance indicator: Clean air delivery rate (CADR)

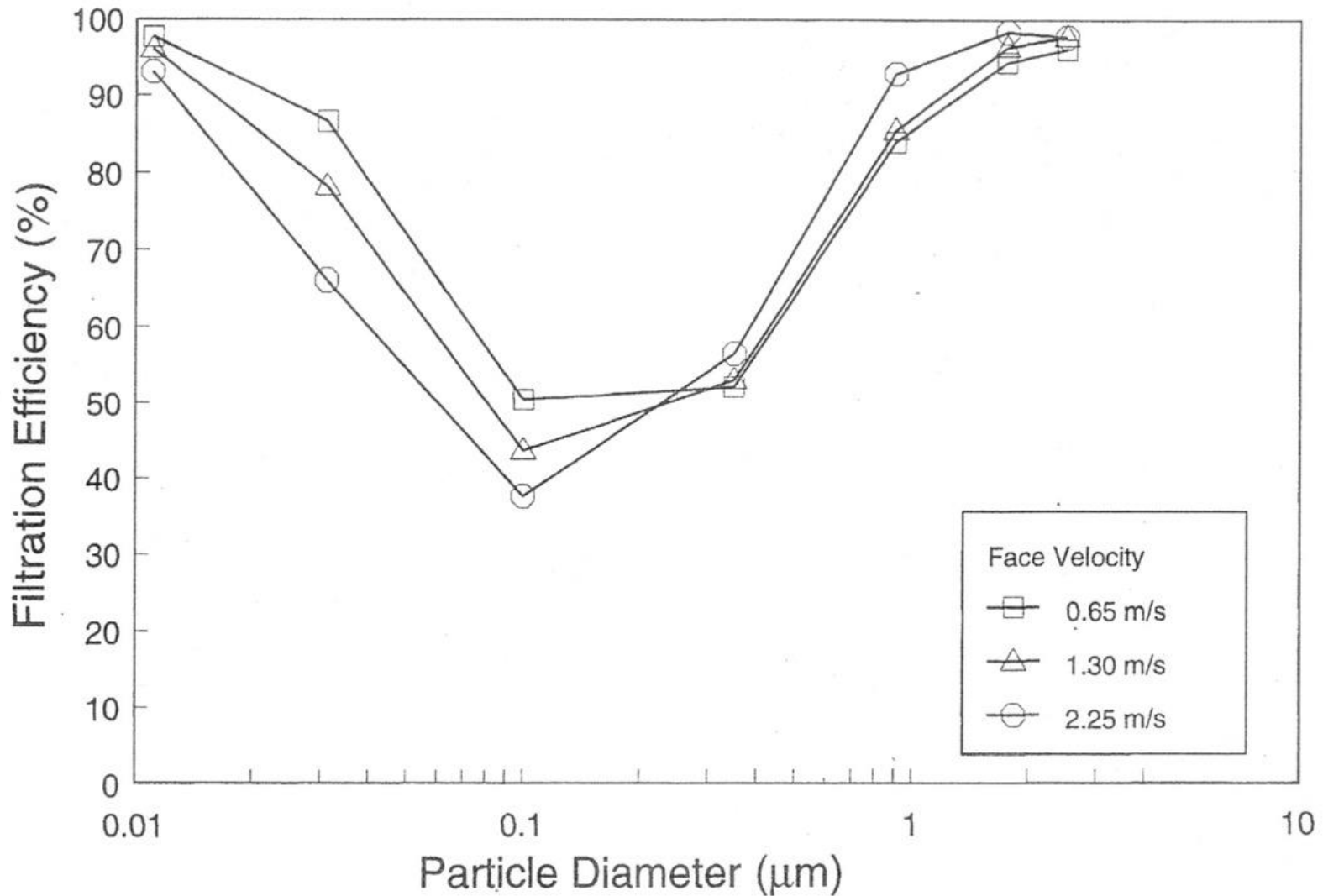
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$$CADR = \eta \cdot Q \left( \frac{m^3}{h} \right)$$



- The effective clean airflow rate through air cleaner which is the equivalent of clean air delivered by the air cleaner
  - It basically tells how useful is to have an air cleaner
  - CADR is typically reported by manufacturers
  - If not, the information related to filtration capacity is not reliable
- CADR is typically reported for the challenge pollutant which was used to examine the performance of air cleaner

# General efficiency: Classic U-shaped curve



# Questions?

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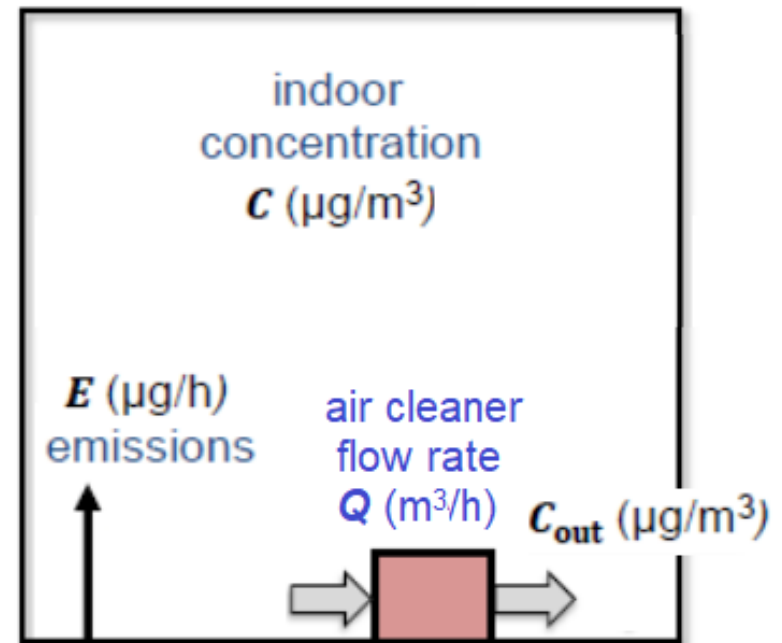


# Example 1

---

- Determine the single-pass efficiency ( $\eta$ ) and clean air delivery rate (CARD) of an air cleaner which is located inside the room. Take these parameters into account:

- Indoor particle concentration is  $35 \mu\text{g}/\text{m}^3$ ;
- Particle concentration at the outlet of an air cleaner is  $12 \mu\text{g}/\text{m}^3$ ;
- Air flow rate through the air cleaner is  $80 \text{ m}^3/\text{h}$ .



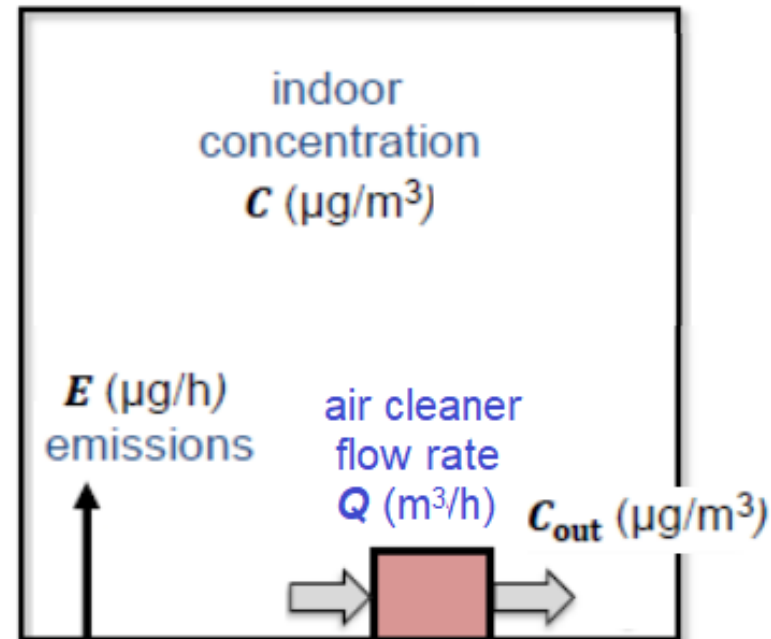
# Example 1: Solution

- Determine the single-pass efficiency ( $\eta$ ) and clean air delivery rate (CARD) of an air cleaner which is located inside the room. Take these parameters into account:
  - Indoor particle concentration is  $35 \mu\text{g}/\text{m}^3$ ;
  - Particle concentration at the outlet of an air cleaner is  $12 \mu\text{g}/\text{m}^3$ ;
  - Air flow rate through the air cleaner is  $80 \text{ m}^3/\text{h}$ .

$$\eta = \frac{C_{in} - C_{out}}{C_{in}} \cdot 100\% = 65.71\%$$

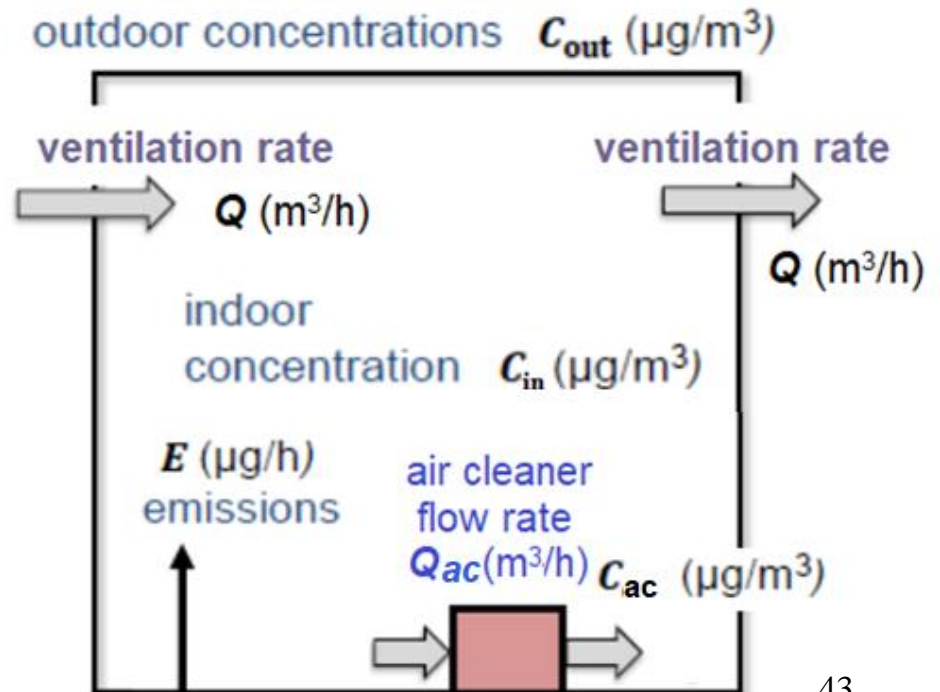
$$CADR = \eta \cdot Q = 0.6571 \cdot 80 = 52.57 \frac{\text{m}^3}{\text{h}}$$

- Follow up thought: If ventilation rate in the same room is higher than the CARD of the air cleaner, that means that ventilation is more effective in removing air pollution than the air cleaner, and vice versa...



# Example 2

- A person smoking indoors releases particles at a rate of  $400 \mu\text{g/h}$ . Particle mass concentration outdoors is  $35 \mu\text{g/m}^3$ .
  - a. Find particle concentration indoors if the outdoor air is supplied at the rate of  $7 \text{ l/s}$ . Assume ventilation effectiveness to be 1.
  - b. If the ventilation effectiveness increases to 1.2, how much ventilation will be needed to keep the same indoor particle level?
  - c. What would be the clean air delivery rate of an added air cleaner with the single-pass efficiency ( $\eta=0.6$ ) and flow rate  $Q_{ac} = 35 \text{ m}^3/\text{h}$ ?



# Example 2: Solutions

---

- A person smoking indoors releases particles at a rate of  $400 \mu\text{g}/\text{h}$ . Particle mass concentration outdoors is  $35 \mu\text{g}/\text{m}^3$ .
  - a. Find particle concentration indoors if the outdoor air is supplied at the rate of  $7 \text{ l/s}$ . Assume ventilation effectiveness to be  $1$ .
  - b. If the ventilation effectiveness increases to  $1.2$ , how much ventilation will be needed to keep the same indoor particle level?
  - c. What would be the clean air delivery rate of an added air cleaner with the single-pass efficiency ( $\eta=0.6$ ) and flow rate  $Q_{ac} = 35 \text{ m}^3/\text{h}$ ?

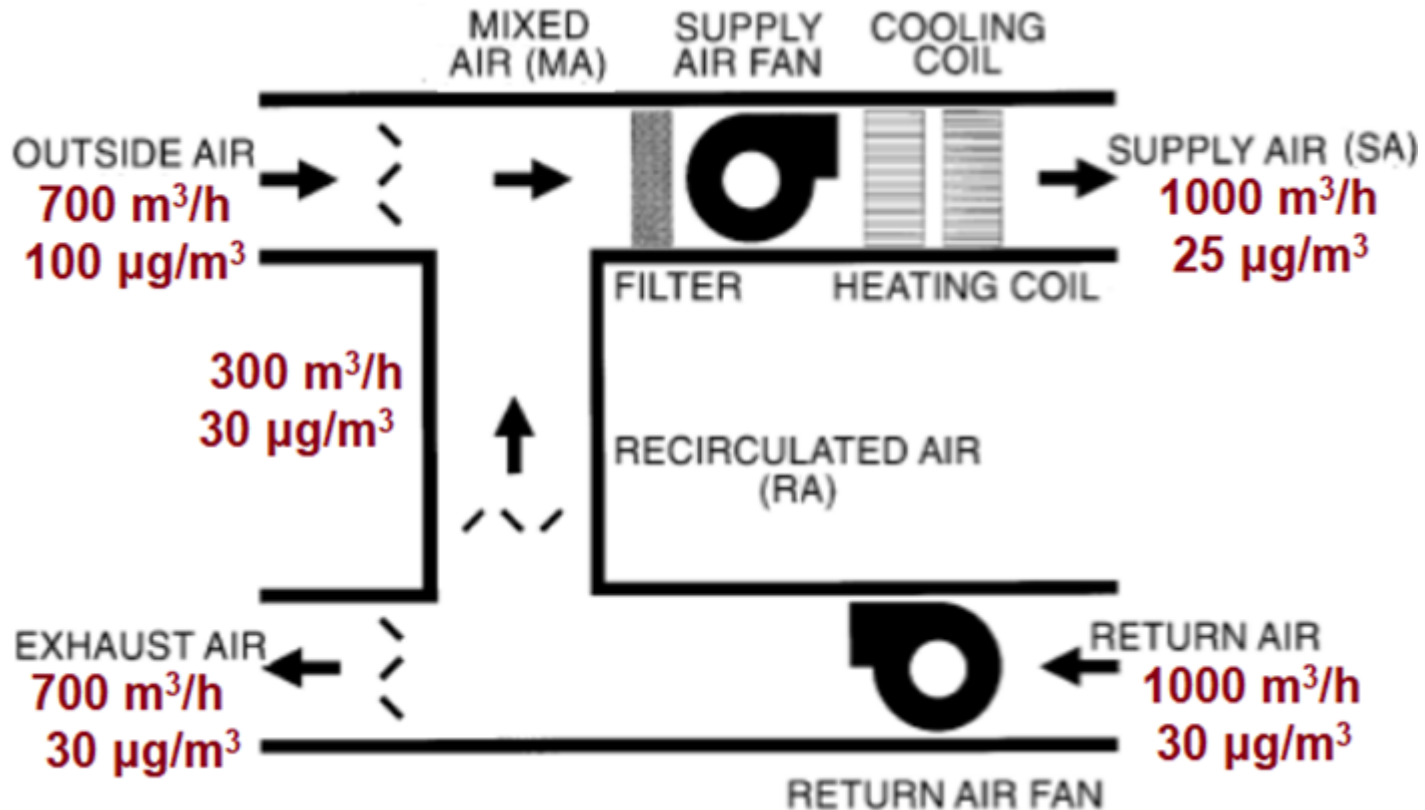
**Solution a):** 
$$Q = \frac{E}{(C_{in} - C_{out}) \cdot \varepsilon_v} \quad 25.2 \frac{\text{m}^3}{\text{h}} = \frac{400 \frac{\mu\text{g}}{\text{h}}}{\left(C_{in} - 35 \frac{\mu\text{g}}{\text{m}^3}\right) \cdot 1} \quad C_{in} = 50.6 \frac{\mu\text{g}}{\text{m}^3}$$

**Solution b):** 
$$Q = \frac{400 \frac{\mu\text{g}}{\text{h}}}{\left(50.6 \frac{\mu\text{g}}{\text{m}^3} - 35 \frac{\mu\text{g}}{\text{m}^3}\right) \cdot 1.2} = 21.36 \frac{\text{m}^3}{\text{h}} = 5.94 \frac{\text{l}}{\text{s}}$$

**Solution c):** 
$$CADR = \eta \cdot Q_{ac} = 0.6 \cdot 35 = 21 \frac{\text{m}^3}{\text{h}}$$

# Example 3

- Determine the single-pass efficiency ( $\eta$ ) and clean air delivery rate (CARD) of the filter in the air handling unit for the conditions summarized on the figure below.



# Example 3: Solutions

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- The key is to determine the particle mass concentration at the inlet of the filter
  - We can do that with a simple mass balance of mixing

$$C_{inlet} = \frac{Q_{ao} \cdot C_{oa} + Q_{ro} \cdot C_{ra}}{Q_{oa} + Q_{ra}} = \frac{700 \frac{m^3}{h} \cdot 100 \frac{\mu g}{m^3} + 300 \frac{m^3}{h} \cdot 30 \frac{\mu g}{m^3}}{700 \frac{m^3}{h} + 300 \frac{m^3}{h}} = 79 \frac{\mu g}{m^3}$$

$$\eta = \frac{C_{ma} - C_{sa}}{C_{ma}} \cdot 100\% = \frac{79 \frac{\mu g}{m^3} - 25 \frac{\mu g}{m^3}}{79 \frac{\mu g}{m^3}} \cdot 100\% = 68.35\%$$

$$CADR = \eta \cdot Q = 0.6835 \cdot 1000 = 683.5 \frac{m^3}{h}$$

# GROUP DEBATE



Who will be today's indoor  
climate champion? 🏆





# Group Debate: Fundamentals of Indoor Climate

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## ◇ **Purpose**

*Think critically about trade-offs in building design & operation (health, comfort, energy, costs).*

## ◇ **Structure (45 min)**

-  5 min – Instructions & group formations
-  10 min – Preparation
-  25 min – Debate rounds (2 min opening, 2 min rebuttal, 4 min debate)
-  5 min – Reflection

## ◇ **Debate Themes**

-  Comfort vs. Energy
-  Natural vs. Mechanical Ventilation
-  Technology vs. Occupant Behavior

## ◇ **Key Reminder**

*No single “correct” answer. It’s about reasoning, perspectives, & discussion.*

# Group Debate: Fundamentals of Indoor Climate

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## ◇ **Structure (45 min)**

- 5 min – Instructions & group formation
- 10 min – Preparation time (groups discuss assigned position)
- 25 min – Debate rounds (2 groups per question, opposing positions):  
2 min opening statement, 2 min rebuttal, 4 min open discussion
- 5 min – Wrap-up reflection: each group summarizes key lessons

## ◇ **Debate Themes**

- **Thermal Comfort vs. Energy:** Should building design prioritize human thermal comfort at all times, even if it means higher energy use? Or should energy efficiency come first, even if comfort is sometimes compromised?
- **Natural vs. Mechanical Ventilation:** In schools and homes, should we rely mainly on natural ventilation (windows, openings) or mechanical systems to ensure good indoor air quality?
- **Technology vs. Occupant Behavior:** What matters more for good indoor climate: smart building technologies (sensors, automation) or the everyday behavior of occupants (opening windows, using blinds, clothing choices)?

# In the next several weeks...(check syllabus)

---

- Next week - No lecture!
  - I will be in the classroom at 17:15 am to take any questions that you may have about the project or lecture notes. Your attendance is optional.
- In two weeks is the final exam – What to study?
  - Focus on IAQ and Ventilation lectures and exercise
  - The exam questions of similar format as for the midterm:
    - **Calculations** (be sure that you fully understand all the calculation examples from the classes, including mass balance model, general psychrometrics, methods for determining ventilation rates, unit conversion.
    - **Open-ended questions** (those you cannot answer with a simple “yes” or “no”, and instead require to critically think and to elaborate on your point). These question won’t necessarily have a single correct answer but will rather examine your perspective described in your own words.
    - **A few quiz questions** with multiple choice answers based on theory. This will count for less points compared to other questions.

# Update on the next exam – Info & Tips

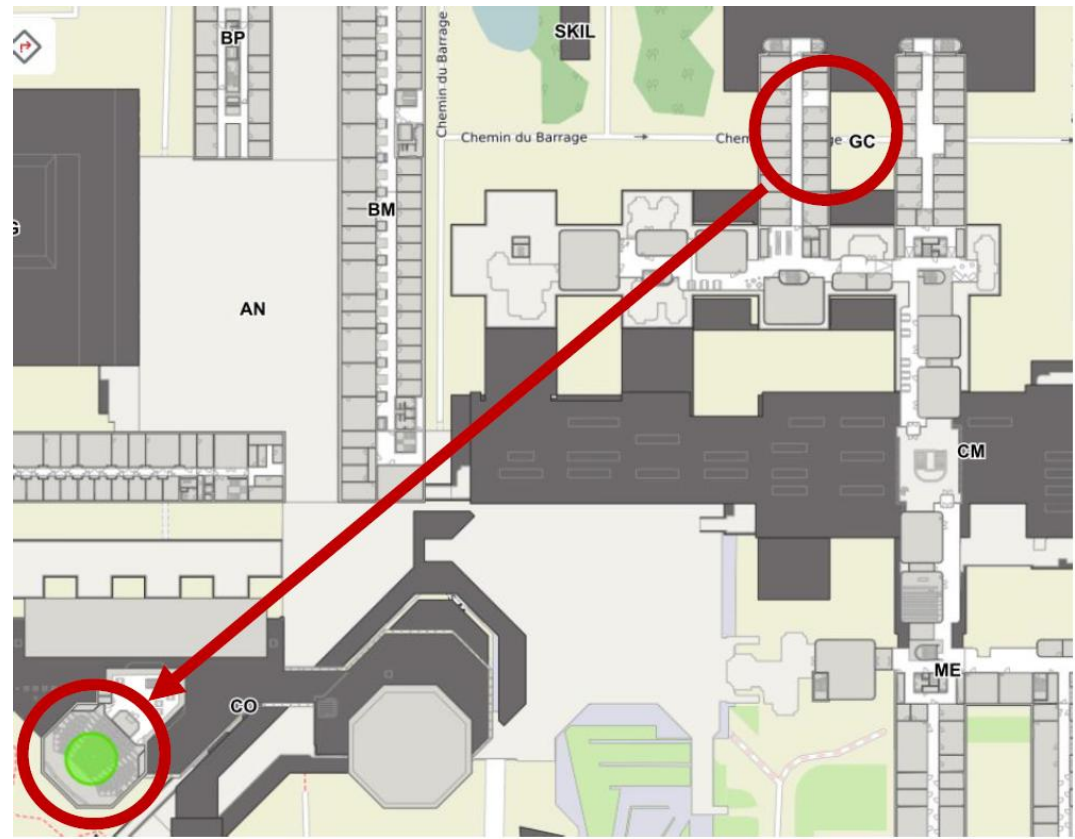
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- This will be an open book exam. You are free to use the lecture materials or computers, but you must work on your own. No internet allowed.
- Make sure that your calculators and psychometric charts are ready.
- Please be sure to show as much work as possible. I may give partial credit for it (in case your end result is incorrect).
- Some of open-ended questions won't have necessarily a single correct answer. For some of these questions how you set up the problem is just as important as whether or not you ultimately get the right answer.
- Please use English language only.
- If you have any questions about the wording of the questions, please raise hand.

# Other information about the exam

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- When will the exam take place?
  - 04 December 2025, at standard time 17:15 – 19:00h
  - Please try to come a bit earlier if possible (~17:00h)
- Where will the exam take place?
  - CO 3
  - Same place as the last time!



# In the next several weeks...(check syllabus!)

- Weeks 14 and 15 (11<sup>th</sup> and 18<sup>th</sup> December)
  - Course project presentations! Who to attend?
  - All of you should attend.
  - Who will present their projects?

Robin Roux	Noah Walker	Thierry Cajoux	Eliot Ferrari	Pierre Zaninetti	Enzo Weideborg
Maria Francisca Marinho	Milo Heim	Nathan Borer	Marylou Rose Chalas	Hannah Silvia Philine	CĂ©lia Marie Naika
Velson Hajra	Arnaud Wencker	Mathieu Roques	Eva Kupeczek	LĂ©onard Gimenez	Anna Billon
Paula Tarazona Rodriguez	Lilia Malika Belin	Nina Dufour	Olivia Mahieu	Cleopatra Moroiianu	Margot Akel
Alexan Floure	Nora Benczur	Laura Monney	Emma Rose MaĂ«wen M	LoĂ«c Pierre Georges	Justin Francis Fernand La
Alicia Durand	Sara Maria Cevallos Chiriboga	Charles Devigny Chavann	Filip Gogolewski	Elise Hochard	Ana Stanescu
NAJA Nour	WOLPERT Phillipe	BORDET Anna	BEL-MERABET Lisa	PUTSEP Kaspar	Juillard Rim Wydad
Felipe Ferrero Fandino	Simone Baliviera	Jonas Becker	Cristina Braun de la Cruz	Sophie Holper	Rosset Aline CĂ©cile
Marxer Elina	Bucher Celia	Verniquet Alice	Laran Antonin	Bernet ThĂ©o	Kerambrun Malo
Lisa Saurel	Sophie Bitar	Noa Clivaz	Victor Monfredo	Huryilmaz Kaan Alie	Chen Shuyi
Guessous Ghali	Emmanuel Ghoussoub	Mateo de la maisonneuv	Dufourd Adel	Quku Arsid	

18 Dec 11 Dec

- Please don't forget to revisit the course syllabus to gain information about the presentation formatting and submission!

# Course objectives (in my own words)

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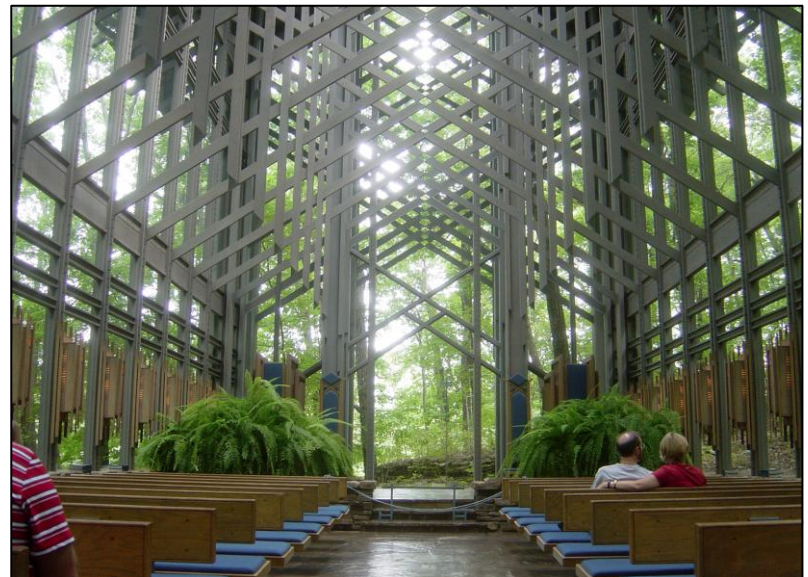
To understand important concepts of indoor environmental quality parameters which concern indoor climate: Thermal comfort and indoor air quality. By the end of the course, you are expected to be able to:

- Have a fundamental understanding of indoor climate theory and contemporary issues encountered in the building design and operation cycles. ✓
- Talk about determinants and assessment methods for human thermal comfort and indoor air quality, and to understand their impact on humans. ✓
- Assess thermal comfort and indoor air quality control mechanisms and determine their effectiveness. ✓
- Read and critically analyze articles in the technical literature on thermal comfort, indoor air quality and ventilation.
- Prepare informative oral presentation.

ongoing

ongoing

What do *WE* think when *WE* hear “climate”



# Summary thoughts and the big picture

---

- Indoor climate isn't really a standalone discipline
  - Involves engineers, architects, public health professionals, analytical chemists, building scientists, architects, contractors, medical professionals, epidemiologists, academics, biologists, psychologists, economists, etc.
  - Many different approaches
  - In this course, you have gained the fundamental understanding
- The big picture is that:
  - We are interested in indoor climate because of its impact on:
    - Worker productivity/safety
    - Human comfort
    - Health effects
    - Material degradation
    - Biological growth/disinfection
    - Energy use

# Summary thoughts and the big picture

---

Buildings are complex systems and are trending toward greater complexity. This is not necessarily a good thing.

Indoor climate has profound influence on occupants, and vice versa. We must not think of buildings without primarily thinking of people!

We have an ample opportunity to reduce energy use and its associated external costs. The challenge is to improve the quality of the indoor climate at the same time.

General notion is that building energy use and good indoor climate are always in conflict. However, if a building is well designed and operated, this will not be the case. More to learn in ENG-445 course.

---

Bravo for surviving the  
course (so far) and thank you  
for being a good class!!!

*“We should design indoor environments that  
are better than the best environment found in  
nature”* — Ole Fanger

