MULIGE ENERGIBESPARELSEER VED BRUG AF LUFTRENSNING

DEPARTMENT OF THE BUILT ENVIRONMENT

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Alireza Afshari

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- **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 , US

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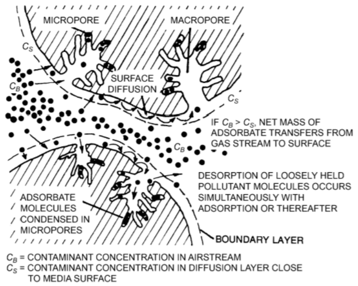
Background

In Denmark **the main focus of research regarding indoor air climate** over the past decades has been focused on **the source control and their effects**.

Much less effort has been concentrated on **the ability of technical solutions** to mitigate the problems and to provide an indoor climate that is not only acceptable but really good.

Therefore, there is a need to investigate possibilities of **using variable return air factors in combination with new, efficient air cleaning technologies** for improving the indoor climate.

https://sciencedatacloud.wordpress.com/2013/11/22/photocatalyst-technology/



https://www.ashrae.org/File%20Library/Technical%20Resources/ASHRAE%20Handbook/I-P_A19_Ch47.pdf

https://www.resema.se/en/products/carbon-chemical-filters/483-kemisorbent.html

http://www.neoakruthi.com/blog/ozone-generator-air-purifier.html

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Background

In many locations in the world, the **outdoor air quality is so bad** that **ventilation decreases the quality of indoor air** rather than it improves it.

In these cases, **the alternative to use ventilation is to substitute** it with **gas-phase air cleaning** so that the indoor air can be kept at high quality.

Even when outdoor air is of a good quality, the use of air cleaning substituting or supplementing ventilation could **reduce the rate of outside air supplied indoors** and thereby **energy can be saved** for its conditioning (heating/cooling) and transporting (fan energy).

Since it is expected that gas-phase air cleaning may in parallel **improve the indoor air quality** and **reduce energy use for ventilation**, it should be considered as **a very interesting technology that can be used in the future.**

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- ✓ Two types of air-cleaning technologies are commonly used in **duct-mounted** and **portable air** cleaners to remove **particles** from the air:
  - fibrous media air filters
  - electronic air cleaners including electrostatic precipitators (ESPs) and ionizers.
- ✓ A number of air-cleaning technologies are designed to either remove **gaseous air pollutants** or convert them to (ideally) harmless byproducts using a **combination of physical and chemical processes**.
  - adsorbent media air filters such as activated carbon,
  - chemisorbent media air filters
  - photocatalytic oxidation (PCO)
  - plasma
  - ozone generators
  - Plants
- ✓ Another type of electronic air-cleaner technology is designed to reduce the number of viable **airborne microorganisms** by killing or deactivating them:
  - ultraviolet germicidal irradiation (UVGI)

ASHRAE Position Document on Filtration and Air Cleaning, 2015

Sophie Kirkman, John Zhai, Shelly L. Mille, 2020

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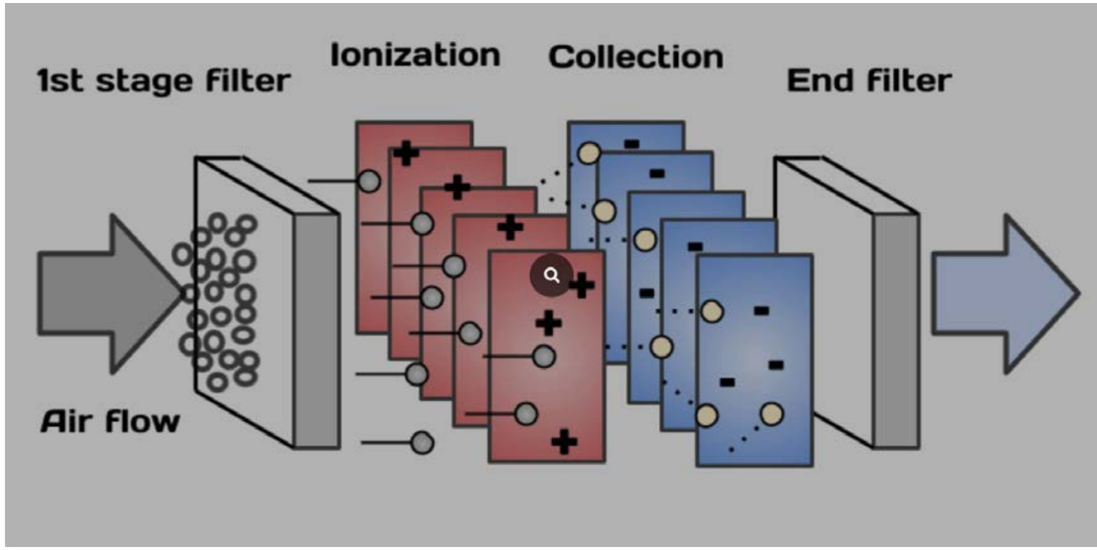
Photo-Catalytic Oxidizers (PCO), **Electrostatic Precipitators (ESPs)**, and **ionizers** are **electronic air cleaners** that use a **powered electrostatic process** or **ultra-violet lights** to charge particles, which then become **attracted to oppositely charged plates** to remove airborne particles.

ESPs and Ionizers are often also called:

- UV Sanitization
- UVGI
- Plasma Air Cleaners
- Photo-Catalytic Oxidizer (PCOs)
- Photo Electrochemical Oxidation (PECO)



https://hawkenvironmental.com/electric-air-cleaners-what-you-need-to-know/

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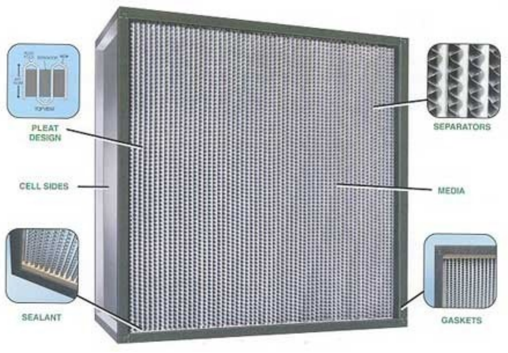
Filtration

- Particulate-filter air cleaners use a fan to blow air through a pleated **fiber filter medium**.
- The filter catches particulate matter mechanically by **impaction, diffusion and interception**, and as the particulate matter builds up, the filtration efficiency improves, up to a point.
- Then the pressure drop is too great, and the filter media must be replaced.

A very common particulate filter is the High-Efficiency Particulate Air (HEPA) filter, which means that the single-pass efficiency of the filter media is 99.97% for 0.3 μm particles.



https://www.indiamart.com/proddetail/hepa-filters-12947131391.html

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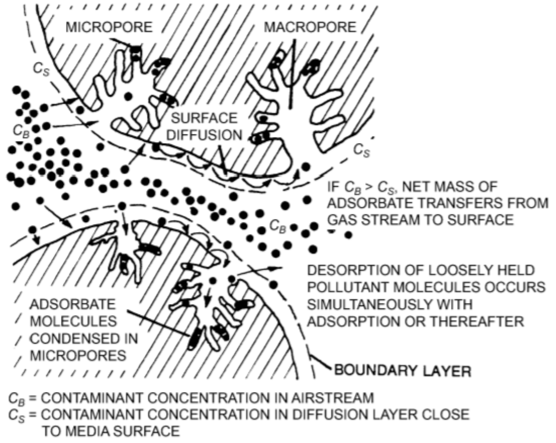
Adsorption

- Gaseous pollutants **adsorb on porous granular** media or **condense in pores** of media.
- Many types of sorbents with **activated carbon** most commonly used.
- Widely available technology
- Can **remove broad range of gaseous pollutants** with moderate to high efficiency



https://www.ashrae.org/File%20Library/Technical%20Resources/ASHRAE k/I-P_A19_Ch47.pdf

- Pollutants can be **released from sorbent into indoor air**
- **Low effectiveness** for low molecular weight pollutants including **formaldehyde**
- Must **periodically replace** sorbent
- Sorbent **lifetime** for indoor air applications **not well understood**
- **Large amount** of sorbent needed **for long lifetime**
- **High** sorbent **cost**
- Often high airflow resistance increasing **fan energy use**
- Installed in heating, ventilating and air conditioning systems or in stand-alone portable air cleaners

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Chemisorbents

- Gaseous pollutants **adsorb on** and **chemically react** with porous granular media

https://www.resema.se/en/products/carbon-chemical-filters/483-kemisorbent.html

- ➢ Widely available technology
- ➢ Can **remove broad range of gaseous pollutants** with **moderate to high efficiency**
- ➢ **High** chemisorbent **cost**
- ➢ Often high airflow resistance increasing **fan energy use**
- ➢ Installed in heating, ventilating and air conditioning systems or in stand-alone portable air cleaners

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Adsorption:

Parameters	Single Pass Efficiency (%)	Reference
Granular activated carbon Ø46mm, 150mm tube ; 7.0 g of adsorbent Thermal desorption (300°C), Air flow (0.06 m3/h)	Benzene: 81.5-91.6 Toluene: 86.6-100 Ethylbenzene: 91.6-99.2 Xylene: 89.9-100	Zuraimi et al., 2018)
High-grade activated carbon filter (portable), Air flow 510 (m3/h)	HCHO: 0.6 ; Toluene: 32.0 n-decane: 40.0 Tetrachloroethylene: 31.3	Chen et al., 2005
Activated charcoal filter (portable), Air flow 225 m3/h)	HCHO: 0.4 ; Toluene: 5.6 n-decane: 6.0 Tetrachloroethylene: 5.2	Chen et al., 2005

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Photocatalytic oxidation:

Parameters	Single Pass Efficiency (%)	Reference
UV light (253.7 nm) TiO2 converter (+MERV11 filter) (in-duct), Air flow (720 m3/h)	Benz: 0.58; Tol: 0.58; Et-Benz: 0.50; Xyl:0.32; EtOH: 0.19%; n-hex: 0.26; HCHO: 0.08	Kadribegovic et al., 2011
UV light (253.7 nm) TiO2 converter (+MERV11 filter) (in duct), Air flow (3600 m3/h)	O3 (UV off): <2 O3 (UV on): 15	Kadribegovic et al., 2011
VUV lights + MnOx/TiO2 on Ni foam catalyst Photocatalyst: 834cm2, 8mm thick, Air flow (120 m3/h)	TVOC (UV off/on): 50.14 / 74.86	Zeng et al., 2020

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Non-thermal plasma:

Parameters	Single Pass Efficiency (%)	Reference
Post-catalytic plasma with different catalysts (Pt/Al2O3, Cu-Mn/TiO2, Fe2O3+MnO2, CuO+MnO2) and energy densities (J/L) Ø42mm tube; 15g of catalyst, Air flow (0.6 m3/h)	Toluene (all catalyst): >90 at RH0%, 2.5J/L Toluene (Pt/Al2O3): 39-61 at RH30-72%, 10J/L O3 (Pt/Al2O3): ≈90 at all RH	Van Durme et al., 2009
Dielectric barrier discharge NTP 6.5g/m2 SiO2 + 6.5g/m2 TiO2 Ø76mm in-coated tube, Air flow (2 m3/h)	Benzene: 29-52 Propionic acid: 10.3-34.7	Zeng et al., 2020

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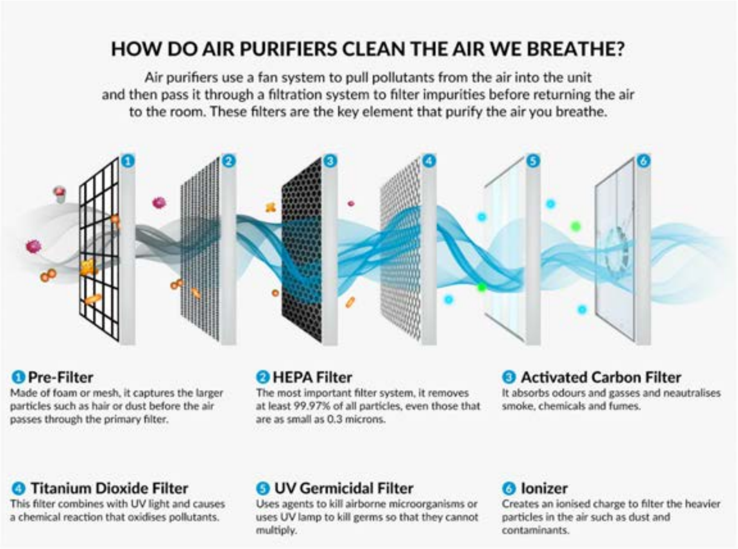
Combined filters

- Many portable and in-duct air cleaners combine more than one air-cleaning technology to accomplish their goals.



https://www.tatacliq.com/que/air-pollution-delhi-buying-air-purifiers/

There are several combined filter systems:

- ✓ Plasma-catalytic hybrid system
- ✓ Biological process + photocatalytic oxidation hybrid system
- ✓ Biological process + adsorption hybrid system
- ✓ Adsorption + photocatalysis hybrid system
- ✓ Hybrid ozonation systems
- ✓ Etc.

PhD project, Aalborg University Copenhagen

- ✓ A new filter material that is able to remove both particles and gaseous pollutants

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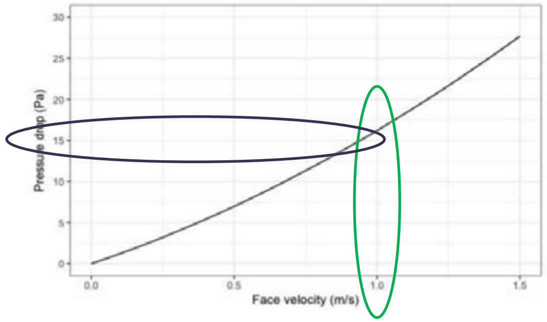
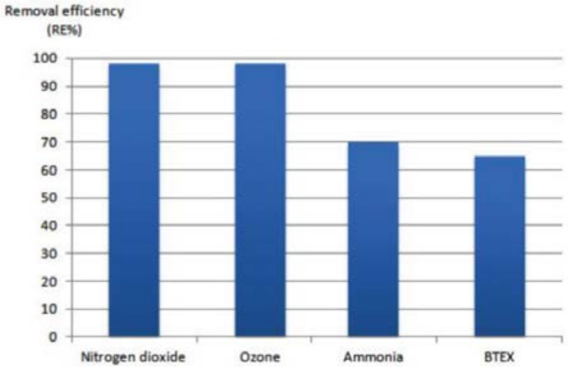
Nano-Carbon Filtration Technology

- Pressure drop: 16 Pa at 1 m/s face velocity
  - Microfibers built up on the face of the filter and caused increased pressure drop.
  - To add a pre-filter to catch the fibers.
  - Typical initial pressure drop of filters: G4 (58Pa), M5 (64Pa), M6 (75Pa), F7 (98Pa), F8 (152Pa) and F9 (180Pa) at an air flow rate of 3400m^3/h.



- Removal rates of key pollutants



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Bingbing Shi, Chalmers University of Technology, Göteborg, Sweden 2012

Filter pressure drop

Air flow 3400 m^3/tim, air velocity in the duct 2,6 m/s, dimensions ca 0,6 m * 0,6 m.

Effect of normalized dust load (g/m2) on relative pressure drop (ΔP-ΔPinitial) of G4, M5-M6 and F7-F8 class filters.

In the figure, the G4, M6 and F7-F8 class filters were operated for 6 months and M5 filter was operated for 14 months.

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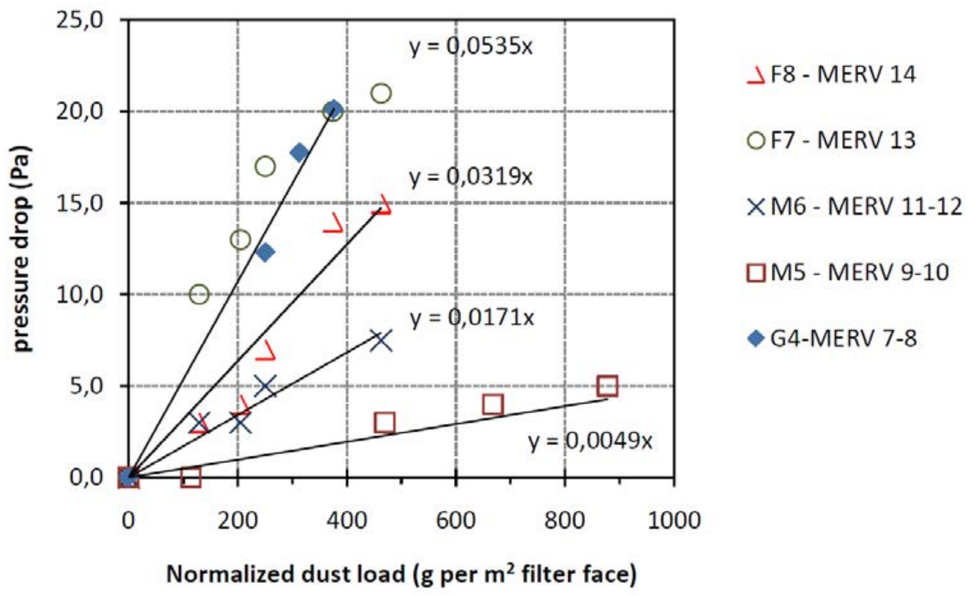

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Choosing between using outdoor air only and outdoor air plus filtered recirculated air is complex, but can be based on **technical or maintenance factors**, **convenience**, **economics**, or **a combination of these**.

https://www.ashrae.org/File%20Library/Technical%20Resources/ASHRAE%20Handbook/I-P_A19_Ch47.pdf

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Energy Concerns

- **Pressure drop** across the gaseous contaminant filter **directly affects energy use**.
- Adsorbent pressure drop **will not increase during normal operation**, unless media settling and compacting occurs.
- In addition to the gaseous contaminant filter itself, **pressure drop through the housing**, any **added duct elements**, and any **particulate filters required up- and/or downstream of the gaseous contaminant filter** must be included in the energy analysis.
- **Replacing outdoor air** with **filtered indoor air** reduces the amount of air that must be conditioned at an added expense in recirculation pressure drop.

https://www.ashrae.org/File%20Library/Technical%20Resources/ASHRAE%20Handbook/I-P_A19_Ch47.pdf

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Economic Considerations

Items Included in Economic Comparisons Between Competing Gaseous Contaminant Removal Systems

Capital Costs	Operating Costs
Added filtration equipment	Replacement or reactivation of gaseous contaminant filter media
Fan	
Motor	Disposal of spent gaseous contaminant filter media
Sensors and controls	
Plenum	Added electric power
Spare media holding units	Maintenance labor
Floor or duct space	

https://www.ashrae.org/File%20Library/Technical%20Resources/ASHRAE%20Handbook/I-P_A19_Ch47.pdf

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SAFTY

- Gaseous contaminant removal equipment generally has a **low hazard potential**.
- Carbon filter banks have been known to **catch fire**, usually from an external source such as a welder's torch.
- Access for safe maintenance and **change-out of adsorbent beds** must be provided.
- A spent carbon profile is required to ensure that the spent carbon is safely **recycled**.
- If adsorbent trays are to be refilled on site, **safety equipment** must be provided to deal with the **dust this generates**.
- Codes and fire authorities for regulations on carbon. One authority requires
  - sprinklers
  - a smoke detector

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Assumptions 1

Filter pressure drop is 80 Pa
Filter pressure drop after one year is increase by 20 Pa (25%)

Filter is responsible for 20% of total pressure drop in AHU

Calculations

AHU total pressure drop = 80 Pa / 0.2 = 400 Pa
AHU total pressure drop after one year = 400 Pa + 20 Pa = 420 Pa

Increment energy/power use after one year = (420 Pa - 400 Pa)/(400 Pa) = **5%**

Assumptions 2

Filter pressure drop is 300 Pa
Filter pressure drop after one year is increased by 75 Pa (25%)

Filter is responsible for 27% of total pressure drop is AHU

Calculations

AHU total pressure drop = 300 Pa / 0.27 = 1100 Pa
AHU total pressure drop after one year = 1100 Pa + 75 Pa = 1175 Pa

Increment energy/power use after one year = (1175 Pa - 1100 Pa)/(1100 Pa) = **7%**

http://belok.se/download/genomforda_projekt/2013-6_Performance%20of%20ionized%20assisted%20air%20filtration.pdf

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Objective of the study

A.1. Energy reduction by cleaning indoor air (recirculation, no outside air) compared to cleaning outside air in areas where the outside air is not good enough for ventilation

A.2. Energy reduction by decreasing the amount of outside air by use of air cleaning

A.3. Energy reduction by using air cleaning together with personalized ventilation systems.

A.4. Minimum performance of air cleaners (effectiveness). Establish a metric of assessing air cleaner efficiency in relation to energy: CADR/kWh where CADR is the clean air delivery rate

APPROACH

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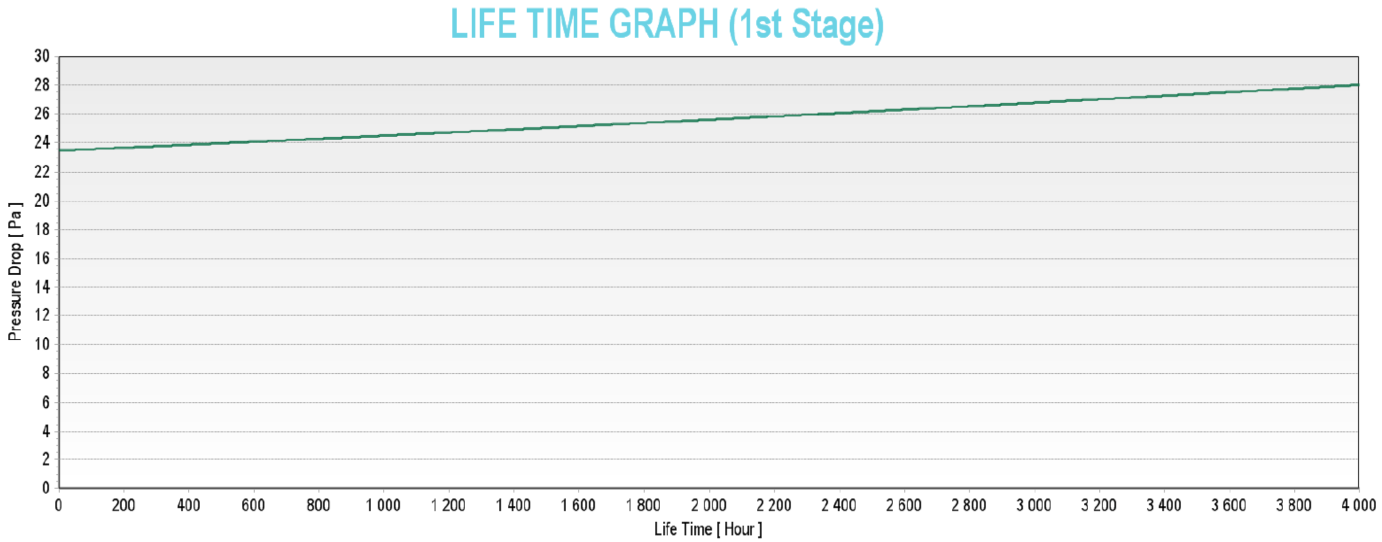
IDA ICE simulation environment

- ✓ Energy use calculation for the entire building
- ✓ Whole-year dynamic simulation

- × **Filters and pressure drop** are not part of IDAICE environment
- × The full HVAC system simulation not possible

Chosen filter:

CAMFILL particle filter HI-FLO XLS F7
Data collected from the company
Dust concentration: PM10 – 20 μg/m3
Compatible for Sjælland level of air pollution



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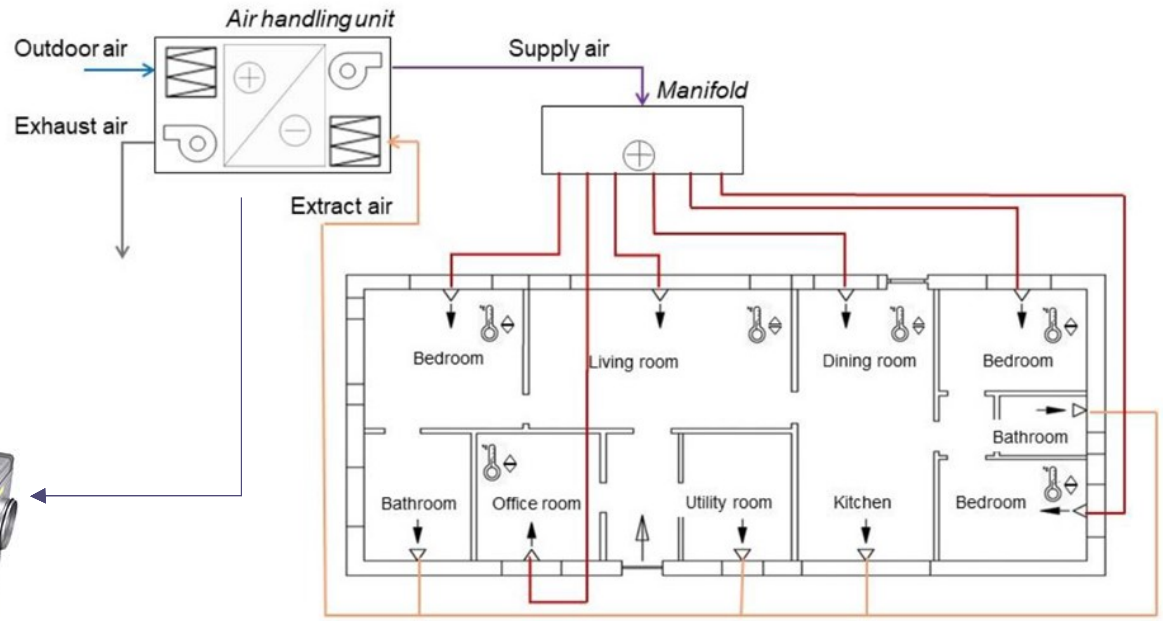
Air Handling Unit: laboratory study from Ph.D. Joanna Polak

Zone	Area [m^2]	Min airflow [l/s]	Supply [l/s]	Extract [l/s]
Bedroom 1	11.6	3.5	6	-
Bedroom 2	11.6	3.5	6	-
Bathroom 1	4.2	1.3	-	15
Kitchen	30.9	9.3	7.8	9
Utility	17.8	5.3	-	9.6
Office room	12.2	3.7	6.7	-
Big bedroom	17	5.1	8.3	-
Living room	46	13.8	13.8	-
Bathroom	10.6	3.2	-	15
Total	**162**	**48.6**	**48.6**	**48.6**

Heat valve ventilation system layout



HERU 160 S EC

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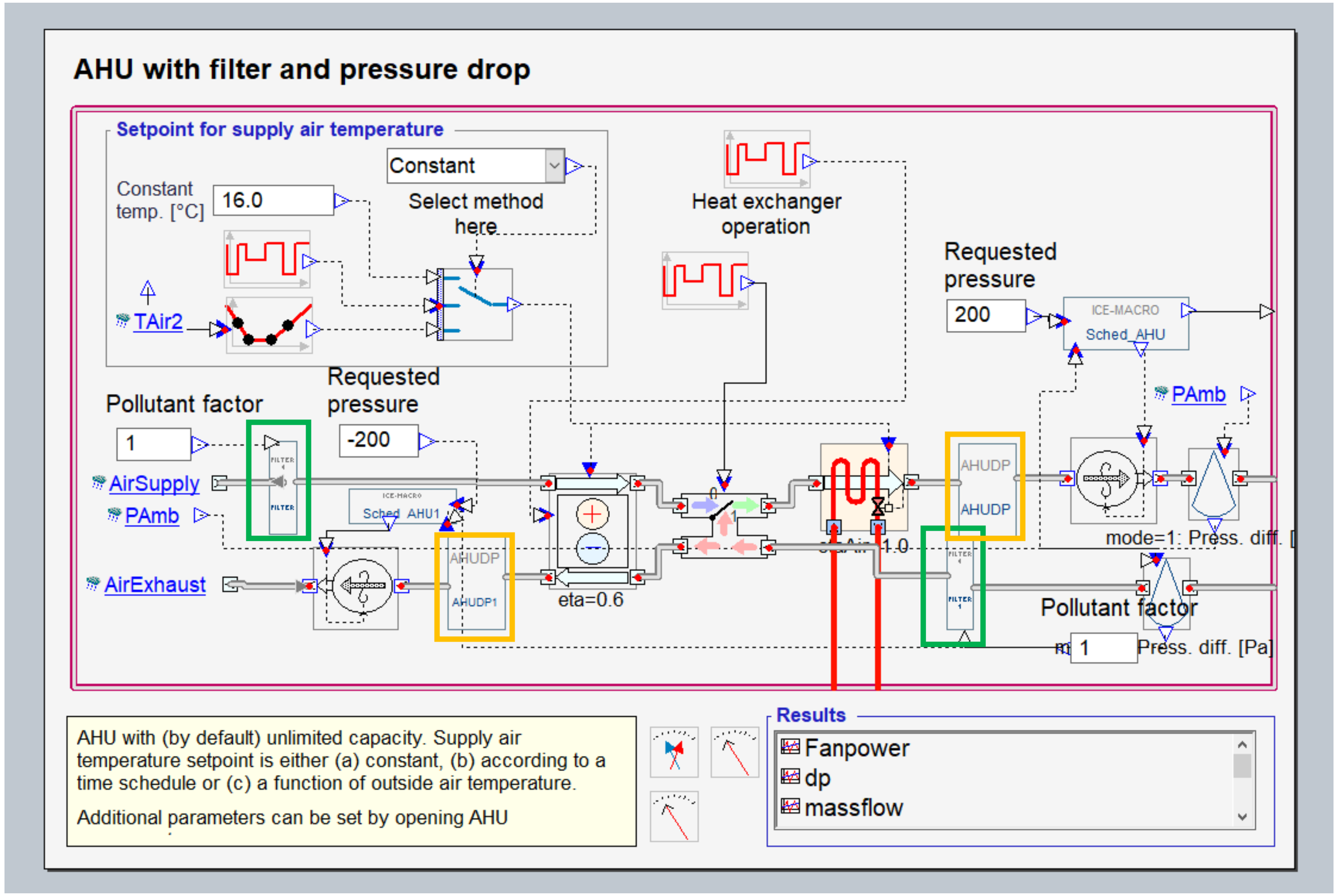
Model in IDAICE
AHU design

- Implementing filter characteristics: the pressure drop increases in time linearly depending on pollutant concentration and air flow.
- The fan energy use is depending on pressure drop and we considered:
  - Filter pressure drop
  - AHU components pressure drops
  - Pressure drop outside the AHU from air ventilation ducts (using data from a real case study from Ph.D. thesis of Joanna Polak)



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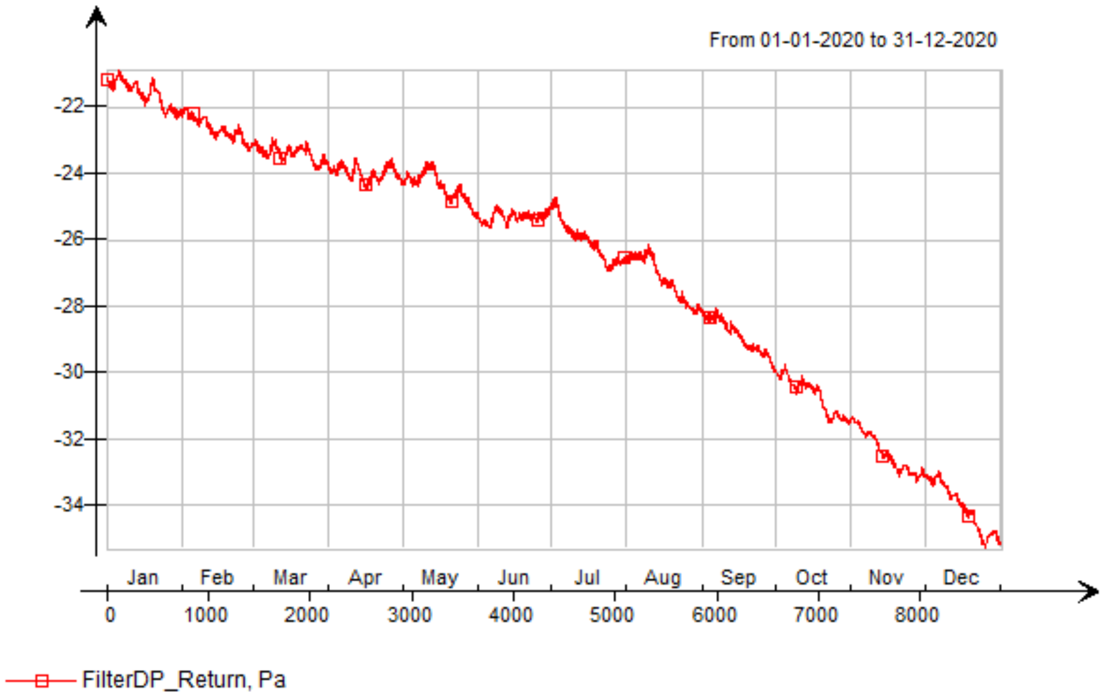
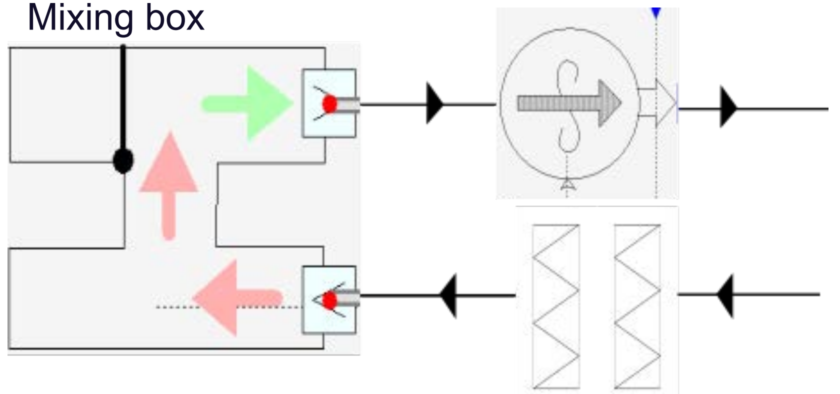
Simulation

- **100 % recirculation** in a year simulation – without supply air – it means that only supply fan is active – **no exhaust fan**





kWh (sensible and latent)

Month	Heating	Cooling	AHU heat recovery	AHU cold recovery	Humidification	Fans
1	0.0	0.0	0.0	0.0	0.0	11.5
2	0.0	0.0	0.0	0.0	0.0	10.7
3	0.0	0.0	0.0	0.0	0.0	11.3
4	0.0	0.0	0.0	0.0	0.0	10.8
5	0.0	0.0	0.0	0.0	0.0	10.9
6	0.0	0.0	0.0	0.0	0.0	10.5
7	0.0	0.0	0.0	0.0	0.0	10.8
8	0.0	0.0	0.0	0.0	0.0	10.8
9	0.0	0.0	0.0	0.0	0.0	10.7
10	0.0	0.0	0.0	0.0	0.0	11.2
11	0.0	0.0	0.0	0.0	0.0	11.0
12	0.0	0.0	0.0	0.0	0.0	11.4
Total	**0.0**	**0.0**	**0.2**	**0.0**	**0.0**	**131.5**

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Simulation

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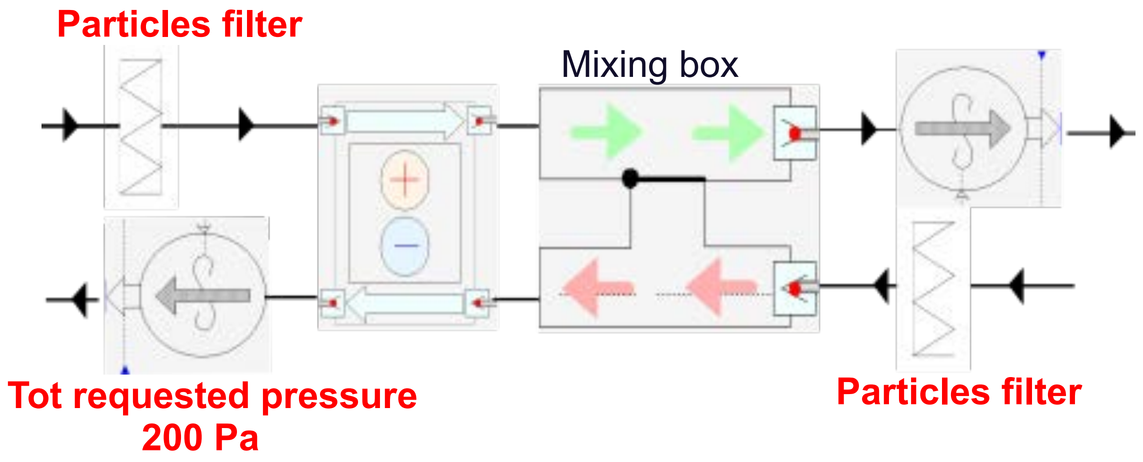
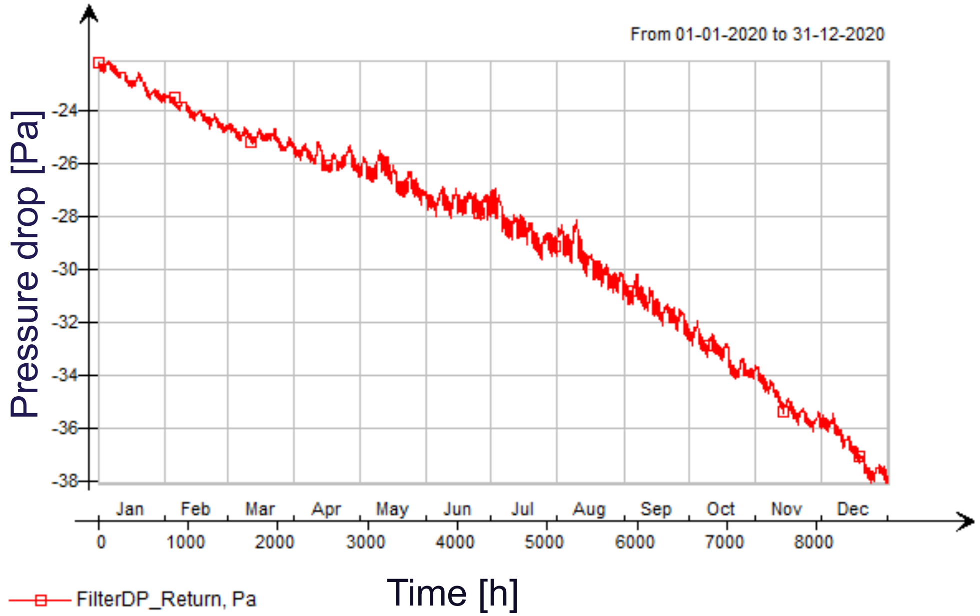
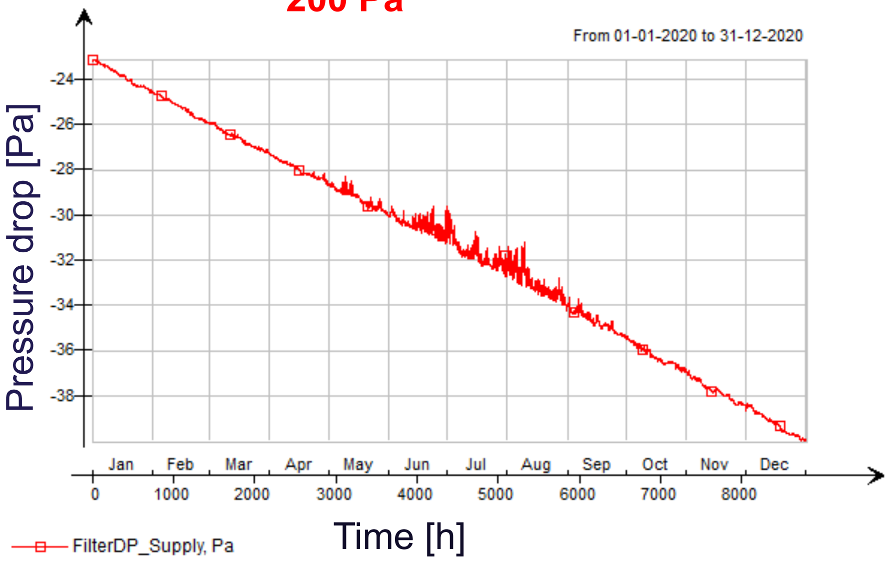


- Graphs: **0% recirculation** along a year of use – in this case we have **supply and exhaust fan are active**





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Energy saving from fan energy use

$$Energy\ Saving = \frac{Energy\ use\ no\ ricirculation\ - Energy\ use\ ricirculation}{Energy\ use\ no\ ricirculation} = 53.2\ \%$$

Next steps

- **Improve mathematical** model about relationship between pollution concentration and pressure drop
- **Energy savings from heating system during recirculation**
- Air quality and thermal comfort

- Several simulation for different scenario will be carried out
  - Filter with adsorbent with different pressure drop
  - Amount of recirculated and outdoor air supply will be changed – recirculation will be used in different time of the day based on outdoor air pollution levels

Thank you for your attention!

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