International Centre for Indoor Environment and Energy

INODOOR BUILT ENVIRONMENT – challenges for health, comfort and productivity versus energy use?

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Buildings use in developped countries 42 % of total energy consumption

- Heating
- Cooling
- Ventilation
- Domestic Hot Water
- Lighting
- Houshold appliances

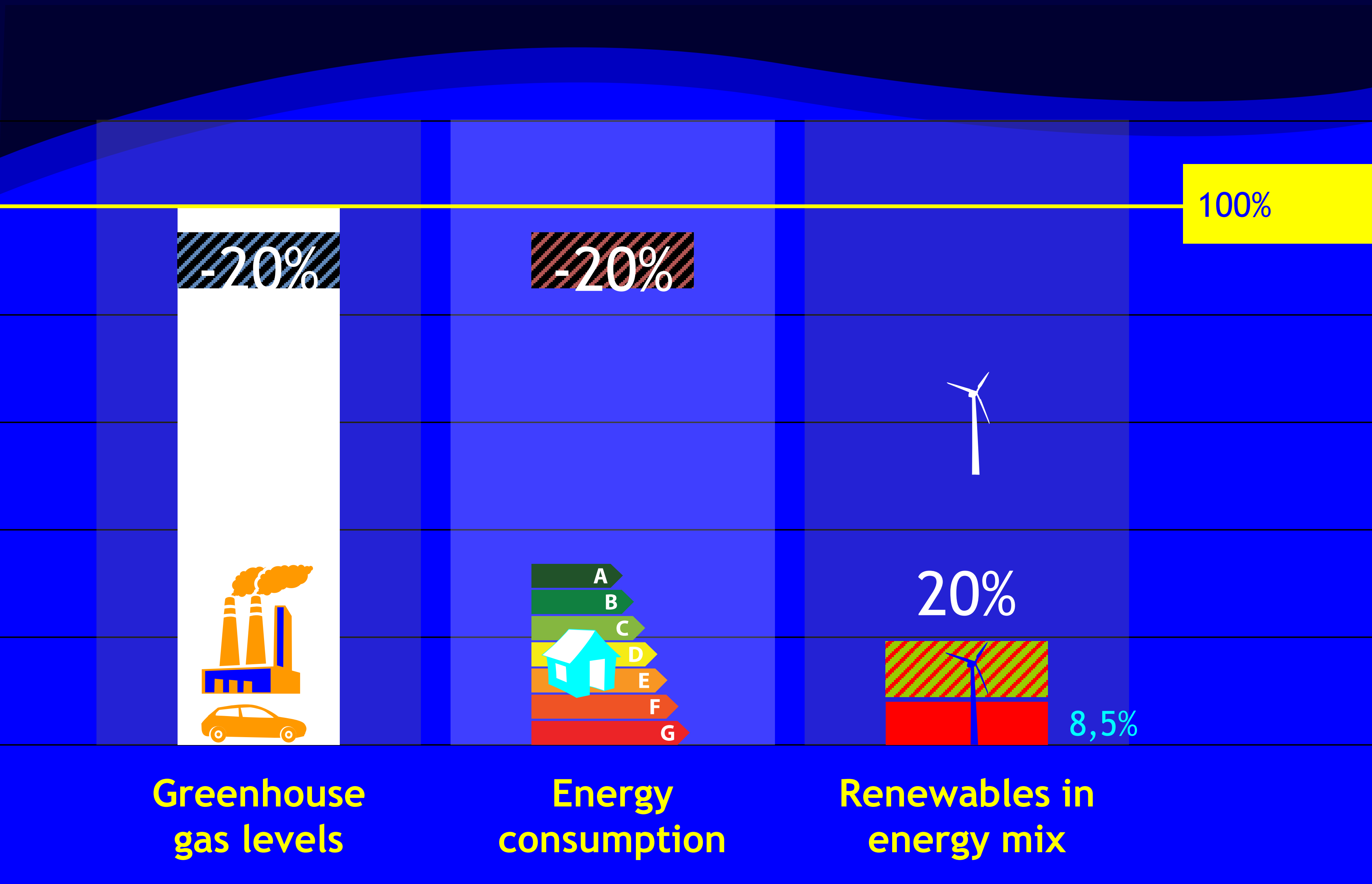
Energy Demand-Energy Efficiency-Energy Sources

- As the resources of fossil fuels are limited and the use of nuclear power is associated with several safety issues there is a worldwide need for reducing the energy demand of buildings.
- Reducing the energy demand is much more efficient and sustainable than increasing energy sources
- When constructing new buildings and renovation old buildings the first priority is to decrease the energy demand

POSSIBLE ACTIONS

- **Decrease energy demands (building design)**
- **Increase energy efficiency (HVAC systems)**
- **Increase use of renewable energy sources (wind, solar, geothermal, biomass)**
- New energy sources (fuel cell)

The 20-20-20 EU policy by 2020



Comprehensive set of legislation to enhance energy efficiency

Services
- Energy **end-use efficiency and energy services** Directive

Buildings
- Energy performance of **buildings Directive (EPBD)**

Generation
- Directive on the promotion of **cogeneration**

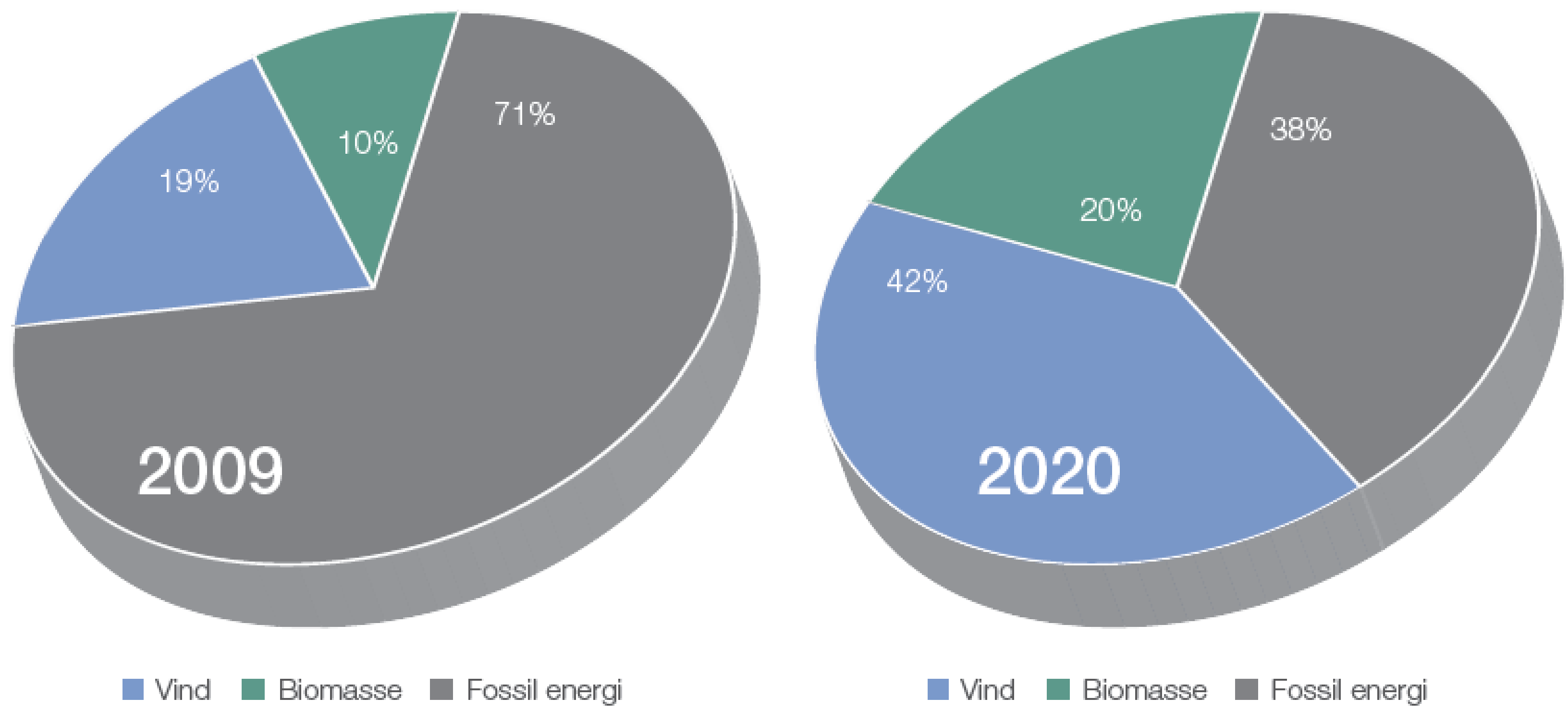
Product Labelling
- Directives for **labelling of e.g. electric ovens, air-conditioners, refrigerators and other domestic appliances**
- Regulation of Energy Star labelling for office equipment

Eco-Design
- Directive establishing a framework for the setting of **eco-design requirements** for energy-using products (implementing directives for **e.g. boilers, refrigerators, freezers and ballasts for fluorescent lighting**

Taxation
- **Directive for the taxation of energy products and electricity**

Directorate-General for Energy and Transport

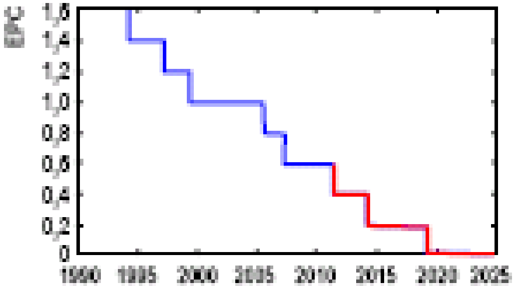
Part of renewable energy sources (wind and bio-fuel) in Denmark (no nuclear)



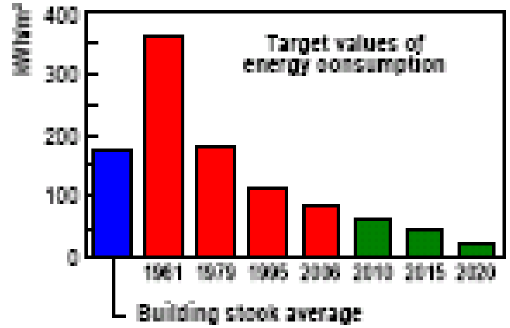
4.2 Andel vedvarende energi i elproduktion 2009 og 2020

The effect og building regulations

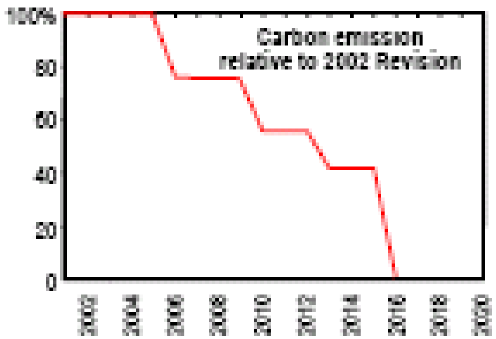
The Netherlands



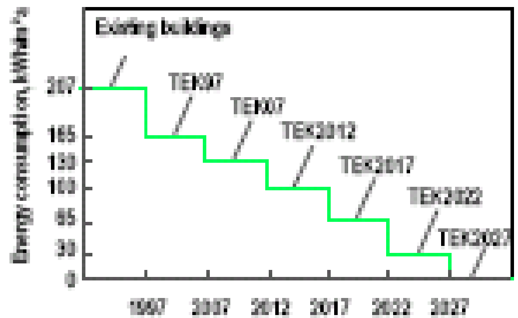
Denmark



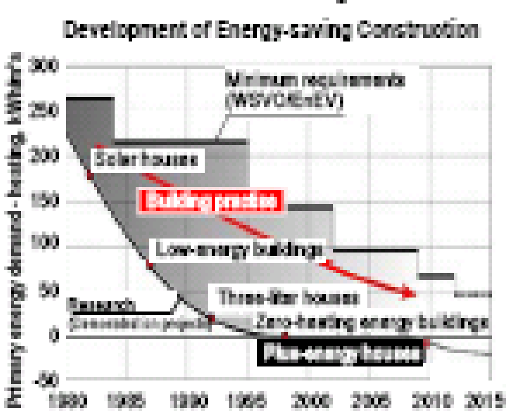
United Kingdom



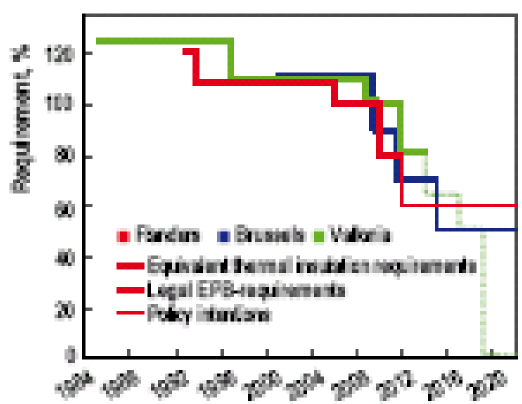
Norway



Germany



Belgium



COMFORT-PRODUCTIVITY
Building costs

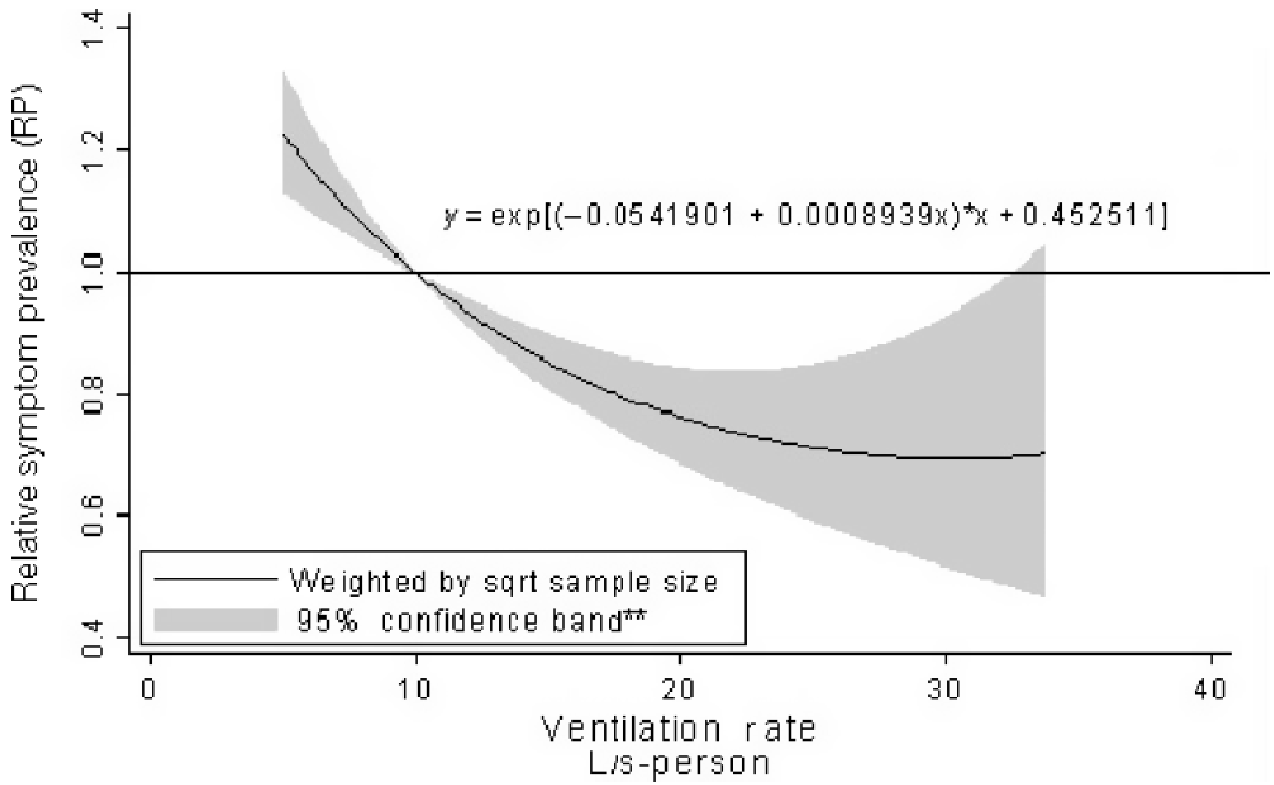
People	100
Maintenance	10
Financing	10
Energy	**1**

This clearly show that buildings are for

people

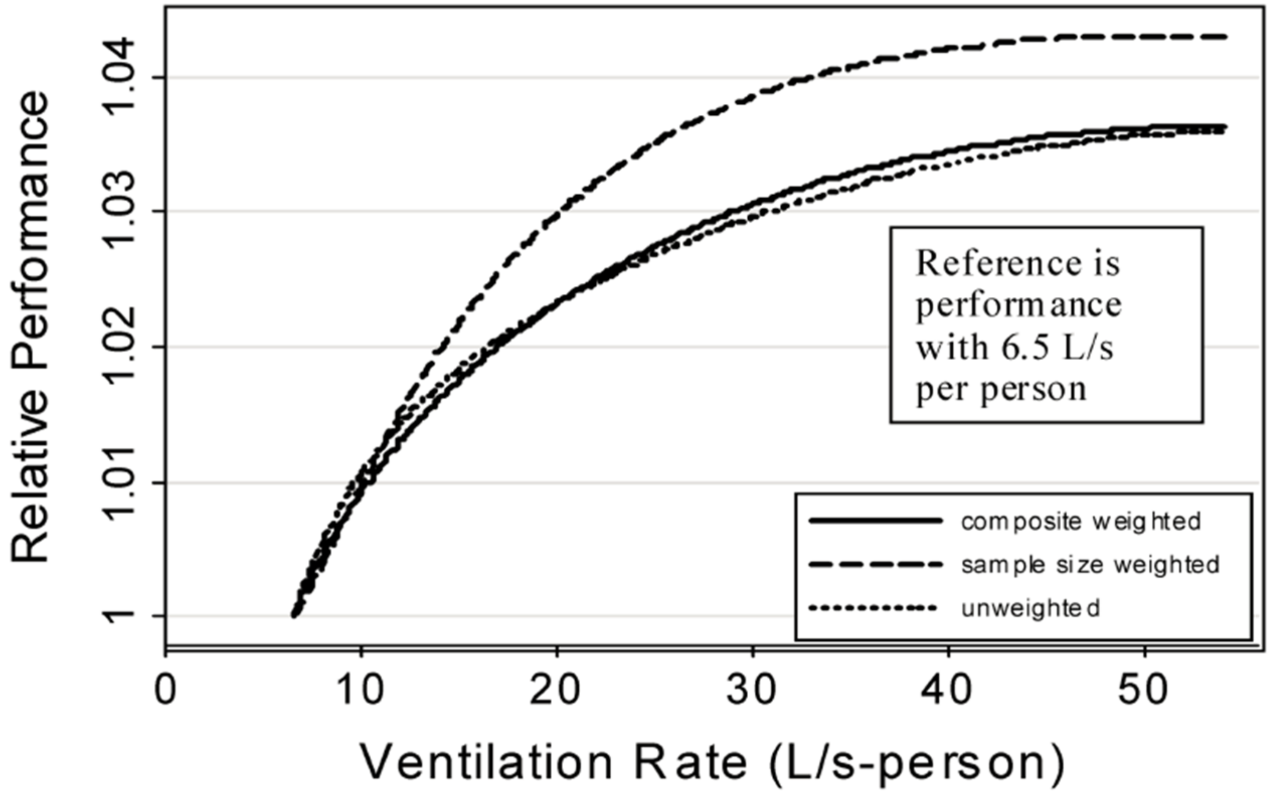
not for saving energy

Ventilation rates too low? SBS Symptoms



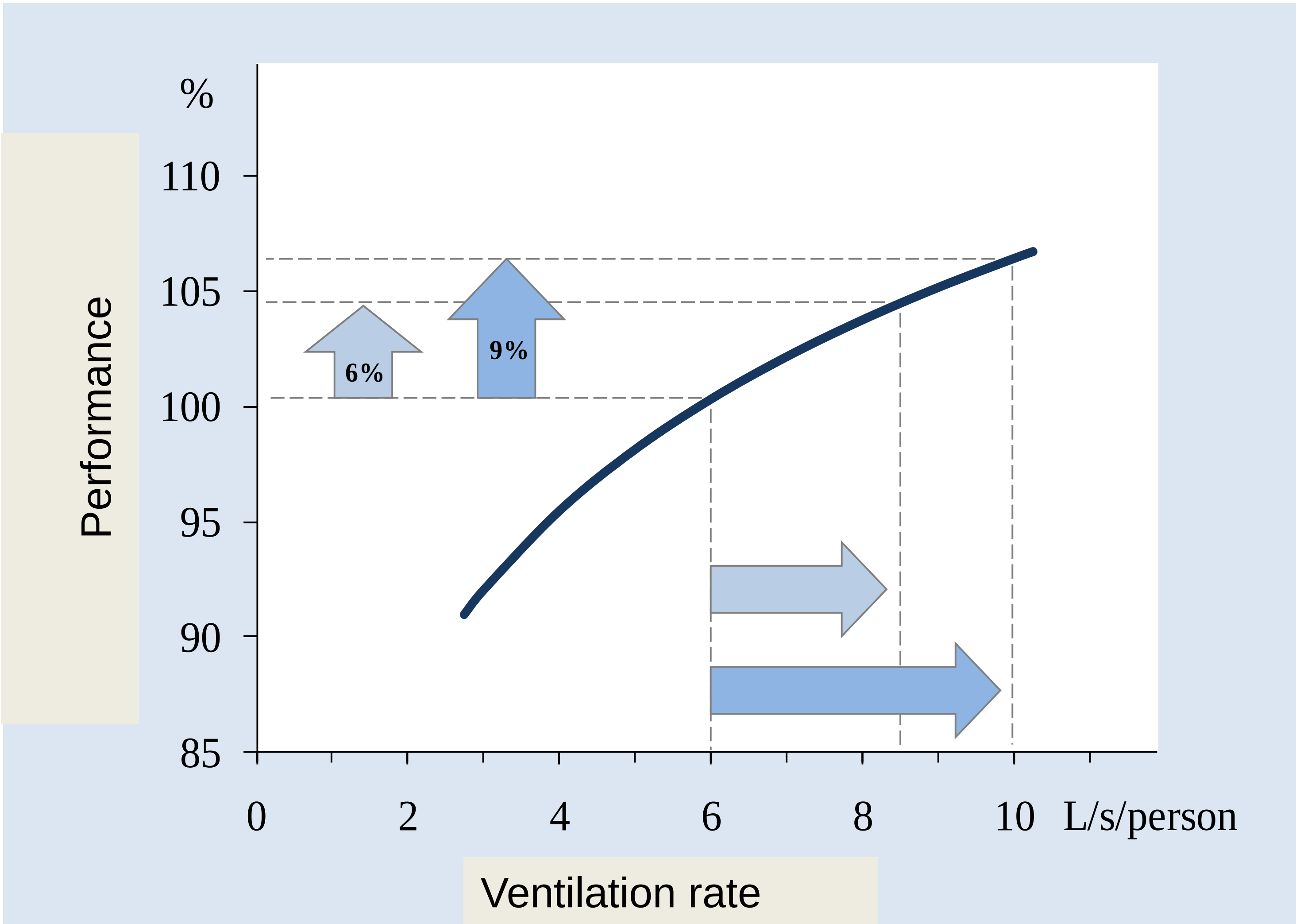
Source: W. Fisk, A Mirer, M. Mendell. 2009. Quantitative relationship of sick building syndrome symptoms with ventilation rates. Indoor Air

Ventilation rates too low? Productivity

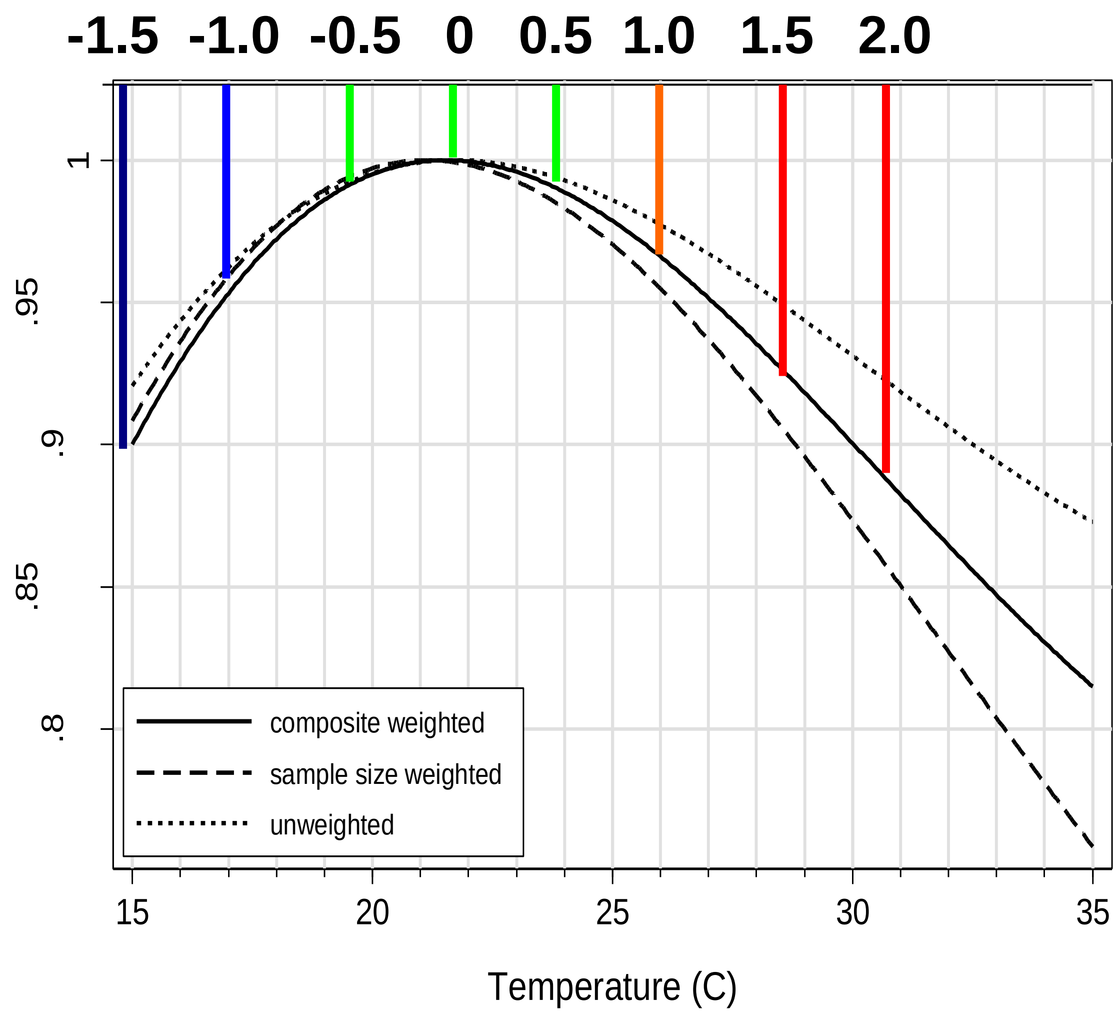


Source: Seppänen, O. and W. Fisk. 2006. Some Quantitative Relations between Indoor Environmental Quality and Work Performance or Health. HVAC&R Research.

Ventilation and performance of school work



PMV-values



from Seppänen and Fisk 2005a

Global impact on people

Achieving Excellence in Indoor Environmental Quality

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

STANDARDS

- ISO EN 7730-2005
  - Ergonomics of the thermal environment – Analytical determination and interpretation of thermal comfort using calculation of the PMV and PPD indices and local thermal comfort effects.
- ASHRAE 55-2013
  - Thermal environment conditions for human occupancy
- ASHRAE 62.1 and 62.2 -2013
  - Ventilation and indoor air quality
- EN15251
  - Indoor environmental input parameters for design and assessment of energy performance of buildings- addressing indoor air quality, thermal environment, lighting and acoustic
- EN 13779
  - Ventilation for non-residential buildings - performance requirements for ventilation and room-conditioning systems

International Standards
Indoor Environmental Quality

- prEN 16789-1 (revision EN15251) and ISO CD 17772
  - Indoor environmental input parameters for the design and assessment of energy performance of buildings.
- DTR 16789-2 and ISO NWI TR 17772:
  - Guideline for using indoor environmental input parameters for the design and assessment of energy performance of buildings.

Categories

Cate-gory	Explanation
I	High level of expectation and also recommended for spaces occupied by very sensitive and fragile persons with special requirements like some disabilities, sick, very young children and elderly persons, to increase accessibility.
II	Normal level of expectation
III	An acceptable, moderate level of expectation
IV	Low level of expectation. This category should only be accepted for a limited part of the year

MODERATE THERMAL ENVIRONMENTS

- GENERAL THERMAL COMFORT
  - PMV / PPD, OPERATIVE TEMPERATURE
- LOCAL THERMAL DISCOMFORT
  - Radiant temperature asymmetry
  - Draught
  - Vertical air temperature difference
  - Floor surface temperature

Recommended categories for design of mechanical heated and cooled buildings

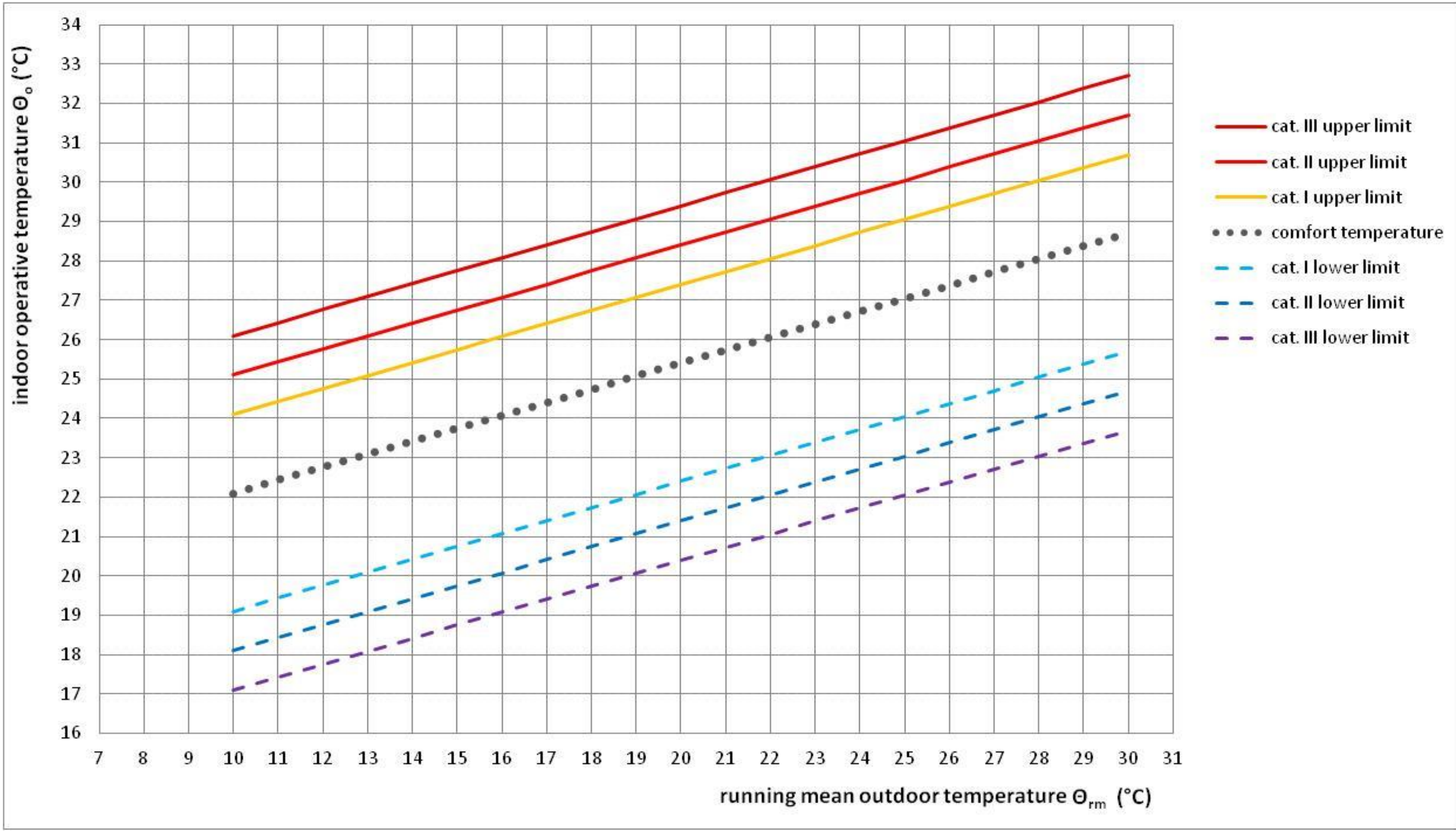
Category	Thermal state of the body as a whole	
	PPD %	Predicted Mean Vote
I	< 6	-0.2 < PMV < + 0.2
II	< 10	-0.5 < PMV < + 0.5
III	< 15	-0.7 < PMV < + 0.7
III	< 25	-1.0 < PMV < + 1.0

Temperature ranges for hourly calculation of cooling and heating energy in three categories of indoor environment

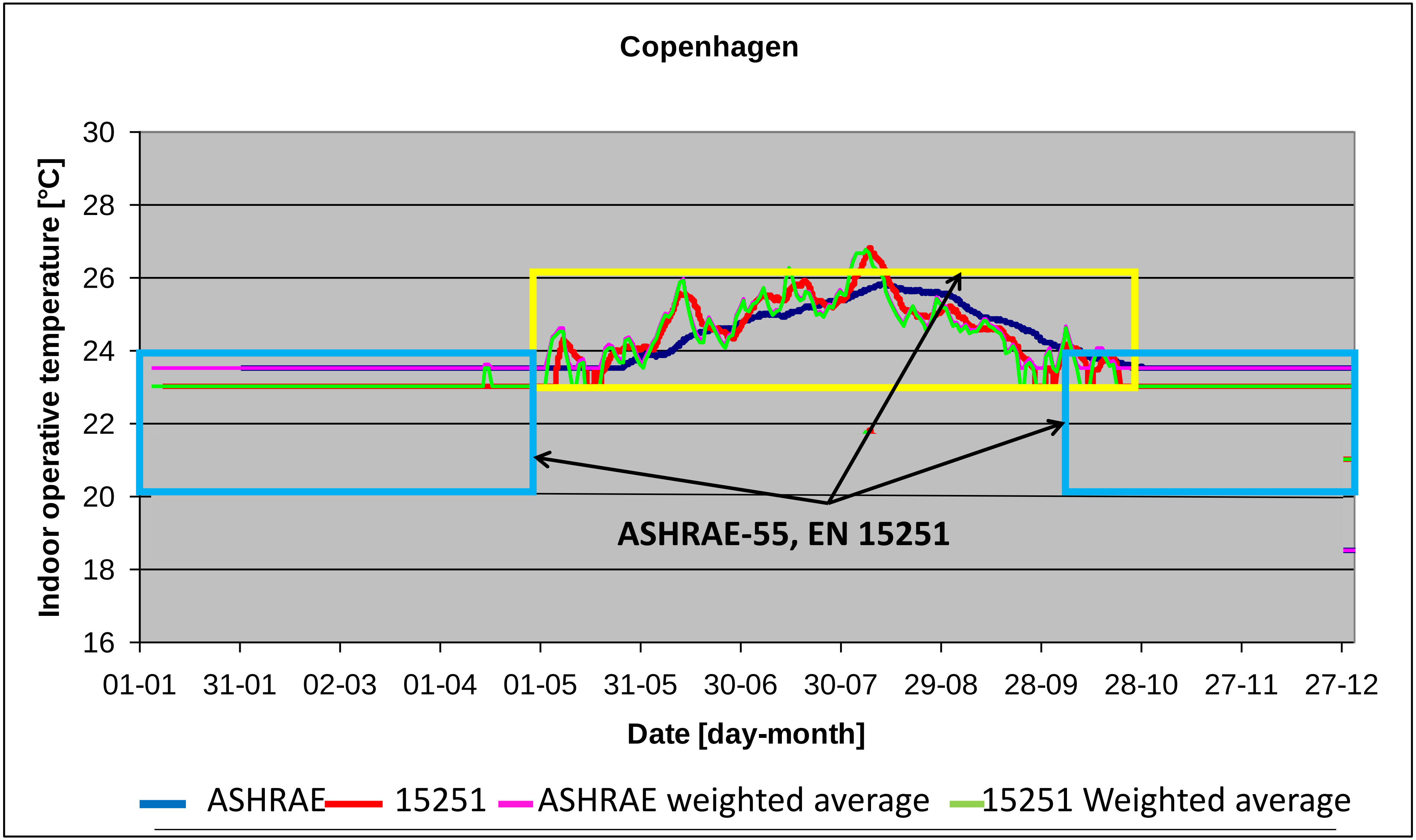
Type of building/ space	**Category**	**Operative Temperature for Energy Calculations** °C	
Offices and spaces with similar activity (single offices, open plan offices, conference rooms, auditorium, cafeteria, restaurants, class rooms, Sedentary activity ~1,2 met		**Heating (winter season), ~ 1,0 clo**	**Cooling (summer season), ~ 0,5 clo**
	I	**21,0 – 23,0**	**23,5 - 25,5**
	II	**20,0 – 24,0**	**23,0 - 26,0**
	III	**19,0 – 25,0**	**22,0 - 27,0**
	IV	**17,0 – 26,0**	**21,0 - 28,0**

ADAPTATION IN NATURAL VENTILATED BUILDINGS ?

- Behavioural
  - Clothing, activity, posture
- Psychological
  - Expectations



$$\Theta_{rm} = (\Theta_{ed\,-1} + 0{,}8\,\Theta_{ed\,-2} + 0{,}6\,\Theta_{ed\,-3} + 0{,}5\,\Theta_{ed\,-4} + 0{,}4\,\Theta_{ed\,-5} + 0{,}3\,\Theta_{ed\,-6} + 0{,}2\,\Theta_{ed\,-7})/3{,}8$$



Copenhagen
Indoor operative temperature [°C]
30
28
26
24
22
20
18
16
01-01
31-01
02-03
01-04
01-05
31-05
30-06
30-07
29-08
28-09
28-10
27-11
27-12
Date [day-month]
ASHRAE-55, EN 15251
ASHRAE
15251
ASHRAE weighted average
15251 Weighted average

Concept for calculation of design ventilation rate

People Component | Building Component

Breathing Zone Outdoor Airflow

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

Minimum l/s/Person

Number of People

Ventilation per Smoker

Number of Smokers

Building Area

Minimum l/s/m²

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

HEALTH CRITERIA FOR VENTILATION

Minimum 4 l/s/person

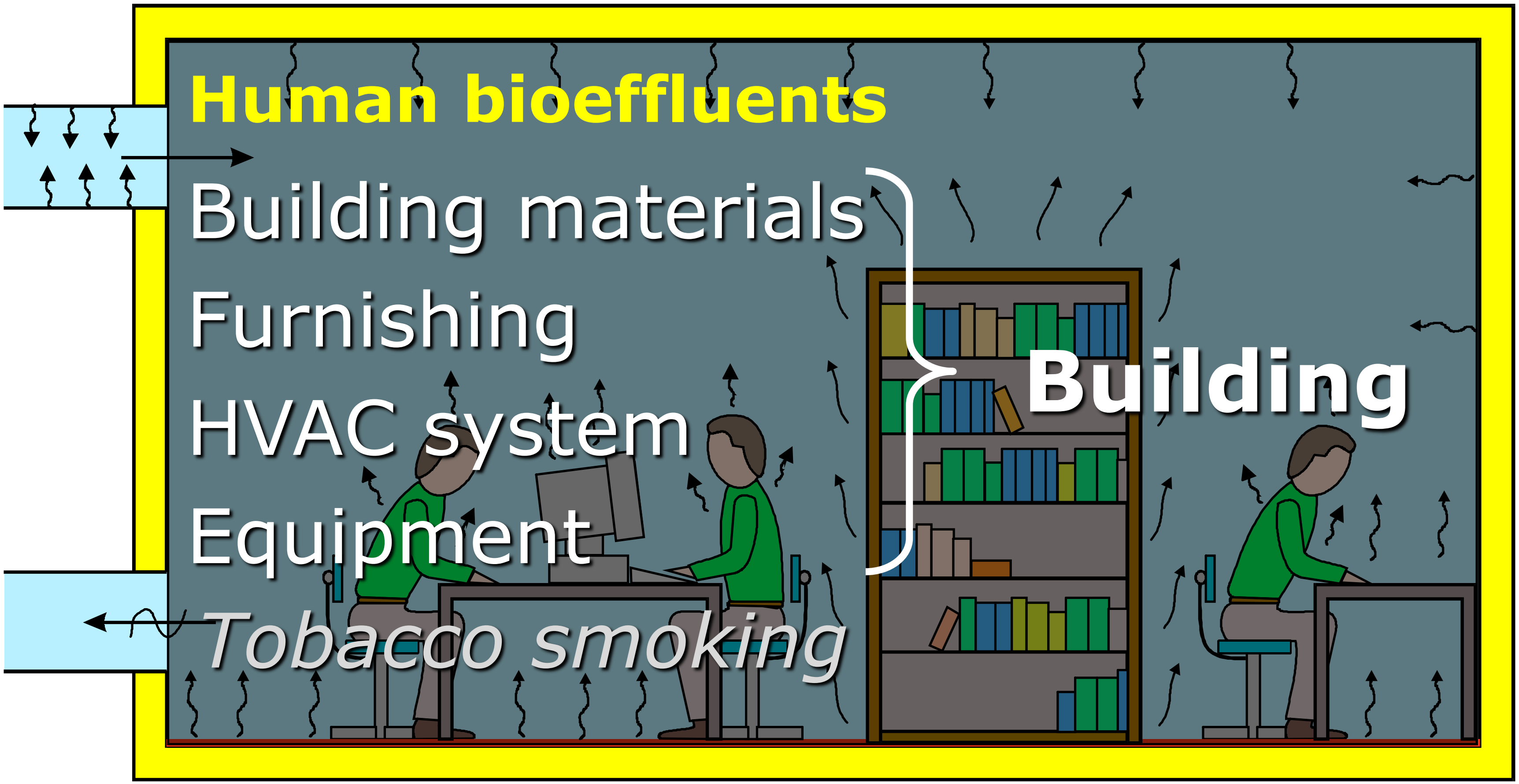
Basic required ventilation rates for diluting emissions (bio effluents) from people for different categories

Category	Expected Percentage Dissatisfied	Airflow per non-adapted person l/(s.pers)
I	15	10
II	20	7
III	30	4
IV	40	2,5*

*The total ventilation rate must never be lower than 4 l/s per person

ASHRAE Standard 62.1 : Adapted persons 2,5 l/s person (Cat. II)

Indoor pollution sources



Design ventilation rates for diluting emissions from buildings

Category	Very low polluting building l/(s m^2)	Low polluting building l/(s m^2)	Non low-polluting building l/(s m^2)
I	0,5	1,0	2,0
II	0,35	0,7	1,4
III	0,2	0,4	0,8
IV	0,15	0,3	0,6
Minimum total ventilation rate for health	4 l/s person	4 l/s person	4 l/s person

Example on how to define low and very low polluting buildings

SOURCE	Low emitting products for low polluted buildings	Very low emitting products for very low polluted buildings
Total VOCs TVOC (as in CEN/TS 16516)	< 1.000 µg/m³	< 300 µg/m³
Formaldehyde	< 100 µg/m³	< 30 µg/m³
Any C1A or C1B classified carcinogenic VOC	< 5 µg/m³	< 5 µg/m³
R value (as in CEN/TS16516)	< 1.0	< 1.0

Example of design ventilation air flow rates for a single-person office of 10 m^2 in a low polluting building (un-adapted person)

Cate-gory	Low-polluting building l/(s*m^2)	Airflow per non-adapted person l/(s*person)	Total design ventilation air flow rate for the room		
			l/s	l/(s*person)	l/(s* m^2)
I	1,0	10	20	20	2
II	0,7	7	14	14	1,4
III	0,4	4	8	8	0,8
IV	0,3	2,5	5,5	5,5	0,55

Specific Pollutans

The ventilation rate required to dilute a pollutant shall be calculated by this equation:

$$Q_h = \frac{G_h}{C_{h,i} - C_{h,o}} \cdot \frac{1}{\varepsilon_v} \qquad \text{Eq (2)}$$

where:

- Q_h is the ventilation rate required for dilution, in litre per second;
- G_h is the pollution load of a pollutant, in micrograms per second;
- $C_{h,i}$ is the guideline value of a pollutant, see Annex B6 , in micrograms per m^3;
- $C_{h,o}$ is the supply concentration of pollutants at the air intake, in micrograms per m^3;
- ε_v is the ventilation effectiveness

NOTE. $C_{h,i}$ and $C_{h,o}$ may also be expressed as ppm (vol/vol). In this case the pollution load G_h has to be expressed as l/s.

WHO guidelines values for indoor and outdoor air pollutants

Pollutant	WHO Indoor Air Quality guidelines 2010	WHO Air Quality guidelines 2005
Benzene	No safe level can be determined	-
Carbon monoxide	15 min. mean: 100 mg/m^3 1h mean: 35 mg/m^3 8h mean: 10 mg/m^3 24h mean: 7 mg/m^3	-
Formaldehyde	30 min. mean: 100 $\mu g/m^3$	-
Naphthalene	Annual mean: 10 $\mu g/m^3$	-
Nitrogen dioxide	1h mean: 200 $\mu g/m^3$ Annual mean: 40 mg/m^3	-
Polyaromatic Hydrocarbons (e.g. Benzo Pyrene A B[a]P)	No safe level can be determined	-
Radon	100 Bq/m^3 (sometimes 300 mg/m^3, country-specific)	-
Trichlorethylene	No safe level can be determined	-
Tetrachloroethylene	Annual mean: 250 $\mu g/m^3$	
Sulfure dioxide	-	10 min. mean: 500 $\mu g/m^3$ 24h mean: 20 mg/m^3
Ozone	-	8h mean:100 $\mu g/m^3$
Particulate Matter PM 2,5	-	24h mean: 25 $\mu g/m^3$ Annual mean: 10 $\mu g/m^3$
Particulate Matter PM 10	-	24h mean: 50 $\mu g/m^3$ Annual mean: 20 $\mu g/m^3$

Energy Efficient Technologies

- **Indoor air quality**
  - **Reduce loads (pollution sources)**
  - **Heat recovery**
  - **Increase system efficiency**
  - **Natural ventilation-Hybrid ventilation**
  - **Air distribution (contaminant removal) effectiveness**
    - **Personal ventilation**
  - **Air cleaning**

- Thermal comfort
  - Reduce loads (building shell, solar screen, internal loads)
  - Increase system efficiency
  - Low Temperatur Heating- and High Temperature Cooling Systems
  - Use of building mass to reduce peaks (Thermo-Active-Building-Systems (TABS))
  - Drifting indoor temperatures

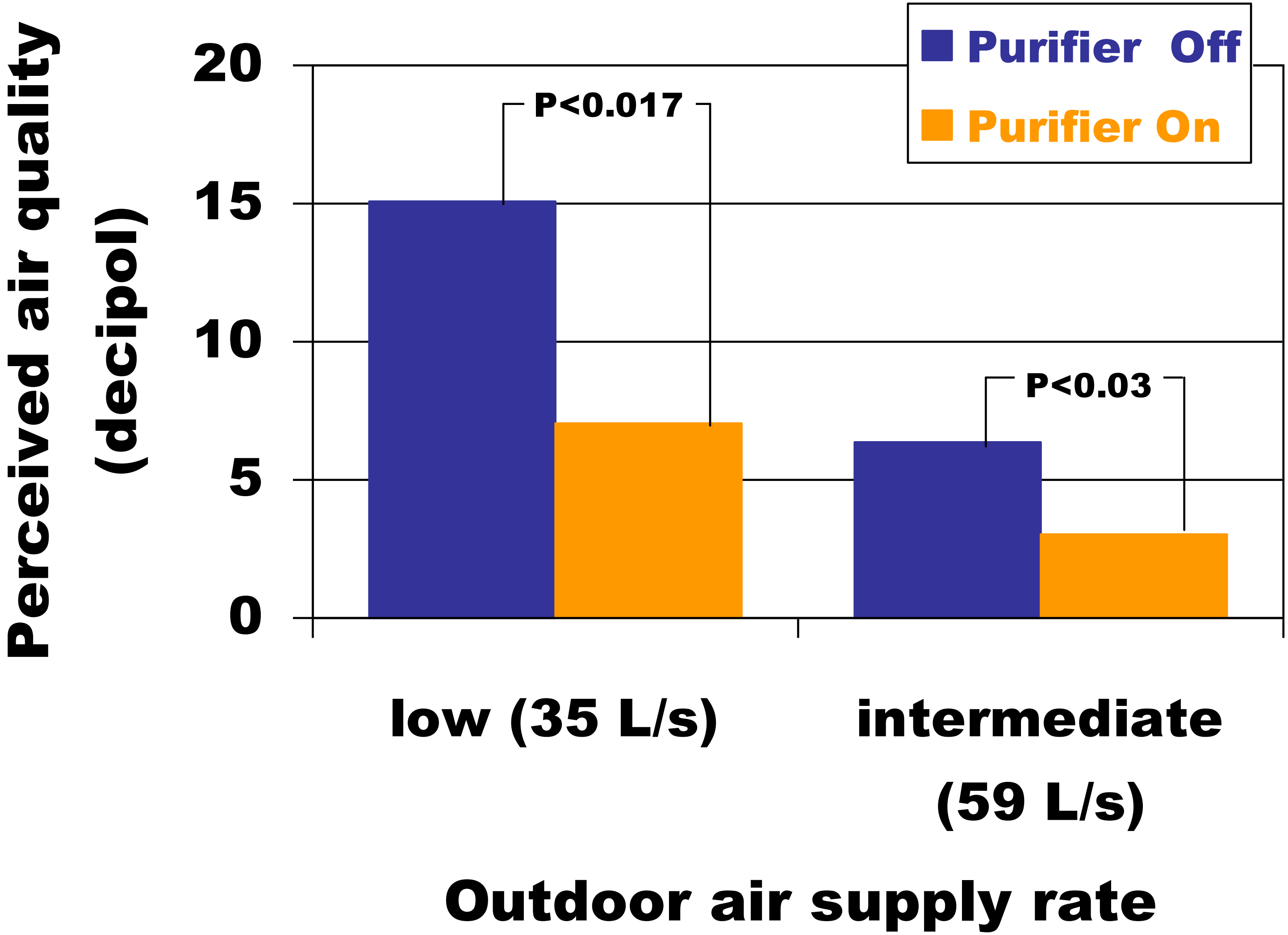
Trends regarding ventilation

- **Increasing use of air cleaning**
  - **Filtration**
  - **Gas phase air cleaning**
- Personalized systems for better comfort and energy savings
- Demand control ventilation
  - Occupant precense
  - CO_2 sensors
  - Artificial nose

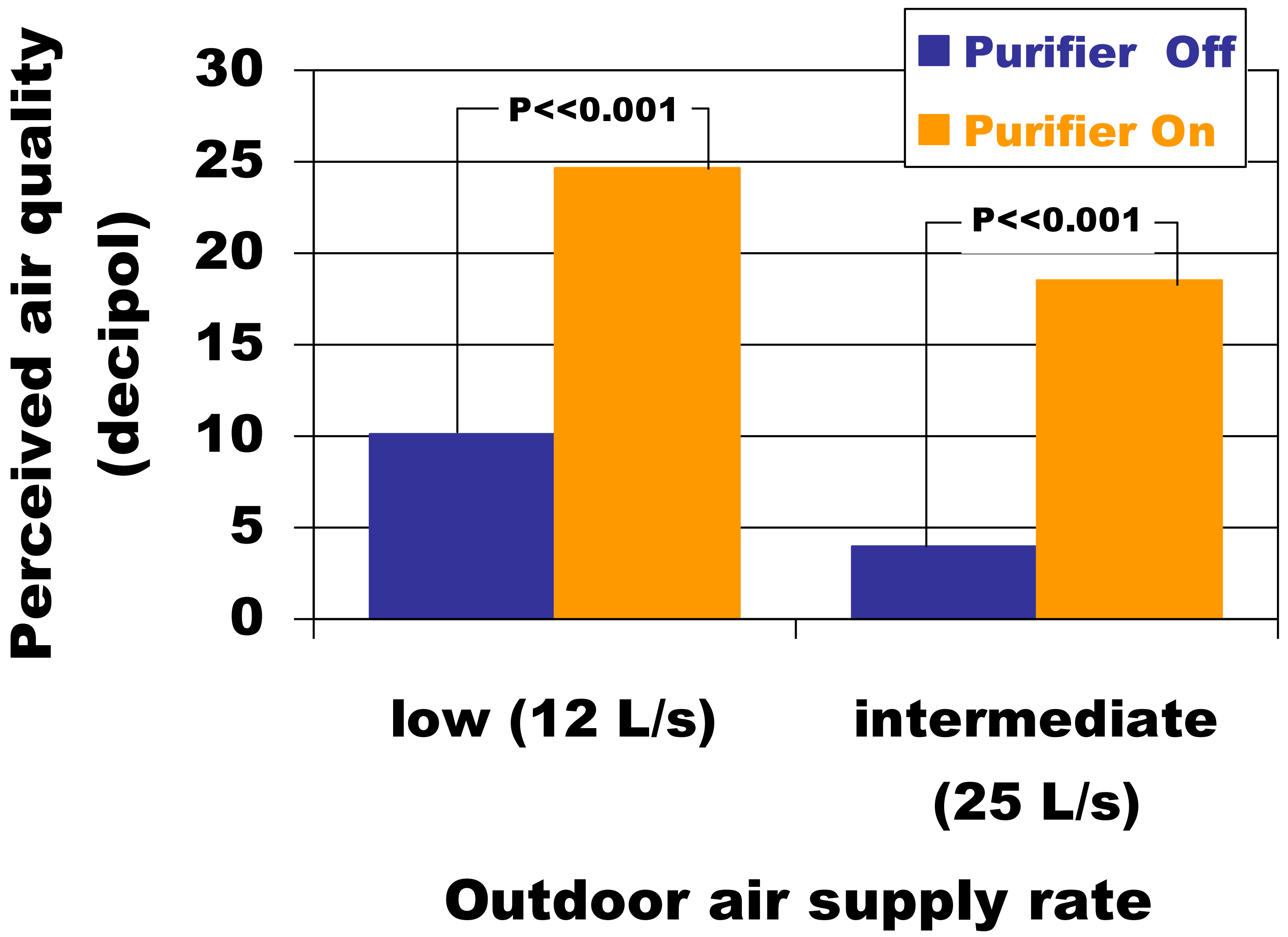
Gas phase air purification technologies

- Photo-catalytic oxidation (PCO)
- Ozone oxidation
- Thermal catalytic oxidation (TCO)
- Plasma oxidation
- Botanic filtration
- Sorption filtration

Results: Bldg mat, PCs, filters

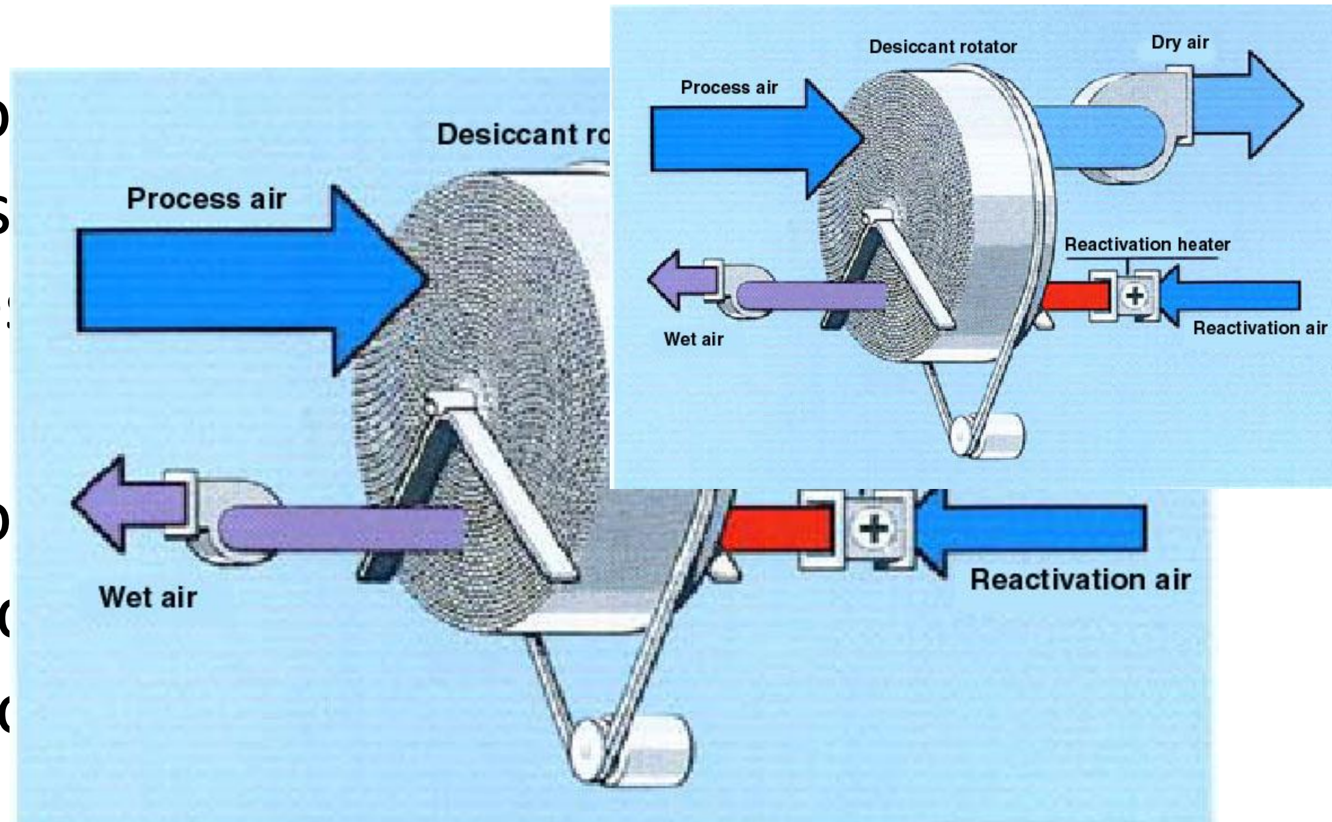


Results: Human bio effluents

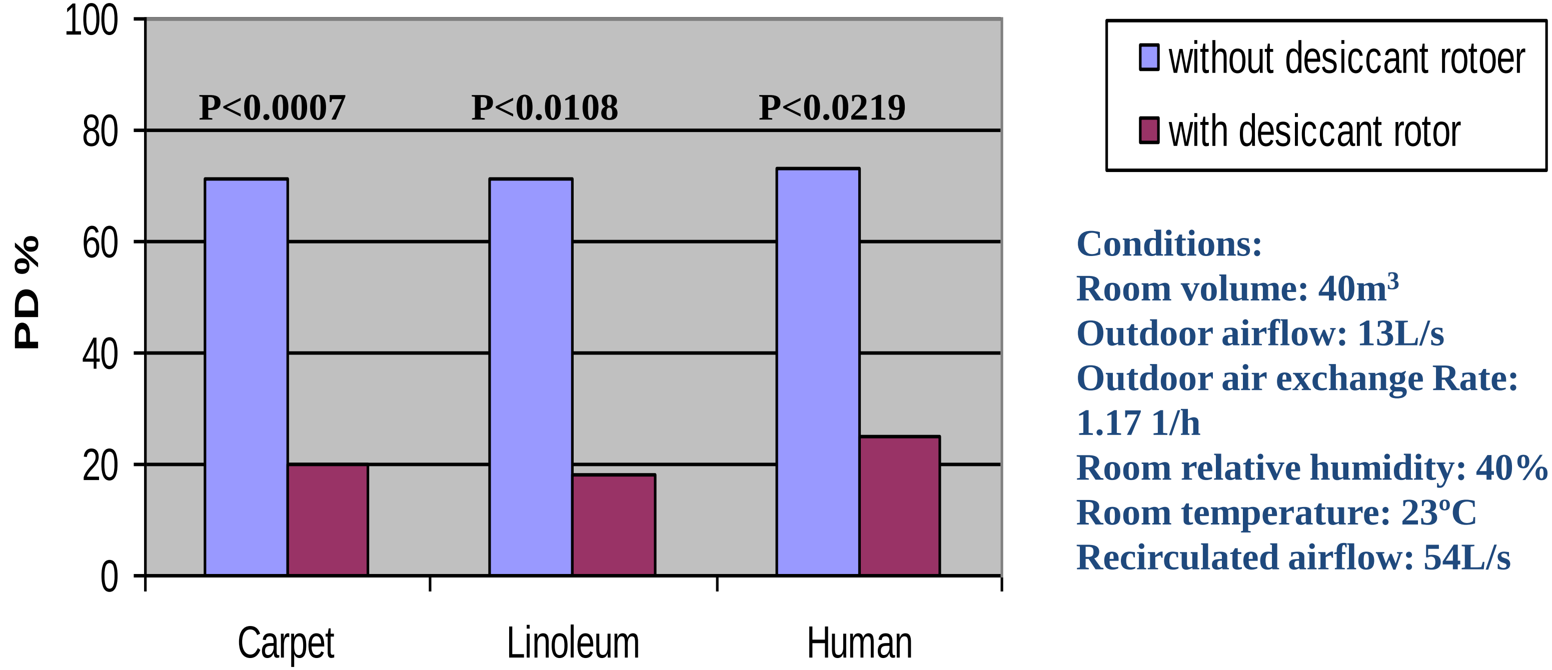


How can a desiccant rotor remove pollutants?

- Adsorptio chemicals the proce the rotor
- Desorptio from the reactivati the rotor

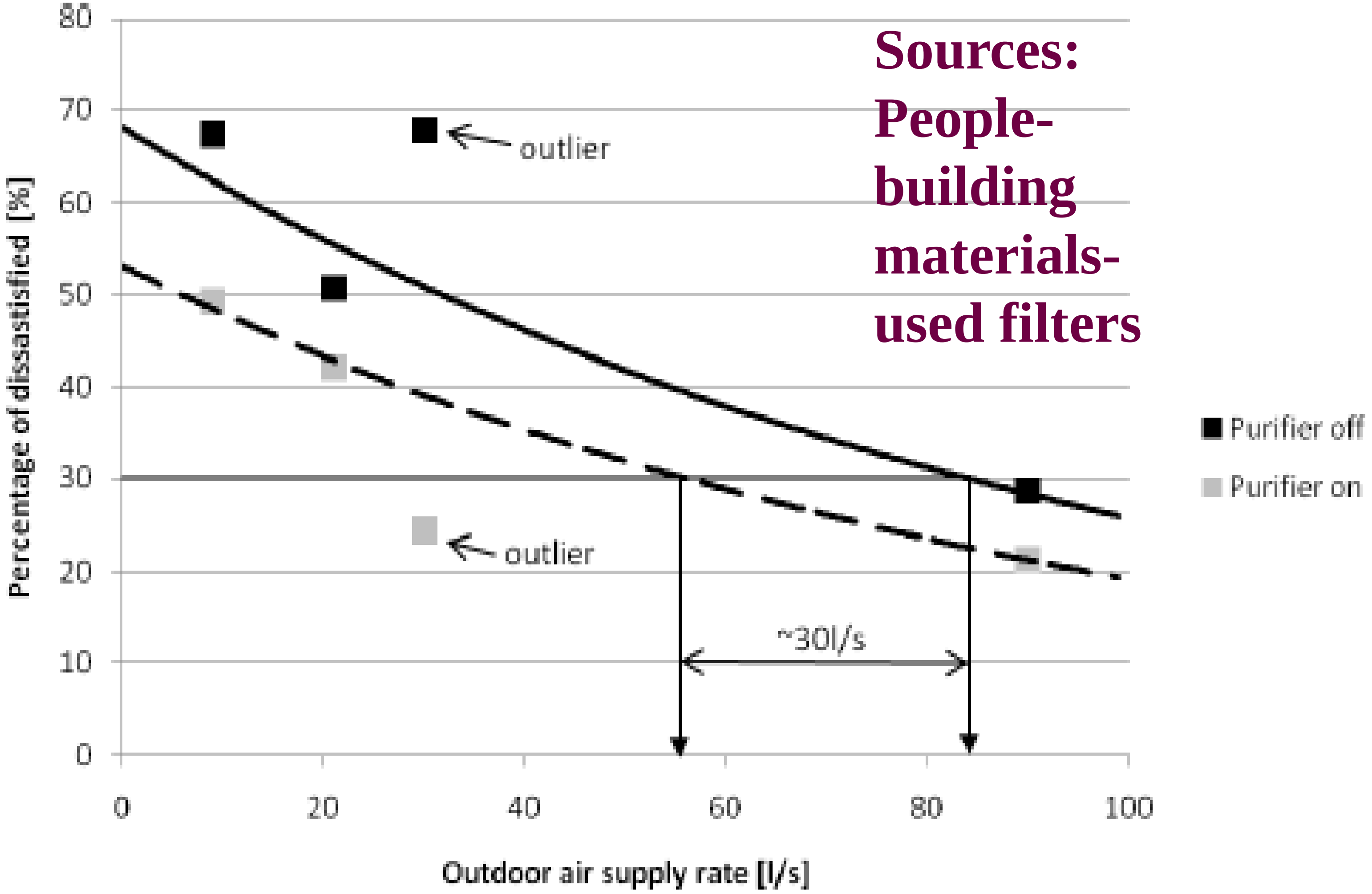


PAQ in PD% with and without desiccant rotor



Conditions:
Room volume: 40m^3
Outdoor airflow: 13L/s
Outdoor air exchange Rate: 1.17 1/h
Room relative humidity: 40%
Room temperature: 23°C
Recirculated airflow: 54L/s

Effect of air cleaning on perceived Air Quality



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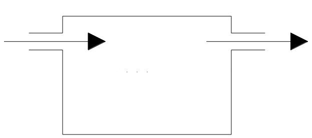
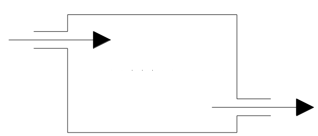
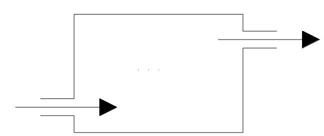
Air Distribution Effectiveness

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

Concentrations:

- C_E **exhaust air**
- C_S **supply air**
- C_I **breathing zone**

CEN Report CR 1752 (1998)

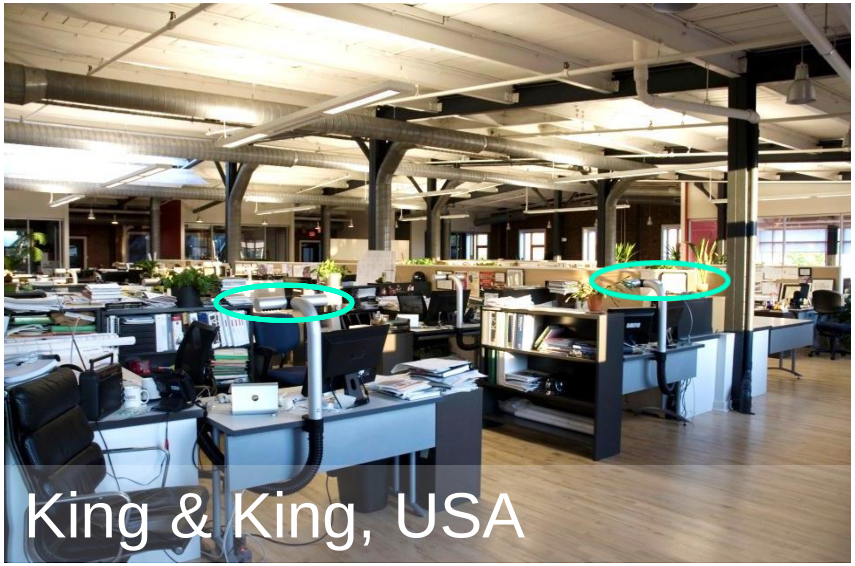
Mixing ventilation		Mixing ventilation		Displacement ventilation		Personalized ventilation	
							
T supply - T inhal °C	Vent. effect. -	T supply - T inhal °C	Vent. effect. -	T supply - T inhal °C	Vent. effect. -	T supply - T room °C	Vent. effect. -
< 0	0,9 - 1,0	< -5	0,9	<0	1,2 - 1,4	-6	1,2 - 2,2
0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

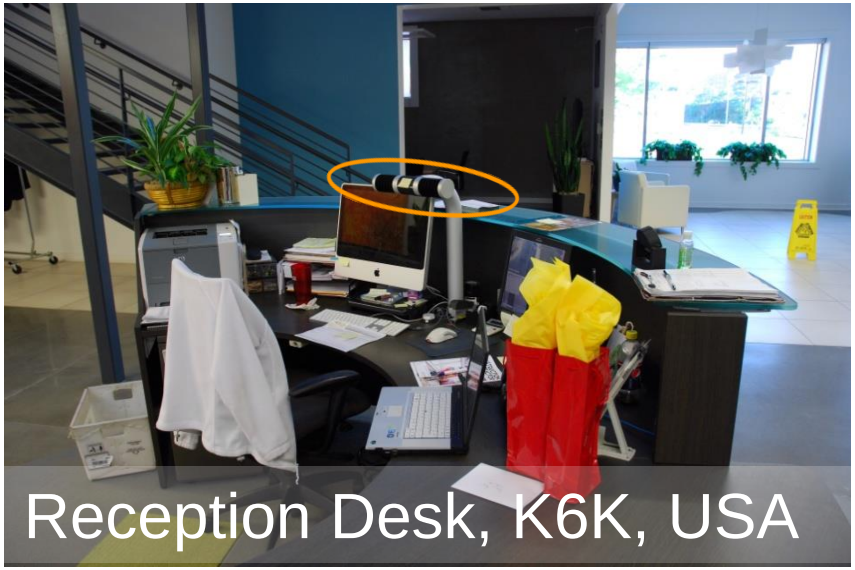
Personalized systems

- Can "standard" criteria be directly applied also to a personal system, where the occupants try to meet their own preferences?
- If the occupants have a personalized system is it then possible to relax on the requirements to the general environment?
- Increased satisfaction

Personalized Ventilation

Personalized Ventilation in Offices





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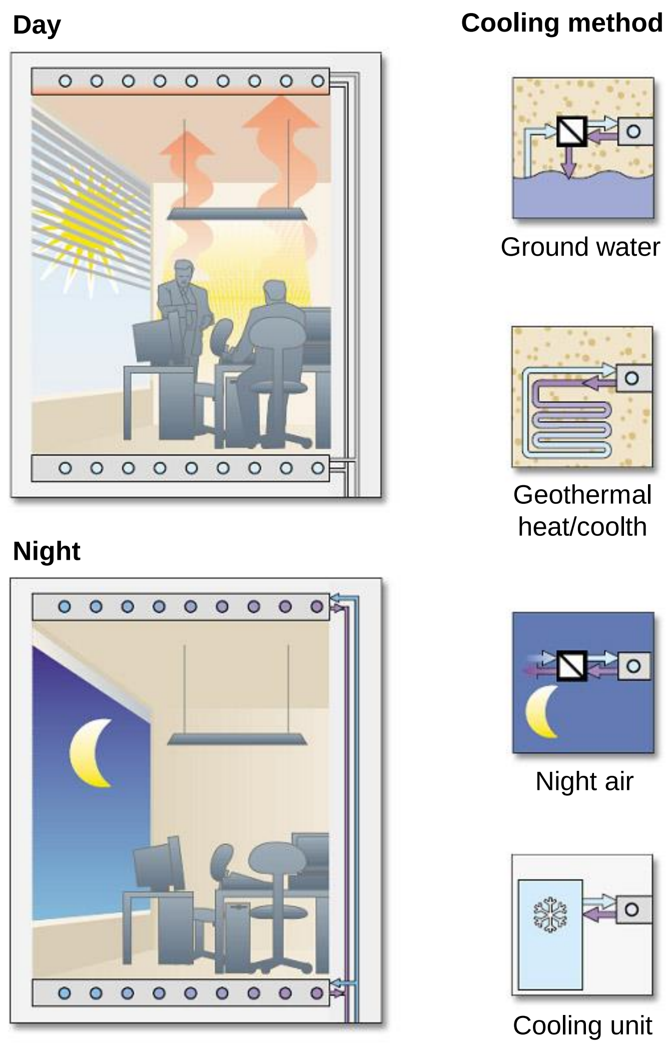
  - **Use of building mass to reduce peaks (Thermo-Active-Building-Systems (TABS))**
  - **Drifting indoor temperatures**

Low-Temperature heating
High-Temperature Cooling

- Heat exchange through large surfaces (floor, ceiling, walls)
- Supply water temperatures:
  - Heating: 25 – 40 °C
  - Cooling: 16 – 23 °C (temperature limited by dew-point to avoid condensation)
- Wide range of systems, solutions both for residential and non-residential buildings

COMBINATION WITH LOW ENERGY SOURCES

- Heating supply temp. : 25 - 40°C
  - heat pumps
  - condensing boiler
  - ground coupling
  - waste heat
  - solar energy
- Cooling supply temp. : 16 - 23°C
  - reversible heat pump
  - ground coupling
  - free cooling
  - air cooled chillers



UPONOR Corporation (2010)

Cooling panels

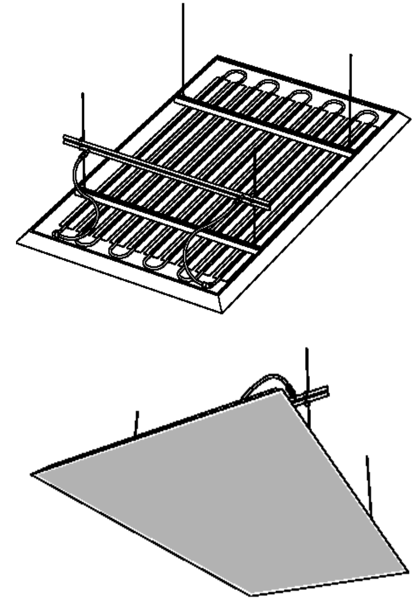
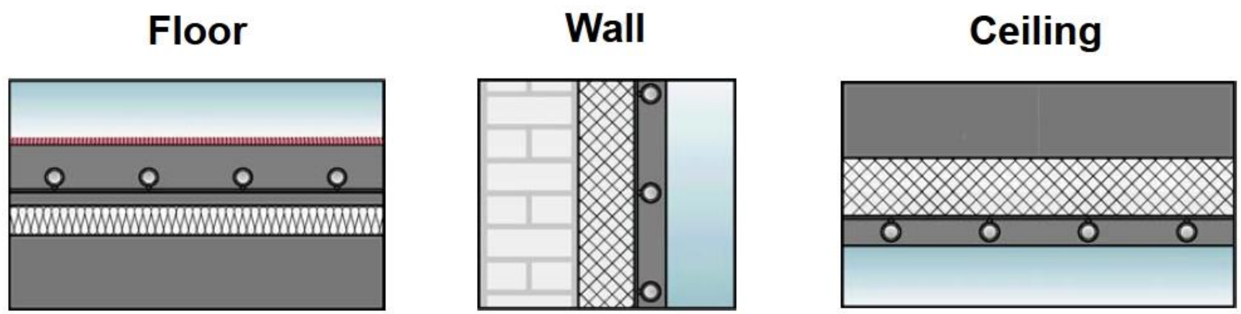
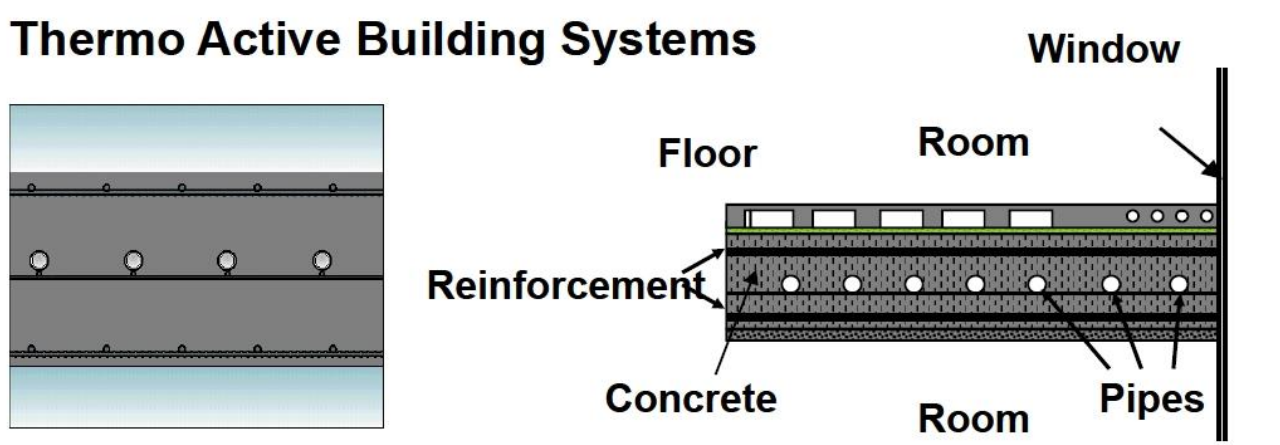


Bild 22 Metallsegel, Kühltechnik

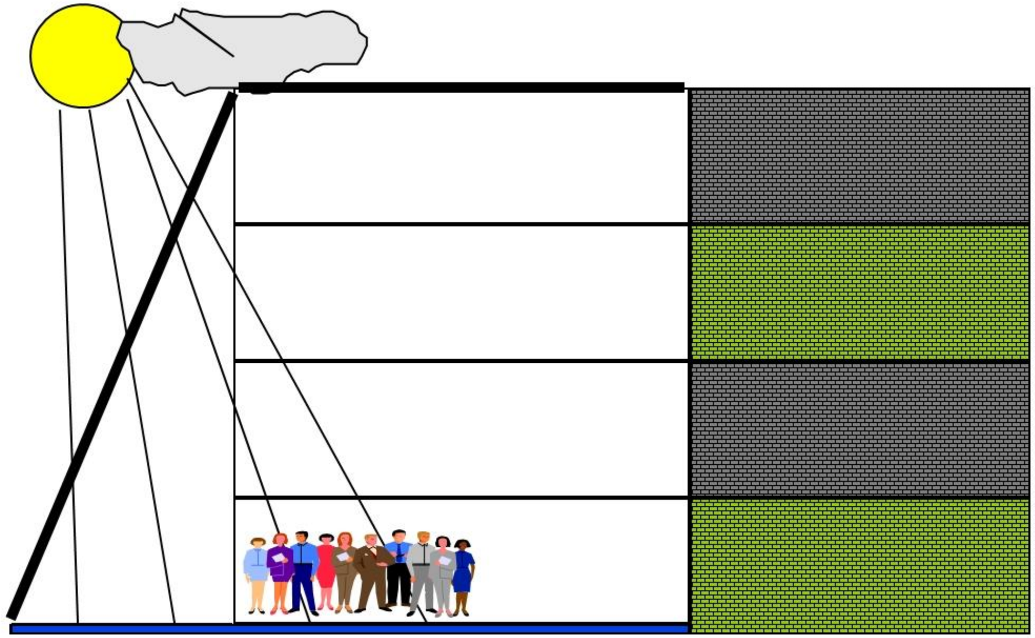
System types

- Water as the heat carrier
- Heat exchange is > 50% radiant
- Different installation concepts
  (thermally coupled or insulated form the building structure)





Additional benefits – large atriums and foyers



- The under-floor cooling system directly removes solar heat gains
- Minimum of such gains influences air temperature
- Comfortable floor surface temperature is maintained at the same time

Large atriums and foyers - examples

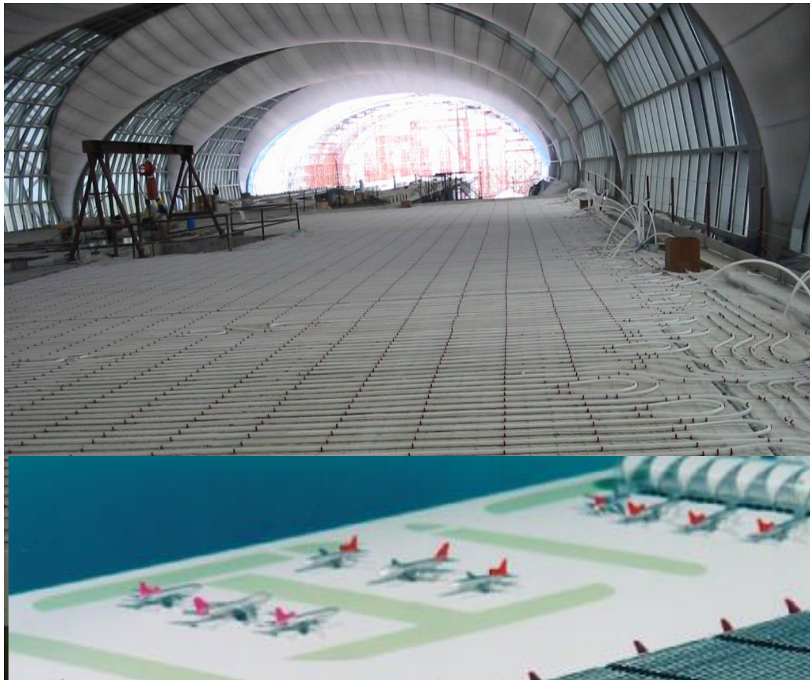
Copenhagen Opera House

Bangkok Airport

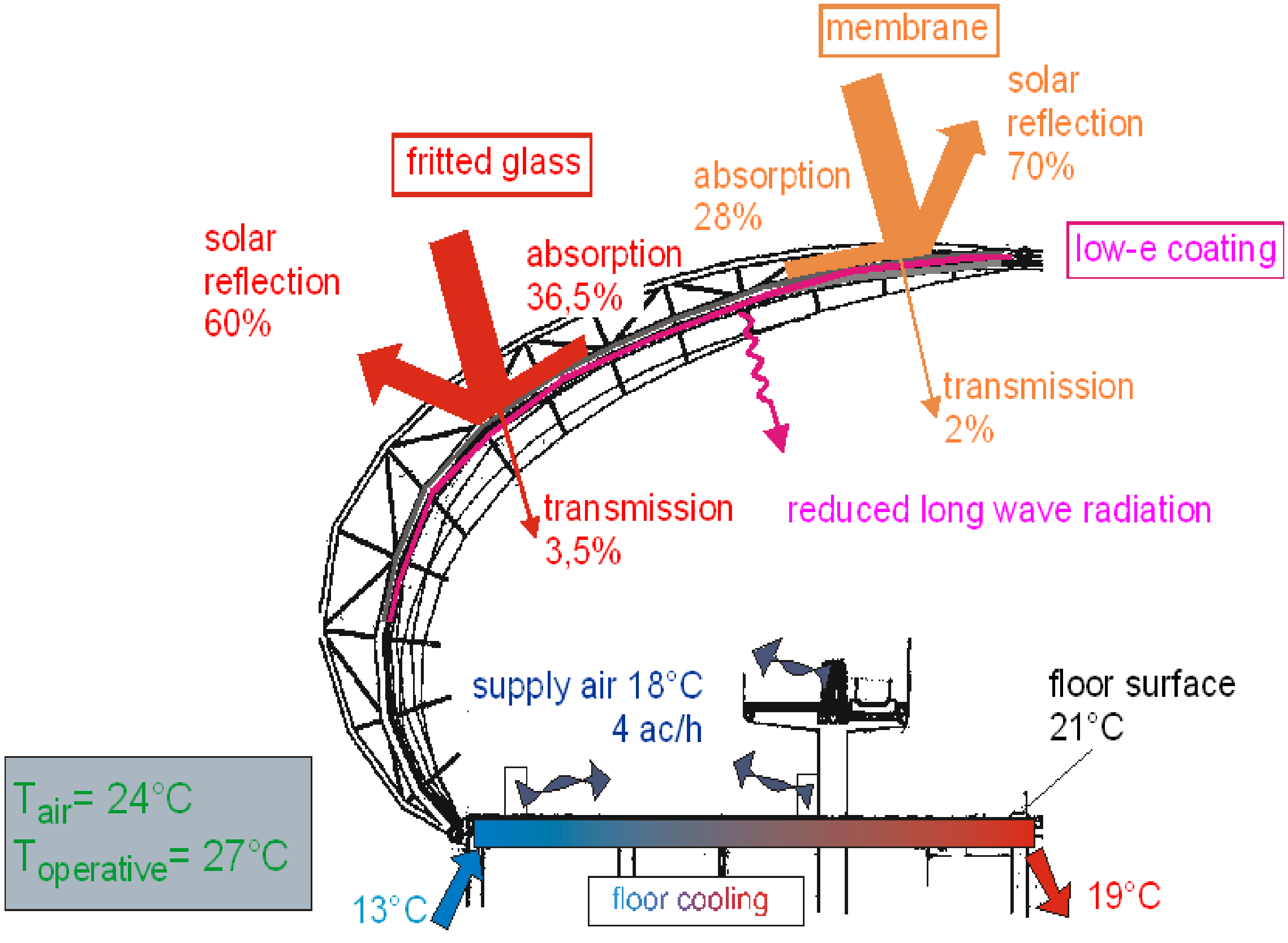
Opera House in Copenhagen: Cooling

- 2,5 MW cooling capacity
- 2 systems – 10/15°C and 15/18 °C
- Free cooling from sea water
- Combined radiant floor heating + radiant floor cooling
- 18 km underfloor cooling tubing
- Quiet cooling walls
- De-humidification condensing coils for ventilation

Airport Bangkok



Airport Bangkok

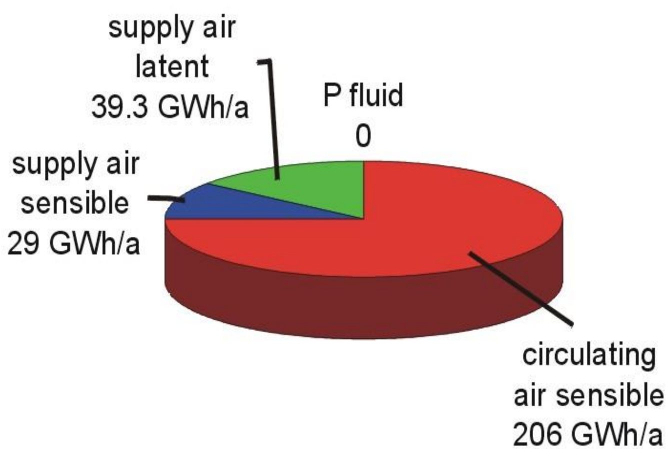


Airport Bangkok

NEW BANGKOK INTERNATIONAL AIRPORT

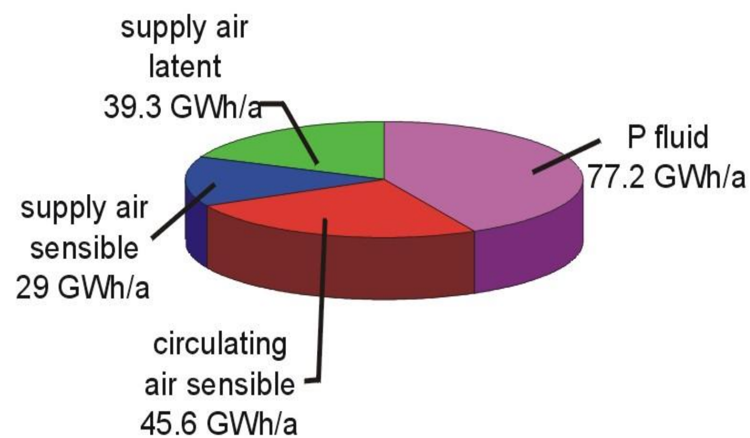
Comparison of Cooling loads entire Airport

Original Concept



total load: 275 GWh/a
739 kWh/m²a

Optimized Concept

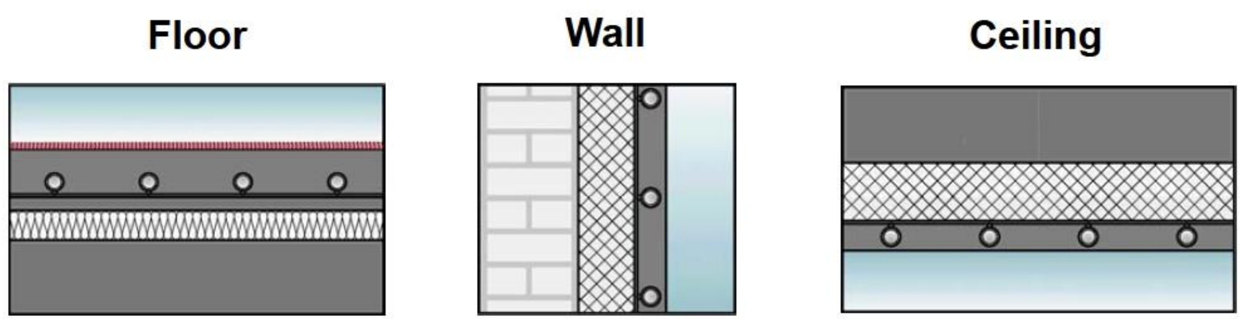


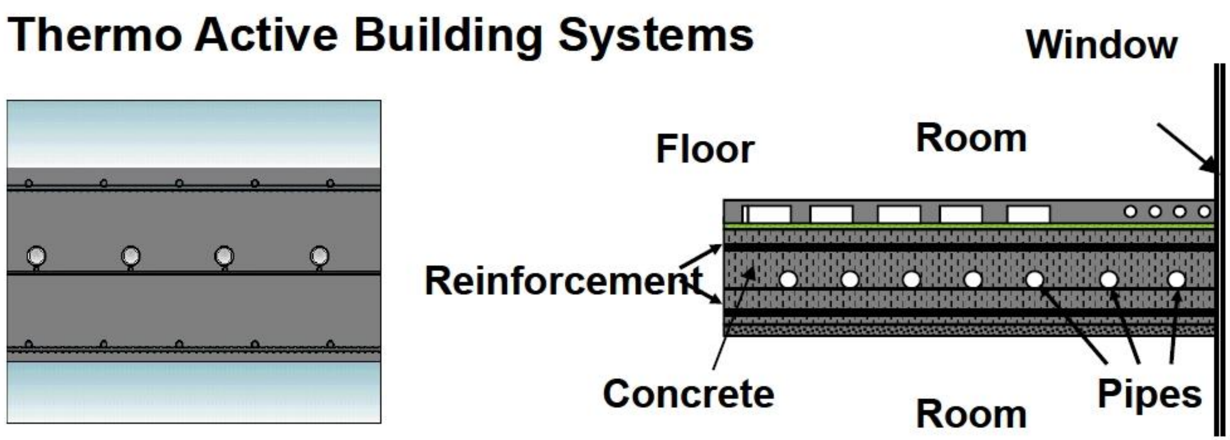
total load: 191 GWh/a
513 kWh/m²a

pic. I D 15

System types

- Water as the heat carrier
- Heat exchange is > 50% radiant
- Different installation concepts
  (thermally coupled or insulated form the building structure)





Concept of Thermo Active Building Systems

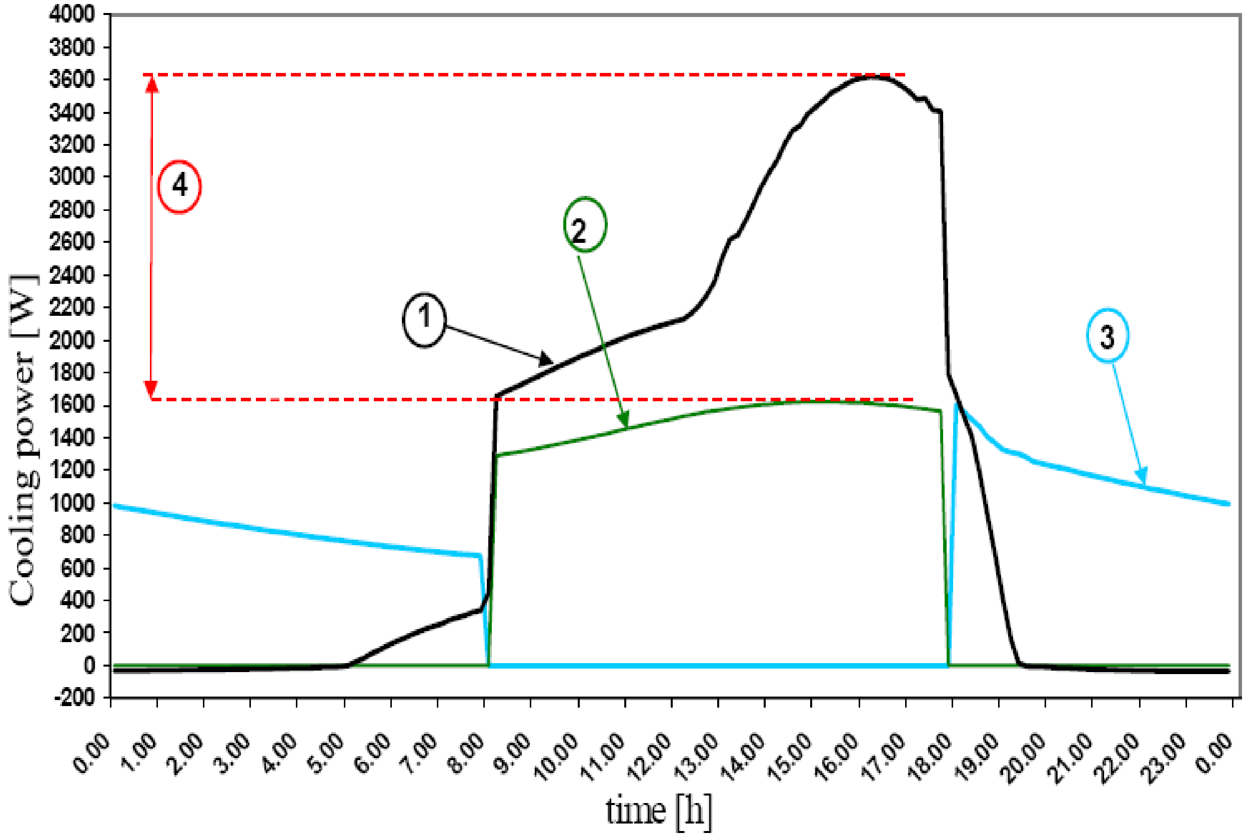
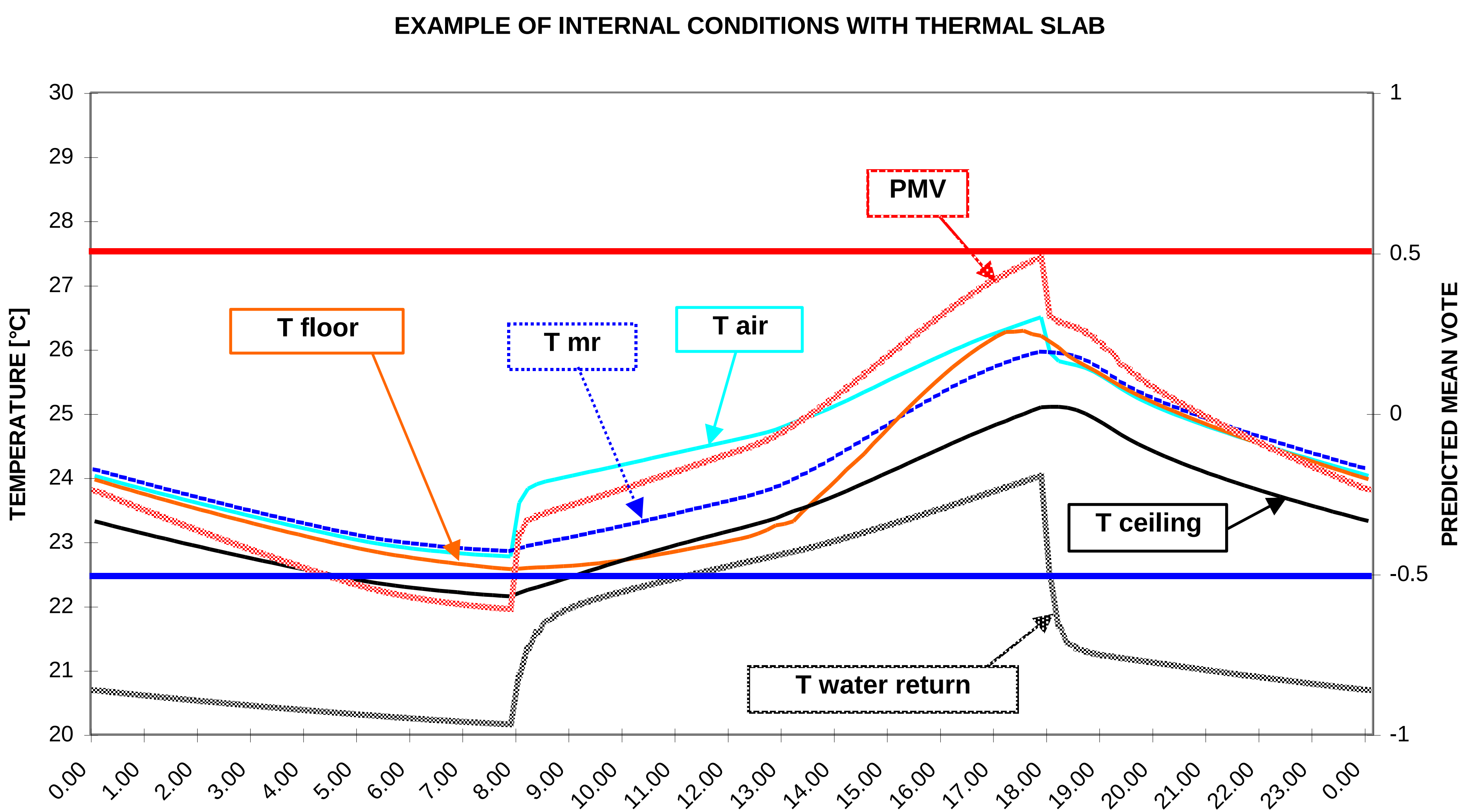


Figure 2 – Example of peak-shaving (reducing the peak load) effect (time vs. cooling power [W],)

Where: 1) heat gain, 2) Power needed for conditioning the ventilation air, 3) Power needed on the water side, 4) Peak heat gain reduction.

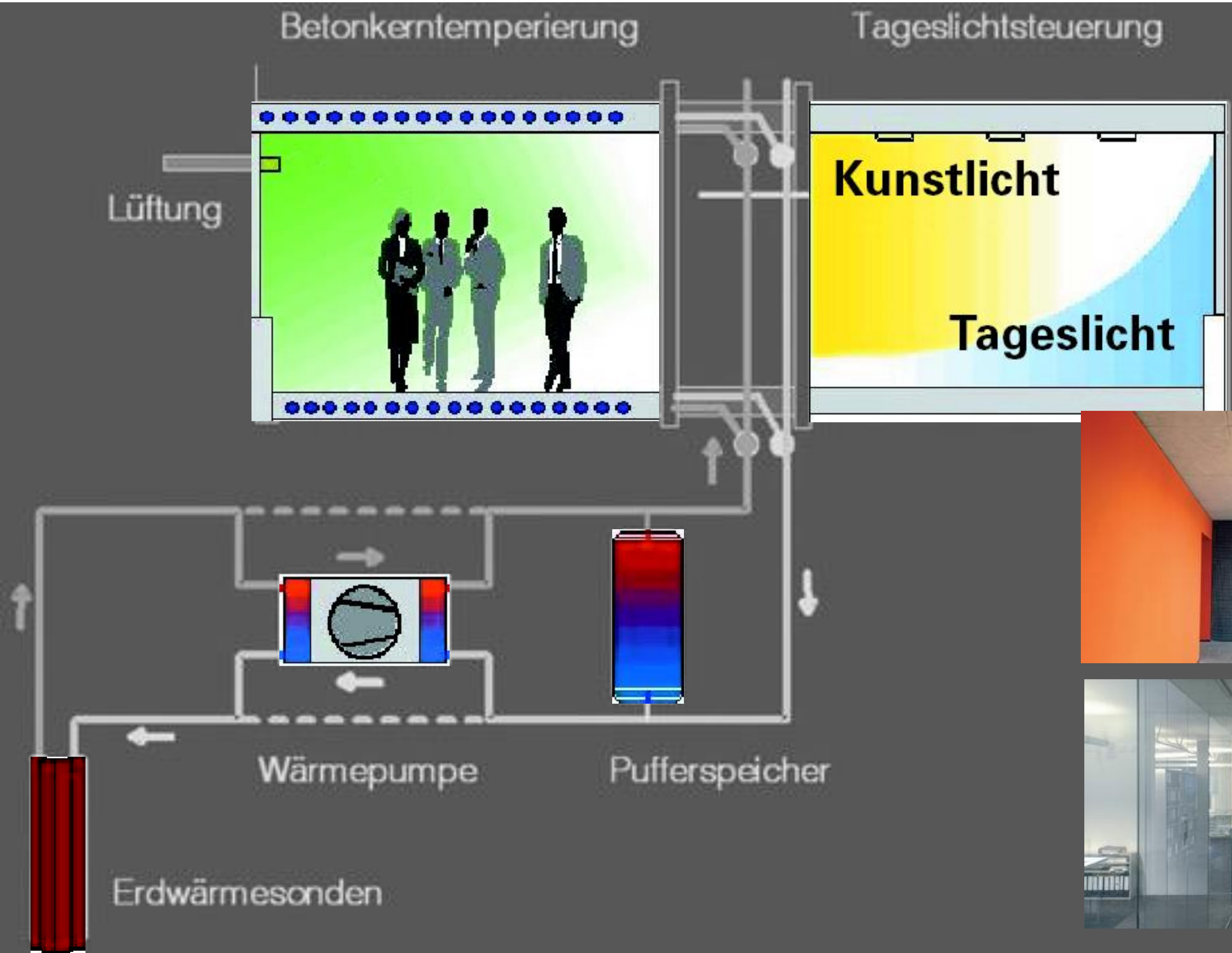
Concept of
Thermo Active Building Systems (TABS)



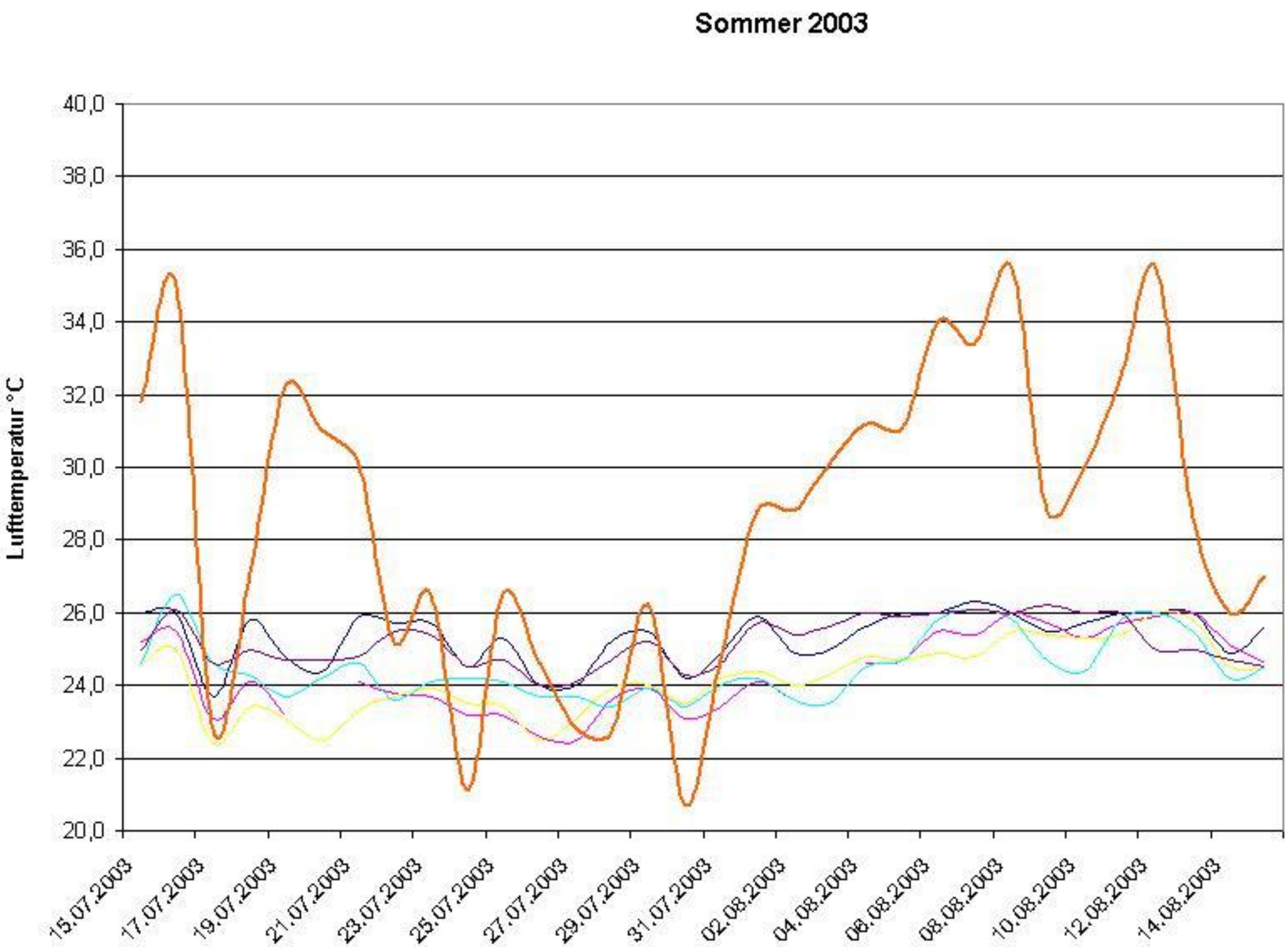
Balanced Office Building (BOB.1)
Aachen, Germany

- Gross floor area 2,151 m²
- 4 storeys
- Efficiently insulated external envelope
- Ground-coupled heating and cooling with TABS
- Ventilation system with heat recovery
- Daylight-controlled lighting
- Rainwater collection for use in toilet flushing

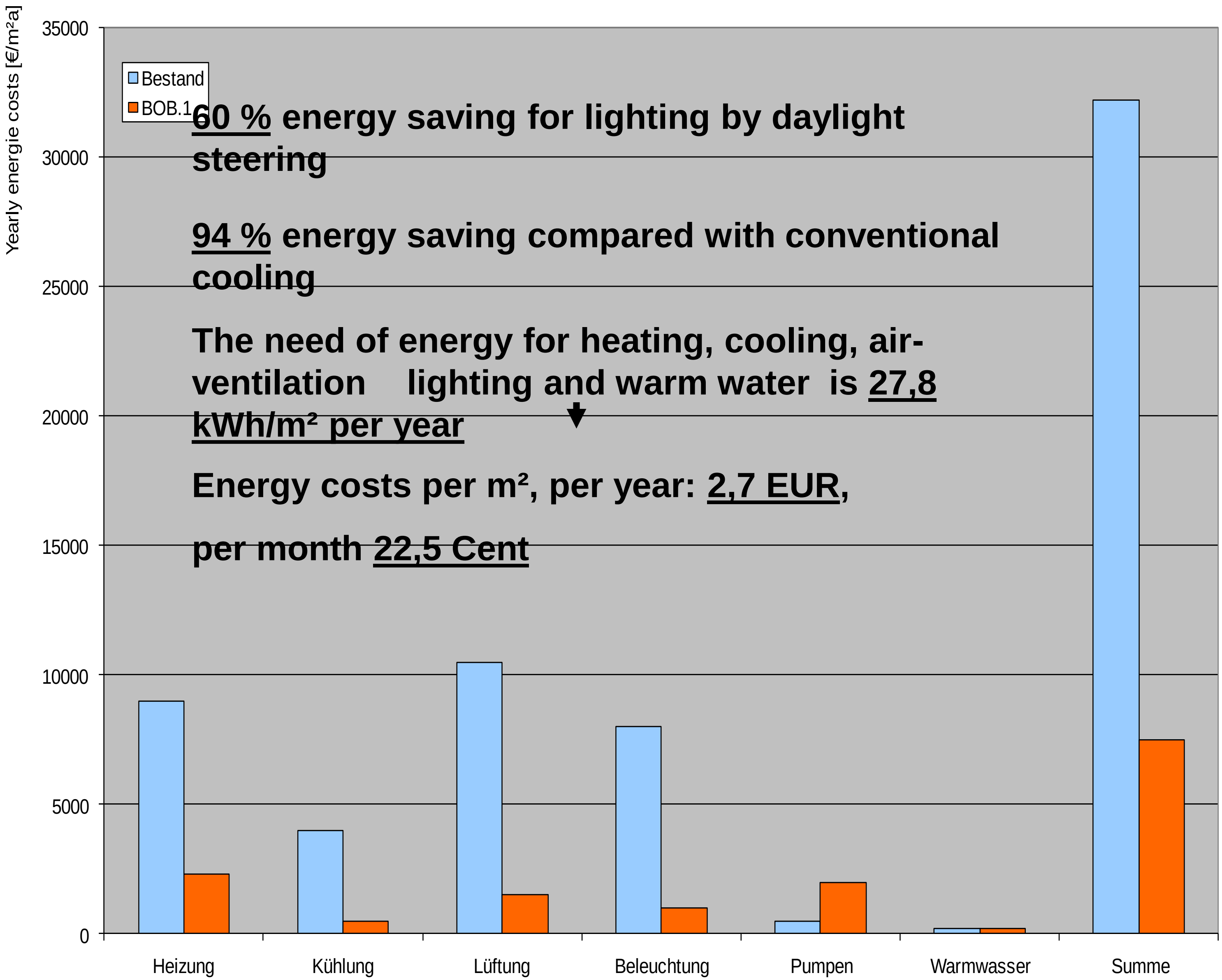
Energy concept in BOB.1



cooling period in BOB.1



Energy efficiency of BOB.1



<u>60 %</u> energy saving for lighting by daylight steering

<u>94 %</u> energy saving compared with conventional cooling

The need of energy for heating, cooling, air-ventilation lighting and warm water is <u>27,8 kWh/m² per year</u>

Energy costs per m², per year: <u>2,7 EUR</u>,

per month <u>22,5 Cent</u>

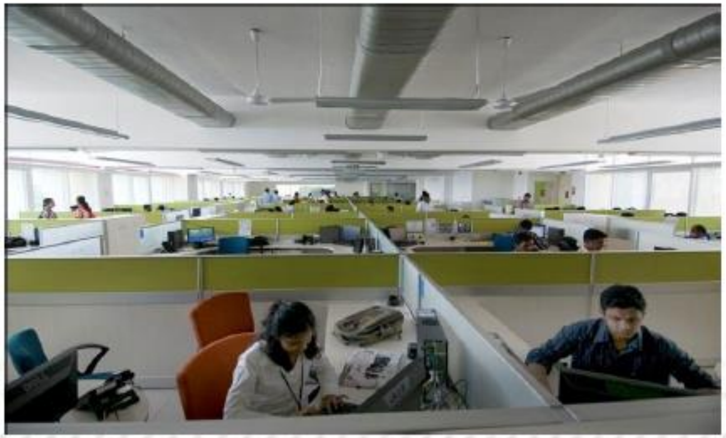
THE WORLD'S LARGEST SIDE BY SIDE COMPARISON OF VAV AND RADIANT COOLING

Figure 1 - Infosys SDB-1 Hyderabad - 125,000 sf of radiant cooling and 125,000 sf of VAV cooling

Sun shading and daylight penetration

RADIANT

VAV



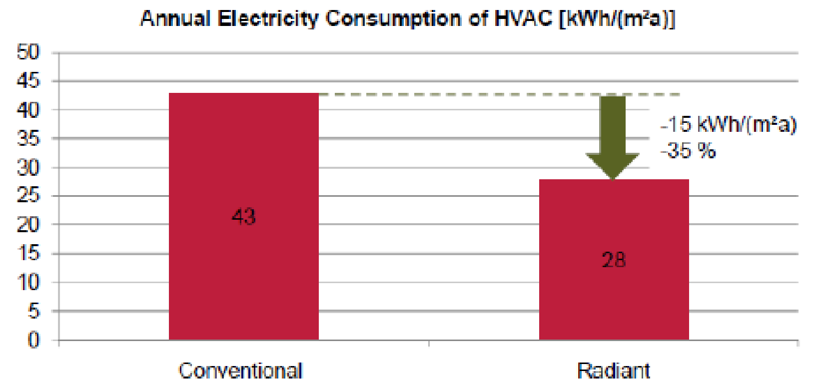
Infosys 18 Tomorrow's Enterprise

Energy

Radiant Cooling – Third Party Evaluation

Evaluation Infosys – Hyderabad, India
2. Analysis of Energy Consumption

SDB1: HVAC



Evaluation Conventional: **HVAC consumption 15 kWh/(m²a) respectively 50 % higher** compared to Radiant.

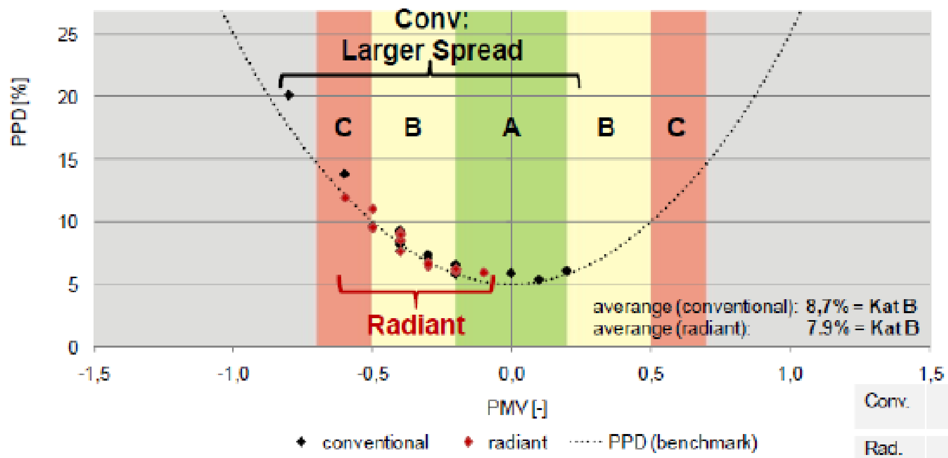
Technische Universität Braunschweig

www.igs.bau.tu-bs.de IGS

Thermal Comfort

Radiant Cooling – Third Party Evaluation

Evaluation Infosys – Hyderabad, India
3. Analysis of Thermal Comfort - PMV



Conv.	- 0,5 [-]
Rad.	- 0,9 [-]

Evaluation
Conventional: Good thermal comfort, but **larger spread of comfort situation**
Radiant: Good thermal comfort,
perceived slightly colder than Conventional = better PPD (7,8 %)

Technische Universität Braunschweig
July 20, 2011 | Univ. Prof. Dr.-Ing. M. Norbert Fisch | IGS - Präsentation | Seite 15
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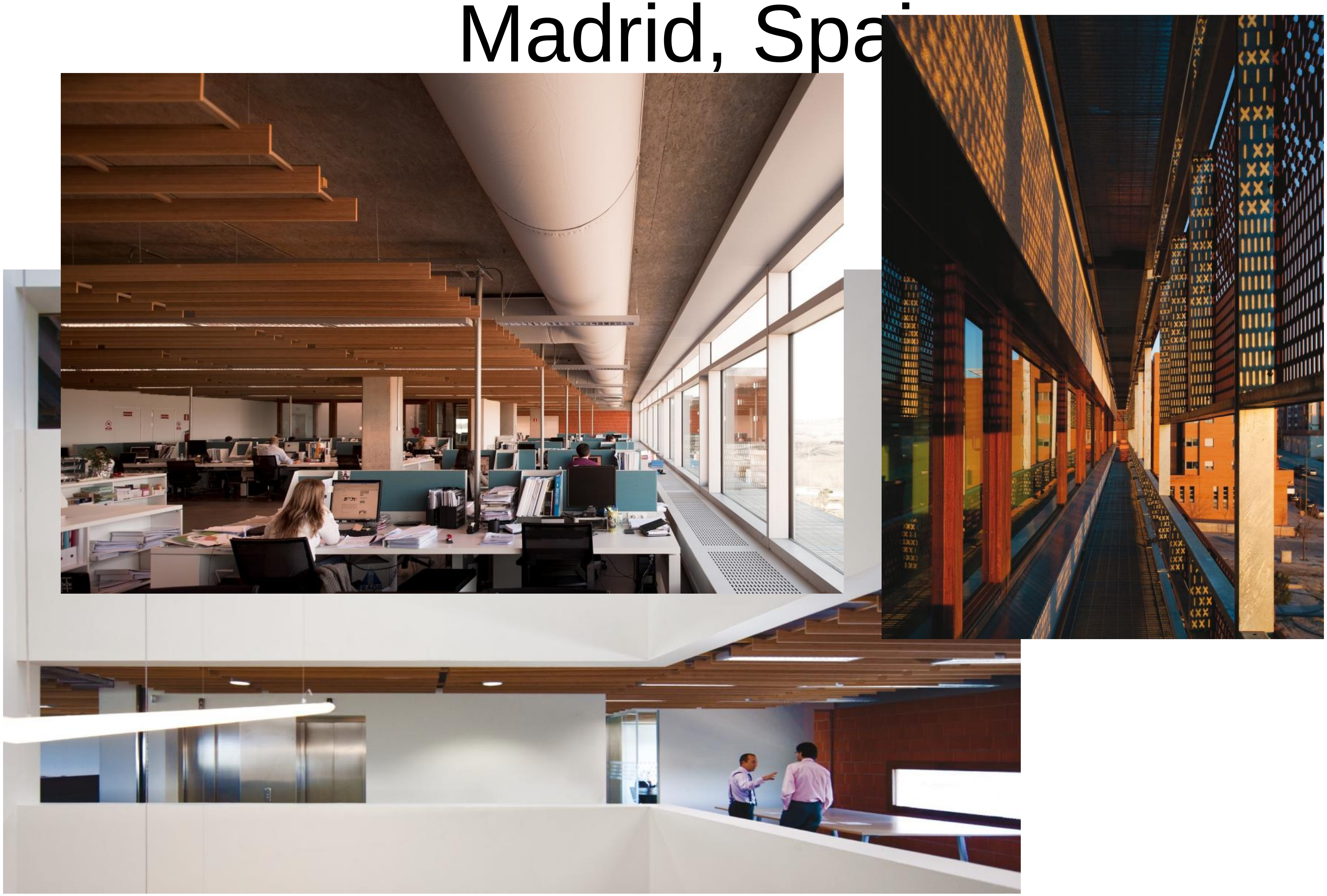
Radiant Cooling – Advantages

- Air system is about 1/5th of a conventional air conditioned building – lesser ducting and lower fan power
- Water is the main medium of heat transfer – pumping energy much smaller compared to fan energy.
- Chilled water temperature in the radiant pipes is 15 to 18 ^{0}C – chillers run at high efficiency
- Perception of thermal comfort is higher compared to a conventional air conditioned building

IDOM Company Headquaters, Madrid, Spai



IDOM Company Headquaters, Madrid, Spain

- 16 000 m2
- Natural & Mechanical ventilation
- External solar shading & green facade
- TABS combinned with free cooling (covers 40-50 kWh/m2)

Energy use

(kWh/m^{2}y)	IDOM HQ	CTE - MADRID	%
Heating + DHW	27,35	77,00	-64,5
Cooling	12,58	85,00	-85,2
Lighting	11,37	34,00	-66,6
Total	51,30	196,00	-73,8

IDOM Company Headquaters, Madrid, Spain

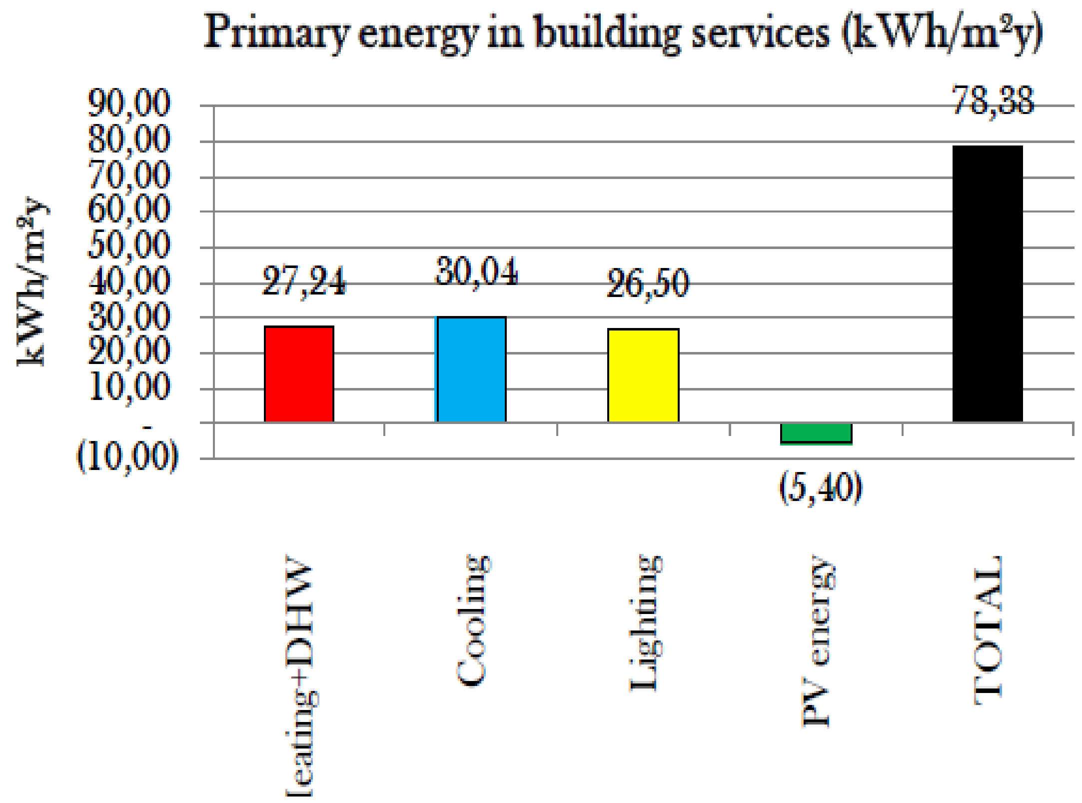


Figure 38. Primary Energy for building services in IDOM Headquarter.

General information

Context, dimensions, costs

General view of industrial area in Padova

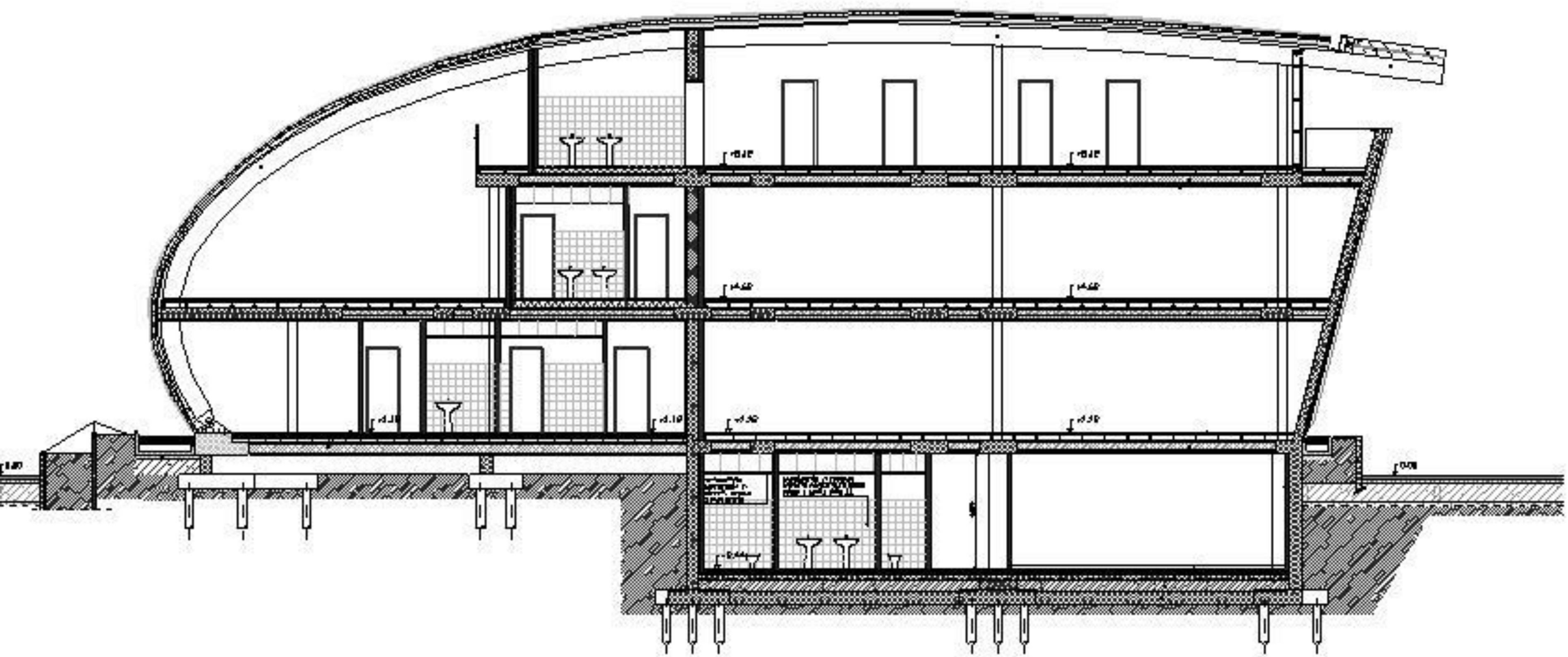
- 2.200 mq
- 8.000 mc
- 4 floors (1undergr.)
- 750 mq *open space*

Construction costs

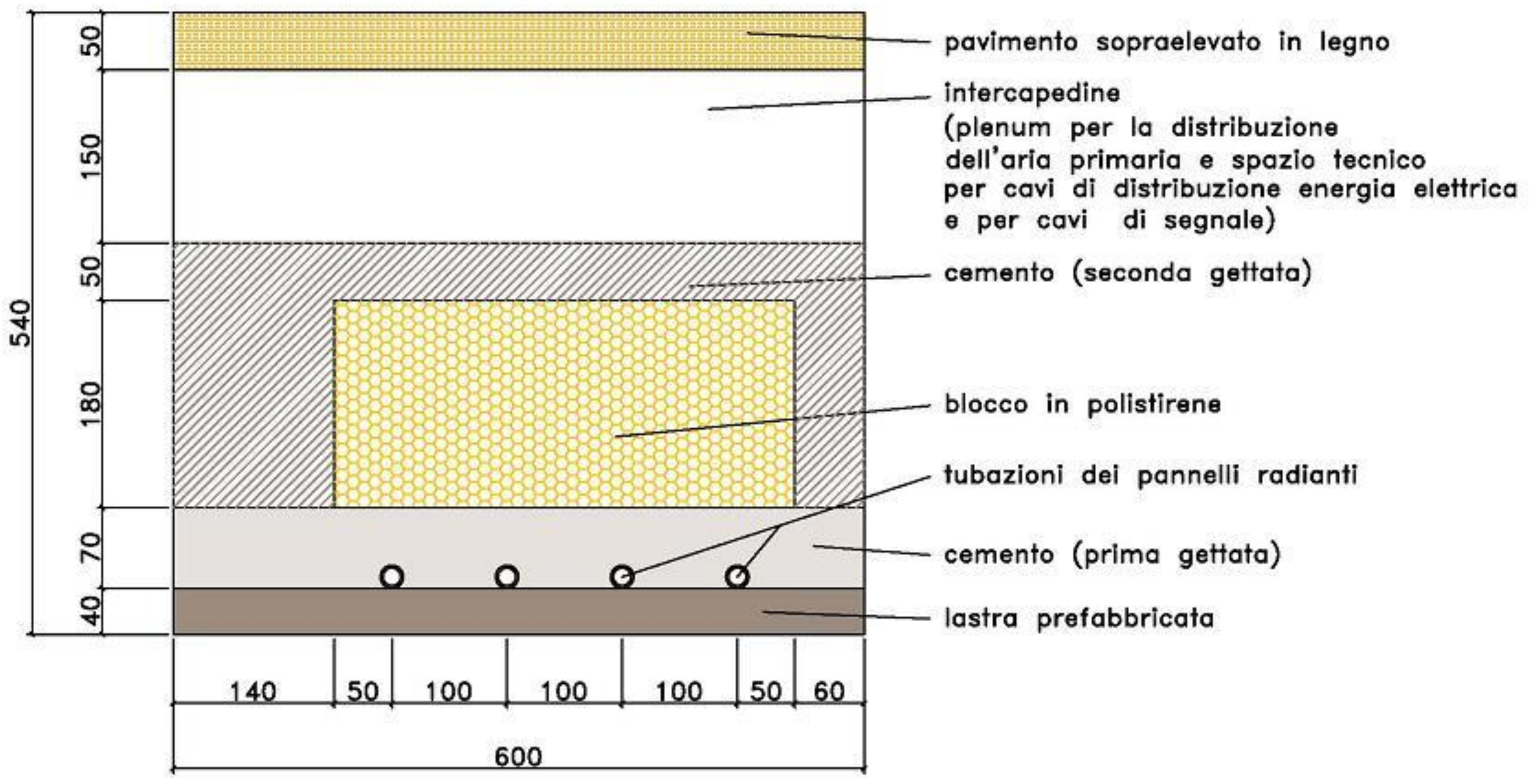
- 1.250 euro per sq.m
- 344 euro per cu.m

The building

Longitudinal section of the OFFICE BUILDING



Active thermal slab radiant panel

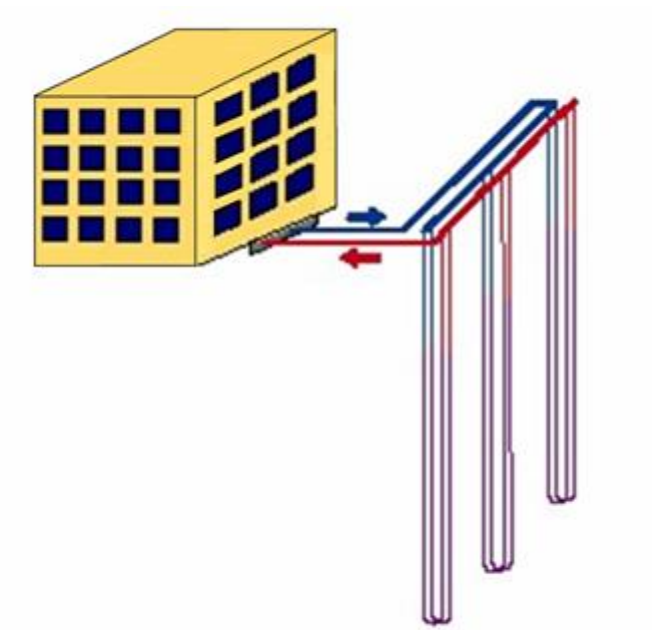


ATTIVAZIONE TERMICA DELLA MASSA

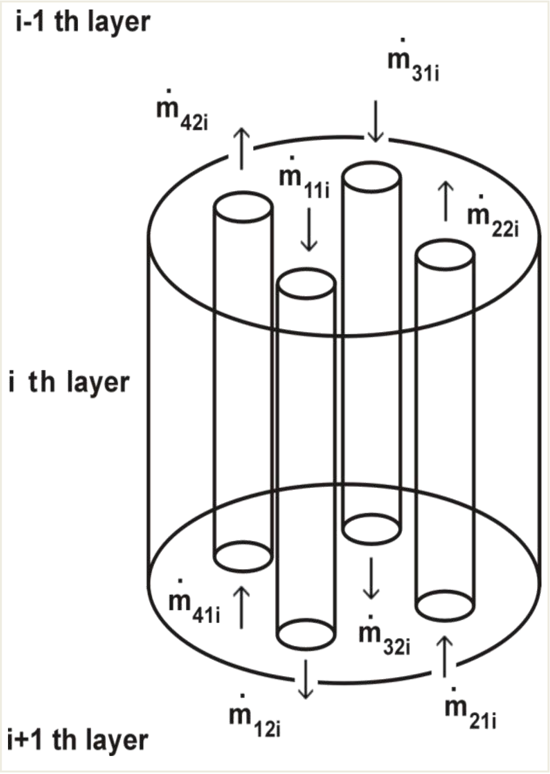
Heat pump and ground coupled heat exchanger

The ground heat exchanger

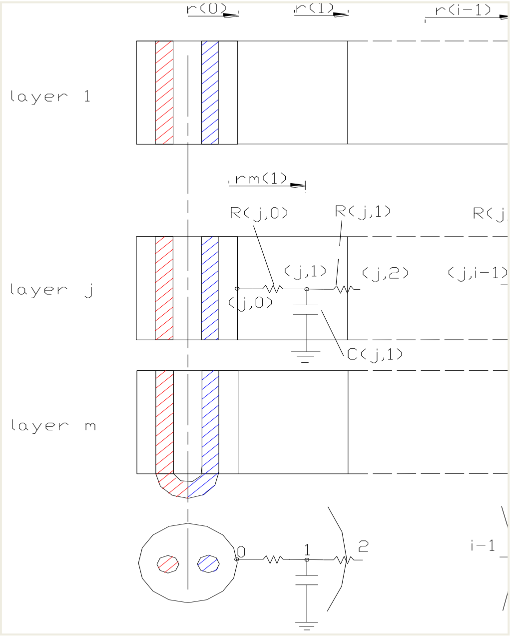
Sketch



Buried pipes model



Ground models



Installing the Ground Heat Exchangers

HEATING PERIOD

129 days

COP average~ 5,7

Specific primary energy requirement : 13,7 $kWh_p/(m^2\ Y)$

Specific heating requirement : 19 $kWh_t/(m^2\ Y)$

Specific electrical energy requirement : 4,9 $kWh_e/(m^2\ Y)$

COOLING PERIOD

175 days

SEER ~ 5,4

Specific primary energy requirement: 21,4 $kWh_p/(m^2\ Y)$

Specific cooling requirement: 29,1 $kWh_f/(m^2\ Y)$

Specific electrical energy requirement: 7,7 $kWh_e/(m^2\ Y)$

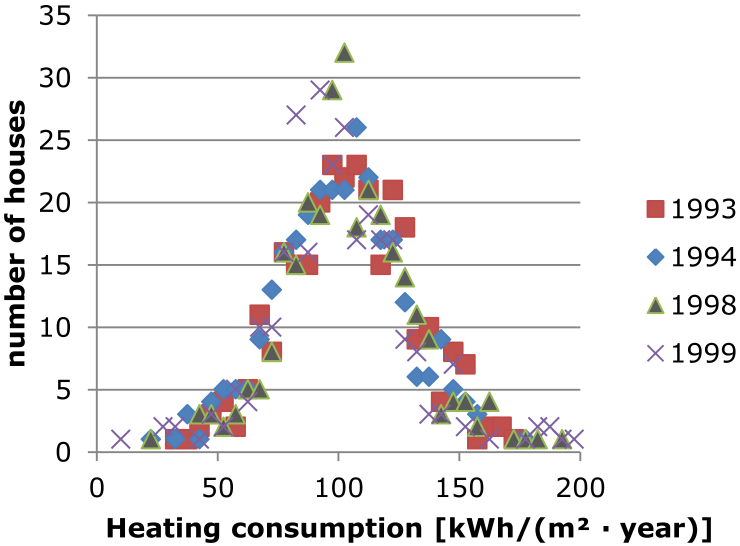
Occupant behaviour, Indoor environment and energy consumption

International Centre for Indoor Environment and Energy

DTU Civil Engineering
Department of Civil Engineering

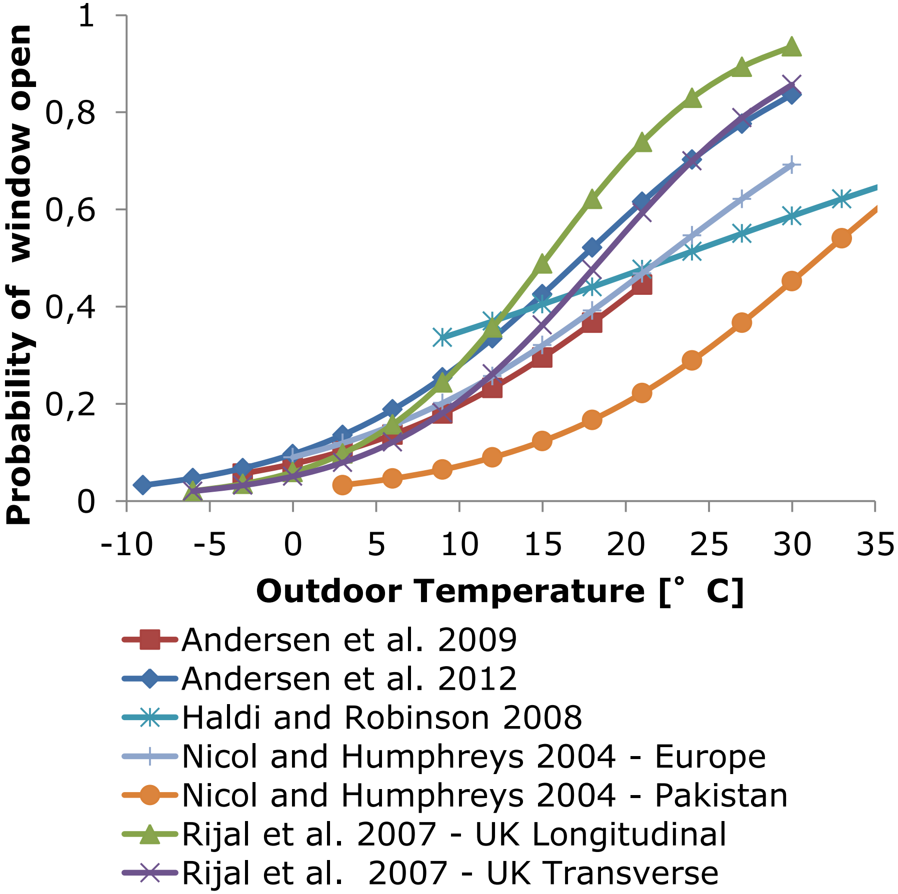
Investigation of heat consumption in 290 identical houses*

- Correction for differences in outer wall area
  - End houses vs. Middle houses
- Highest consumption up to 20 times higher than lowest
- Stable consumption distribution over time
- No measurements of indoor environment



Models of occupants' window opening behaviour

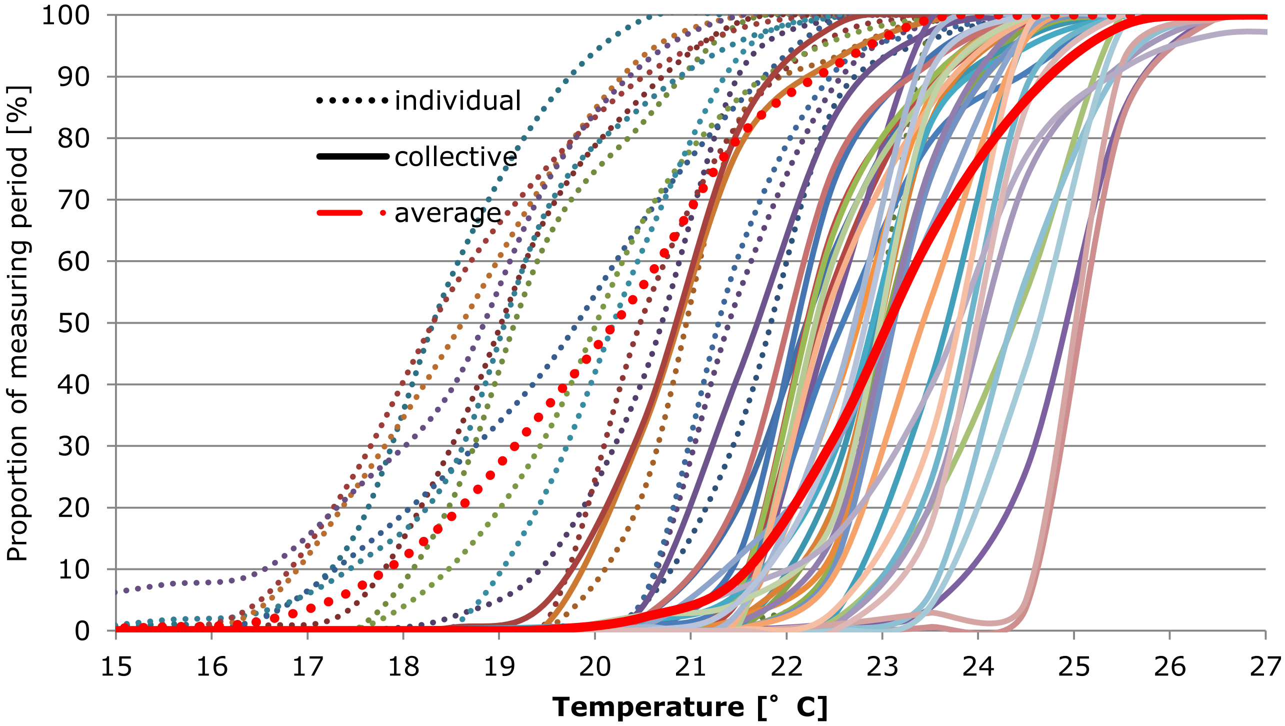
- Many models
- Most, only rely on thermal environment
  - Is that enough?
  - Which one should I use?
- Lack of validation
- Lack of validation methods



Shared or individual heating cost

Interviews of 10 residents

- Possible to heat all apartments to comfortable condition
- Individual billing
  - focus on heat savings
  - Accepted uncomfortable conditions to save money
- Collective billing
  - Focus on health, comfort and avoiding moisture problems



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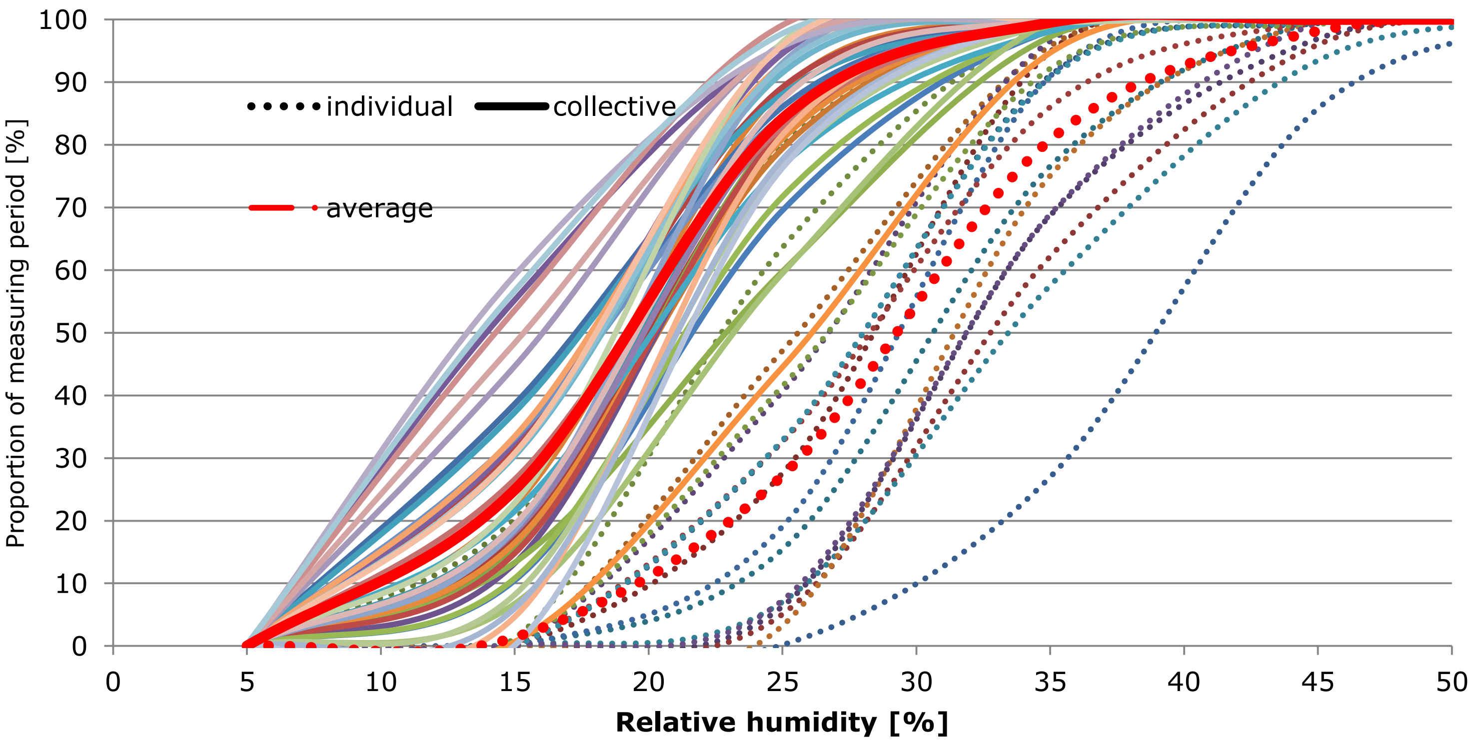
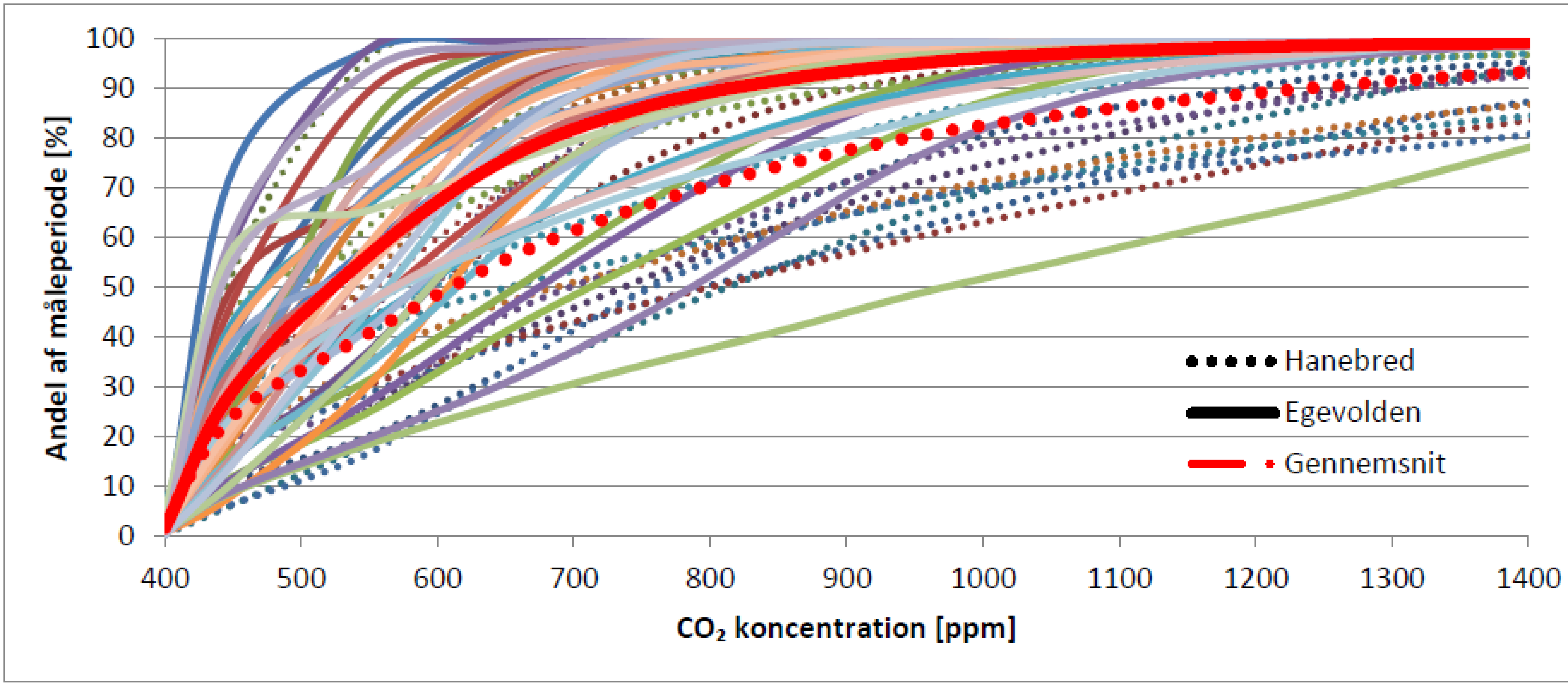


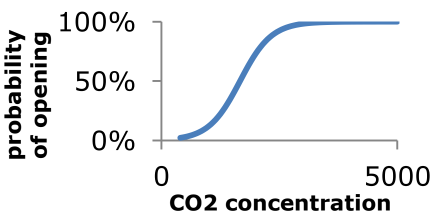
Shared or individual heating cost



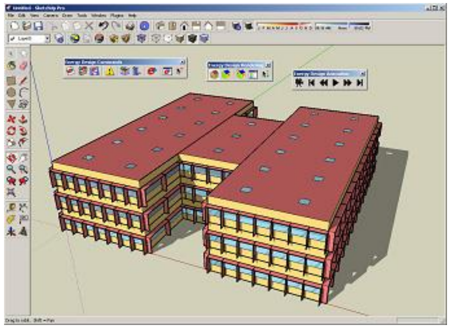
From deterministic to stochastic modelling

Stochastic models

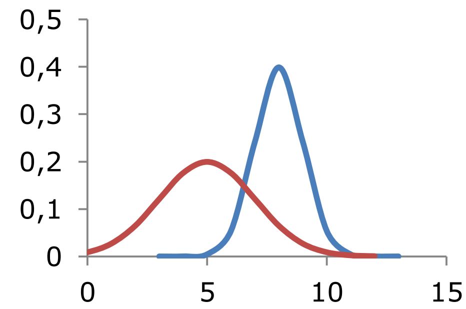
- Window opening
- Heating set-points
- Cooling set-points
- lighting
- …



Deterministic model of physical aspects



Probability distribution of performance indicators



Energy Efficient Technologies

- Indoor air quality
  - Reduce loads (pollution sources)
  - Heat recovery
  - Increase system efficiency
  - Natural ventilation-Hybrid ventilation
  - Air distribution (contaminant removal) effectiveness
    - Personal ventilation
  - Air cleaning

- Thermal comfort
  - Reduce loads (building shell, solar screen, internal loads)
  - Increase system efficiency
  - Low Temperatur Heating- and High Temperature Cooling Systems
  - Use of building mass to reduce peaks (Thermo-Active-Building-Systems (TABS))
  - Drifting indoor temperatures


THE VALUE CHAIN OF IEQ
LIGHT
AIR QUALITY
EMPLOYEE PERFORMANCE
THERMAL COMFORT
SOUND
1 • Building Research
2 • Occupant Comfort & Health Research
3 • Building Design
4 • Component Manufacturing, Installation & Commissioning
5 • Operation & Occupant Behaviour