DTU

ICIEE
International Centre for Indoor Environment and Energy

Lavtemperatur-opvarmning og højtemperatur-køling

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ICIEE.DTU Research Team
Radiant Heating and Cooling Systems

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Lavtemperatur-opvarmning og højtemperatur-køling

- Kendte systemer
- Gulvvarme er ofte standard i boliger.
- Nye randbetingelser
  - Forsyning
  - CO_2 emission fra bygninger i drift
  - CO_2 emission under produktion, installation og vedligehold

Fremtidig energiforsyning i Danmark

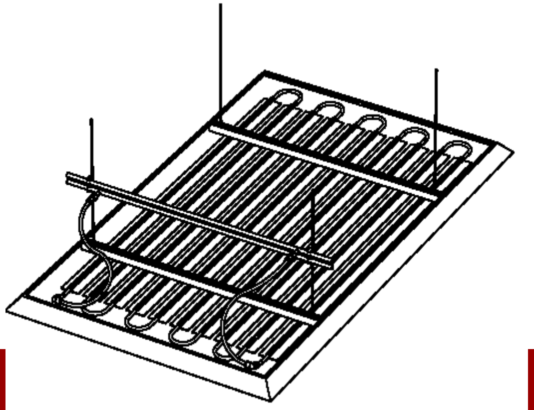
- Fjernvarme og Fjernkøling
  - Lavtemperatur fjernvarme
    - Lav temperatur (55/25°C)
    - Ultra-lav temperatur med elektrisk “boosting” (45/25 °C)
    - Ultra-lav temperatur med varmepumpe “boosting” (35/20 °C)
  - Sænkning at returtemperatur
- El
  - Varmepumpe
  - Individuel PV-anlæg
- Energilagring
  - Termisk lagring (bygning, systemer)
  - Elektrisk lagring (batterier, bil)
- Elnet
  - Varierende forsyning
  - Varierende priser

What is Low Temperatur 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

Suspended cooled ceilings

Bild 22 Metallsegel, Kühltechnik

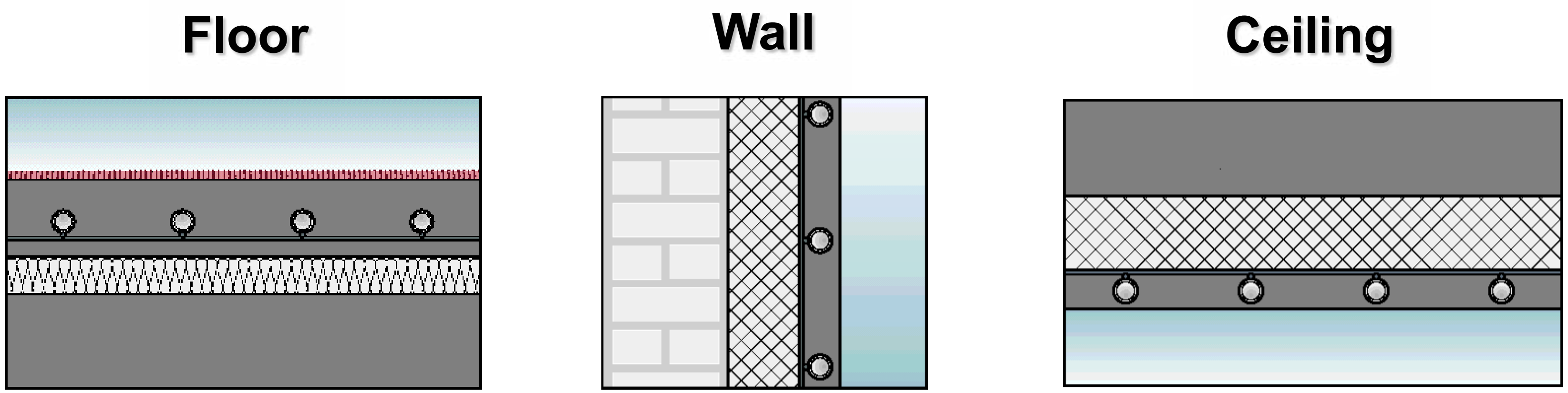


Suspended cooled ceilings

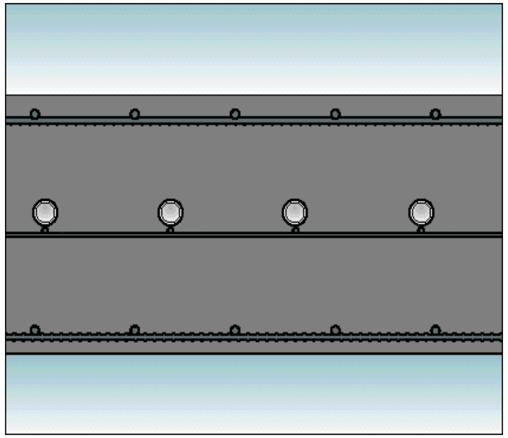
Top view and bottom view of
Comfort Panel HL

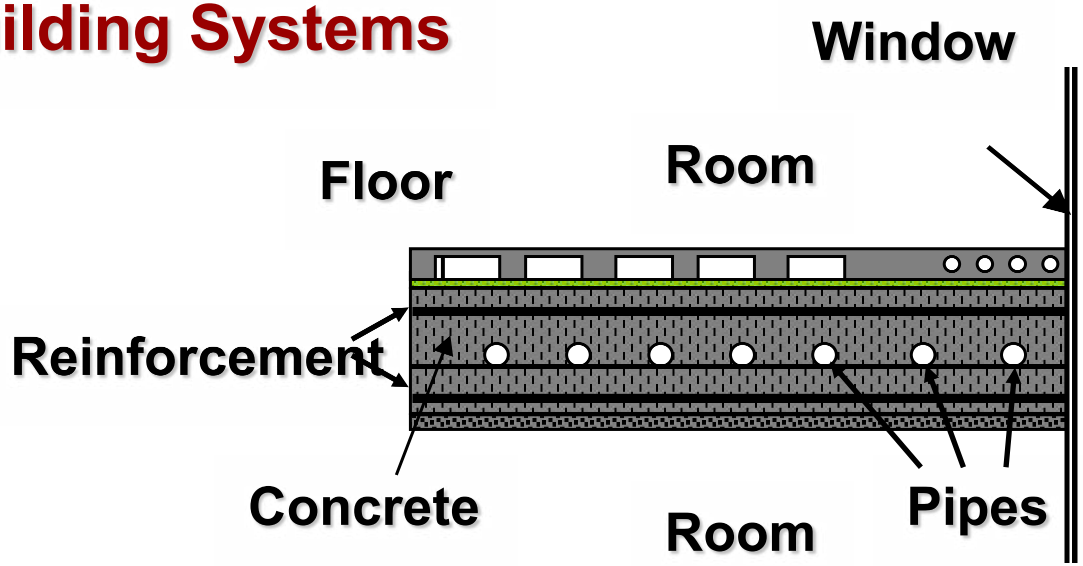
Capillary Tubes

Radiant surface heating and cooling systems

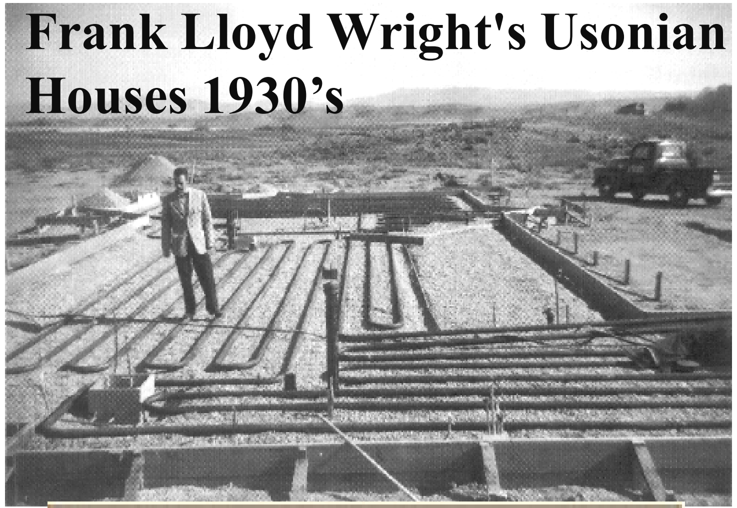


Thermo Active Building Systems





HISTORY



A lightweight floor slab was used and the traditional basement was dispensed with. By using steam or hot water piping, it became possible to heat the floor, therefore eliminating the need for radiators. The overall result was heat without a draft or temperature variation of the most comfort - cool head and warm feet.

c. 10,000 B.C., China, the word “kang,” can be traced back to the 11th century B.C. and originally meant, “to dry” before it became known as a heated bed.
c. 5,000 B.C., evidence of baked floors are found foreshadowing early forms of “kang” and “dikang” (heated floor) later “ondol” (warm stone) in China and Korea, respectively.

HISTORY

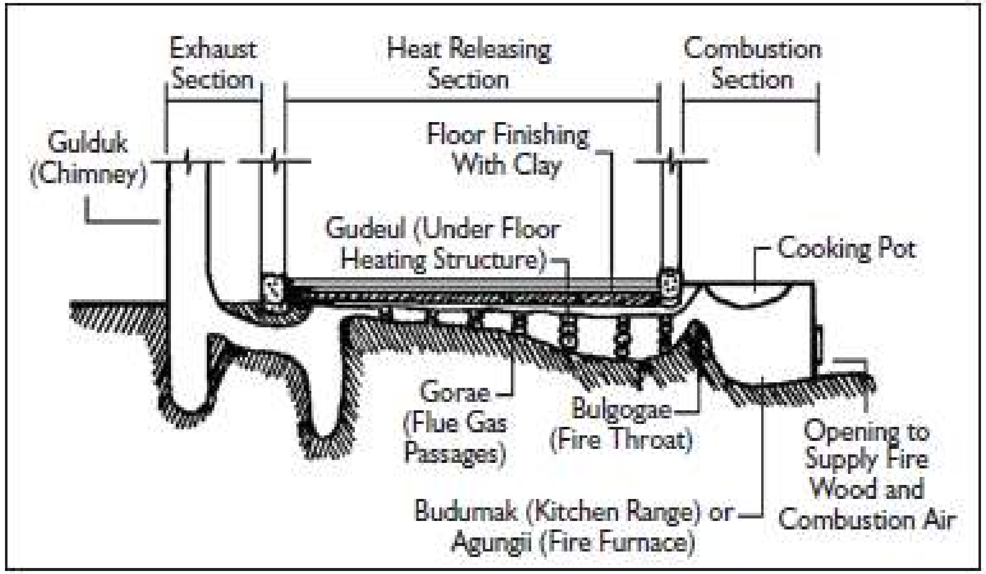


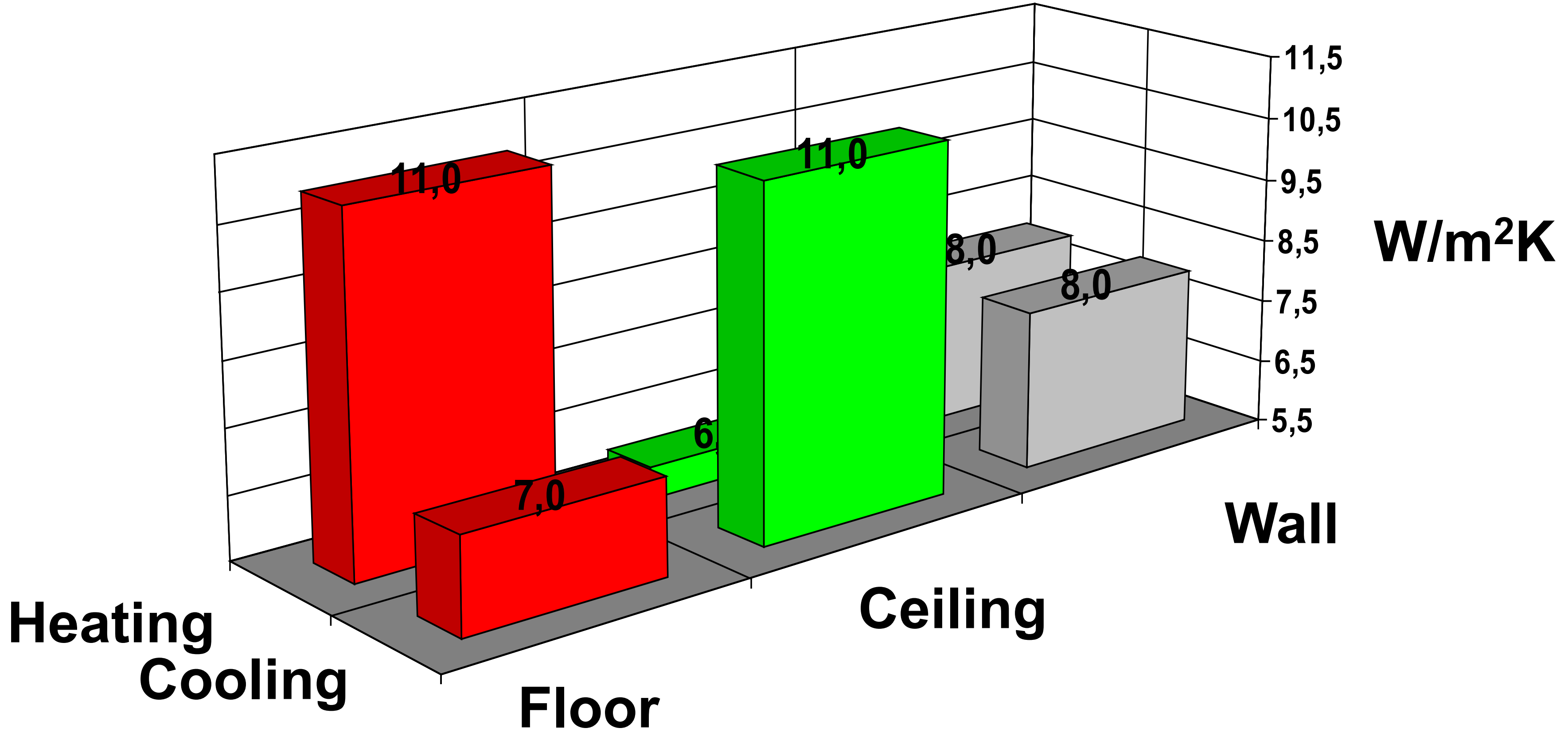
Figure 2: Structure of entirely ondol floored room.[9]

Hypocausts were used from the third century B.C. in ancient Europe.

Determination of Heating and Cooling Capacity

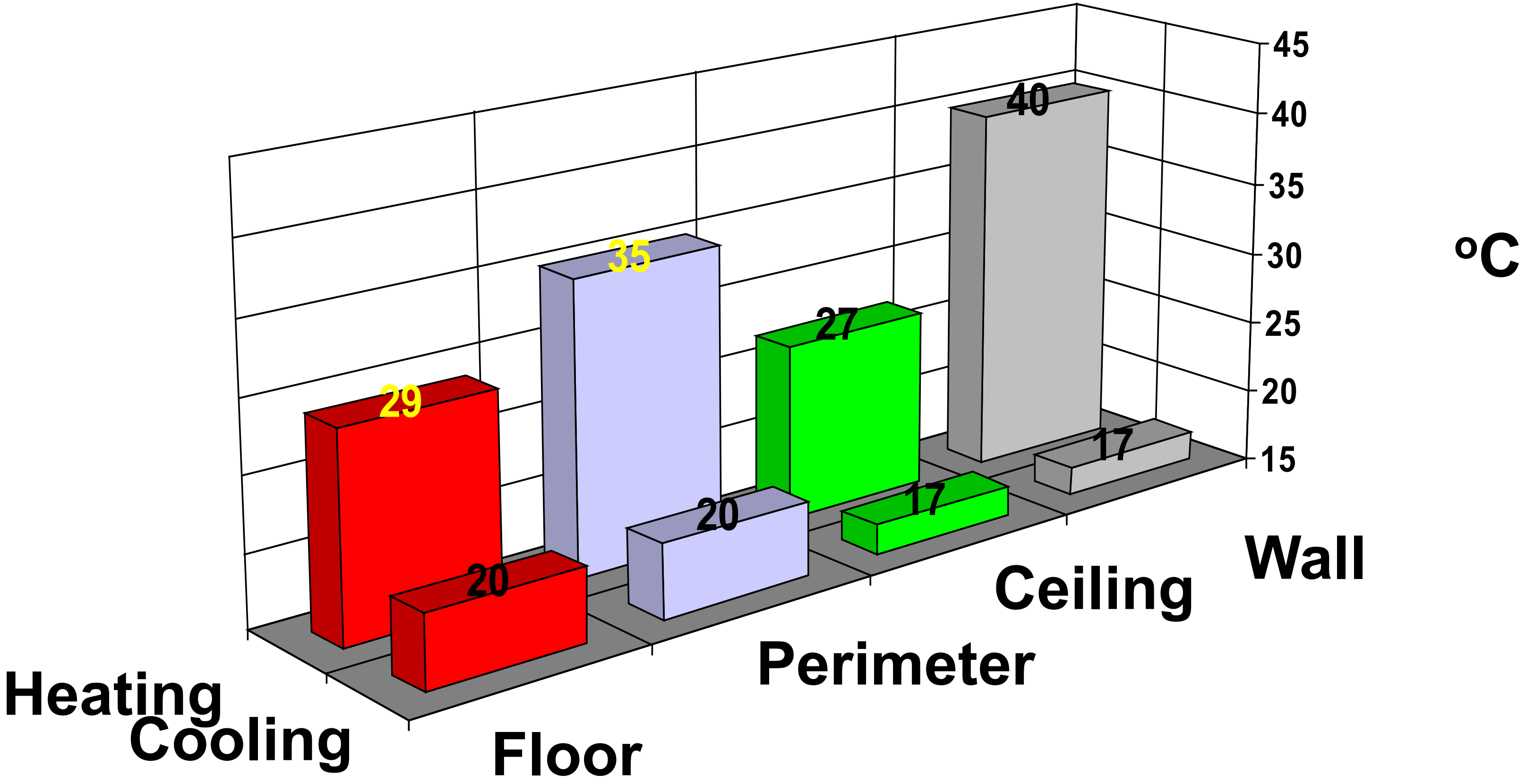
SURFACE HEATING AND COOLING

Heat transfer coefficient

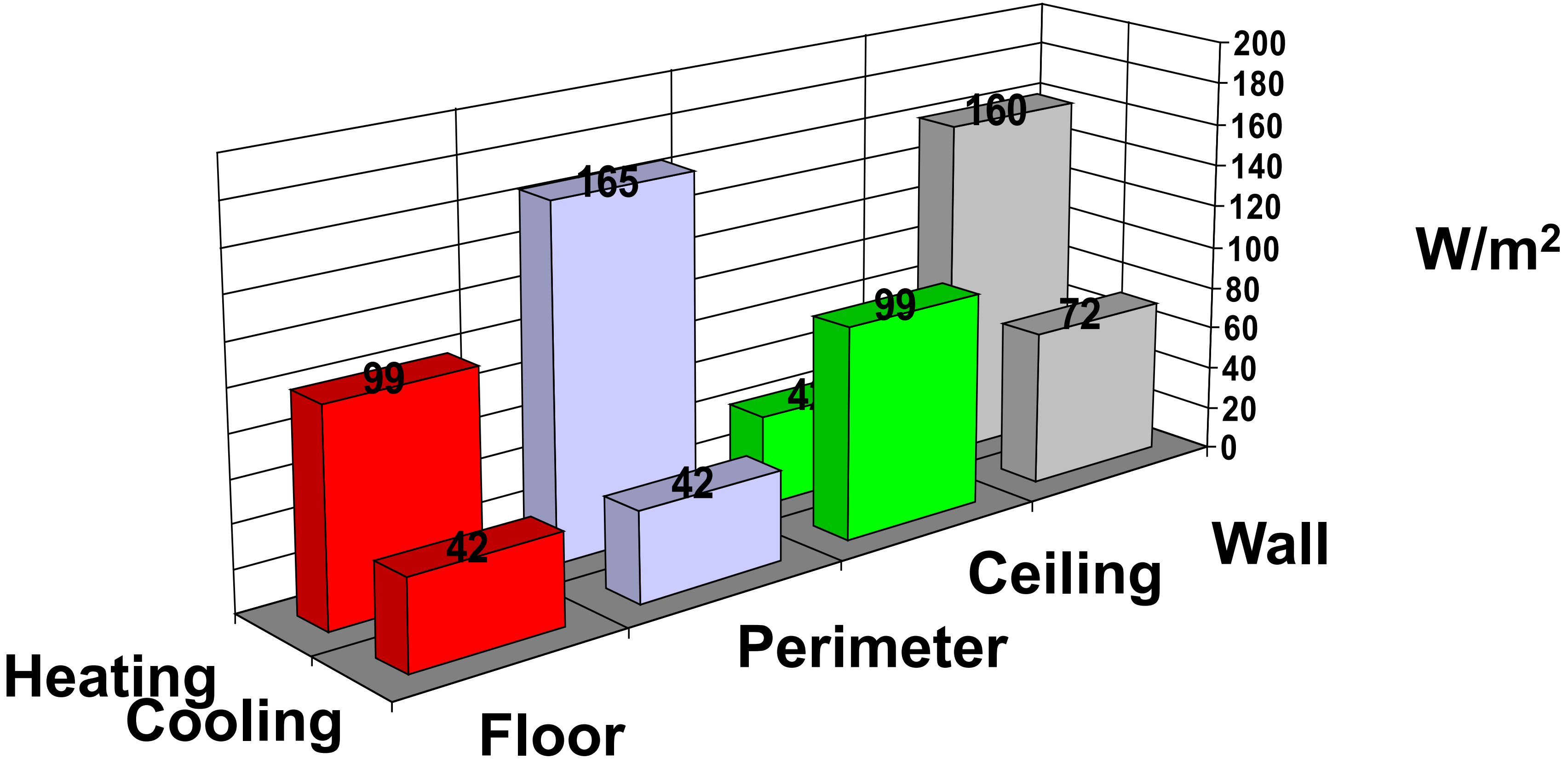


SURFACE HEATING AND COOLING

Max. - Min. Surface temperature

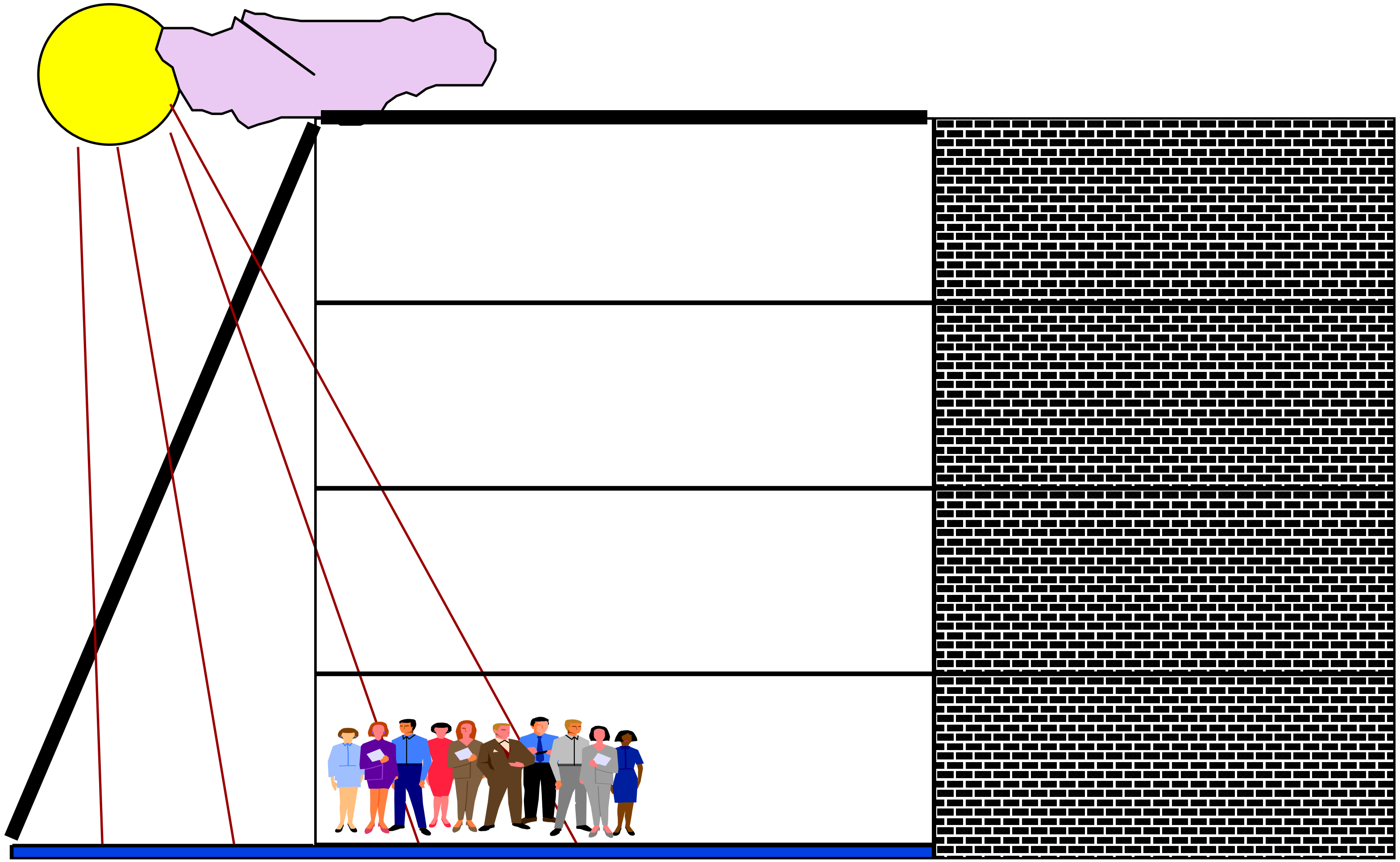


MAXIMUM HEATING AND COOLING CAPACITY

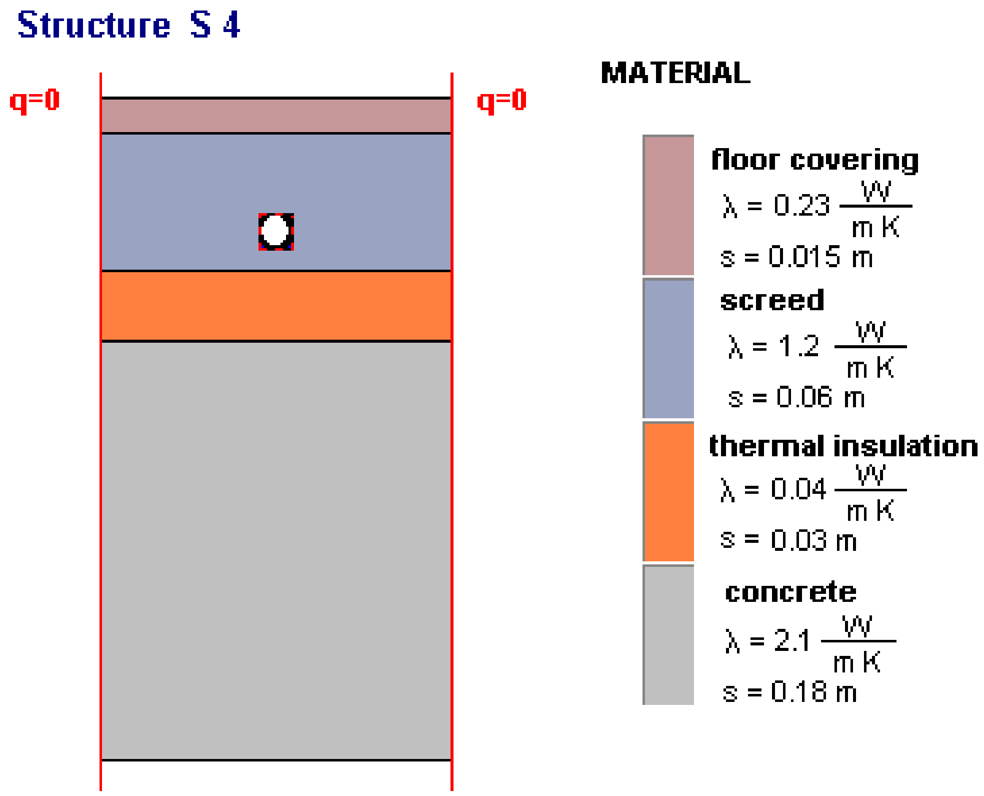


Radiant Floor Cooling

More than 100 W/m^2

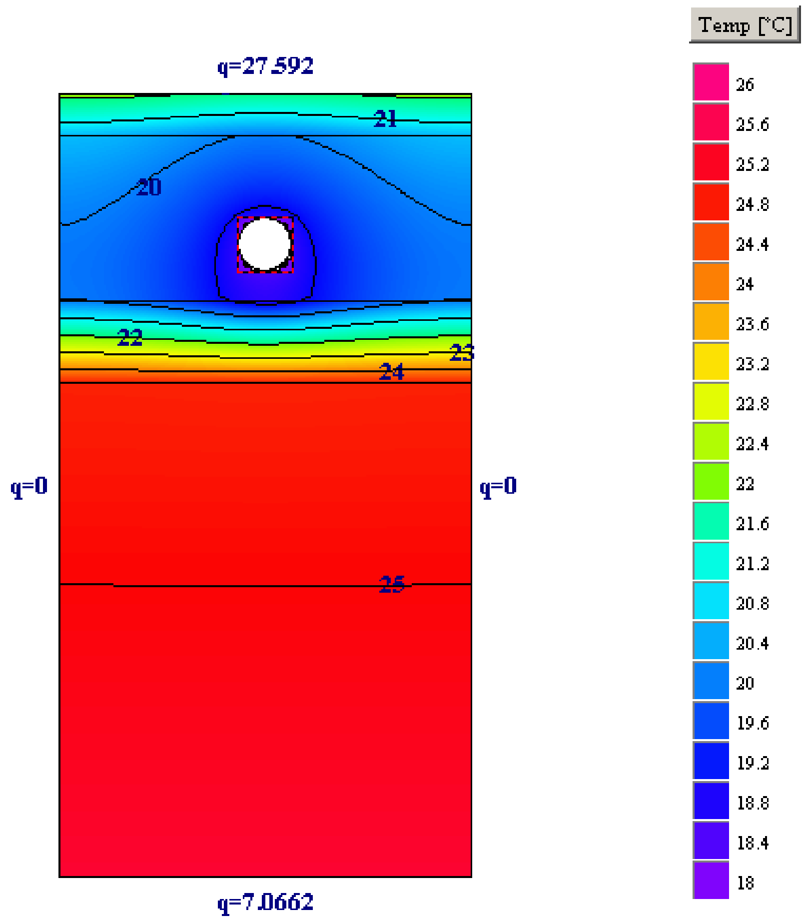


Method for verification of FEM and FDM calculation programs



Method for verification of FEM and FDM calculation programs

W/m2	$Btu_{IT}/(ft^2*h)$
10	3,2
20	6,3
30	9,5
40	12,7
50	15,8
60	19,0
70	22,2
80	25,4
90	28,5
100	31,7

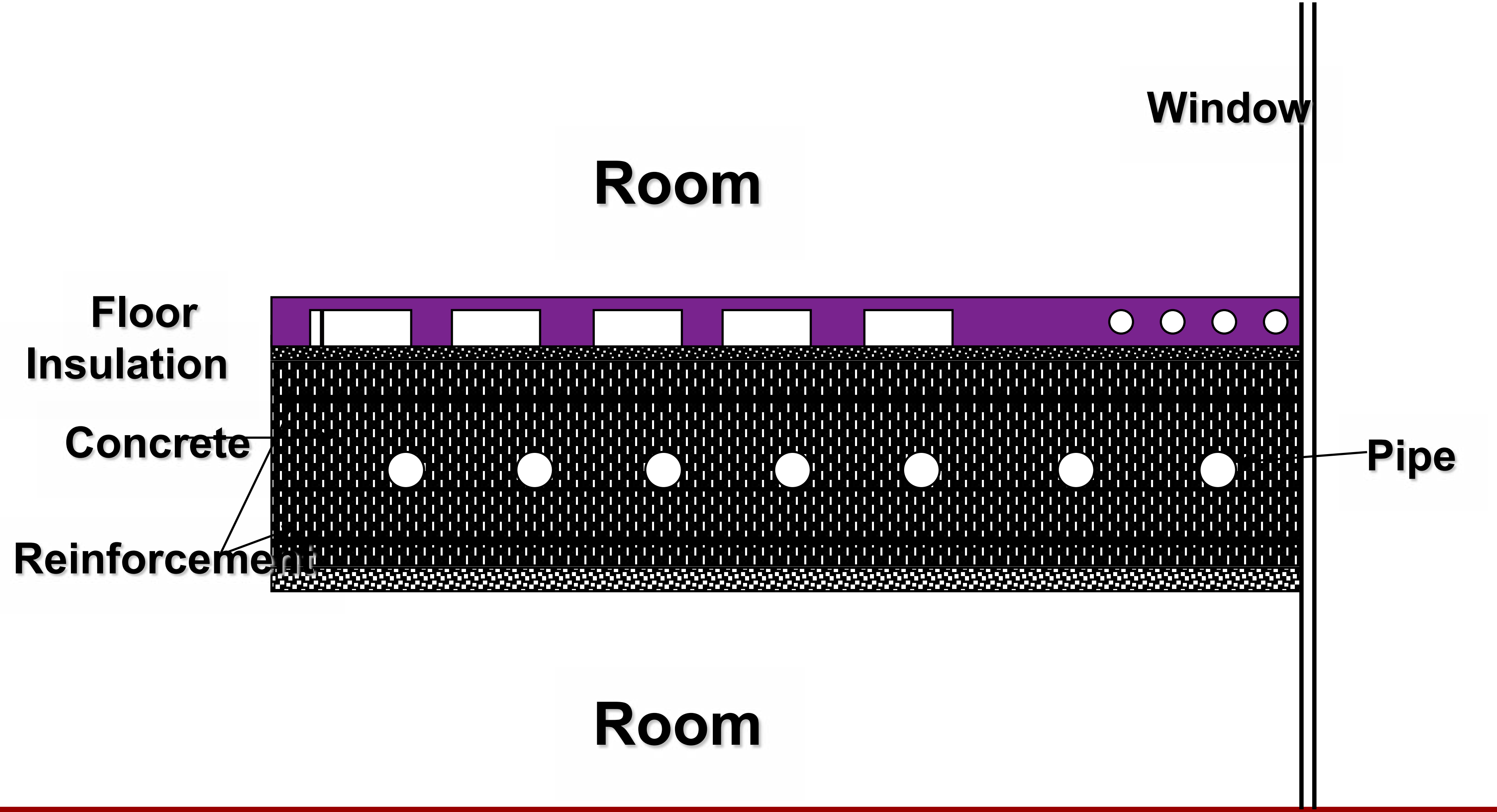


degC	F
17	62,6
18	64,4
19	66,2
20	68
21	69,8
22	71,6
23	73,4
24	75,2
25	77
26	78,8
27	80,6
28	82,4
29	84,2
30	86
31	87,8

Standards

- DS EN ISO 11855 Building environment design – Embedded radiant heating and cooling systems
- Part 1: Definitions, symbols, and comfort criteria
- Part 2: Determination of the design heating and cooling capacity
- Part 3: Design and dimensioning
- Part 4: Dimensioning and calculation of the dynamic heating and cooling capacity of Thermo Active Building Systems (TABS)
- Part 5: Installation
- Part 6: Control
- Part 7: Electrical heating systems

TABS
Thermo Active Building Systems



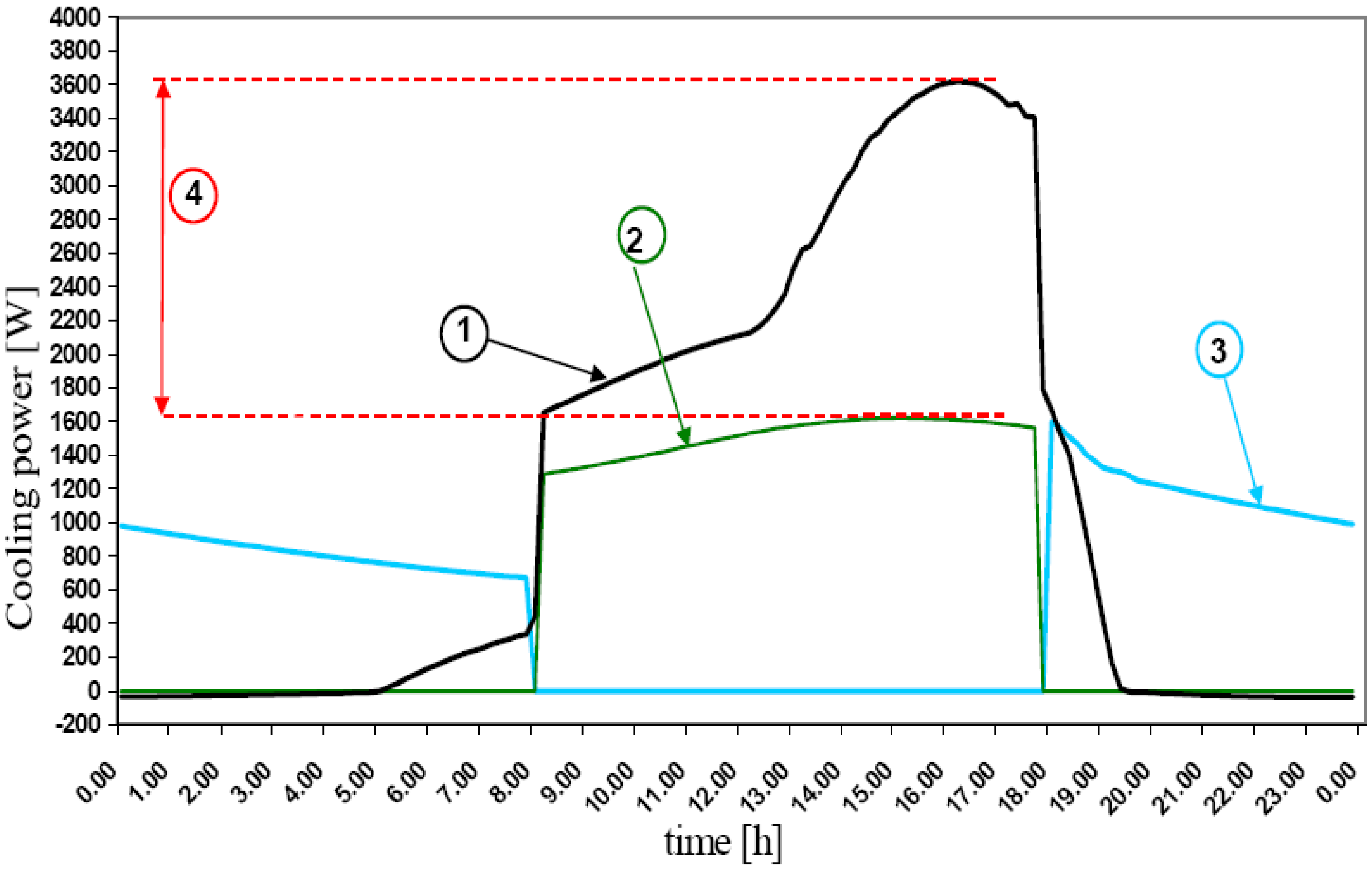
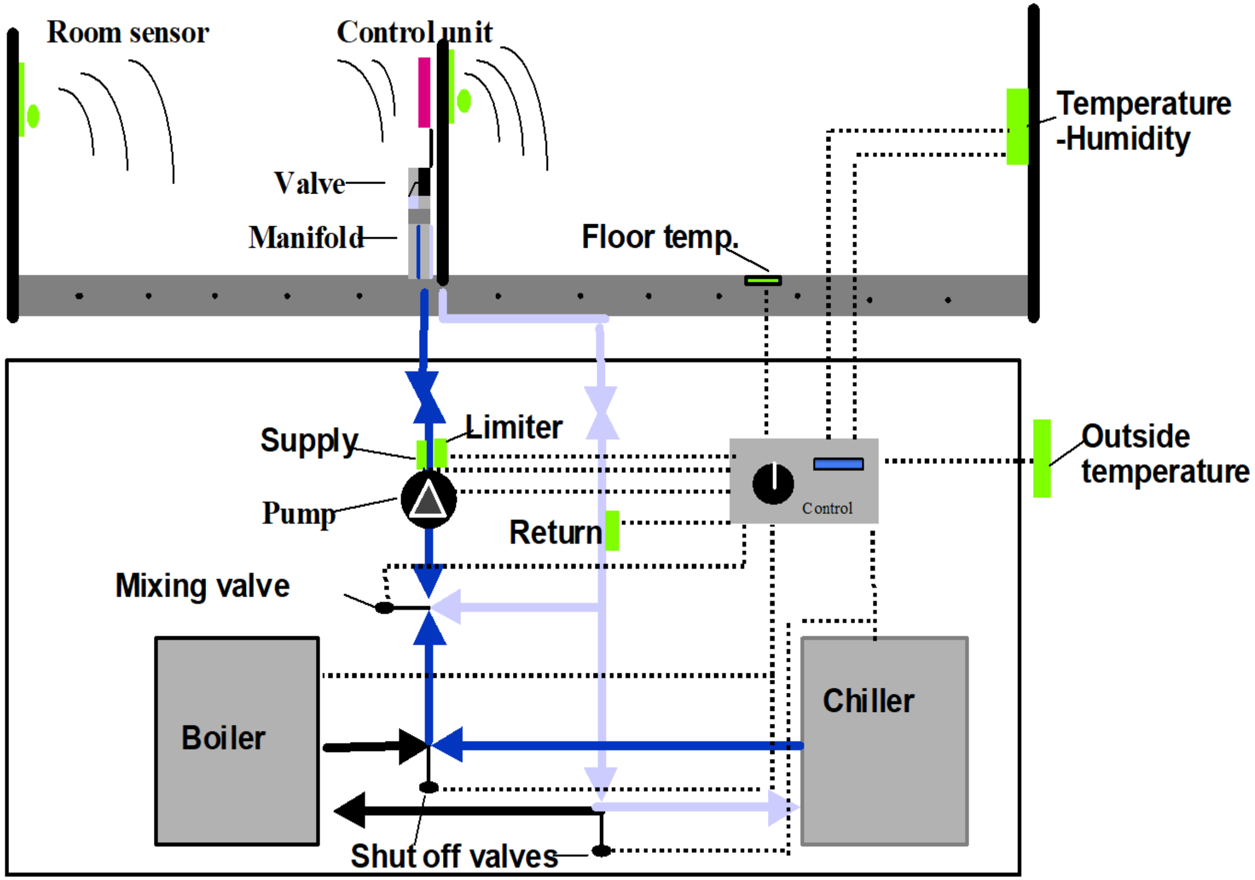


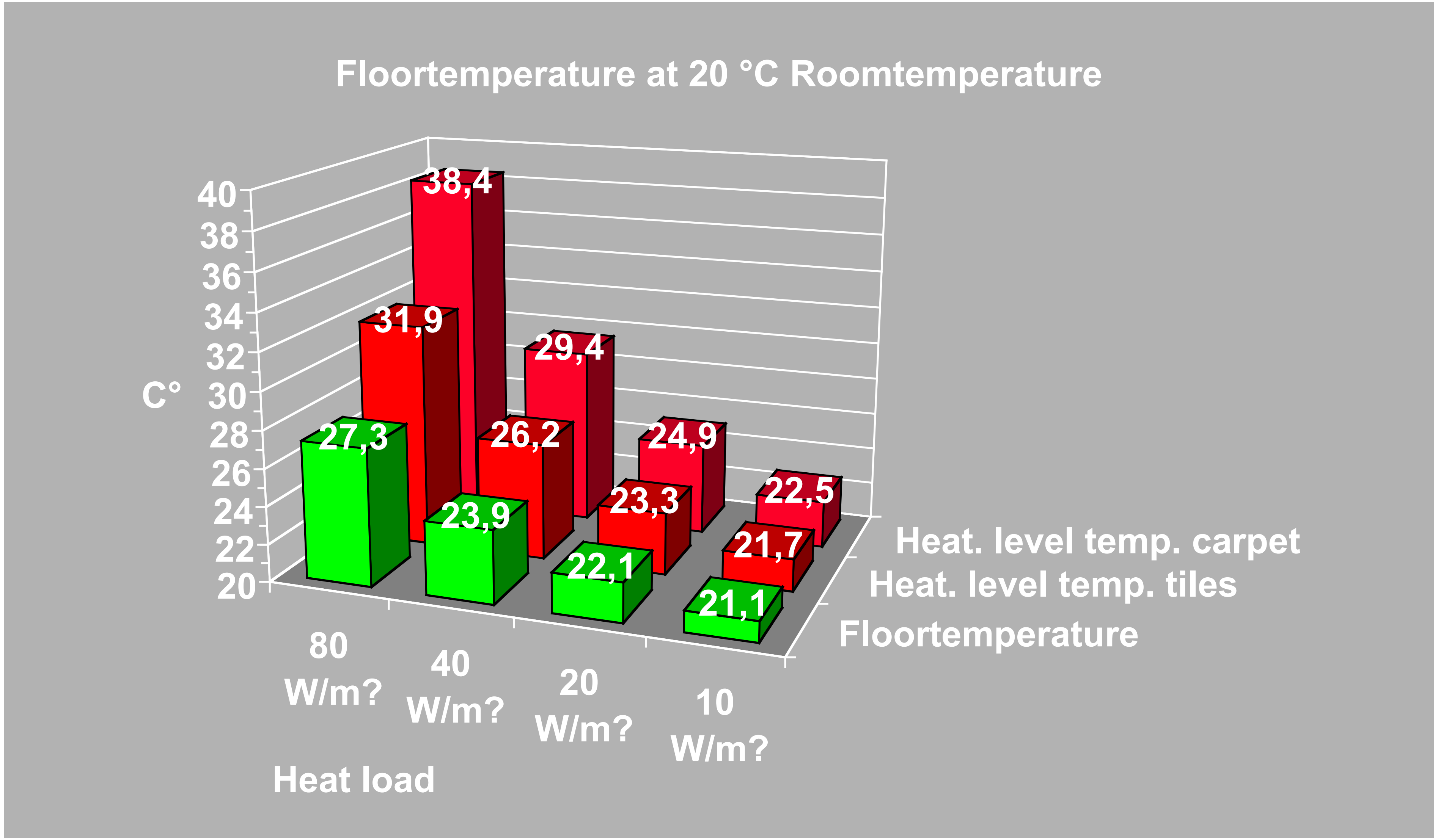
Figure 2 – Example of peak-shaving (reducing the peak load) effect (time vs. cooling power [W],)

Control of radiant heating and cooling systems

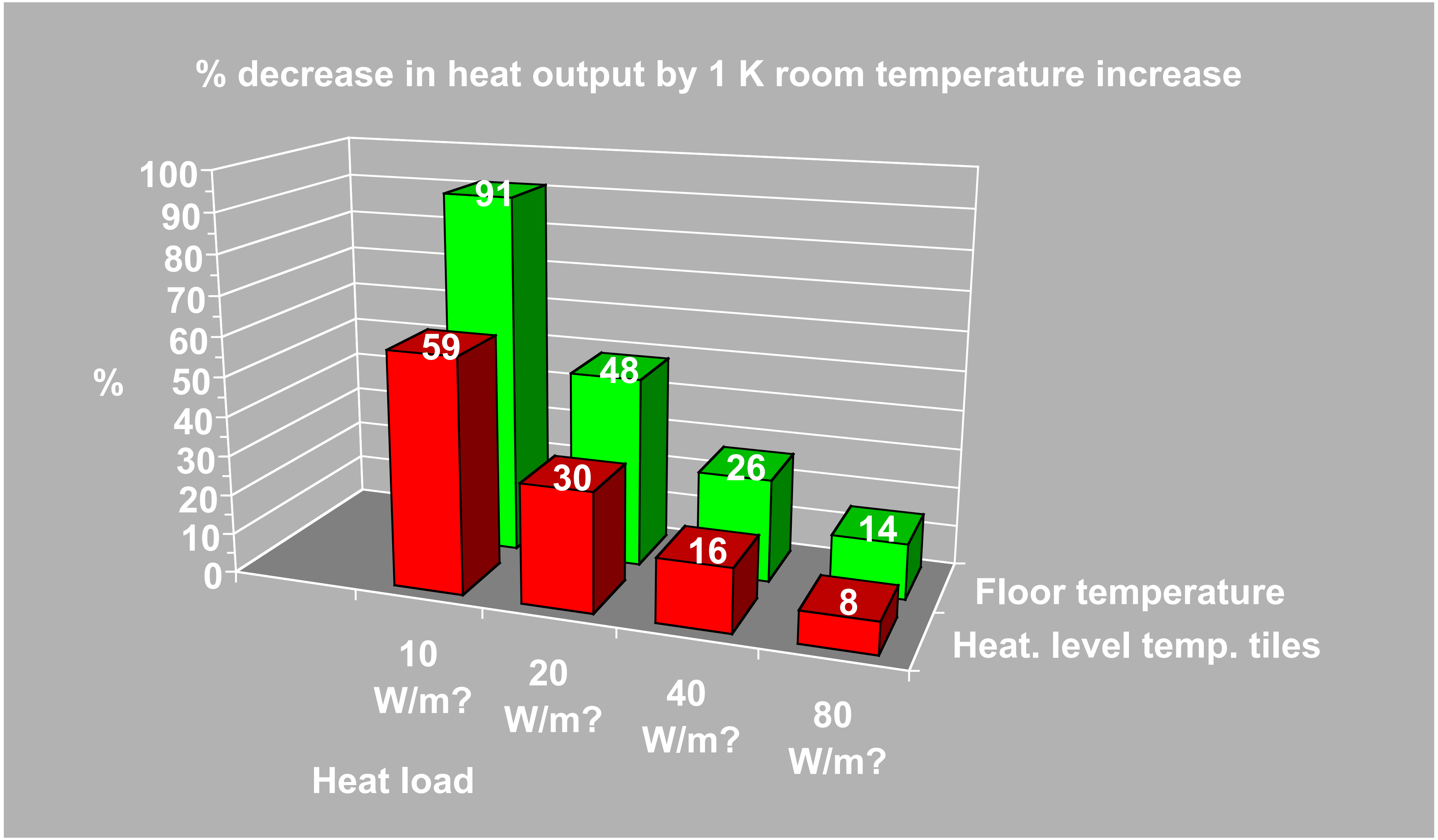
Control of a combined floor heating-cooling system with individual room control



SELF CONTROL



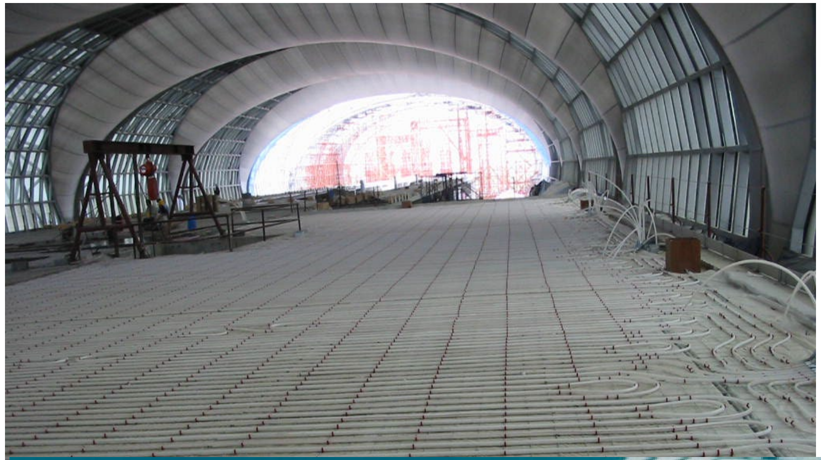
SELF CONTROL

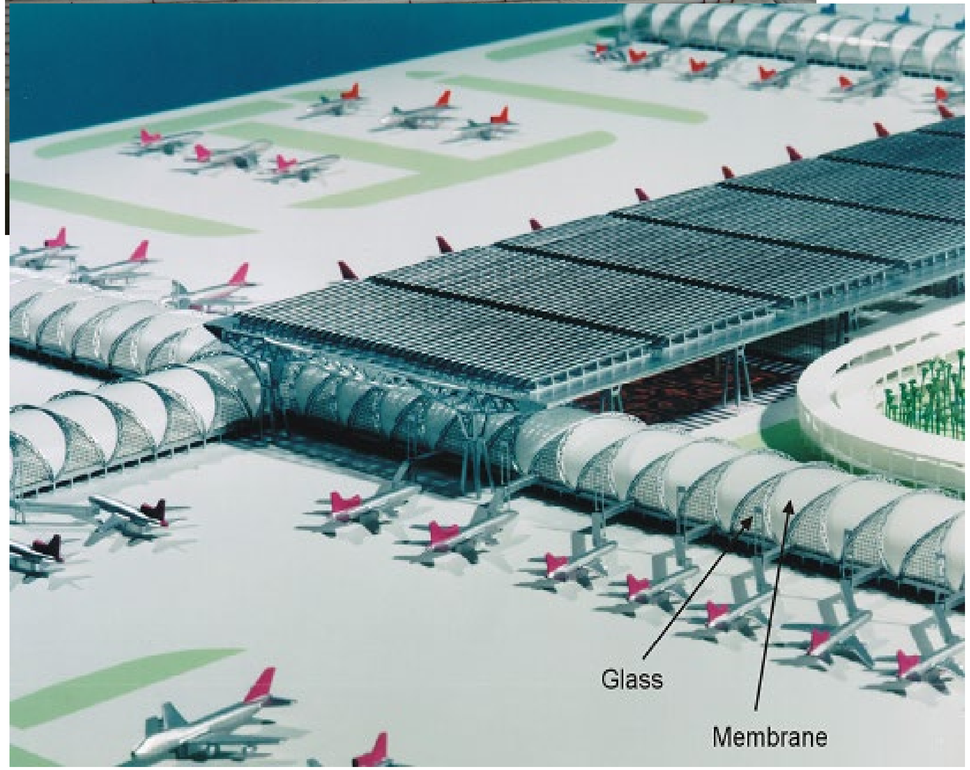


Construction and Installation Technologies

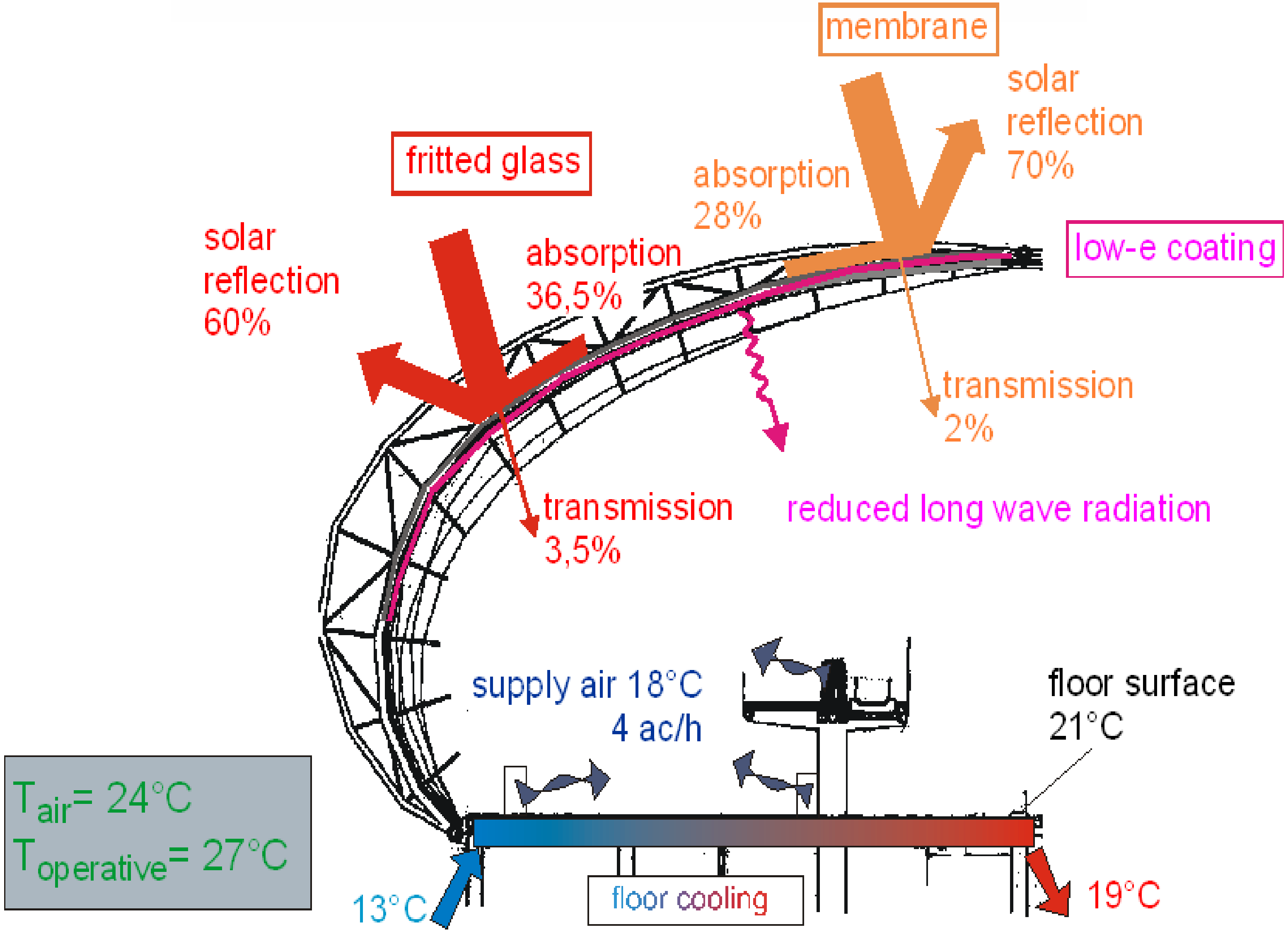
Examples

Airport Bangkok

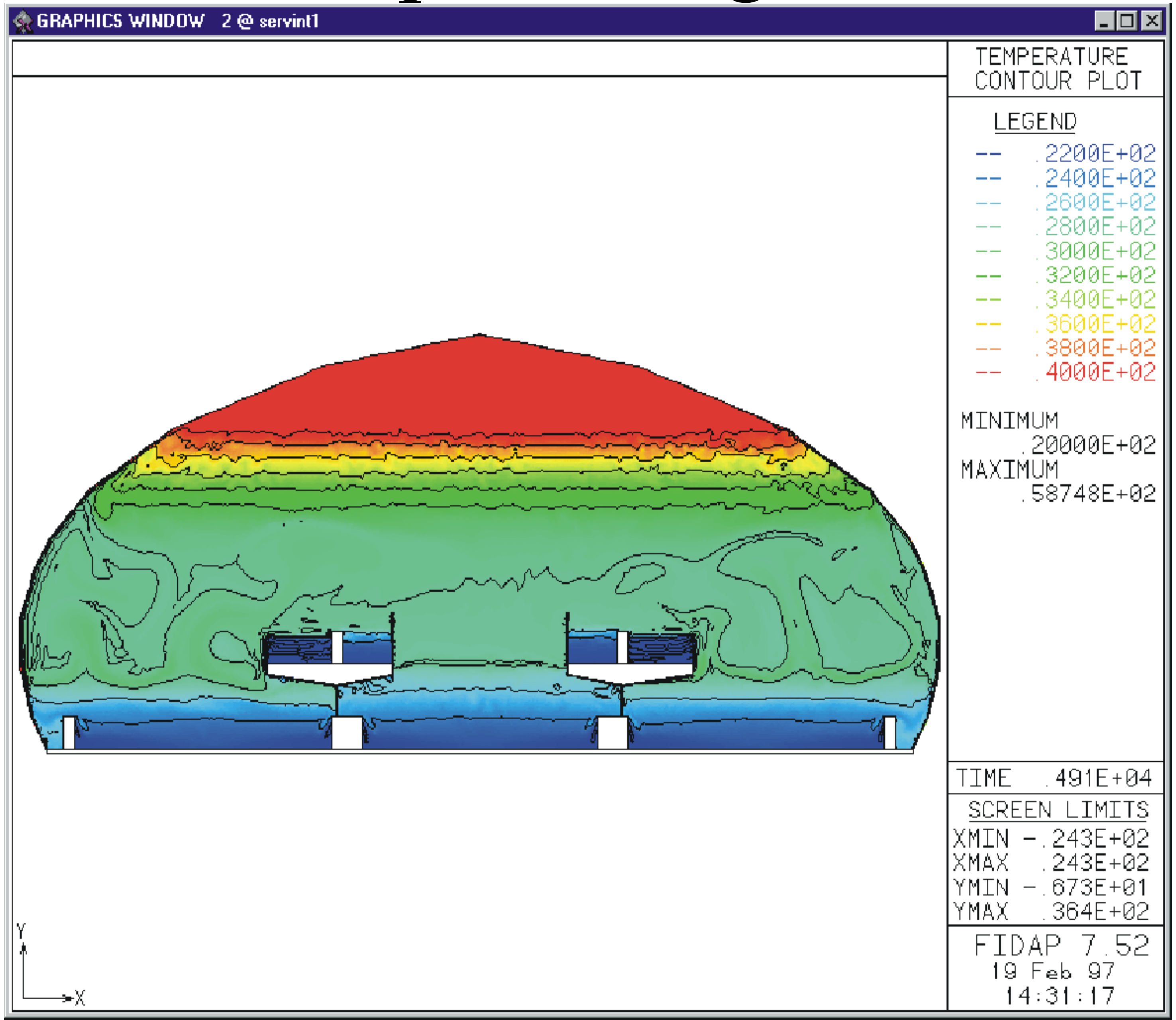




Airport Bangkok



Airport Bangkok



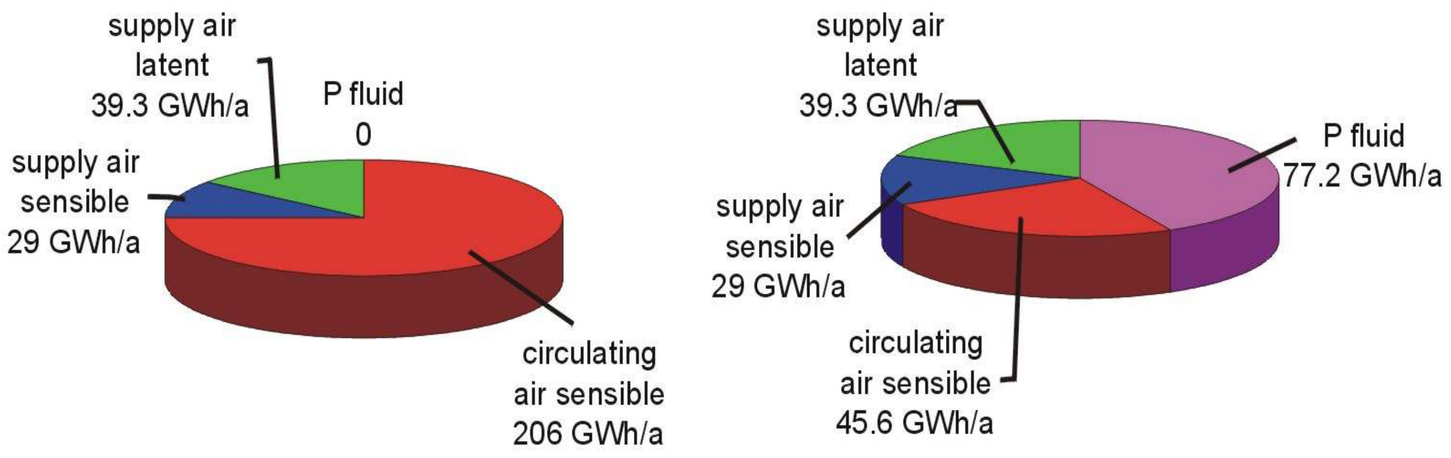
Airport Bangkok

NEW BANGKOK INTERNATIONAL AIRPORT

Comparison of Cooling loads entire Airport

Original Concept

Optimized Concept



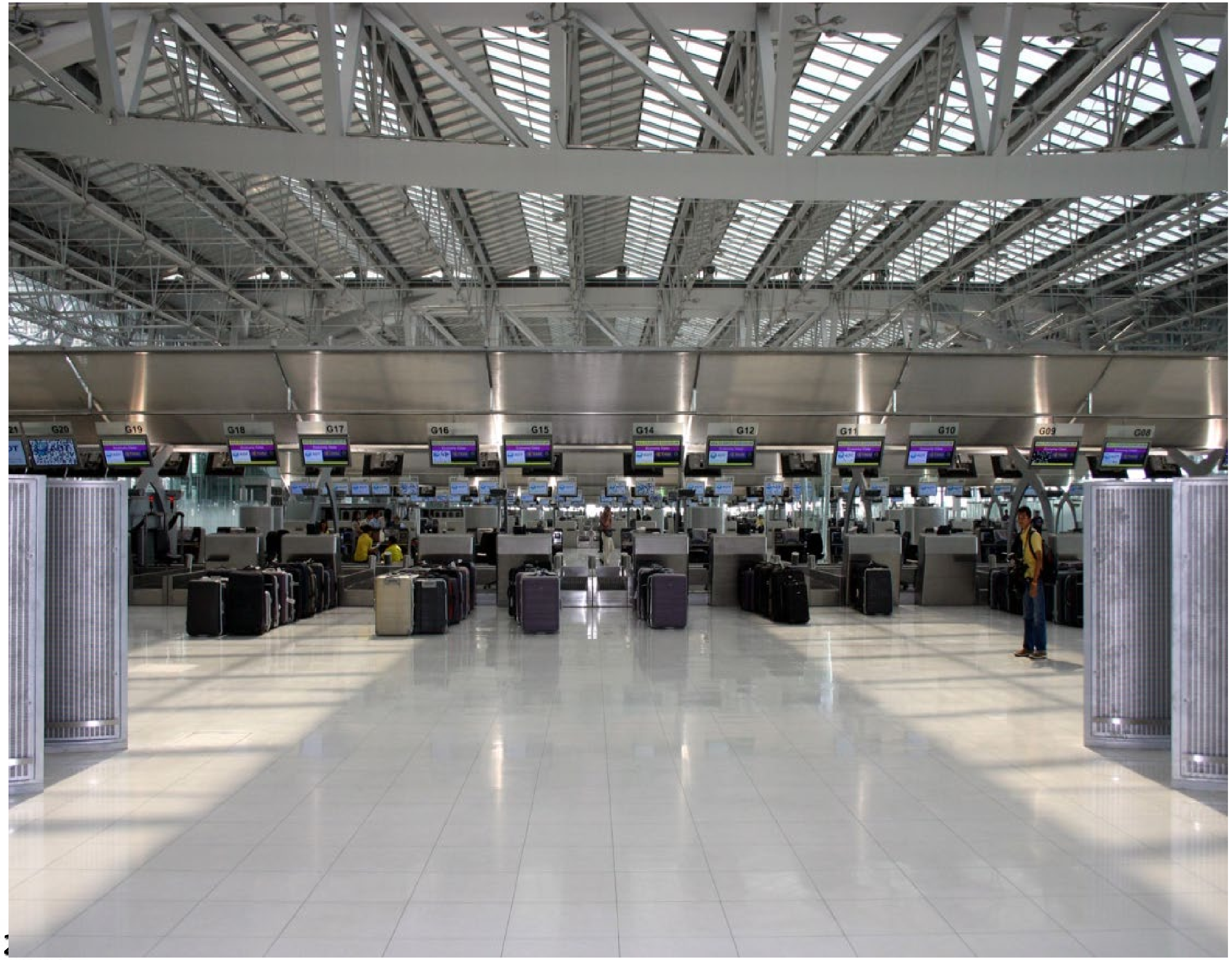
total load: 275 GWh/a
739 kWh/m²a

total load: 191 GWh/a
513 kWh/m²a

pic. I D 15

Installation of PEX pipes

Terminal building

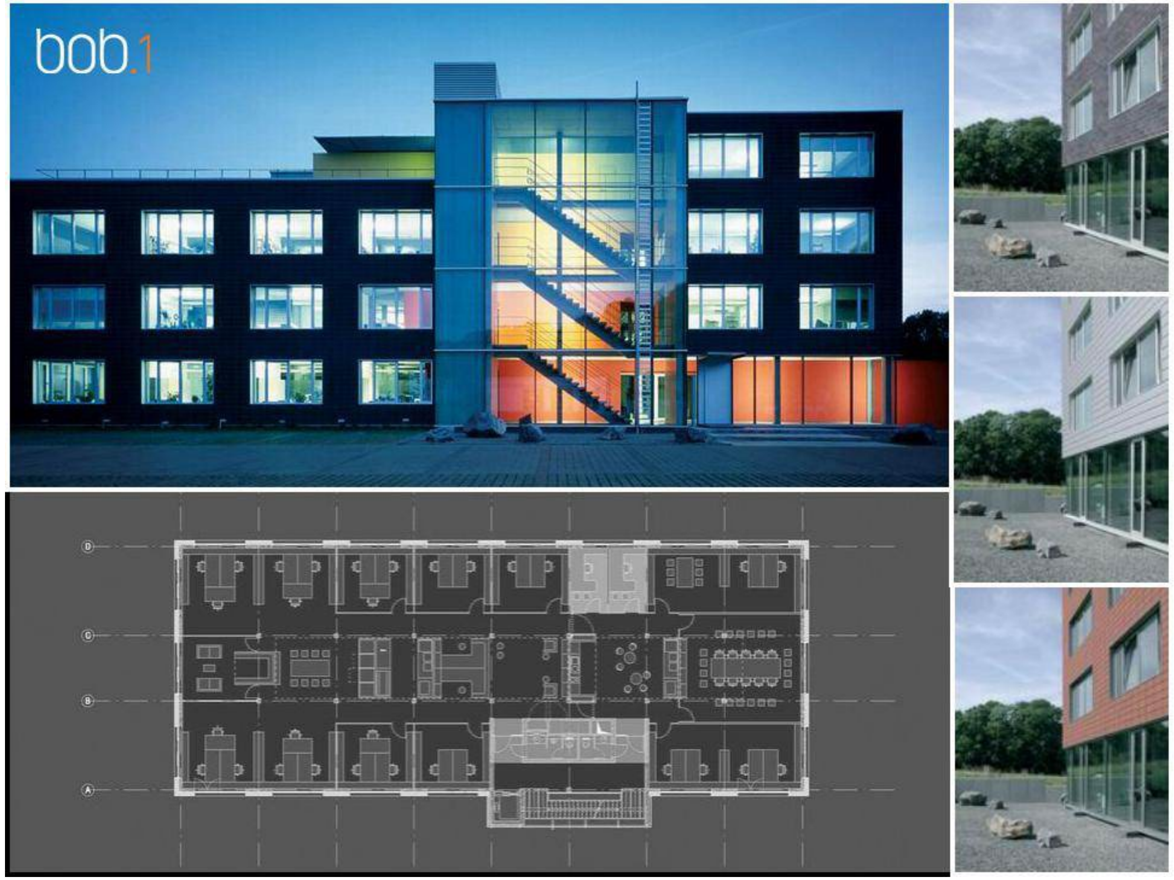



2006/ 3/ 8

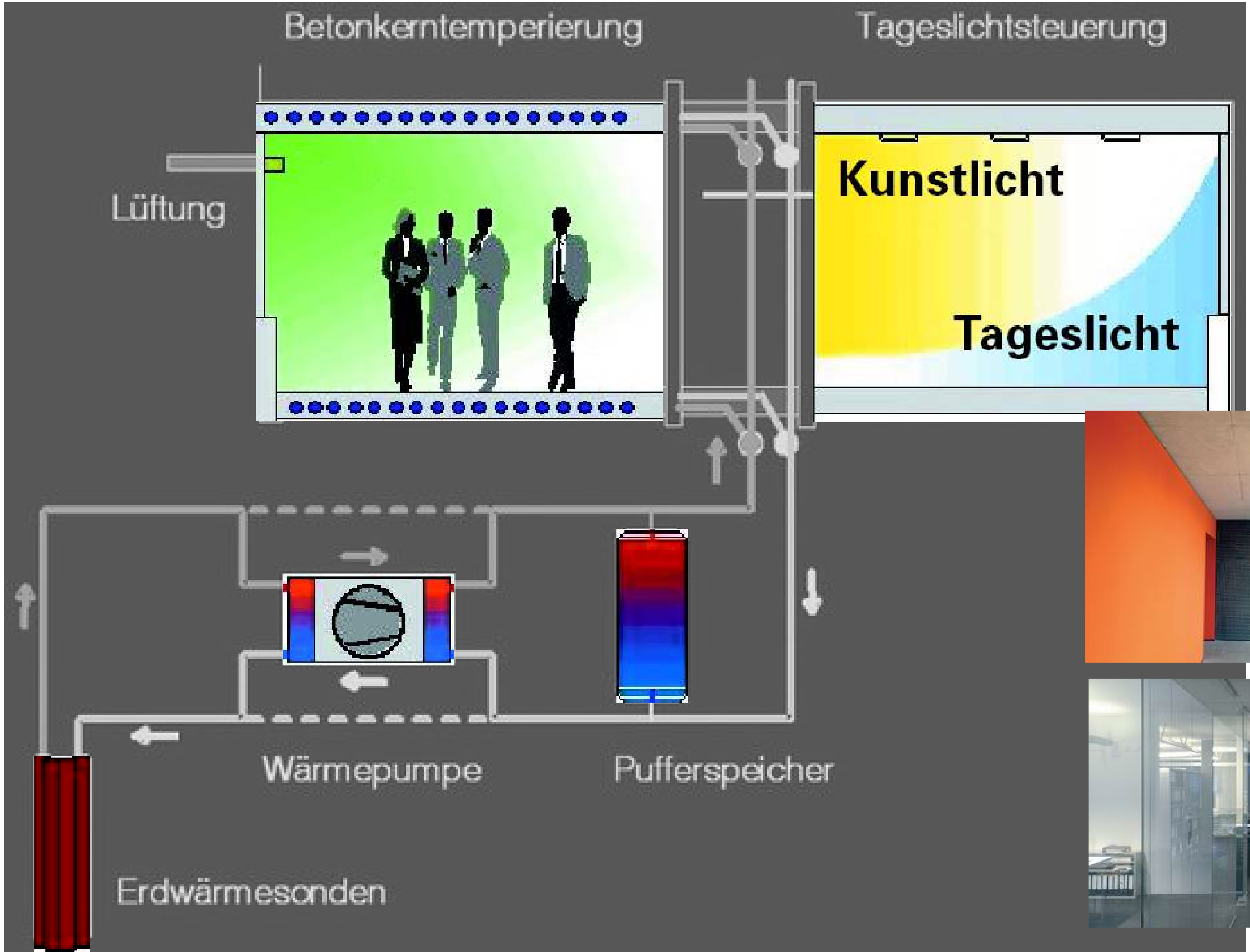

2006/ 3/ 8
$T_{supplyW}$ = 13 ºC
T_a = 16 ºC
T_d = 10 ºC

Balanced Office Building (BOB.1)
Aachen, Germany

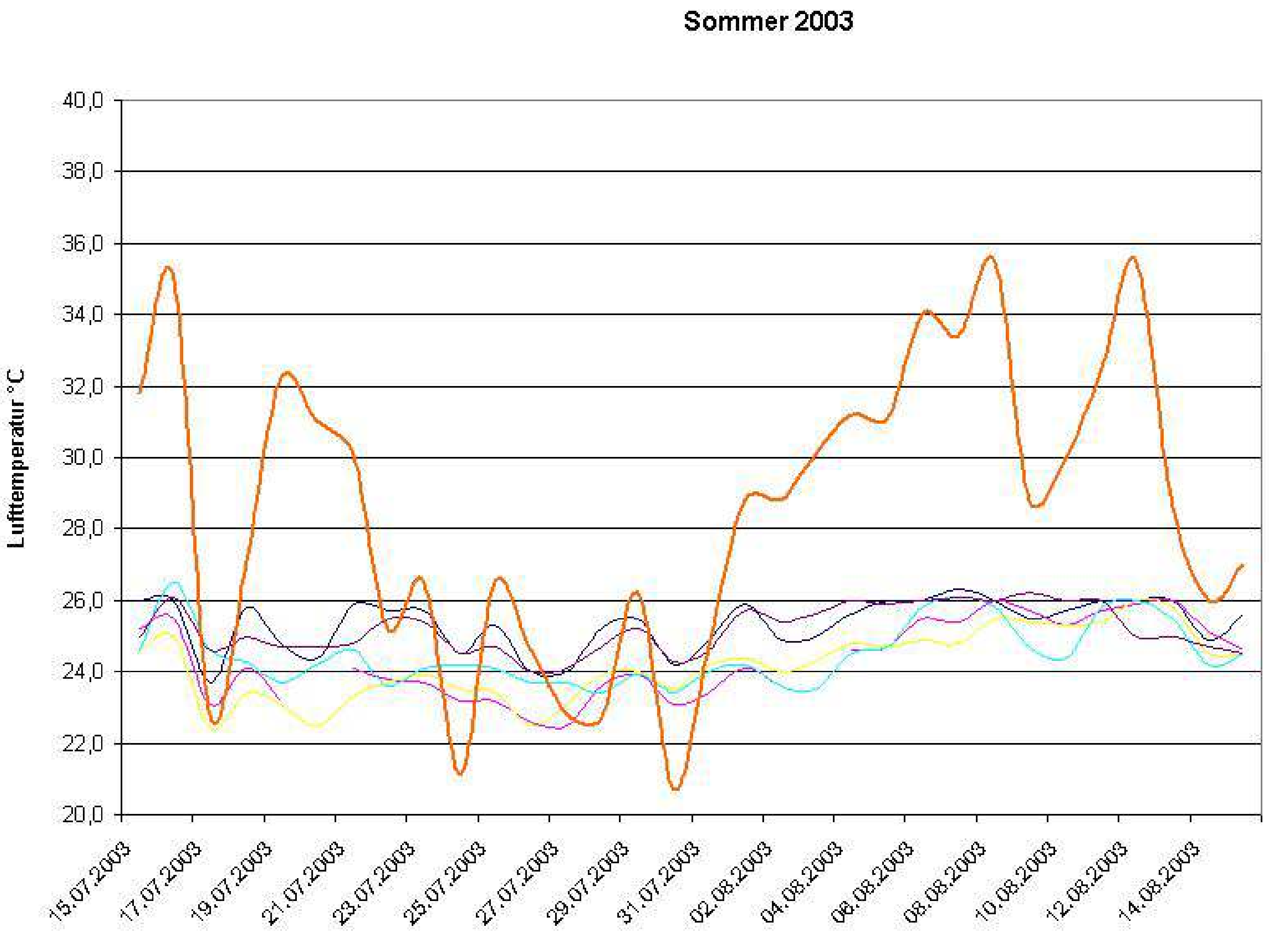
- Gross floor area 2,151 m²
- 4 storeys
- Efficiently insulated external envelope
- Ground-coupled heating and cooling with TABS
- Ventilation system with heat recovery
- Daylight-controlled lighting
- Rainwater collection for use in toilet flushing

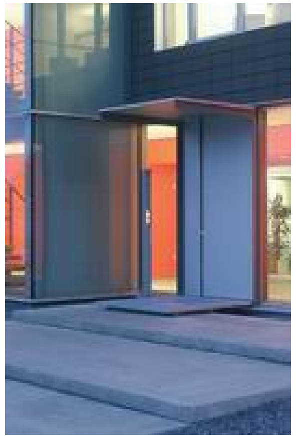


Energy concept in BOB.1

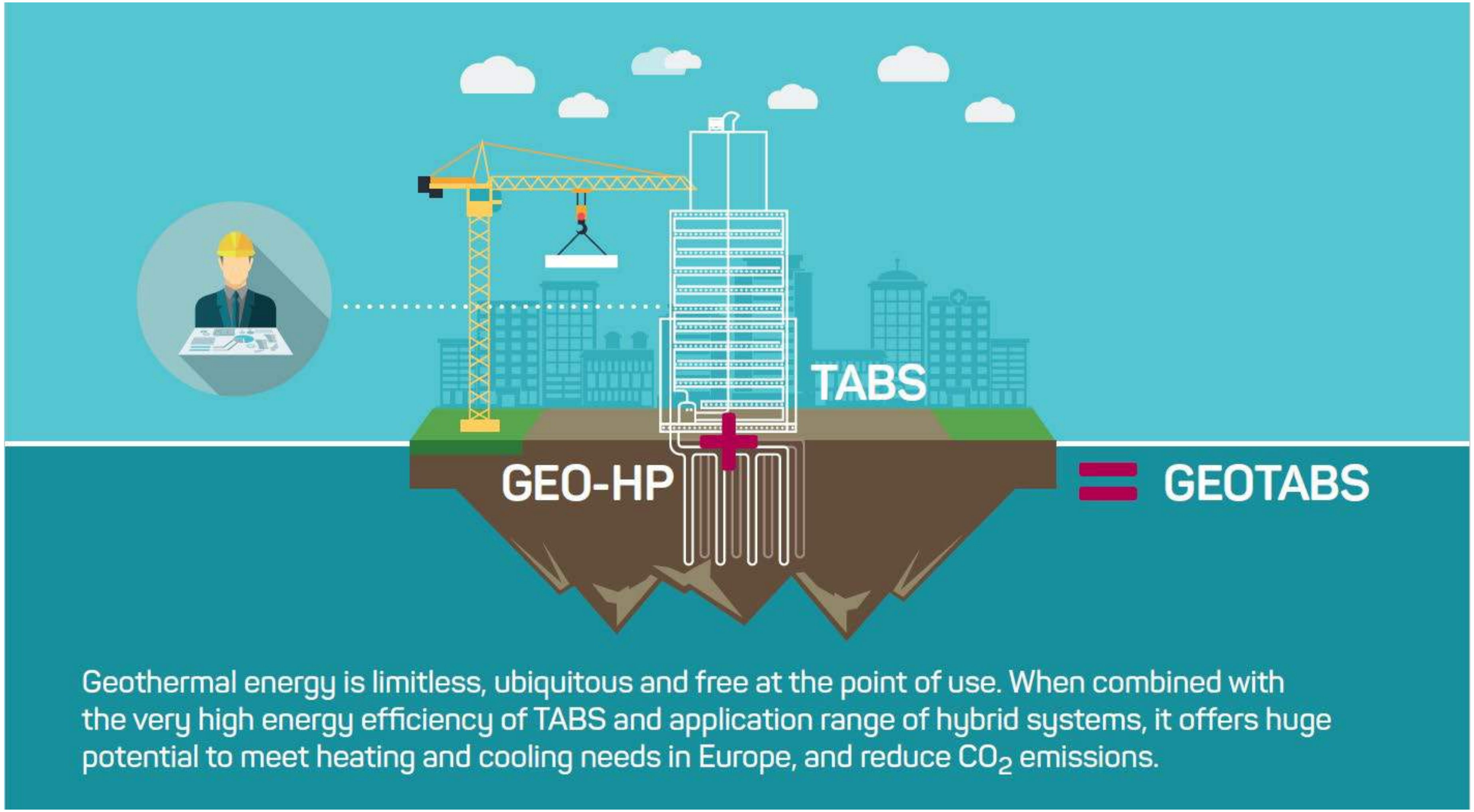


cooling period in BOB.1





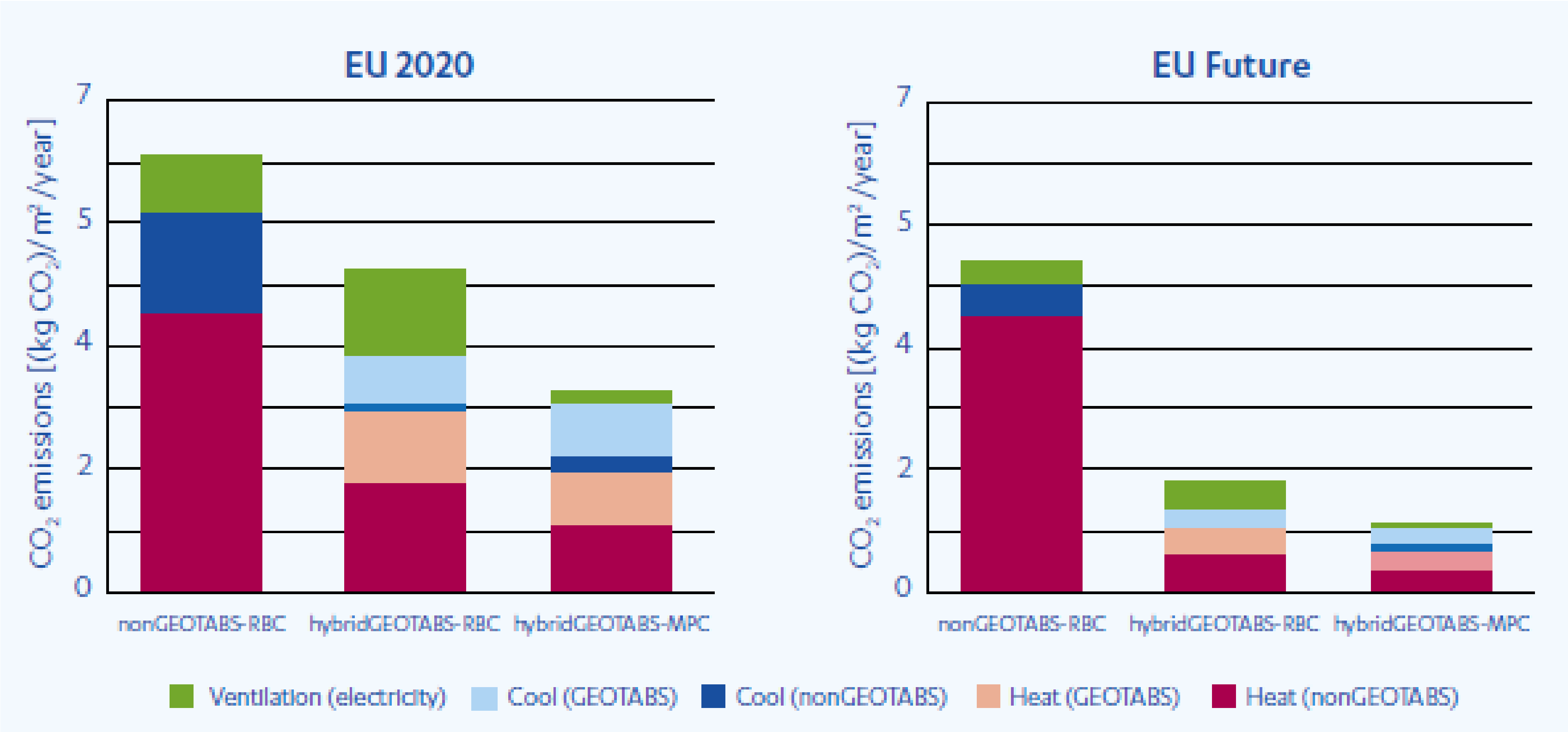
EU Project: Hybrid GEOTABS



https://www.hybridgeotabs.eu/

Boydens et al., Renewable and Storage-integrated Systems to Supply Comfort in Buildings, A&S/books, 2021
D5.2 & 5.3, Review of comfort, productivity, and health in hybrid MPC GEOTABS buildings, DTU & MU, hybridGEOTABS

Energy and CO_2 emission savings



Introducing GEOTABS as a primary system reduces CO2 emissions by about 26%, and additional savings of 38% are achieved by replacing the RBC with MPC.

The savings from MPC are mainly due to the reduction of electricity and preheating in the ventilation system and reduction of heating demands of the secondary system.

Yearly CO2 emissions by net-conditioned area for a nonGEOTABS-RBC, hybridGEOTABS-RBC and hybridGEOTABS-MPC office building simulation, considering the CO2 emissions in the average EU lectricity mix in 2020 (260 g CO_2/kWh) (left) and a low-carbon electricity mix (90 g CO_2/kWh) (right)

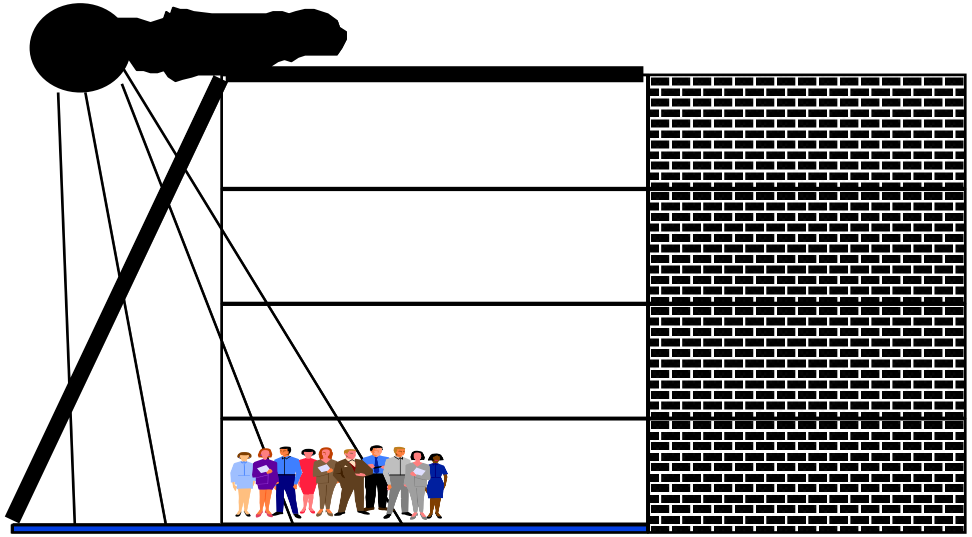
Demonstration buildings

a. Solarwind office building
b. Infrax office building
c. Ter Potterie elderly home
d. Libeznice primary school

Conclusions

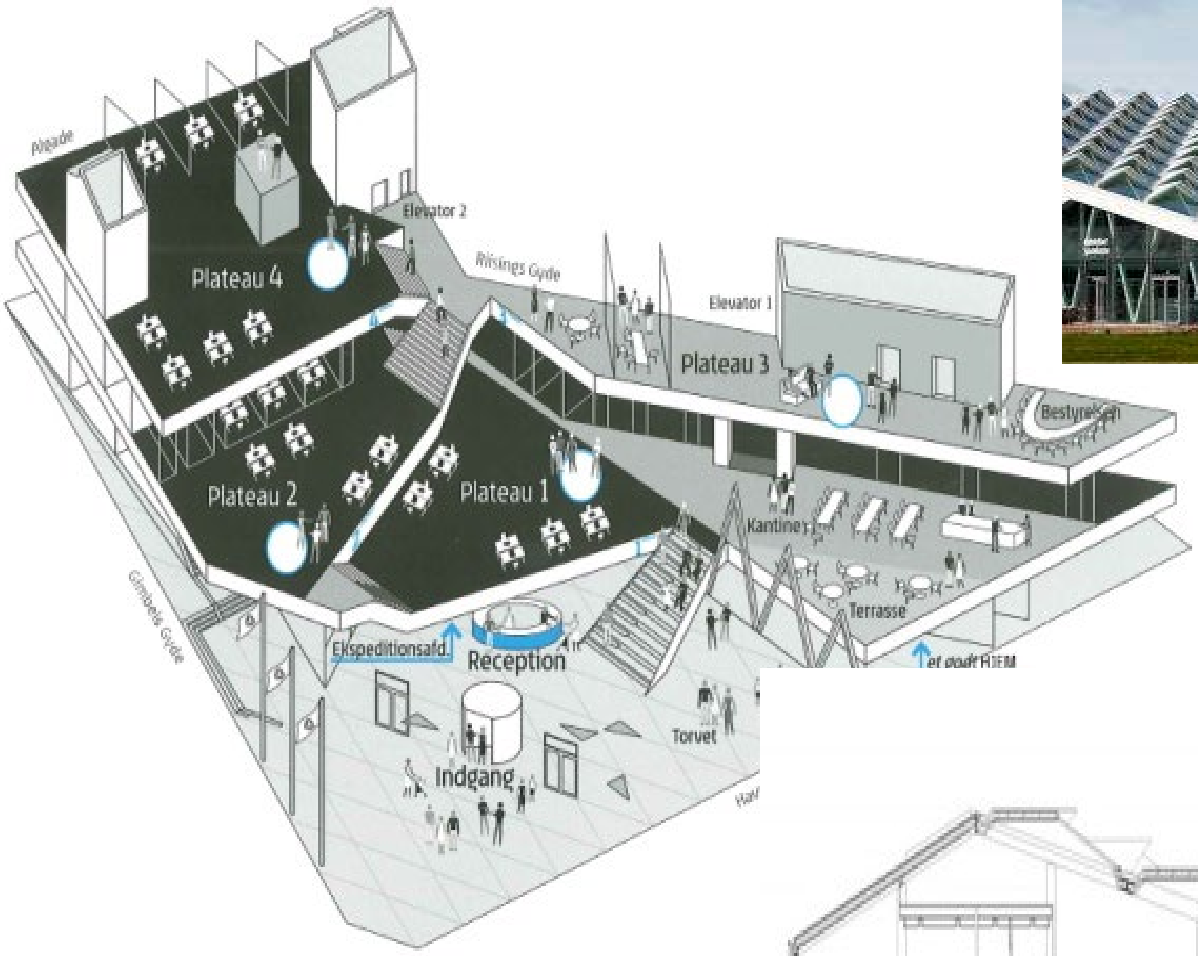
- No significant difference in IEQ between RBC and MPC according to physical measurements
- On average, IEQ-aspects were rated as good by the building occupants
- Despite a very uniform climate large interindividual differences were found
- MPC significantly improved energy-efficiency without any negative influences on the indoor climate

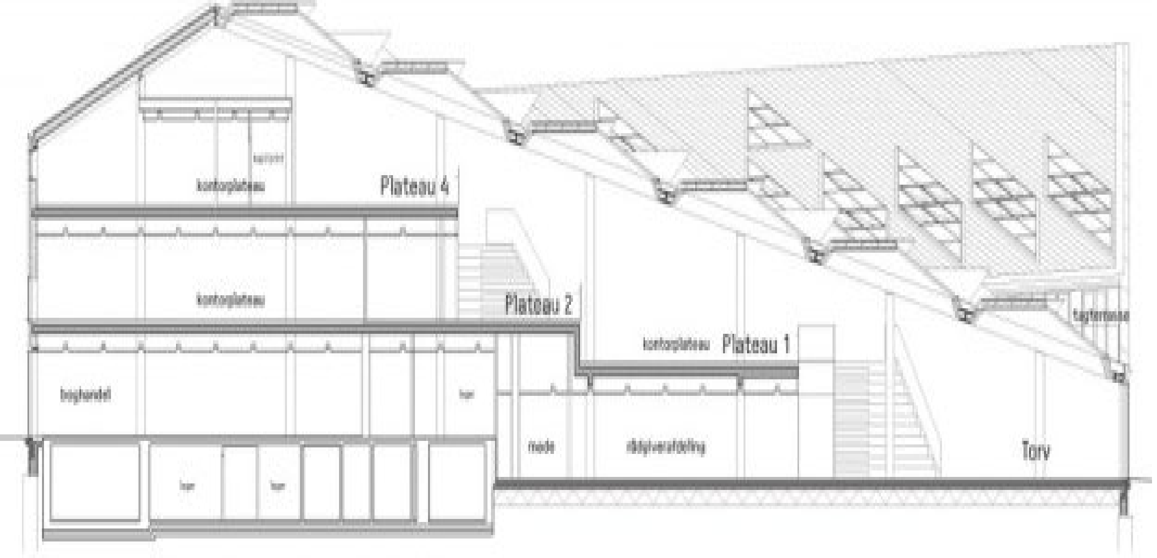
Radiant Floor Cooling



Opera House in Copenhagen
Summer indoor climate in Foyer

- Radiant floor cooling with stone cover down the structural slabs to reduce peak cooling load
- High air change by displacement ventilation system.
- Humidity control prevents condensation on floor.


Algade
Elevator 2
Risings Gyde
Elevator 1
Plateau 4
Plateau 3
Bestyrelsen
Plateau 2
Plateau 1
Kantine
Terrasse
Ekspeditionsafd.
Reception
Torvet
Indgang


kontorplateau
Plateau 4
kontorplateau
Plateau 2
kontorplateau
Plateau 1
boghandel
møde
rådgiverafdeling
Torv

References / South, West Europe

- Modern Old Port of Savona,
  NW coast of Italy

  — Underfloor heating for 140 high-end residential apartments and shopping area at ground level

- Dolce Vita Tejo, Lisbon, Portugal

  — one of Europe’s largest shopping centre, floor heating and cooling

Industrial heating/cooling application: BWM World Munich, Germany - 2007

- 16.500 m² of floor, glass and steel, architecture in the **BWM museum**
- 5,000 m² of industrial radiant cooling and heating with PE-Xa pipes integrated into the hall floor = **massive invisible cooling or heating panel**
- Full architectural freedom provided: An experience which appeals to all senses, allowing visitors to experience **the fascination of mobility**
- Energy-saving and environmentally friendly operation

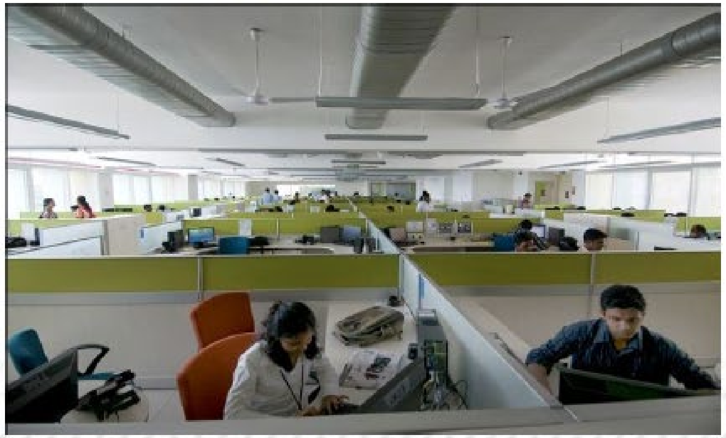
THE WORLD'S LARGEST SIDE BY SIDE COMPARISON OF VAV AND RADIANT COOLING

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

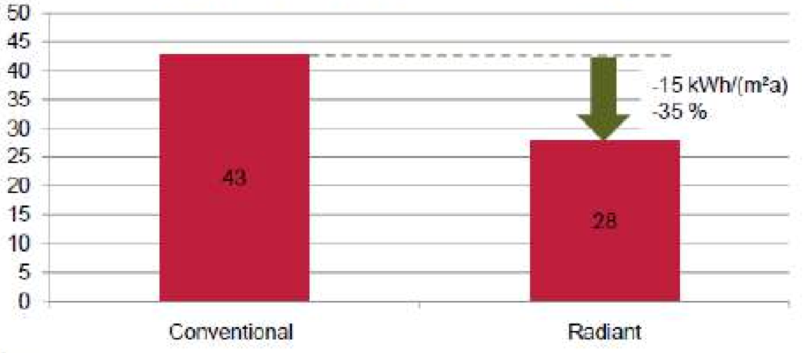
Energy

Radiant Cooling – Third Party Evaluation

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

SDB1: HVAC

Annual Electricity Consumption of HVAC [kWh/(m²a)]

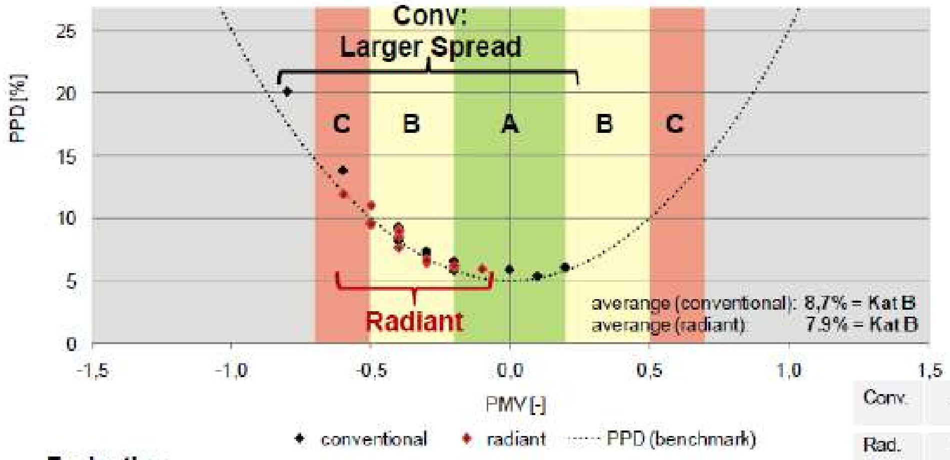


Evaluation Conventional: **HVAC consumption 15 kWh/(m²a) respectively 50 % higher** compared to Radiant.

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 %)

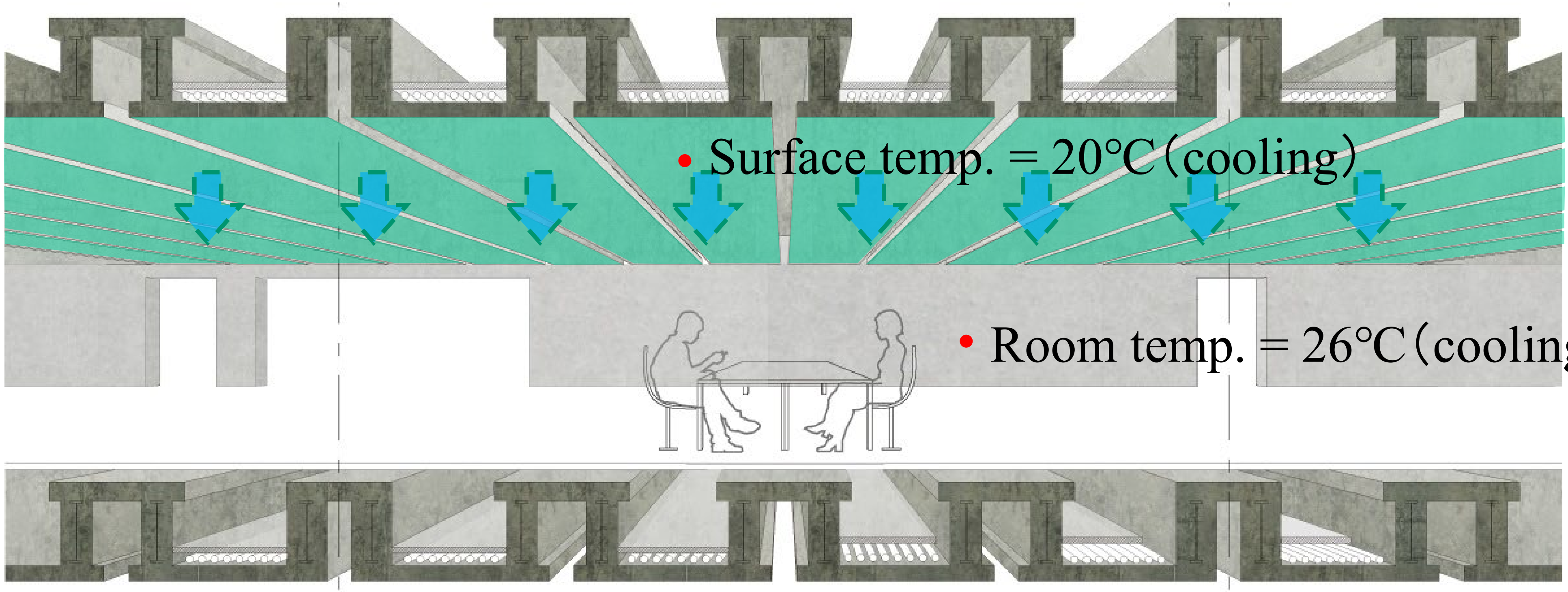
Technische Universität Braunschweig

July 20, 2011 | Univ. Prof. Dr.-Ing. M. Norbert Fisch | IGS - Präsentation | Seite 15

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

Shogakukan Building

Radiation Cooling and Heating



Healthy and comfortable

・Improvement in quality of room air by increasing supply rate of fresh air.

Energy Conservation

・Reduction in heat transfer energy by converting heating medium (air→water).

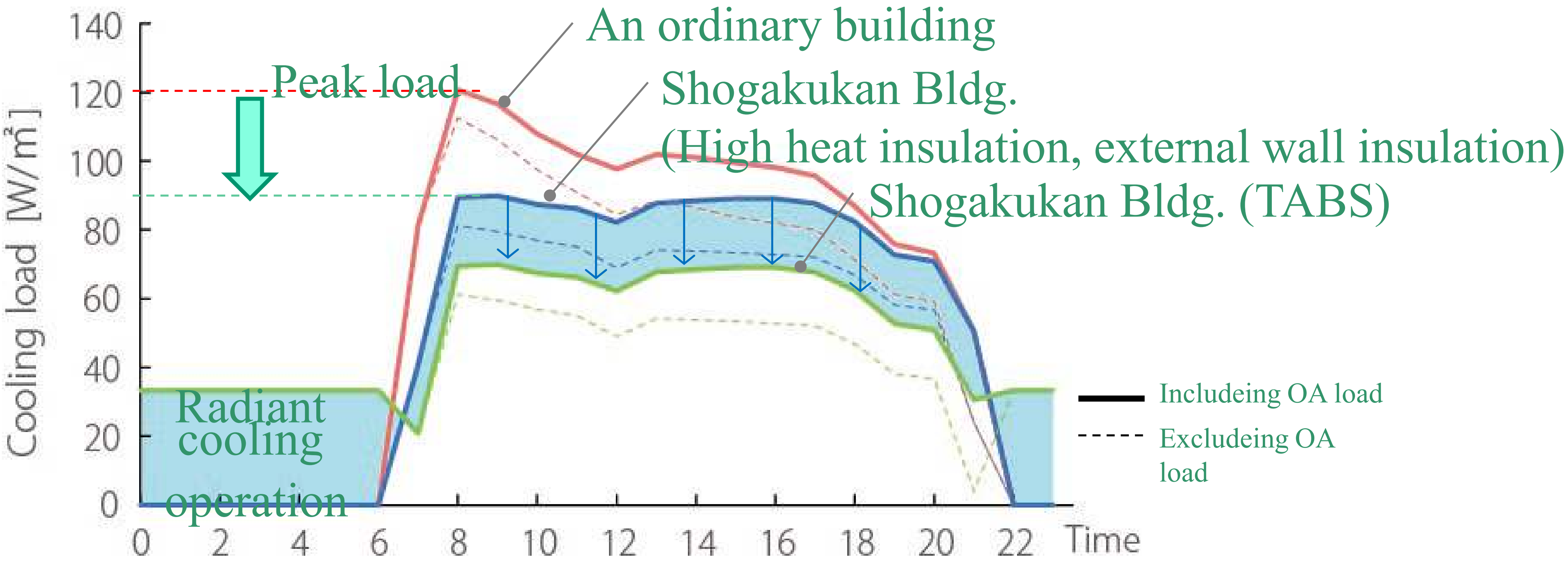
・Improvement in heat pump COP by raising temperature of supply chilled water.

TABS

With the situation that nuclear power plants remain inoperable, the electricity in Japan is still tight.

⇒ **Reduce power demand**

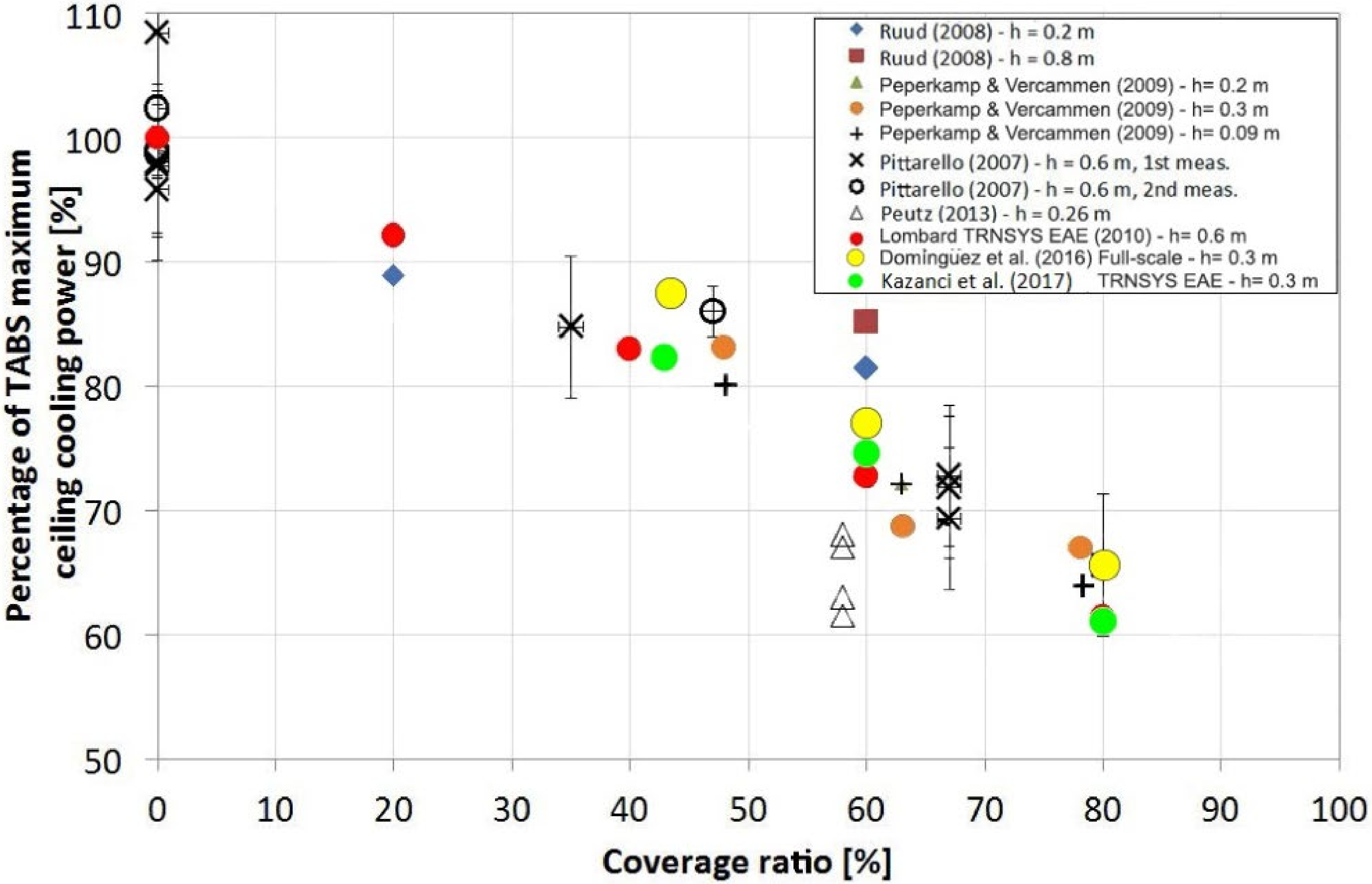
～ Comparison of the cooling loads ～



Run radiant operation at night ⇒ 20W/㎡ is decreased in daytime

TABS-ACOUSTIC

- Cooling performance reduction as a function of the ceiling coverage ratio

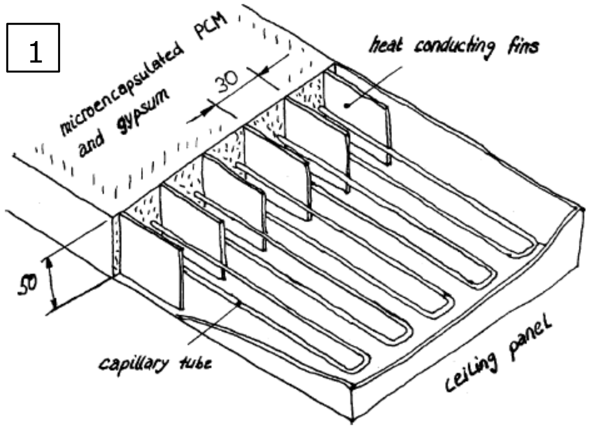


Adapted from Lombard, 2010 and Dominguez et al. 2017. *h* in the legend is the distance between the ceiling and sound absorbers

How to get similar TABS benefits in existing buildings?

International Centre for Indoor Environment and Energy

1



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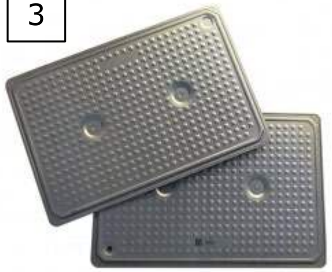
3



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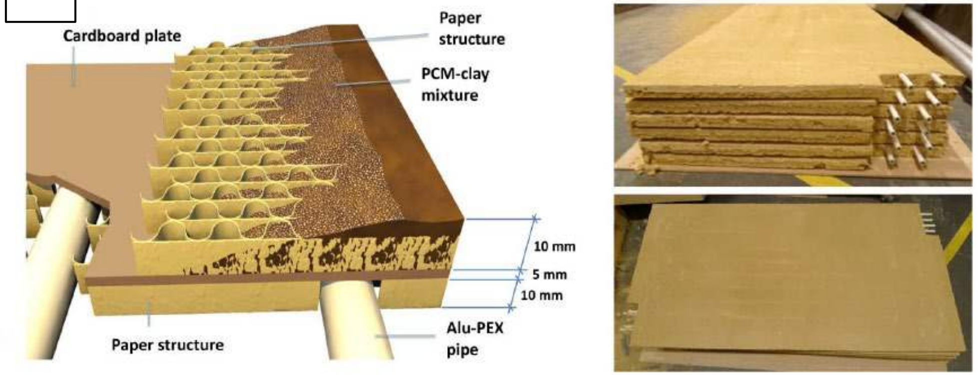
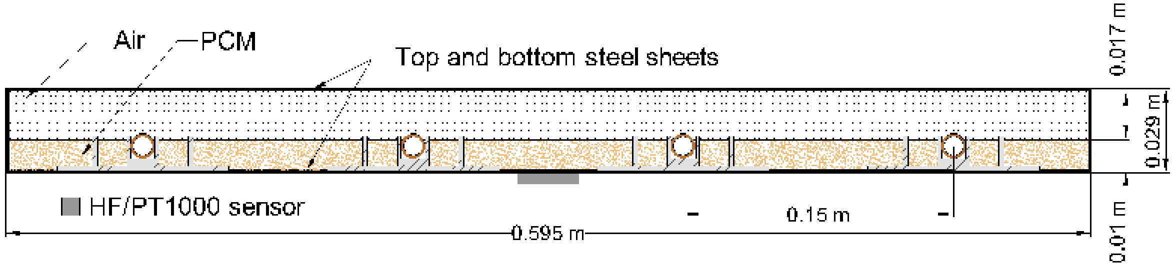


Radiant ceiling panels **with Phase Change Materials (PCM)**

5



[1]Markus Koschenz and Beat Lehmann, "Development of a thermally activated ceiling panel with PCM for application in lightweight and retrofitted buildings", Energy and Buildings, 2004

[3]R. T. GmbH, "rubitherm.eu," Rubitherm, 2022. [Online]. https://www.rubitherm.eu/en/index.php/productcategory/makroverkaspelung-csm. [Accessed 21 April 2022]

[4]Thermacool Panel and Tile, Phase Change Materials | PCMs | Ceiling Systems : ThermaCool, [Accessed 21 April 2022]

[2]Georgi Krasimirov Pavlov, "Building Thermal Energy Storage", PhD Thesis DTU, 2014

[5]Bogatu et al., An experimental study of the active cooling performance of a novel radiant ceiling panel containing phase change material (PCM), Energy and Buildings, 2021

ZERO-Carbon Emission Buildings

- Carbon emission during operation
- Carbon emission during production, maintenance, destruction

Whole Life Carbon Emission Distribution for Average Commerical Building

Annual: **225** KWh/M²

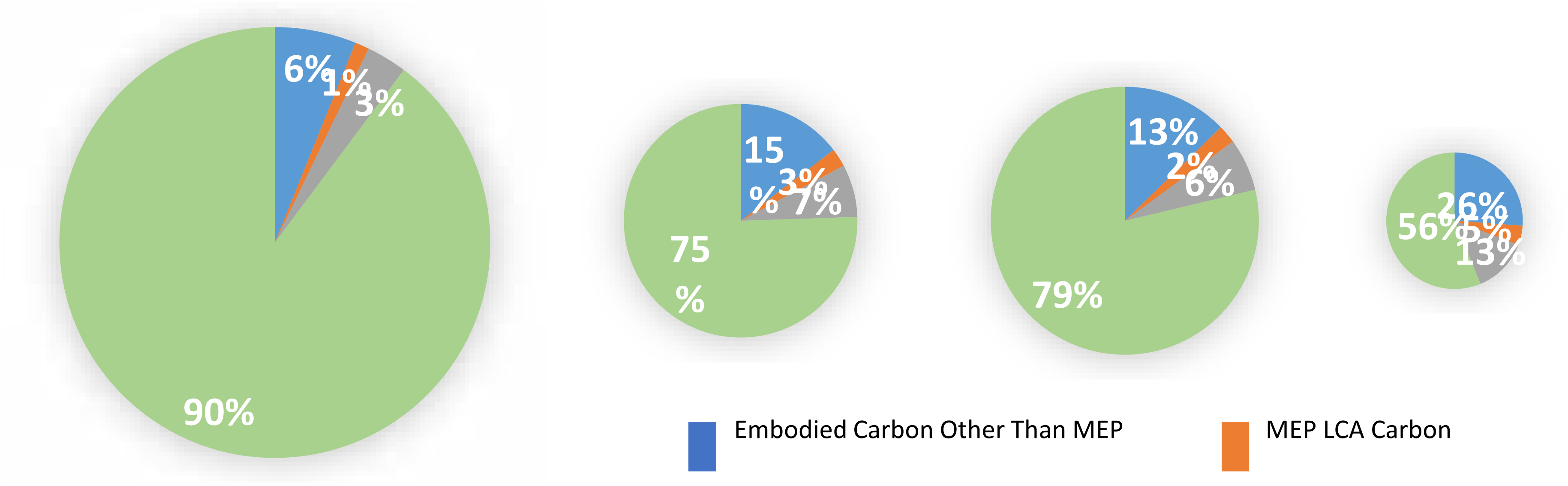
Annual: **100** KWh/M²

Global Average Grid
(0.475 kg CO_2/KWh)

Cleaner Grid (Spain)
(0.167 kg CO_2/KWh)

Global Average Grid
(0.475 kg CO_2/KWh)

Cleaner Grid (Spain)
(0.167 kg CO_2/KWh)



Embodied Carbon Other Than MEP

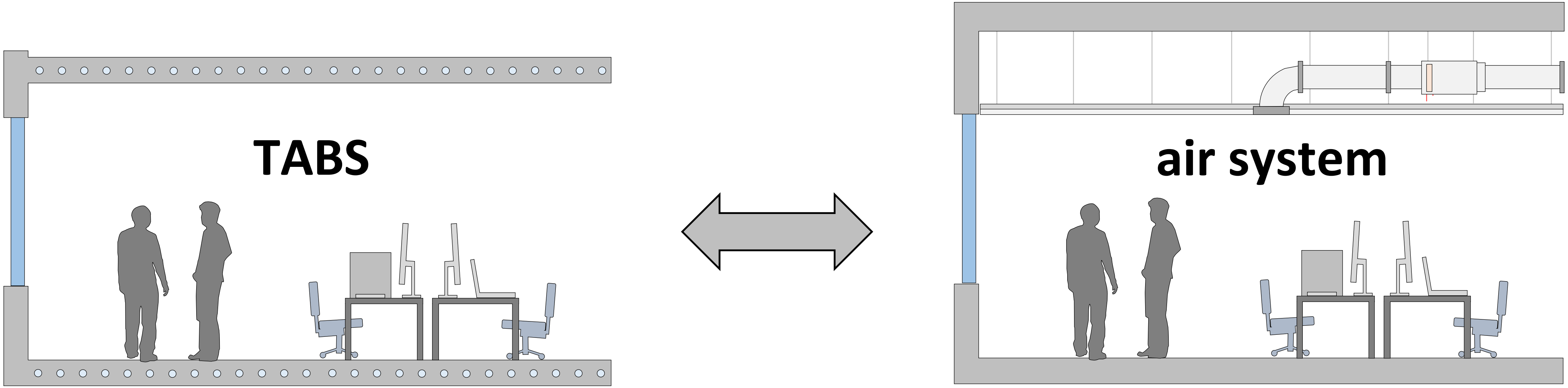
MEP LCA Carbon

Refrigerant LCA Carbon

Operational Carbon

https://www.iea.org/reports/global-energy-co2-status-report-2019/emissions

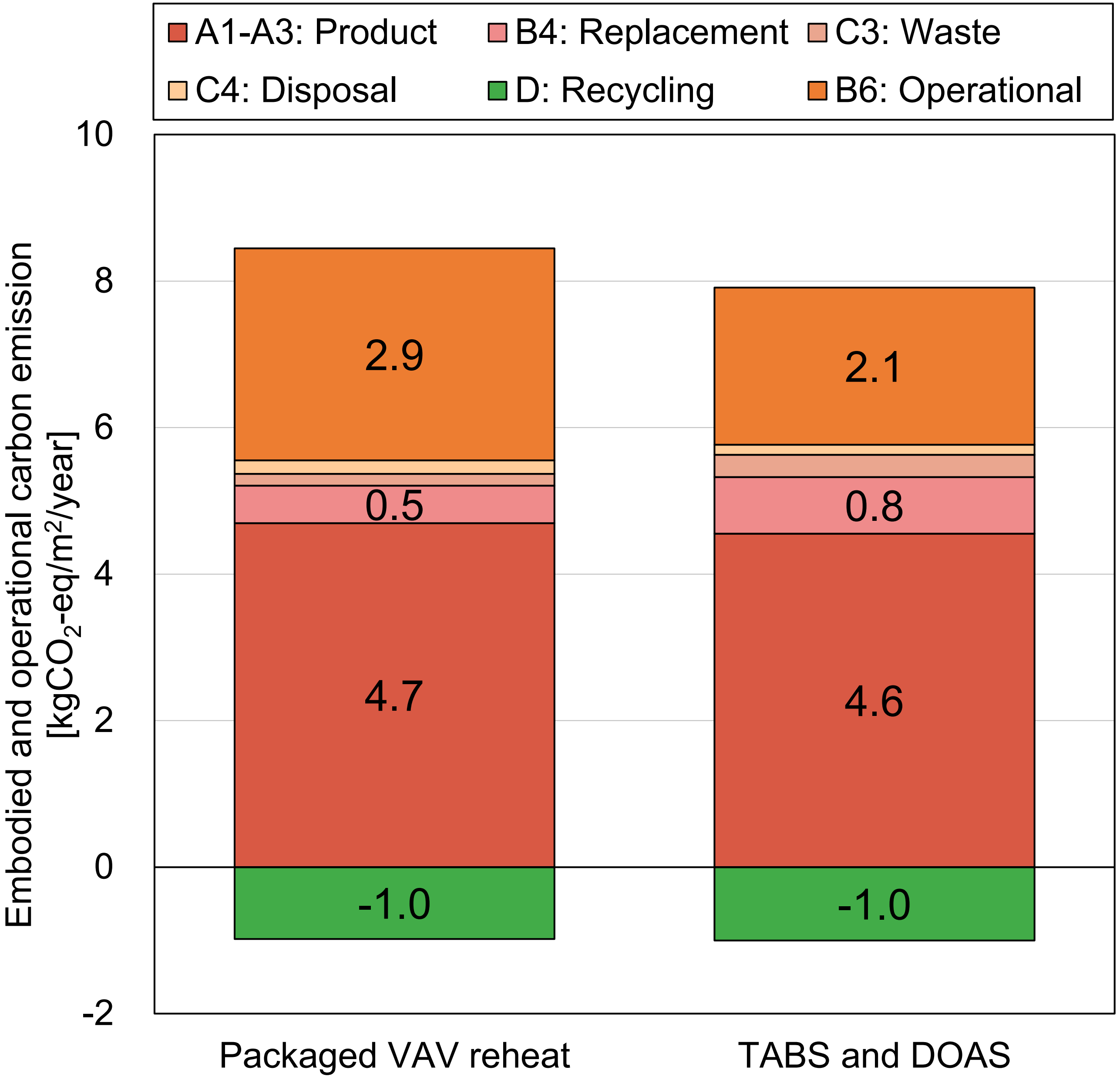
Operational and embedded carbon in TABS and air system



- Energy efficiency and sizing
- Embedded carbon of MEP
- Floor height and non-ceiling panel
- Renewable resource (Geothermal)

Utilities	Emission Factors, GWP [$kgCO_2$-eq/kWh]	
	EN/ISO 52000-1:2017 Table B.16	Building Regulations, (BR18)
Electricity	0.420	**0.187**
District Heating	0.260	**0.105**

Case study results



Konklusion

Også under fremtidige krav til:

- Lav CO_2 emission i brugsfasen
- Lav CO_2 i produktion, vedligeholdelse af systemer
- Øget brug af regenererbar energi (vind, PV, jordvarme etc.)
- Flexibelt energiforbrug
- Et komfortabelt og produktivt indeklima

Er lav-temperatur opvarmning og høj-temperatur-køling "et godt tilbud"