Energy Efficient HVAC retrofits for improving the indoor environmental quality

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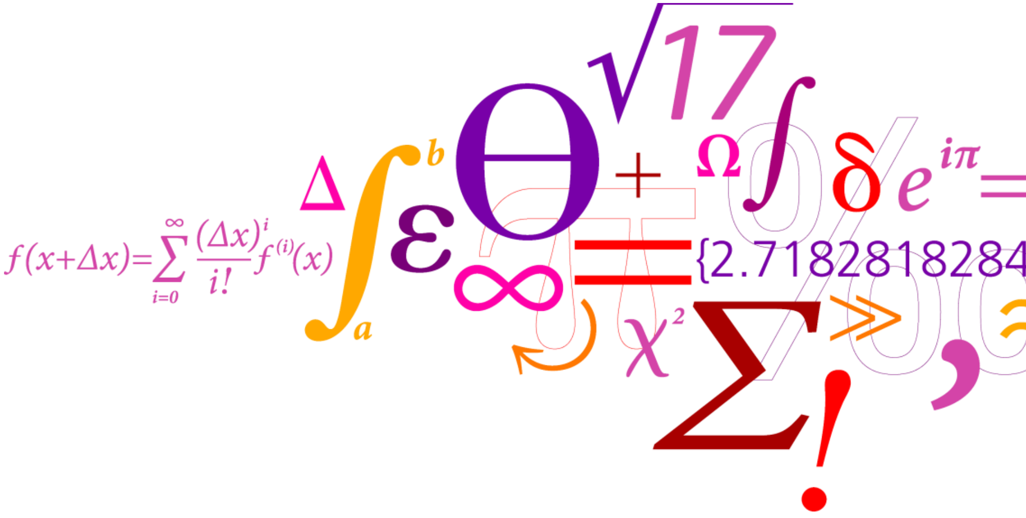
Professor



International Centre for Indoor Environment and Energy
Department of Civil Engineering

Achieving Excellence in Indoor Environmental Quality

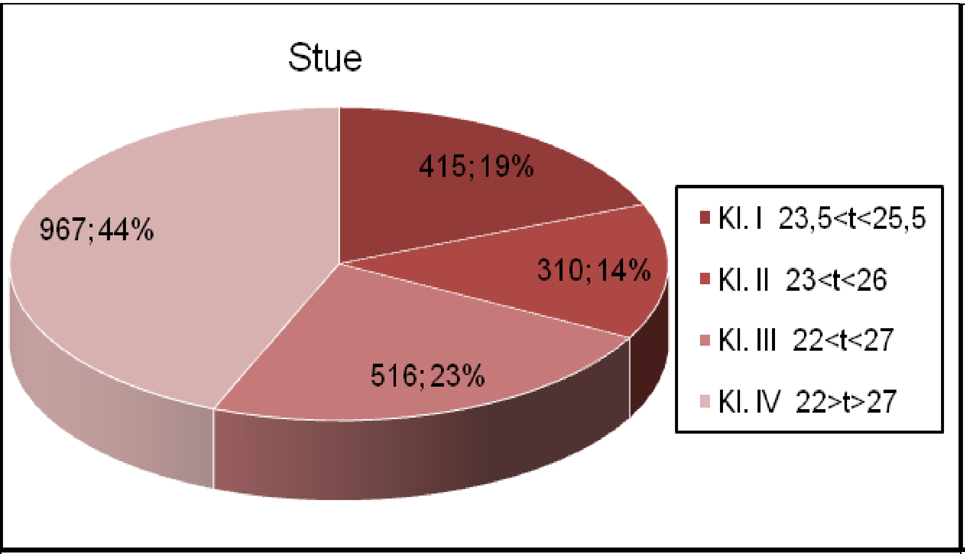
- Physical factors
  - Thermal Comfort
  - Air quality (ventilation)
  - Noise-Acoustic
  - Illumination
- Personal factors
  - Activity
  - Clothing
  - Adaptation
  - Expectation
  - Exposure time

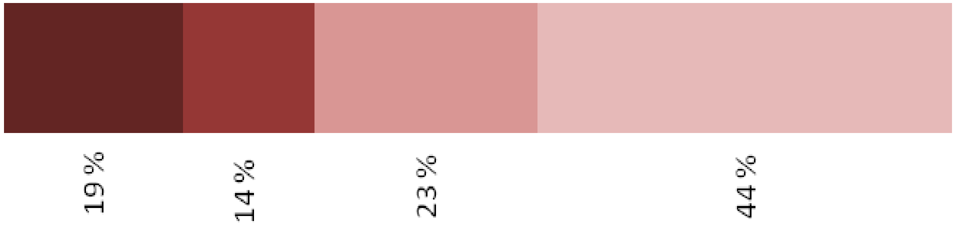
Indoor Air Quality and Thermal Comfort in Zero Energy Buildings

- Thermal Comfort
  - More uniform conditions (radiant asymmetry, vertical air temperature differences)
  - Less draught risk (reduced heat supply, no cold surfaces)
  - Less difference between air and operative temperature
  - ”Over heating”
  - Is individual room control important?
    - Comfort
    - Energy
- Indoor Air Quality
  - Tighter buildings
  - Cannot rely on infiltration
  - Can you heat with the ventilation system?
    - Air distribution
    - Ventilation effectiveness
    - Individual room control

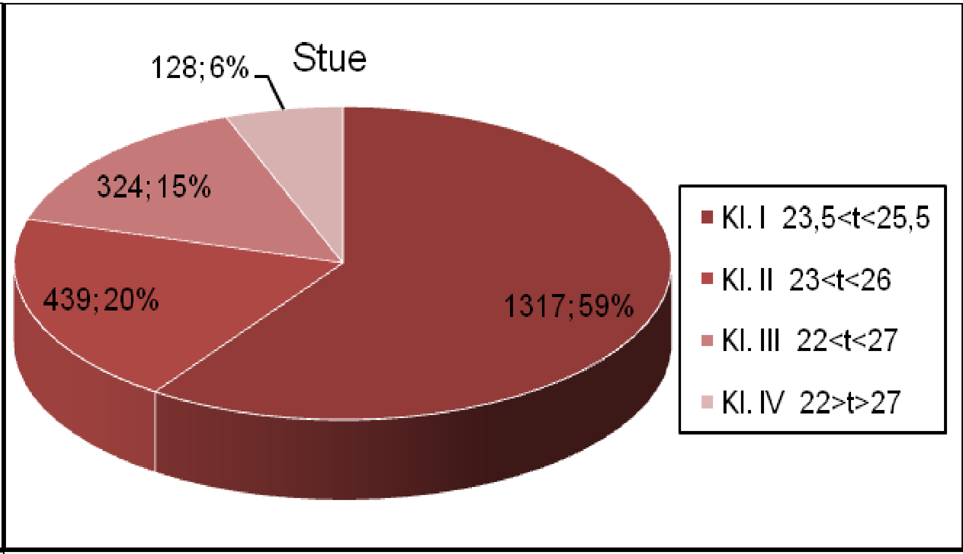
Effect of internal blinds

NO BLINDS



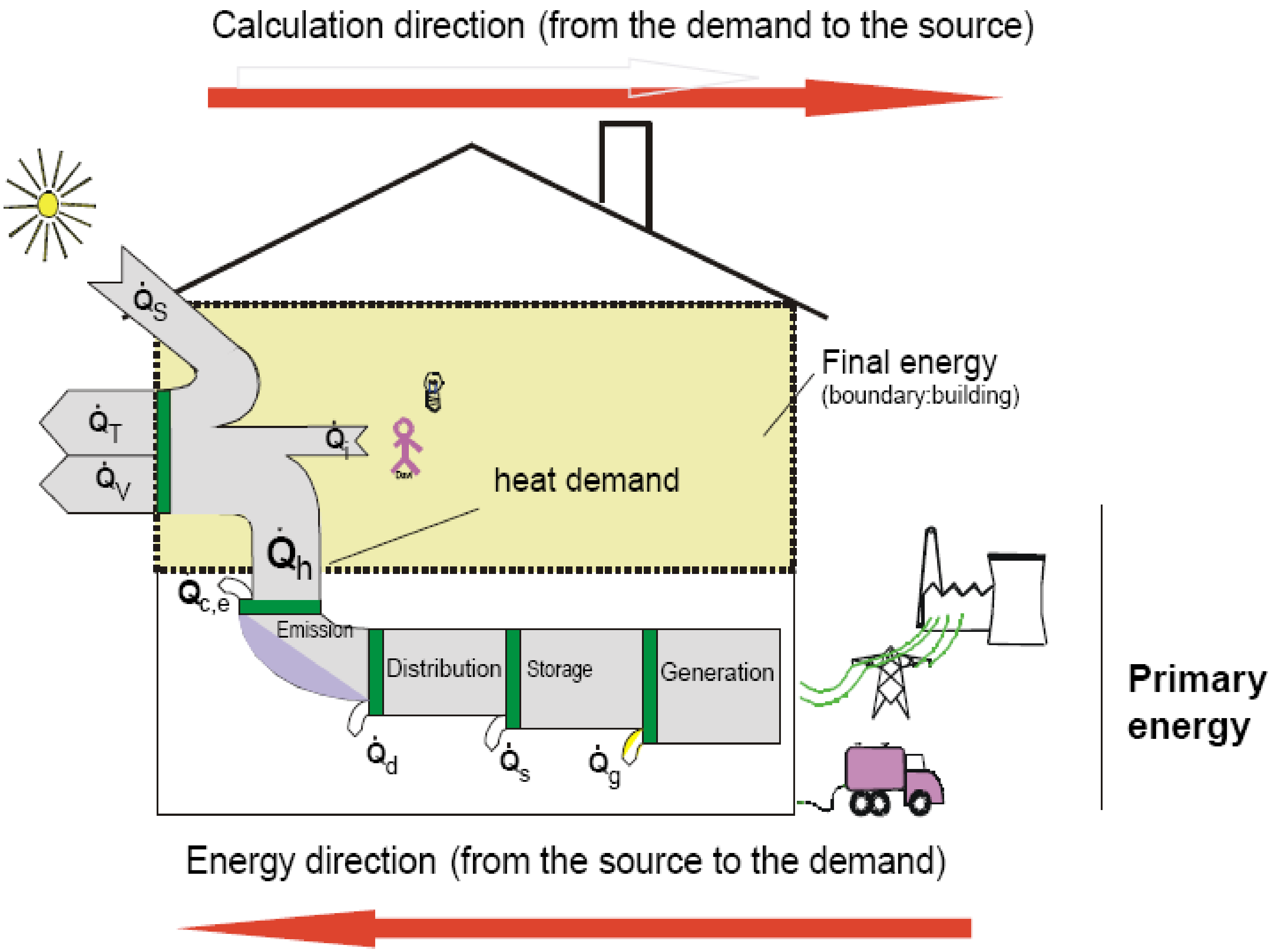


BLINDS



Calculation concept and building-system boundaries for heating EN15316-1

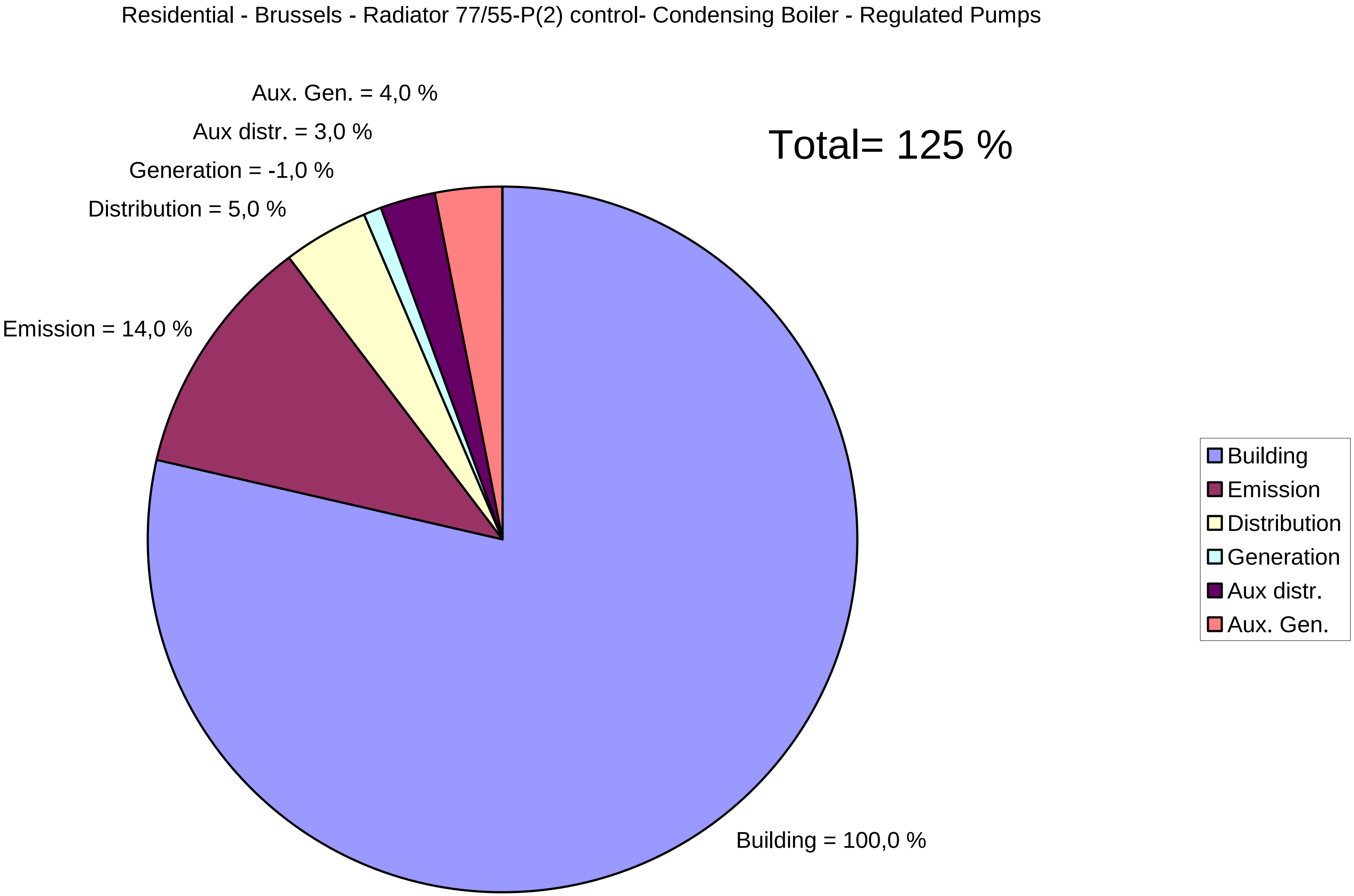
Energy performance of heating systems



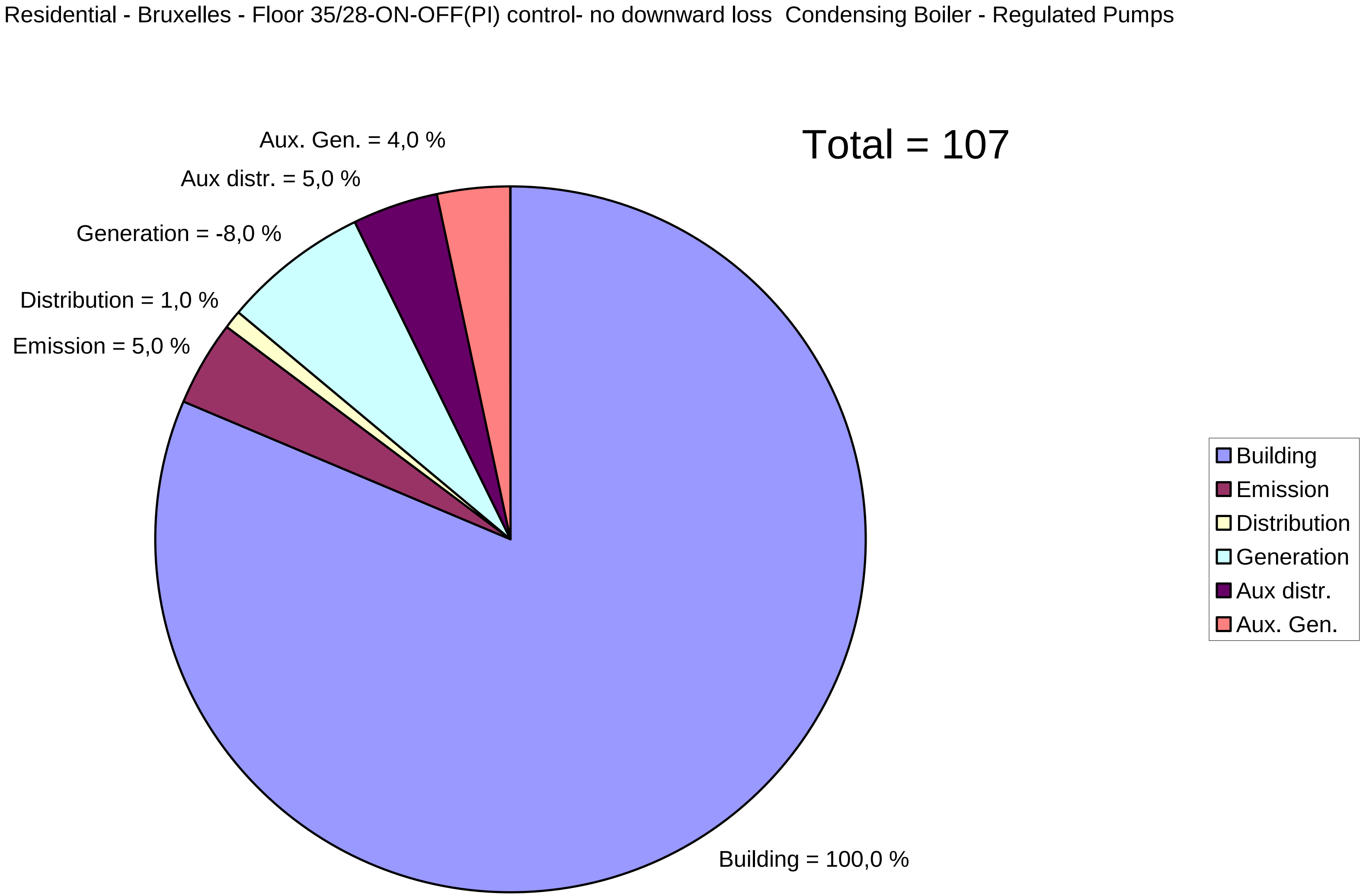
Heat generation system

- The calculation of losses from heat generation systems:

• Boilers	EN15316-4.1
• Heat pumps	EN15316-4.2
• Co-generation CHP	EN15316-4.4
• District heating	EN15316-4.5
• Solar heating	EN15316-4.3
• Biomass	EN15316-4.7
• Other renewables	EN15316-4.6

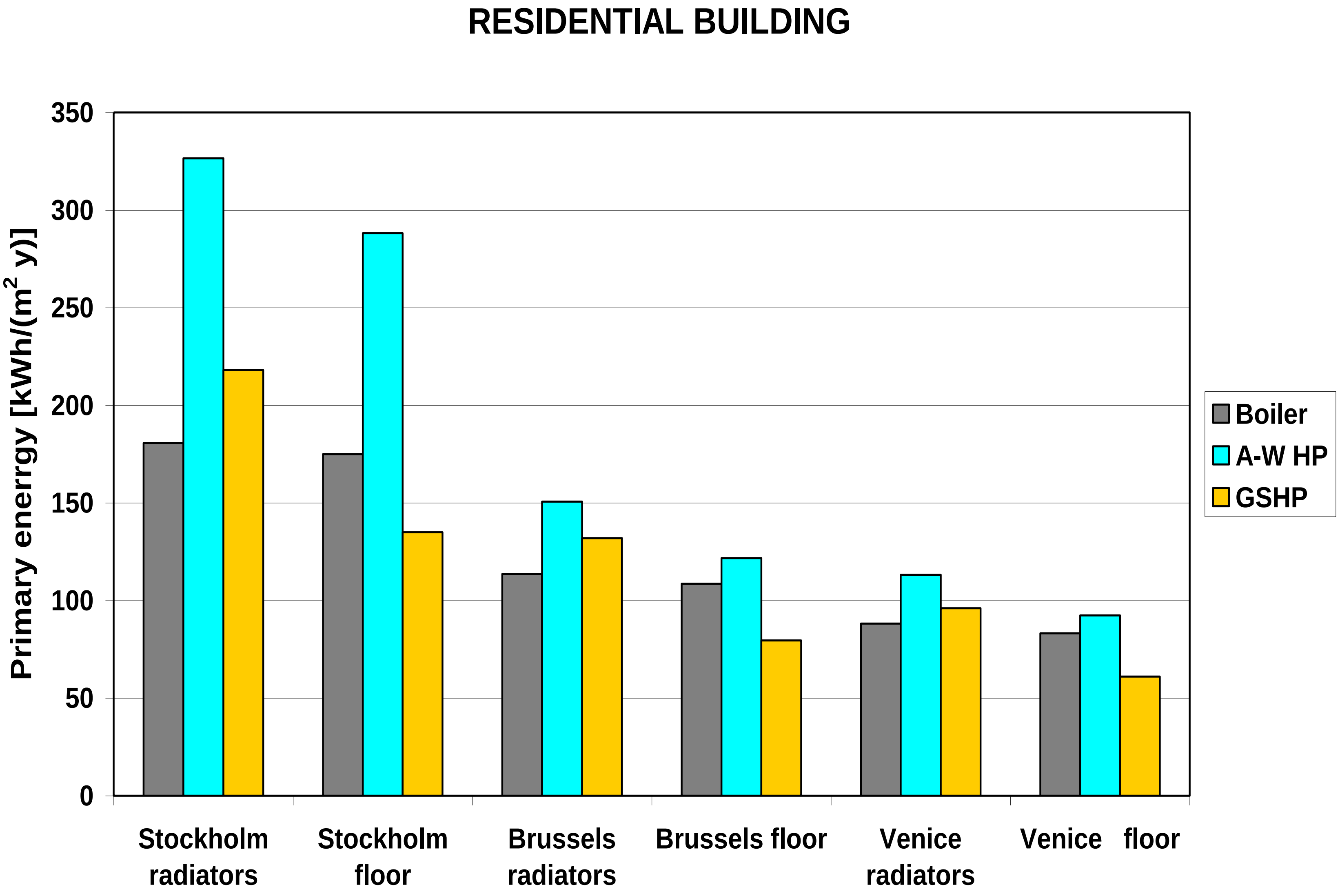


Primary energy for a radiator system 77/55 (supply-return temperature), thermostat with 2 K proportional band, condensing boiler and regulated pump. 85% of distribution losses are assumed to be recovered.

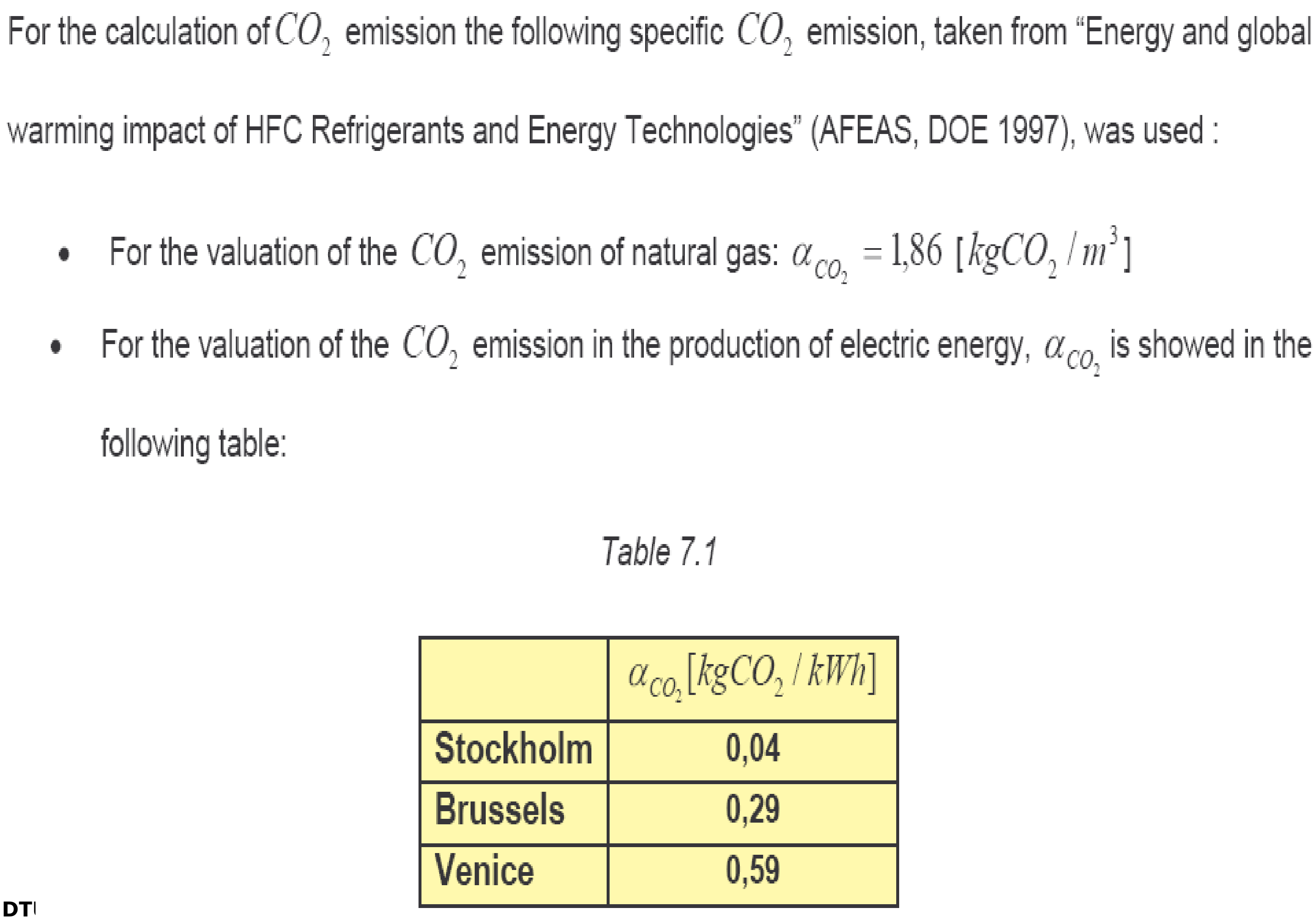


Primary energy for a floor heating system 35/28 (supply-return temperature), ON-OFF control, condensing boiler and regulated pump. No downward losses. 85% of distribution losses are assumed to be recovered .

Primary Energy



CO2 EMISSION



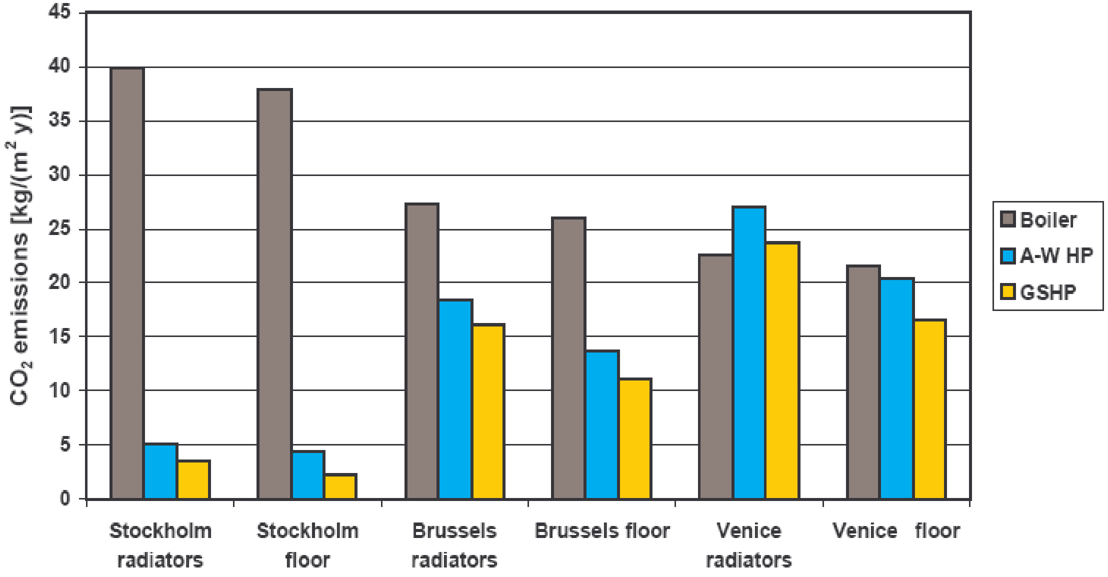
For the calculation of CO_2 emission the following specific CO_2 emission, taken from “Energy and global warming impact of HFC Refrigerants and Energy Technologies” (AFEAS, DOE 1997), was used :

- For the valuation of the CO_2 emission of natural gas: $\alpha_{CO_2} = 1{,}86\ [kgCO_2 / m^3]$
- For the valuation of the CO_2 emission in the production of electric energy, α_{CO_2} is showed in the following table:

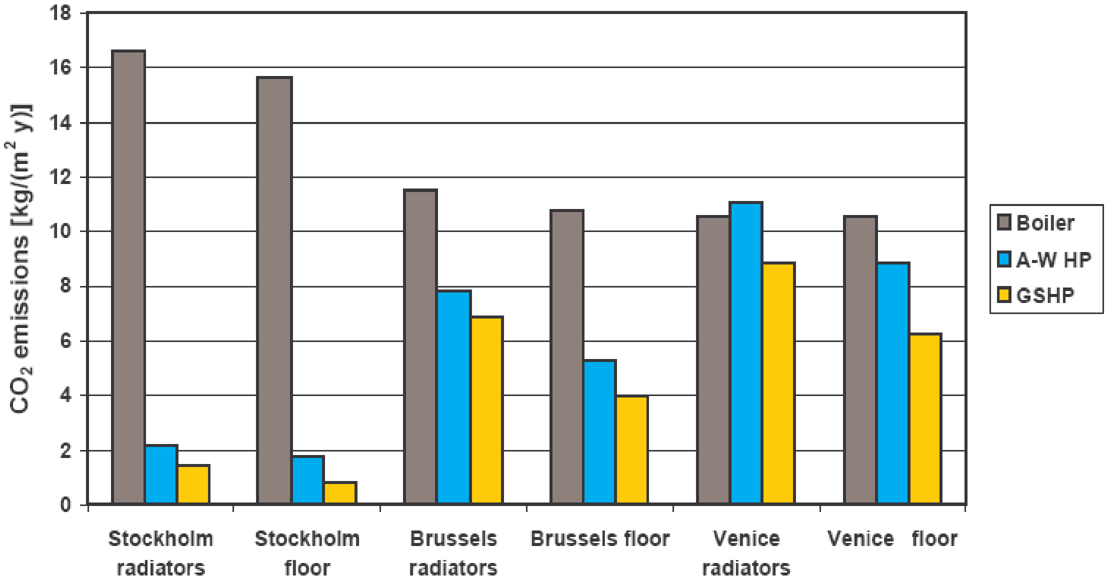
Table 7.1

	$\alpha_{CO_2} [kgCO_2 / kWh]$
Stockholm	0,04
Brussels	0,29
Venice	0,59

RESIDENTIAL BUILDING

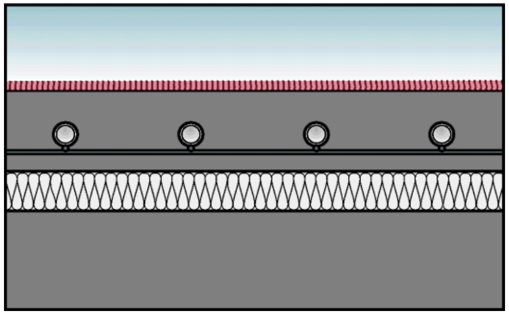


OFFICE BUILDING

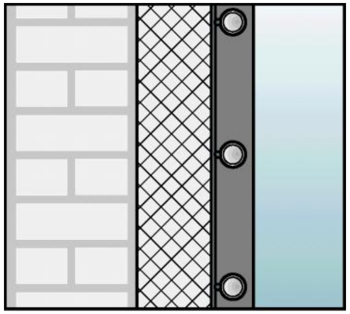


Radiant surface heating and cooling systems

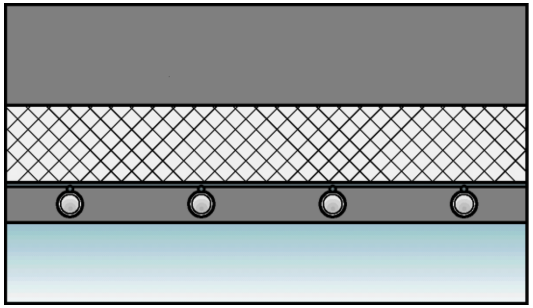
Floor



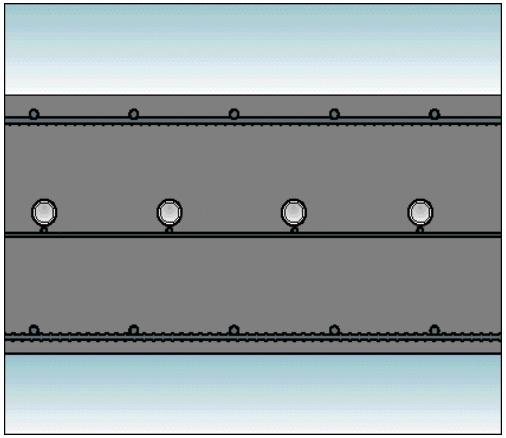
Wall

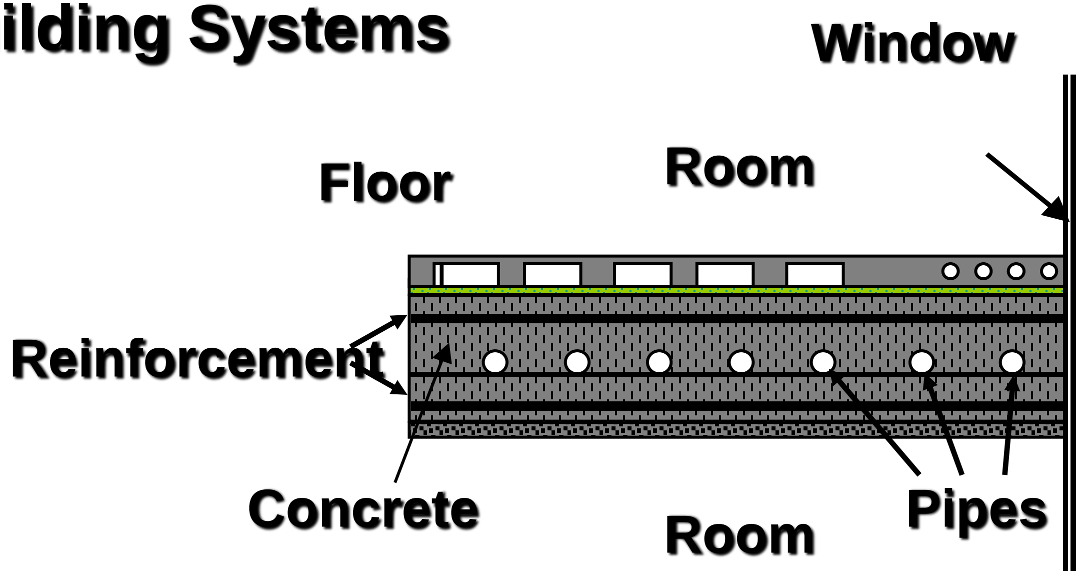


Ceiling



Thermo Active Building Systems





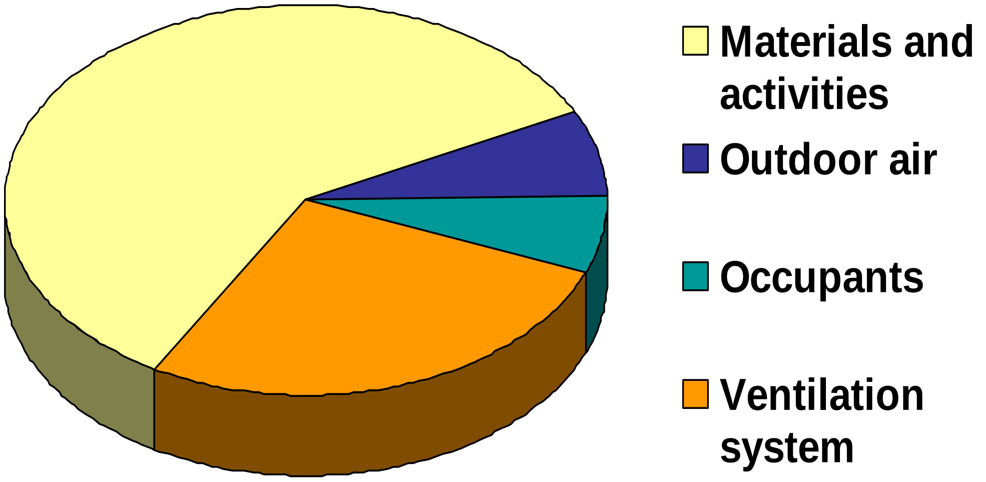
Kapillarrohr - Systemtechnik

Montage Putzkühldecke unter GK-Decke mit O-SB 20

Renovation with radiant heating and cooling

European Audit Project to Optimise Indoor Air Quality and Energy consumption in Office Buildings

Sensory pollution load- perceived air quality



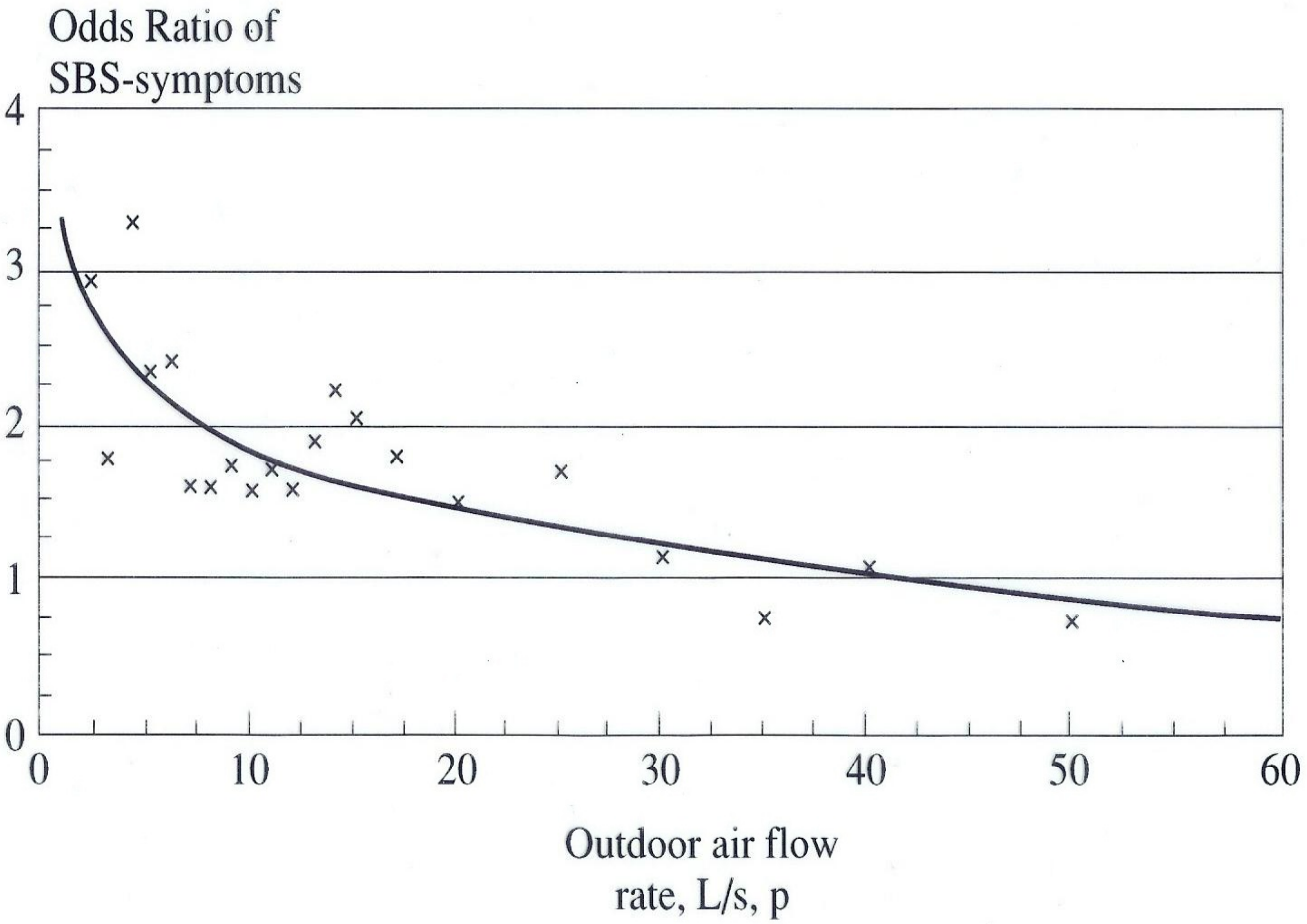


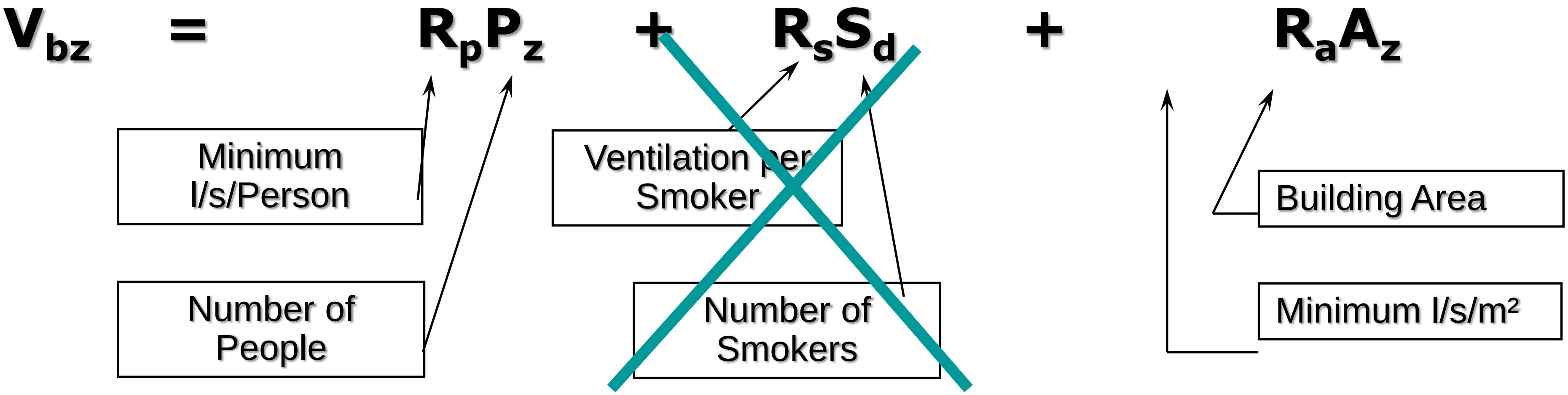
Figure 1. Adjusted odds ratio of SBS for low outdoor air flow rate in commercial buildings [3]

Concept for calculation of design ventilation rate

People Component

Building Component

Breathing Zone Outdoor Airflow



$$V_{bz} = R_pP_z \cancel{+ R_sS_d} + R_aA_z$$

Minimum l/s/Person

Number of People

~~Ventilation per Smoker~~

~~Number of Smokers~~

Building Area

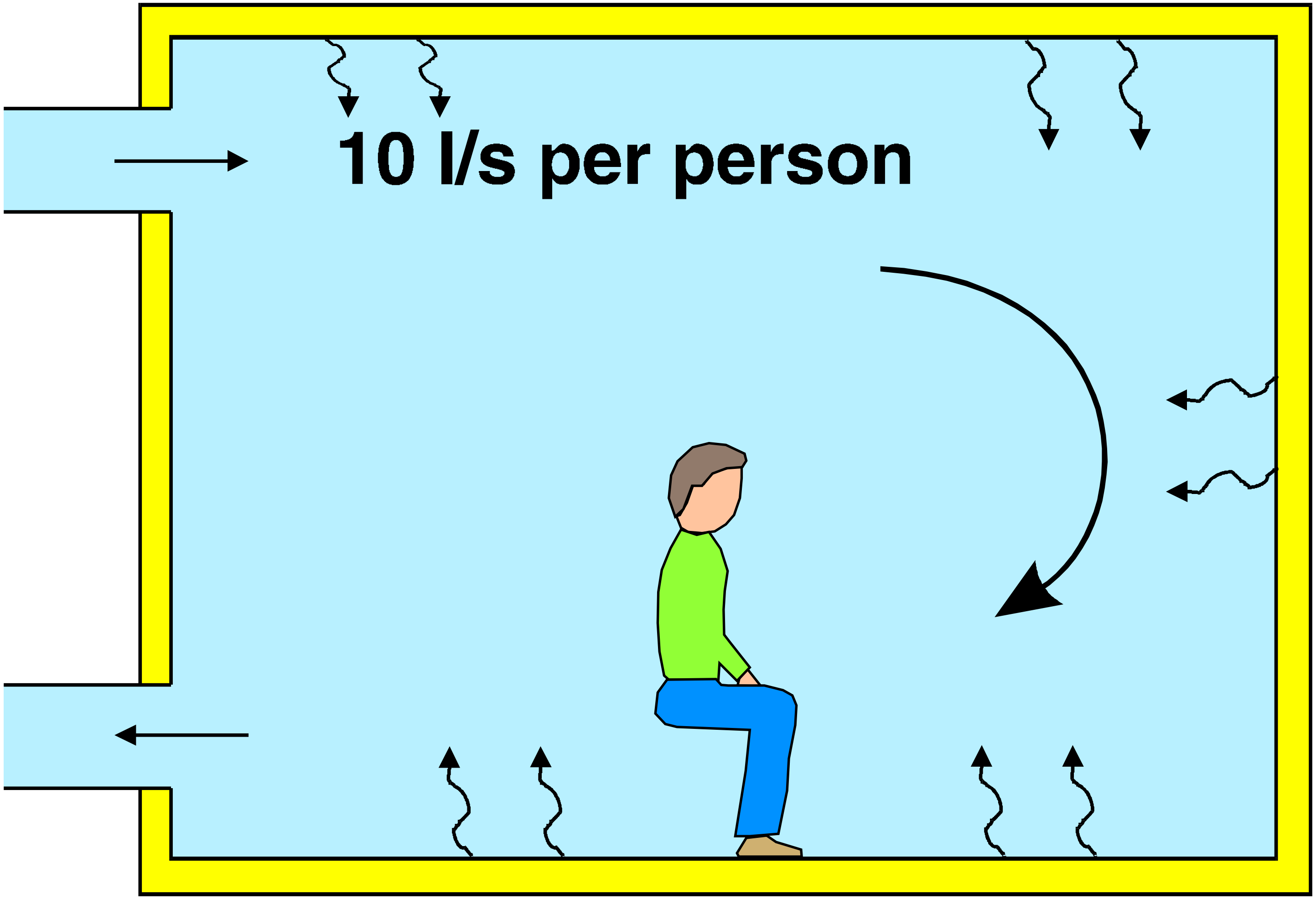
Minimum l/s/m²

Basic Ventilation

		Airflow for building emissions pollutions (l/s/m^2)		
Category	Airflow per person l/s/pers.	Very low polluting building	Low polluting building	Non low polluting building
I	1O	0,5	1	2
II	7	0,35	0,7	1,4
III	4	0,2	0,4	0,8

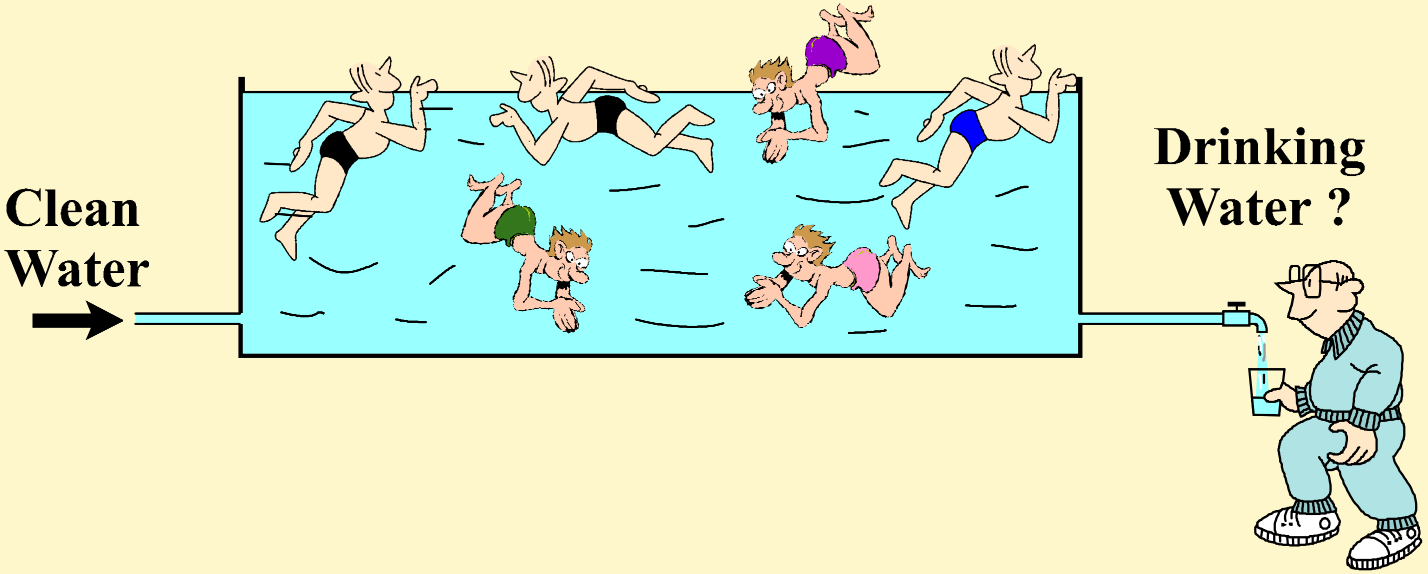
Total outdoor airflow (V_{tot}),

$$V_{tot} = V_{bz} / \varepsilon$$



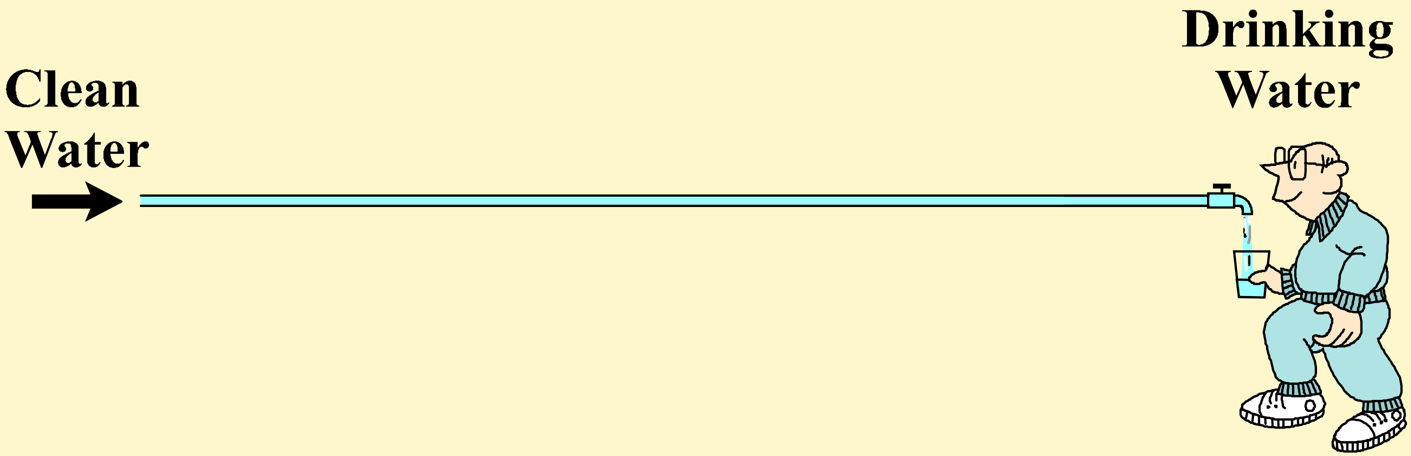
10 l/s per person

Ventilation today ...



Clean Water

Drinking Water ?



Clean Water

Drinking Water

Round Movable Panel

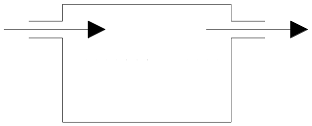
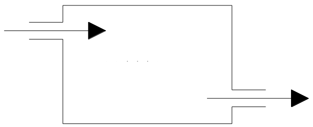
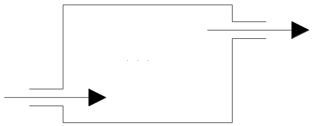
Headset

Ventilation Effectiveness

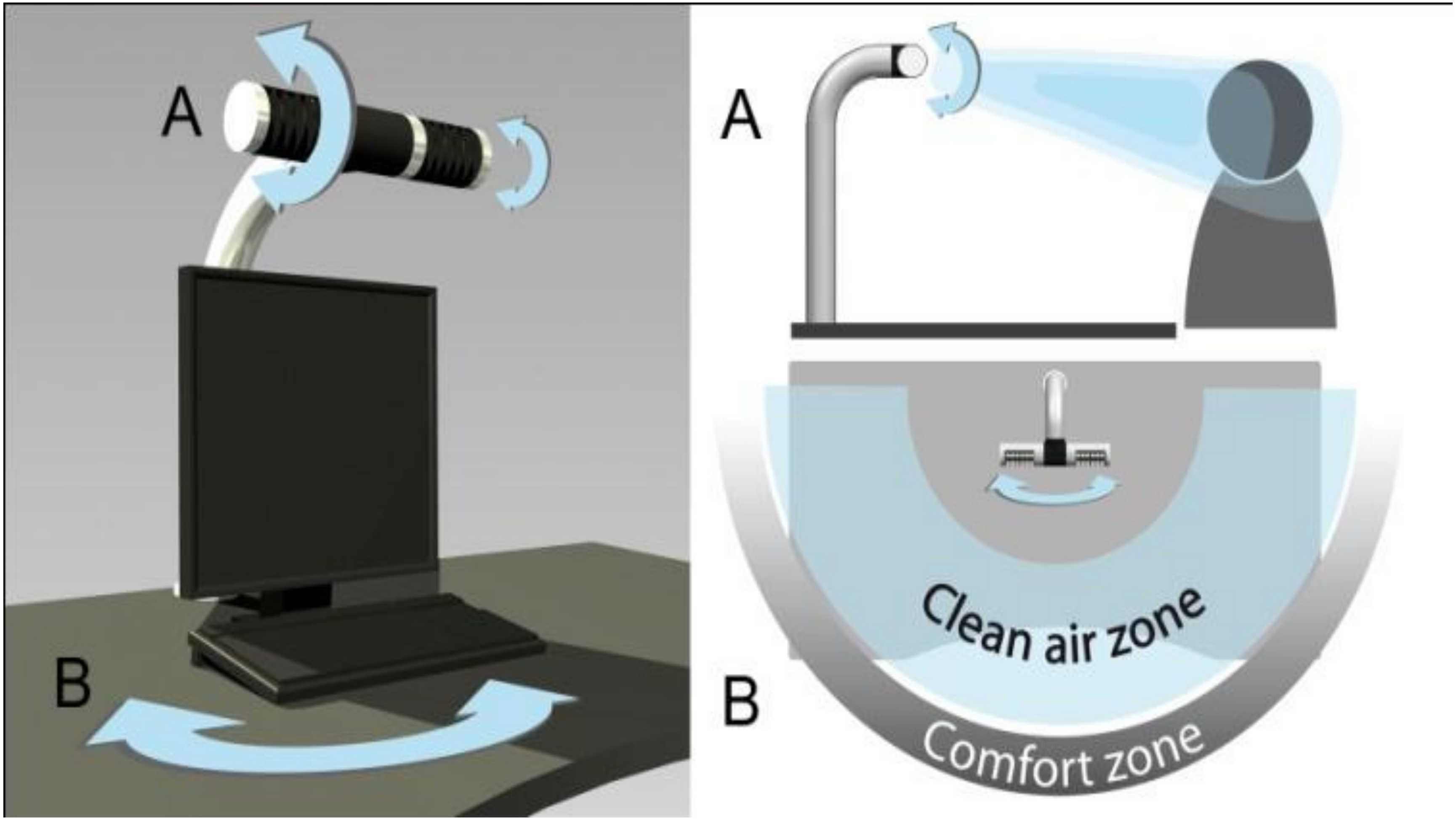
$$\varepsilon_V = \frac{C_E - C_S}{C_I - C_S}$$

Concentrations:
C_E exhaust air
C_S supply air
C_I breathing zone

CEN Report CR 1752 (1998)

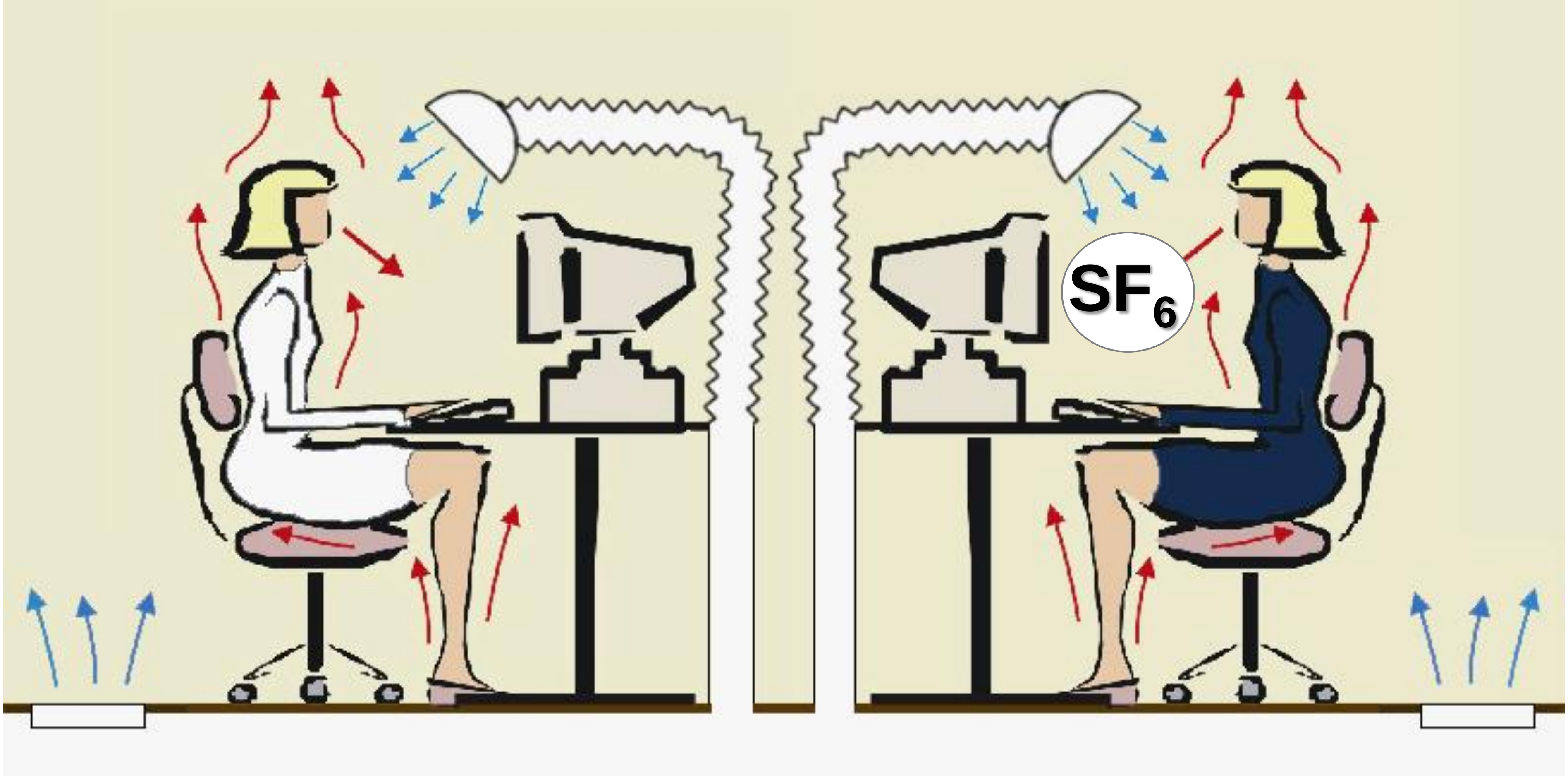
Mixing ventilation		Mixing ventilation		Displacement ventilation		Personalized ventilation	
							
T supply - T inhal °C	Vent. effect. -	T supply - T inhal °C	Vent. effect. -	T supply - T inhal °C	Vent. effect. -	T supply - T room °C	Vent. effect. -
< 0	0,9 - 1,0	< -5	0,9	<0	1,2 - 1,4	-6	1,2 - 2,2
0 - 2	0,9	-5 - 0	0,9 - 1,0	0-2	0,7 - 0,9	-3	1,3 - 2,3
2 - 5	0,8	> 0	1	>2	0,2 - 0,7	0	1,6 - 3,5
> 5	0,4 - 0,7						

Personalized systems



Spreading of decease

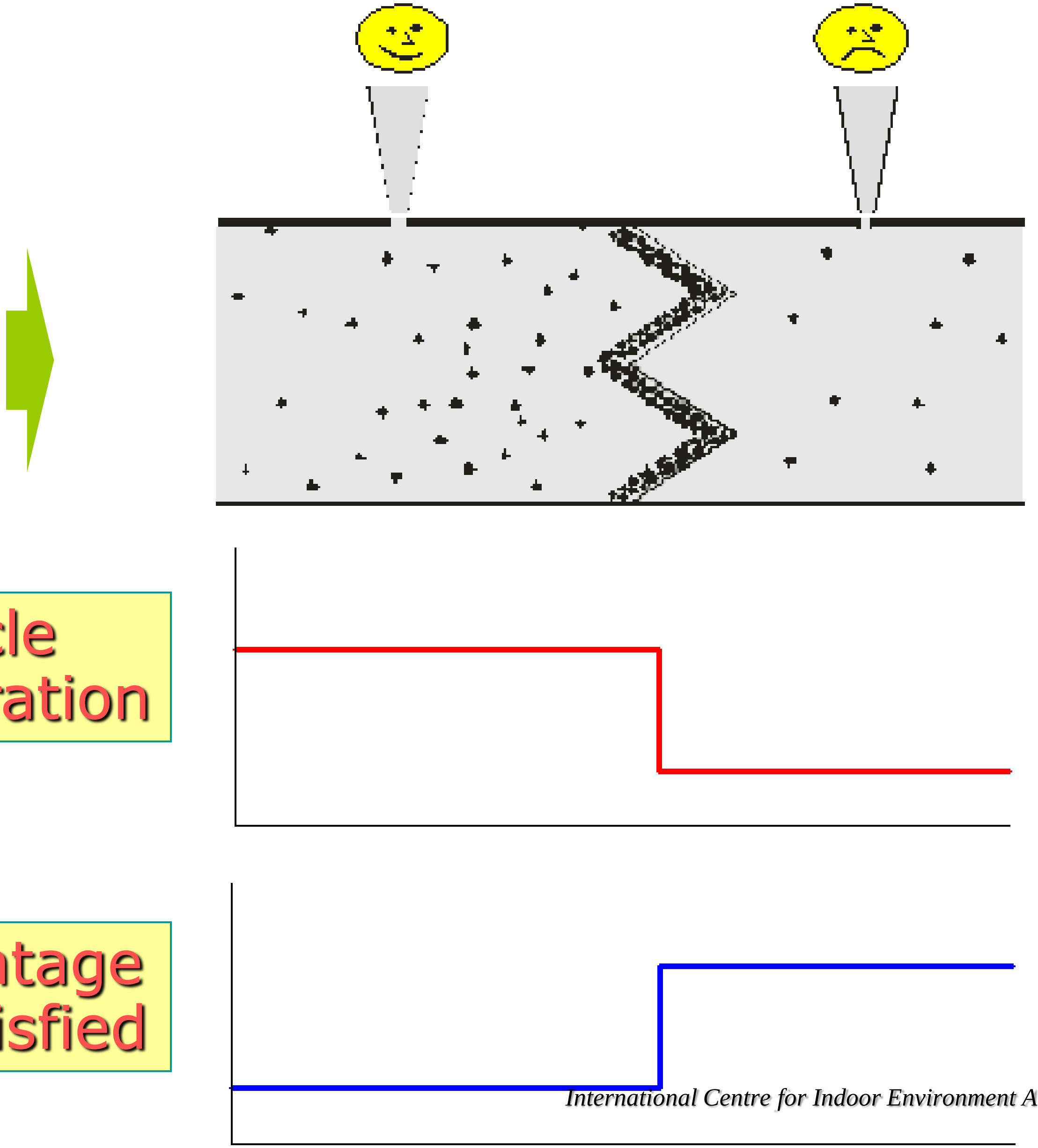
Exposed **Polluting**



AIR CLEANING

- Filters
- Photo catalytic Oxidation (PCO)
- Electrostatic
- Desiccant air cleaners
- Others

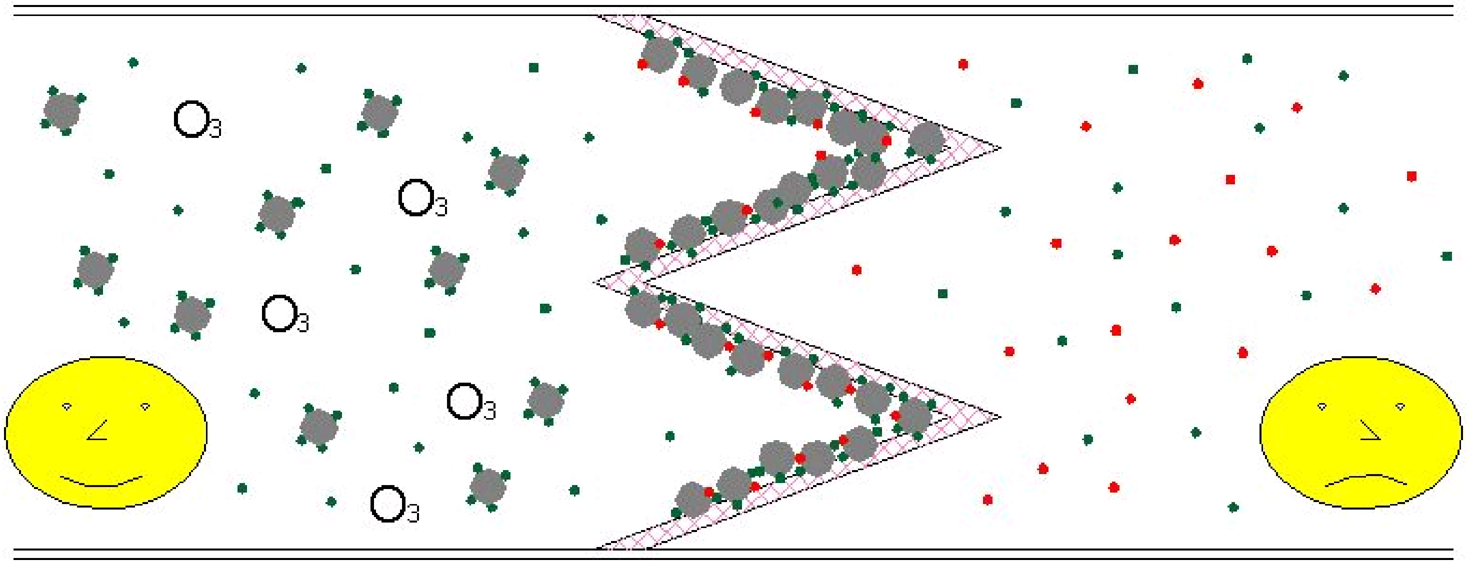
Why do filters pollute ?



Particle concentration

Percentage Dissatisfied

Hypotheses



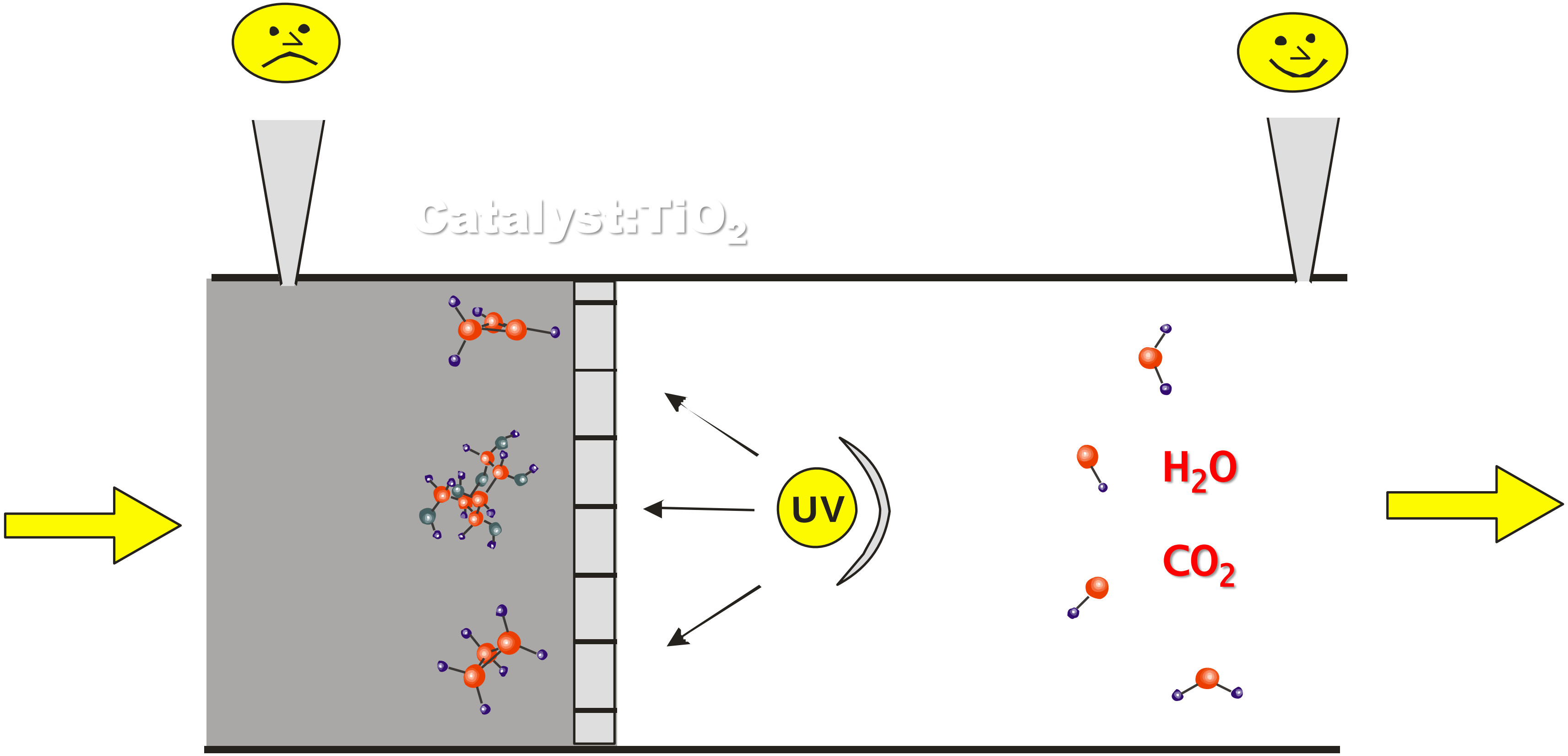
SVOCs sorbed on particles

Oxidized SVOCs

SVOCs in gas phase

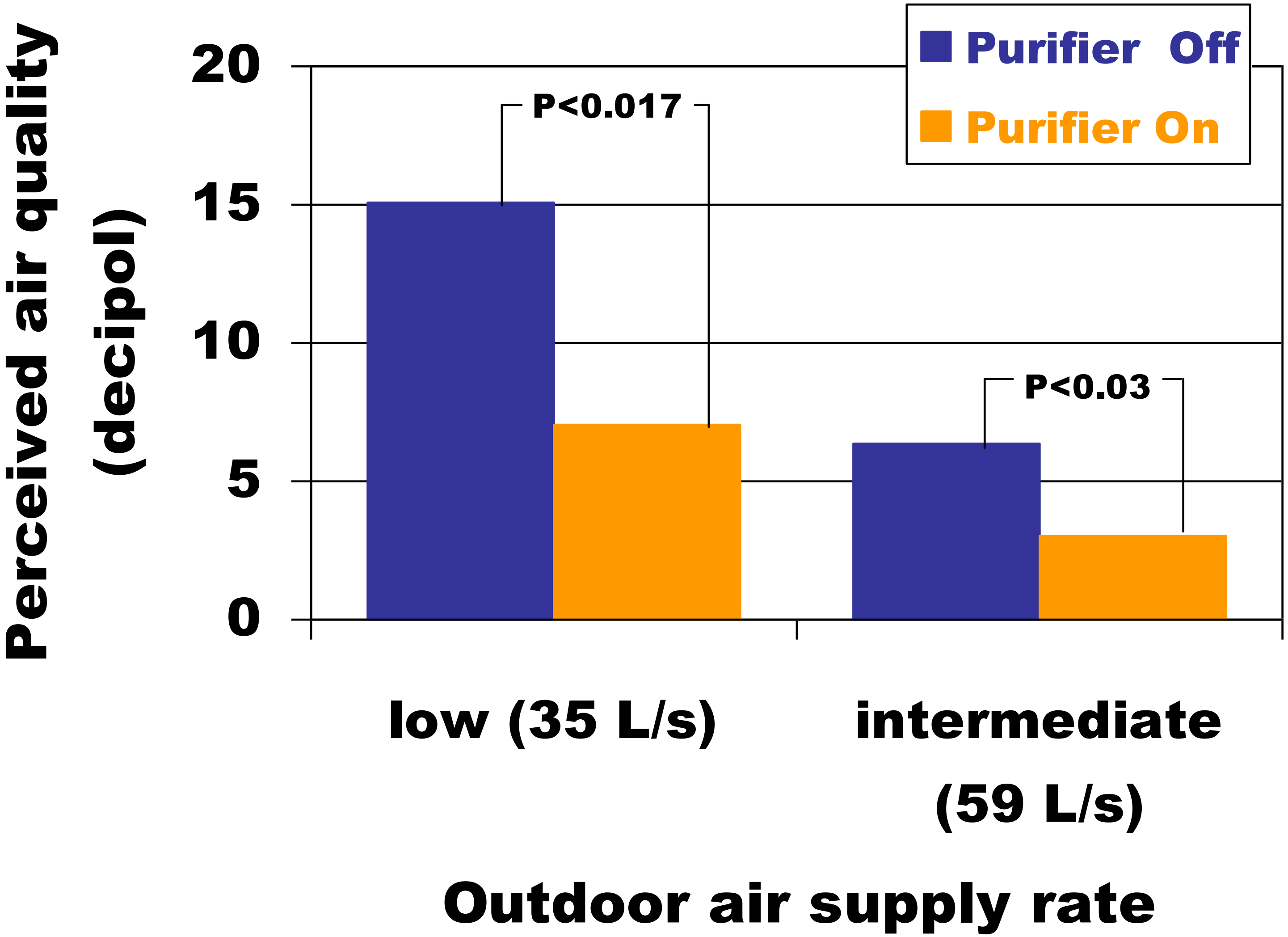
Unreacted SVOCs

Photo catalytic Oxidation (PCO)

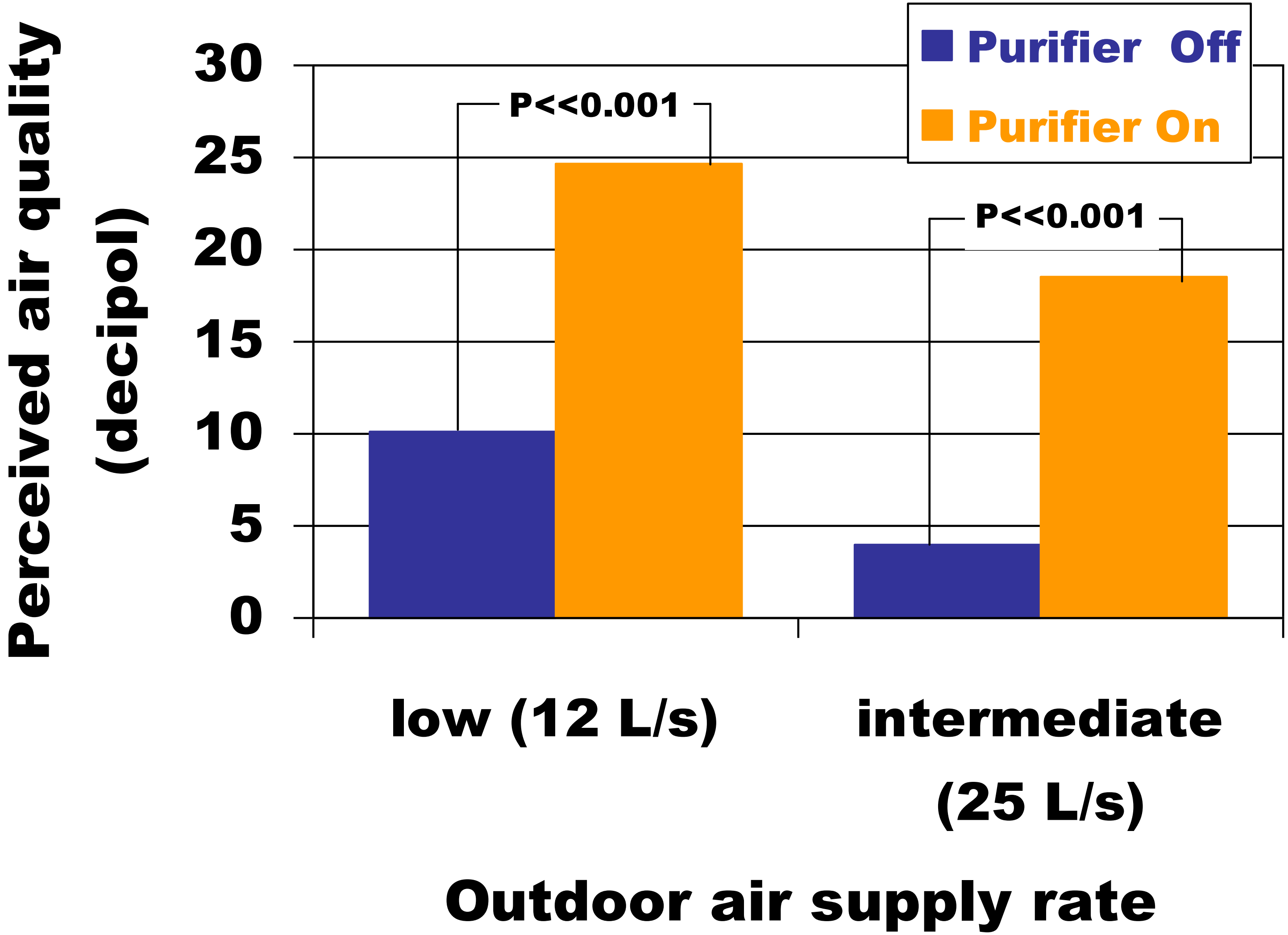


Adsorption of contaminants **Photocatalytical reaction** **Desorption of final products**

Results: Bldg mat, PCs, filters



Results: Human bio effluents




Destilled
water


Natural
mineral
water

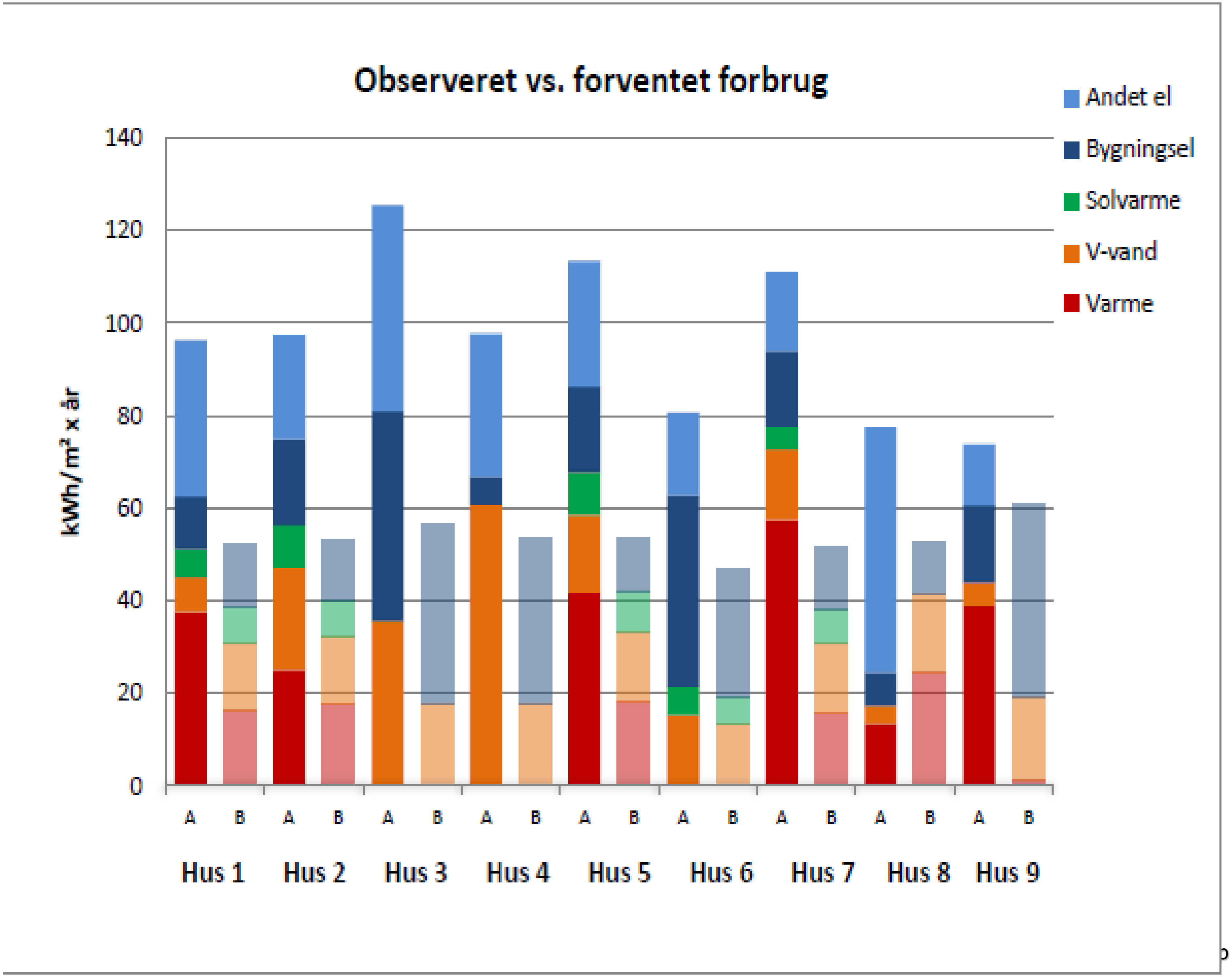
AIR CLEANING

- The criteria for the ventilation rates 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 as:
-
- $\varepsilon_{PAQ} = Q_o / Q_{AP} \cdot (PAQ/PAQ_{AP} - 1) \cdot 100$ %
- where
- ε_{PAQ} air cleaning efficiency for perceived air quality
- Q_o ventilations rate in l/s
- Q_{AP}
- PAQ perceived air quality without the air cleaner, decipol
- PAQ_{AP} perceived air quality without the air cleaner, decipol
-
- The Clean Air Delivery Rate is calculated as:
- $CADR = \varepsilon_{PAQ} \cdot Q_{AP} \cdot (3,6/V)$ h^{-1}
- where
- $Q_{AP} \cdot$ air flow through the air cleaner l/s
- V volume of the room m^3.

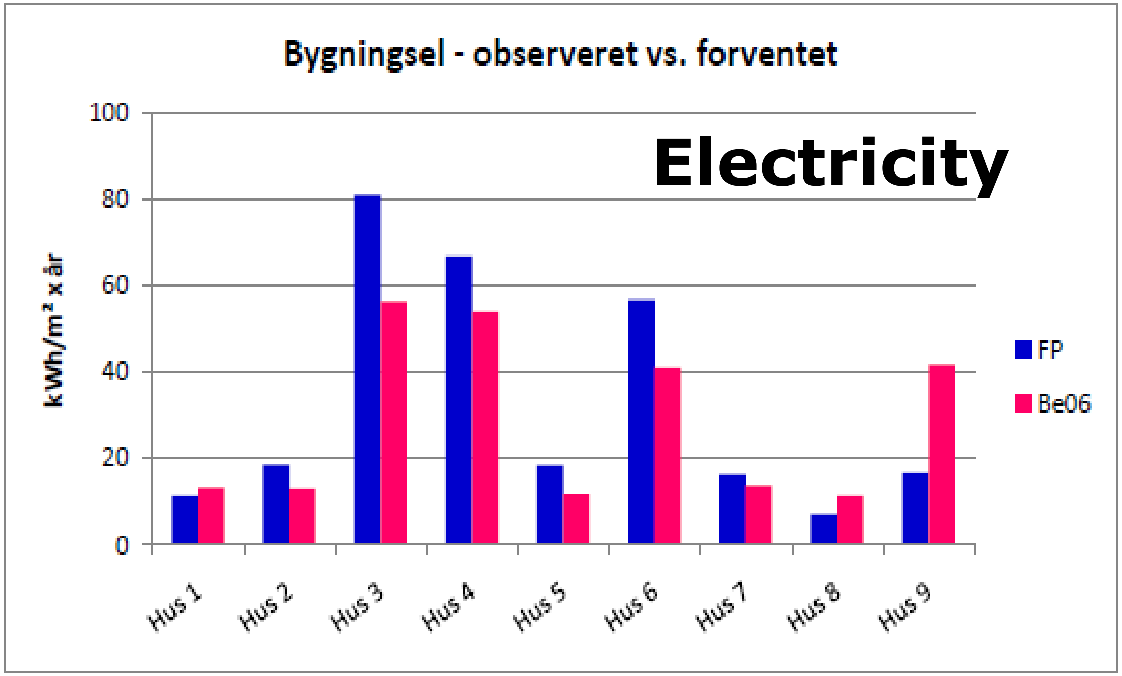
Demand Controlled Ventilation

- Commercial buildings
  - Level of occupancy
- Residential buildings
  - Time of day (at home, outside)
  - Occupied room (living room, bedroom)
- Need for more representative sensors
- Control concepts

Measured – Predicted Energy

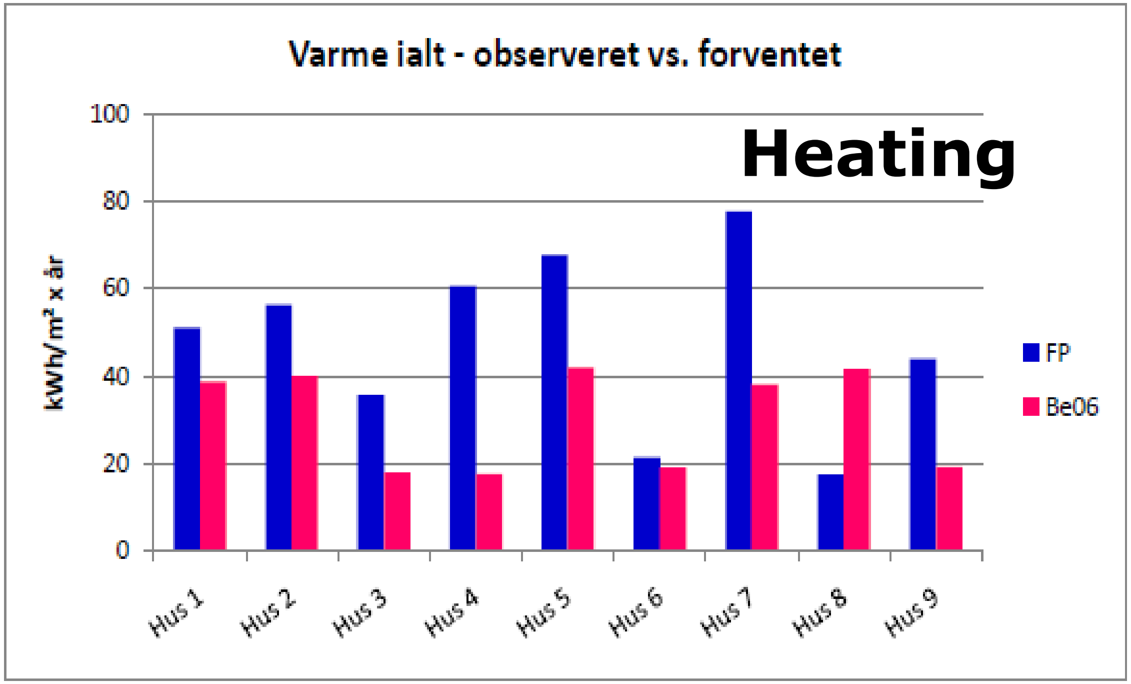


Measured – Predicted



Electricity

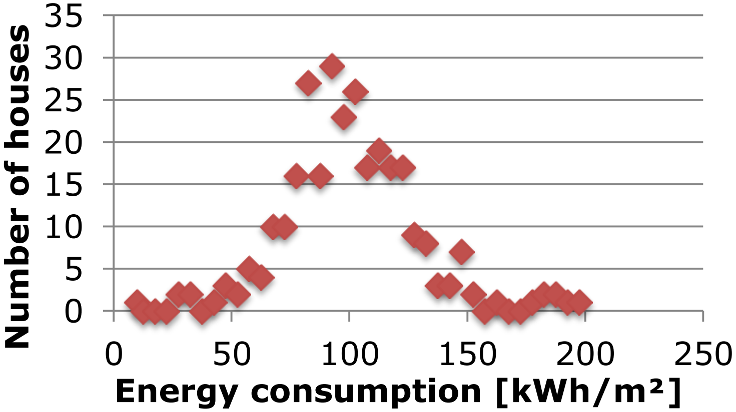
Figur 7: Bygningsel. forbrug i de 9 huse. Beregnet som primært energiforbrug. I huse med varmepumpe regnes alt



Heating

Investigation of heat consumption in 290 identical houses

- Highest consumption up to 20 times higher than lowest
- Savings
  - 90 % if all use same as lowest consumer
  - 45 % if all use same as the 10 % lowest
  - 30 % if all use same as the 25 % lowest



Occupant Behaviour

- Can impact the energy consumption with a factor 3-6
- Often main reason why predicted energy use do not match measured energy use
- Assumptions regarding occupant behaviour are used as input parameters to energy calculation
  - Set point
  - Window opening
  - Solar shading
  - Time of occupancy
  - Etc.
- A topic dealt with by IEA ECBCS Annex 53

Simulation of the effects of occupant behaviour on indoor climate and energy consumption

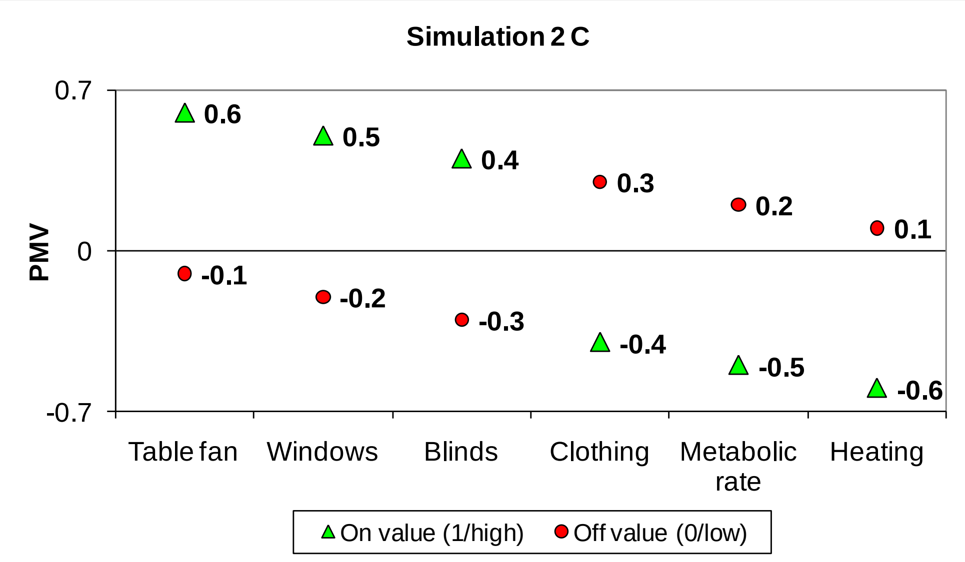
- The simulated occupant could manipulate four different environmental controls
  - table fan
  - window opening
  - Blinds
  - Heating
- two personal controls
  - clothing insulation
  - metabolic rate
- All control actions were carried out with the aim of keeping the PMV value within predefined limits

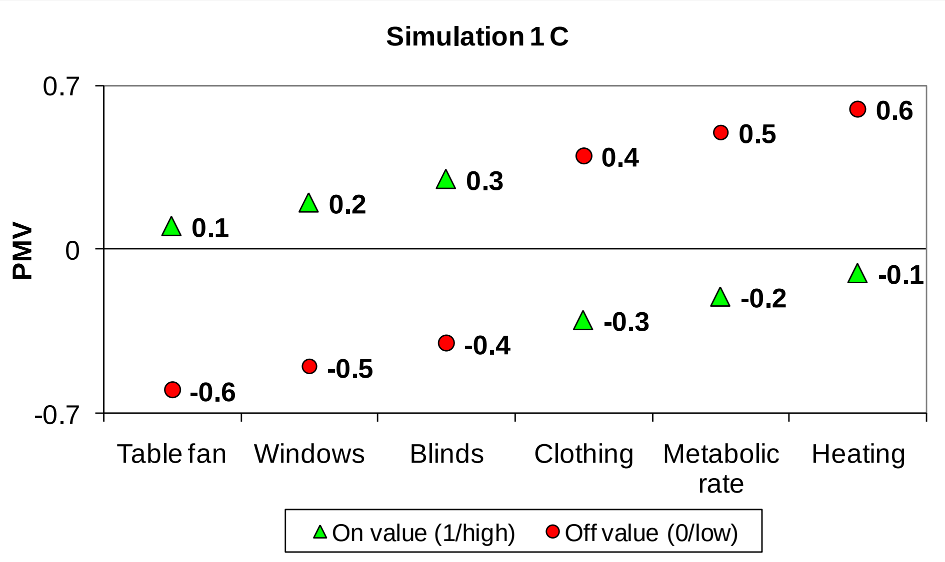
Simulations – Behaviour patterns and criteria

Criterion	Behaviour pattern 1	Behaviour pattern 2
A (-0.2<PMV<0.2)	Simulation 1A	Simulation 2A
B (-0.5<PMV<0.5)	Simulation 1B	Simulation 2B
C (-0.7<PMV<0.7)	Simulation 1C	Simulation 2C

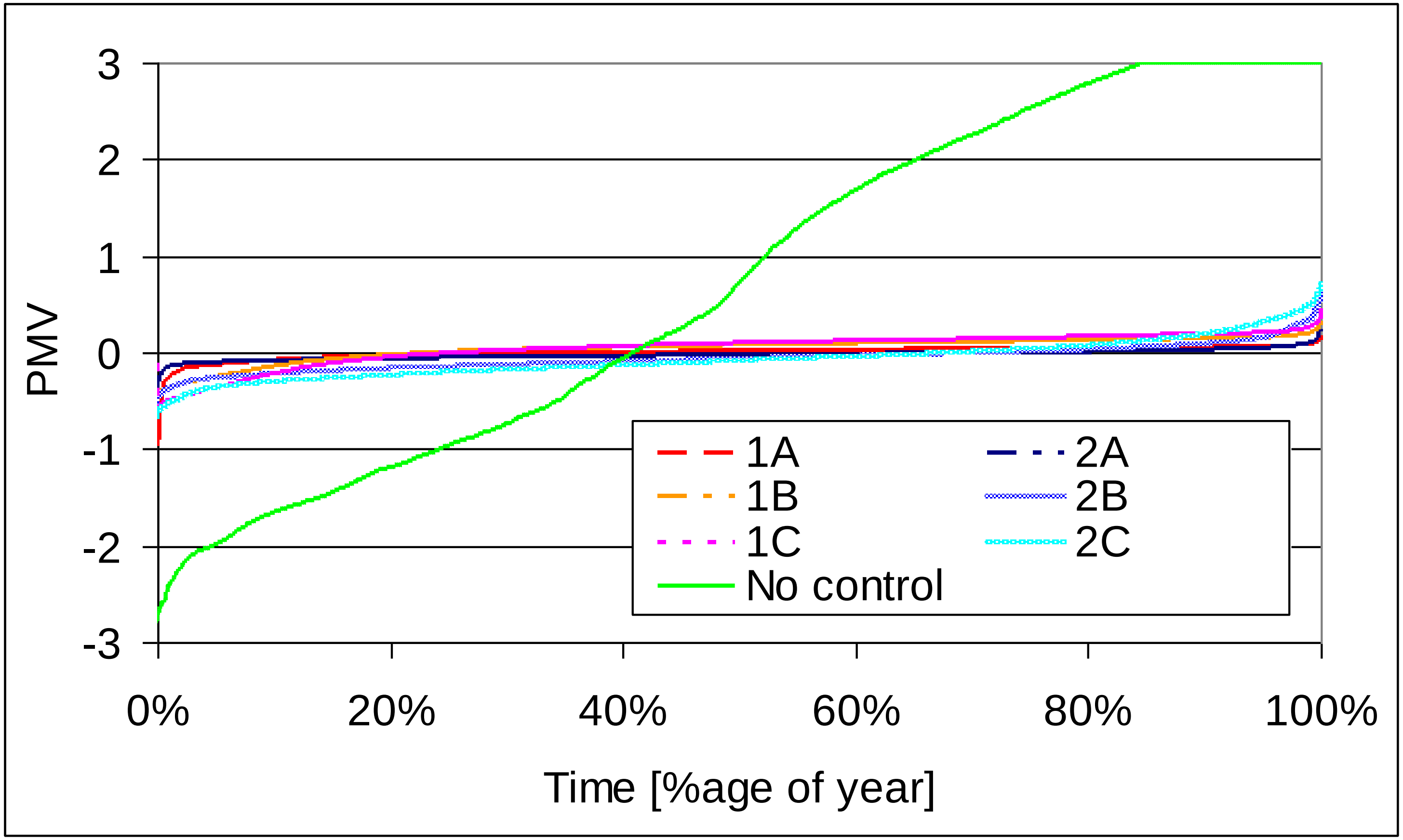
- **Behaviour pattern 1:**
  Energy expensive

Behaviour pattern 2:
Energy efficient



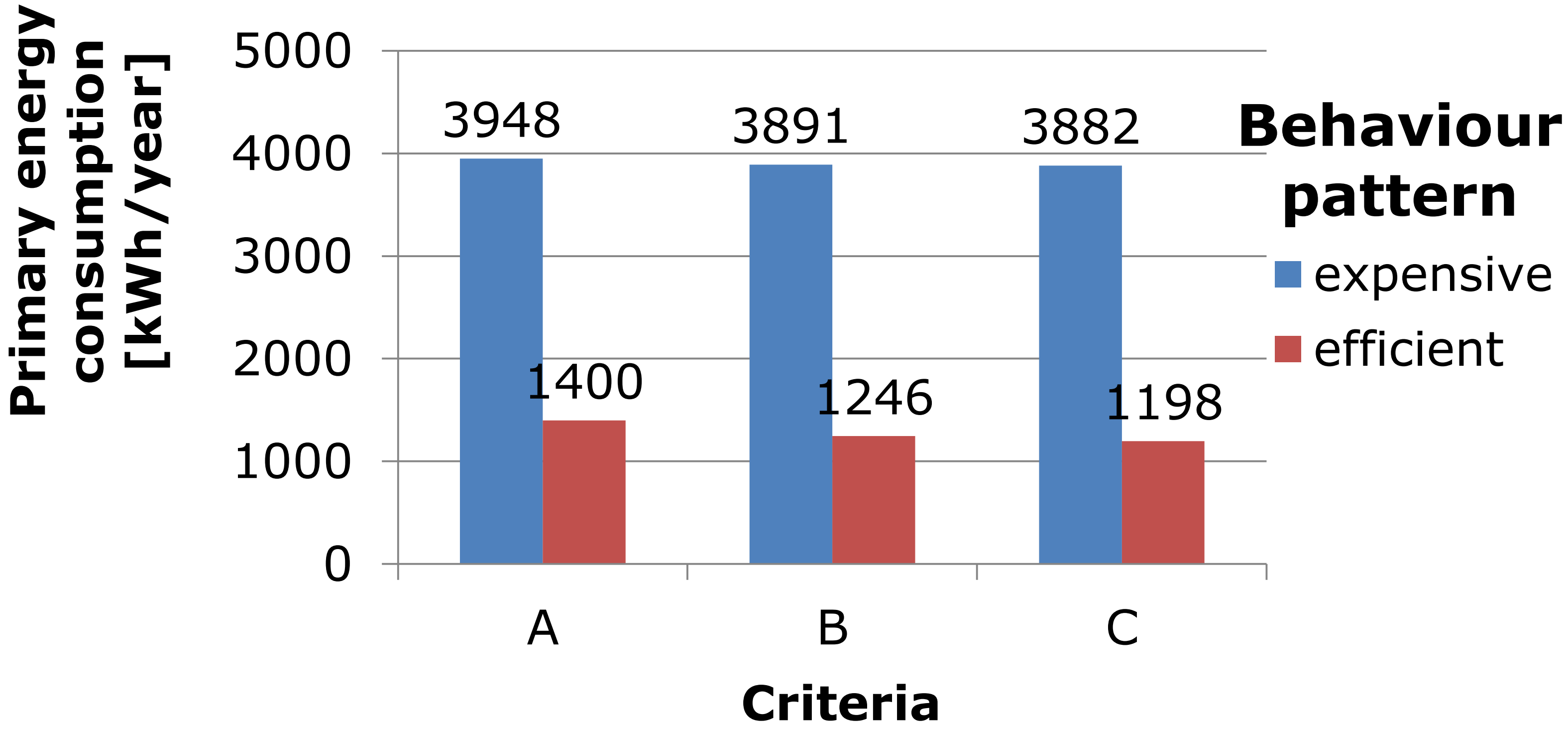


Simulation of the effects of occupant behaviour on indoor climate and energy consumption



Duration curves for the PMV index in the 6 simulations and for the reference simulation. The figure shows how long time (in percentage of a year) the PMV index was below a certain value.

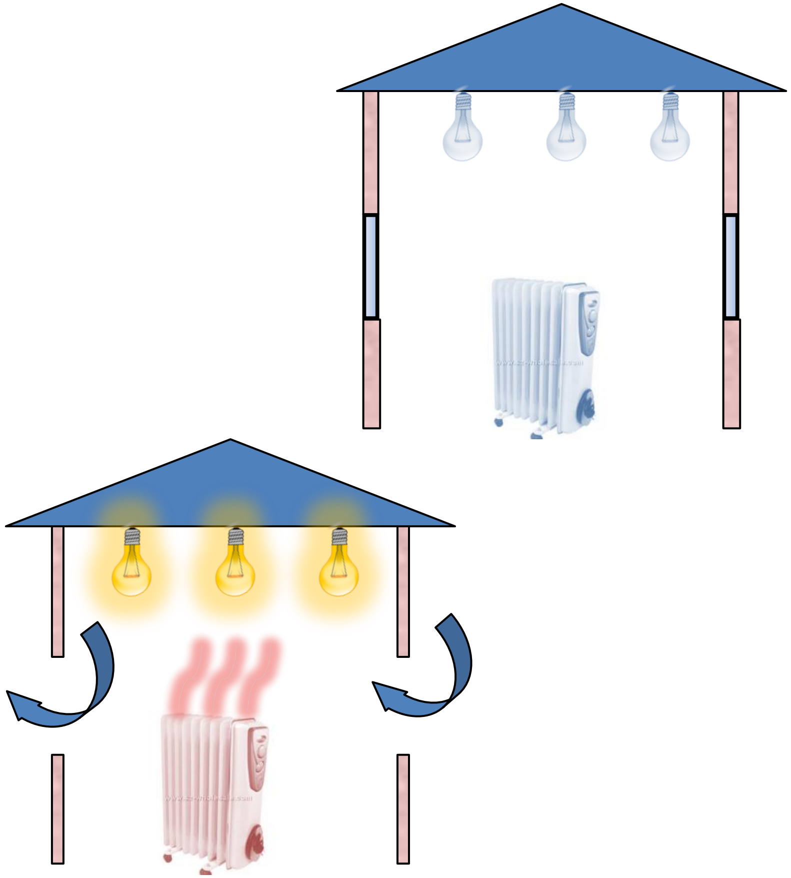
Results - Energy



- Simulated behaviour patterns – realistic?
- Drivers behind behaviour?

Occupant behaviour and energy consumption

- Simulation study:
  - Occupant behaviour can affect energy consumption by more than 300 %
- Literature survey
  - In identical dwellings, the highest energy consumption is typically 2-3 times as high as the lowest
  - Differences as high as 600 % has been observed

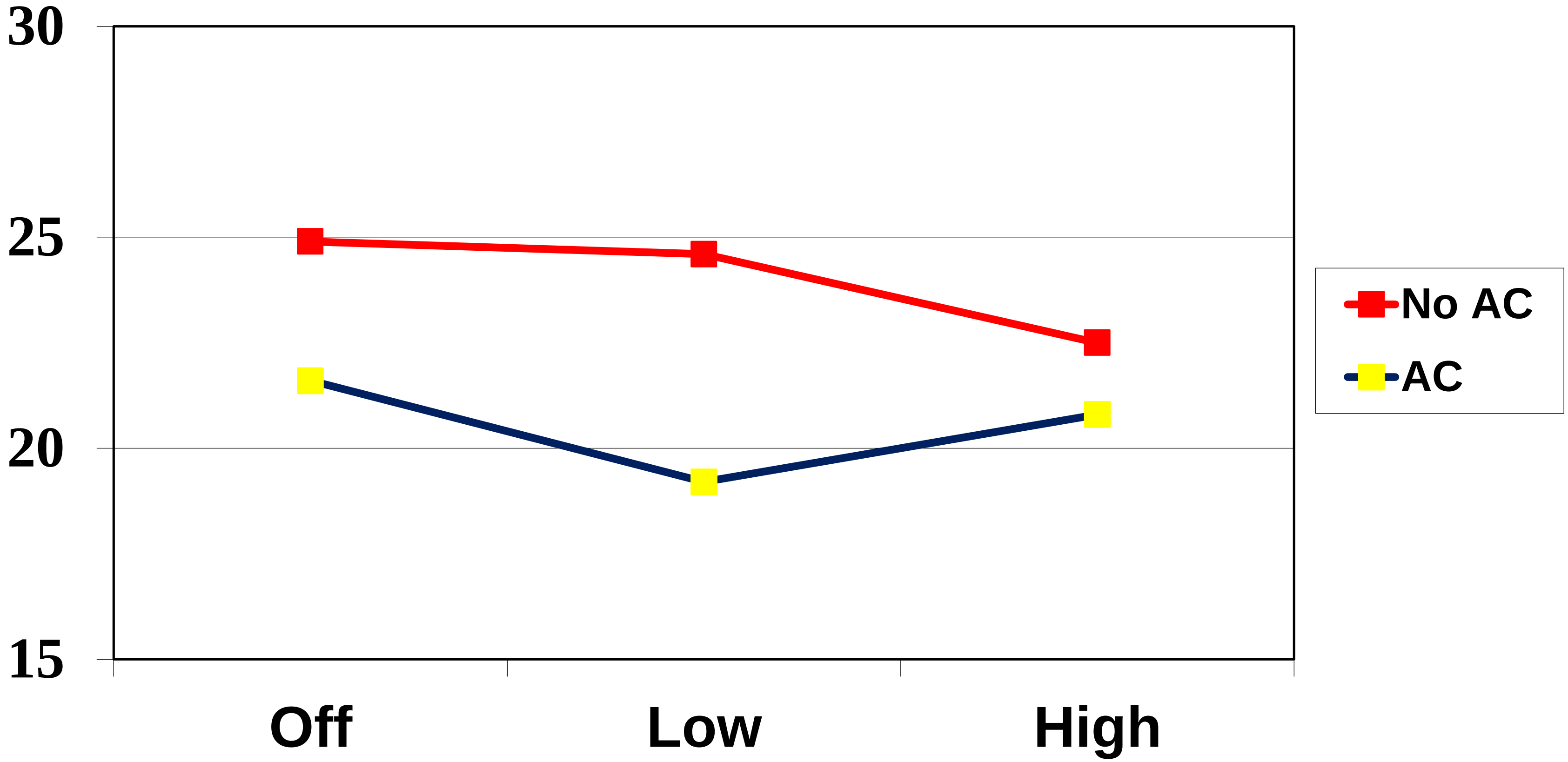


Behaviour changes as a tool of energy conservation?

- Is it possible to achieve energy savings by facilitation of behaviour changes?
- Can direct and current information about consequences of actions facilitate behaviour changes?
- Will information about actual price of heating and advice about behaviour facilitate changes in habits?

Summertime classroom T in ° C

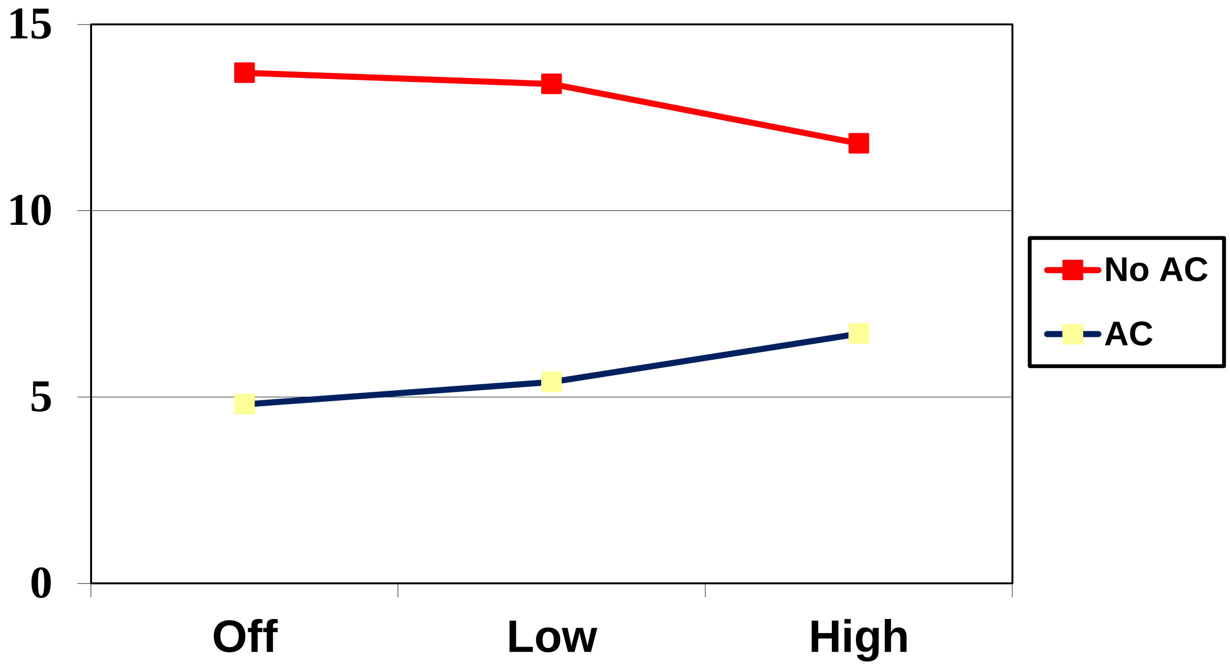
(NB: Different classes with natural/mechanical ventilation)



Mechanical ventilation

Hours/week with windows open

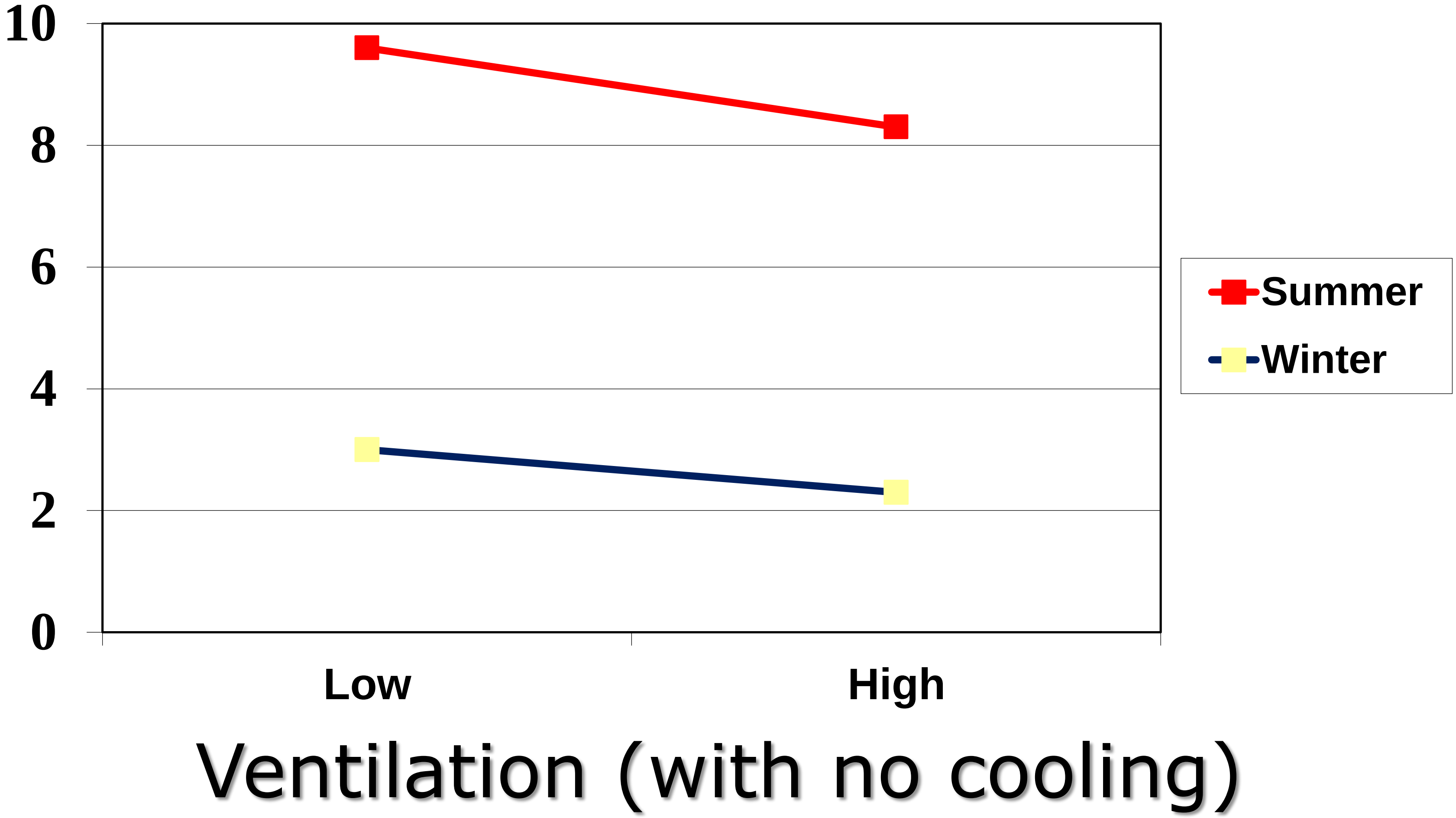
(NB: Different classes with natural/mechanical ventilation)



Mechanical ventilation

Hours/week with windows open

(NB: different classes in winter & summer)

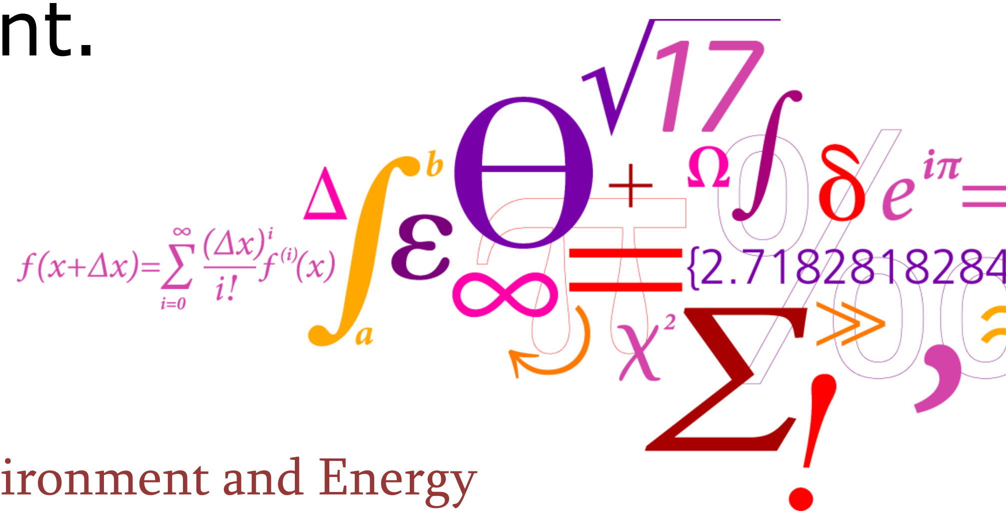


Indoor Air Quality and Thermal Comfort in near Zero Energy Buildings

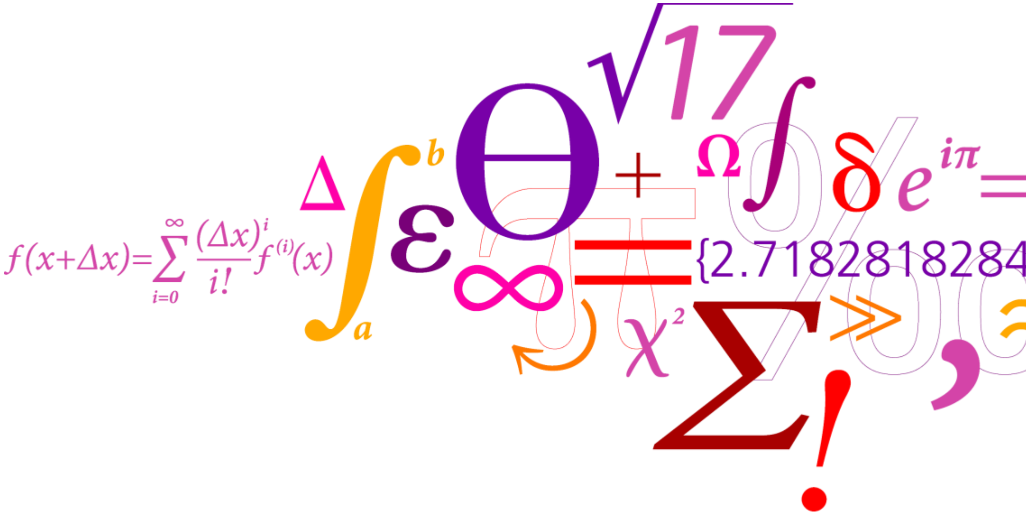
- Thermal Comfort
  - More uniform conditions (radiant asymmetry, vertical air temperature differences)
  - Less draught risk (reduced heat supply, no cold surfaces)
  - Less difference between air and operative temperature
  - Is individual room control important?
    - Comfort
    - Energy
- Indoor Air Quality
  - Tighter buildings
  - Cannot rely on infiltration
  - Can you heat with the ventilation system?
    - Air distribution
    - Ventilation effectiveness
    - Individual room control

If an energy efficient measure also improve the indoor environment it will

- Lower Health Risk
- Increase Comfort
- Increase Productivity
- Always be cost efficient.



Thank you for your attention!



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