
DTU
Possibilities and limitations for using water based radiant heating and cooling systems.
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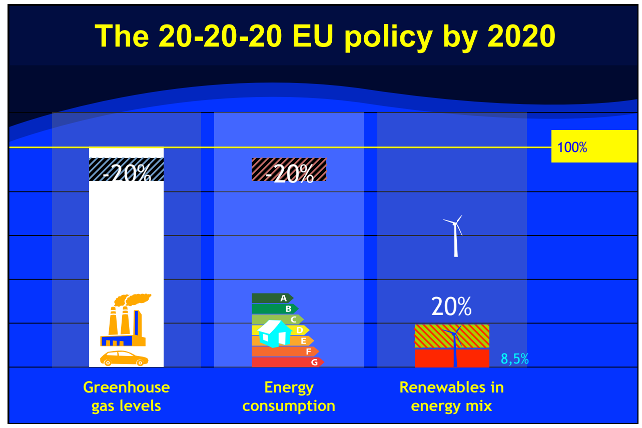
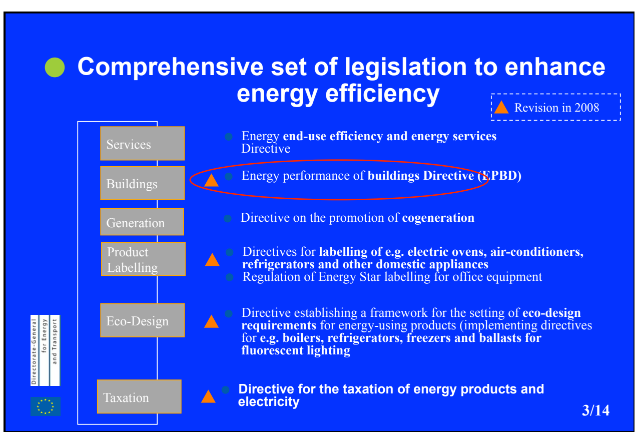
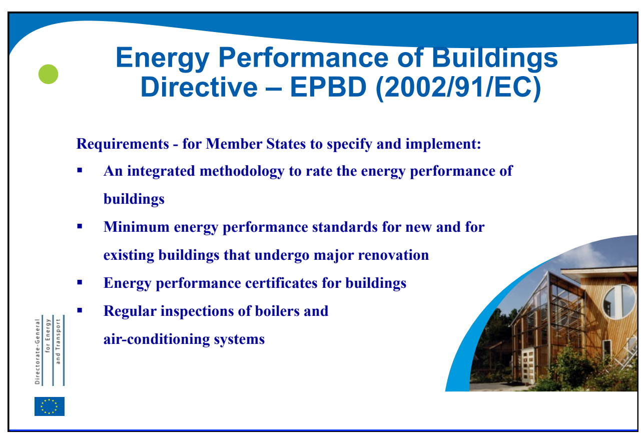
I C I E E

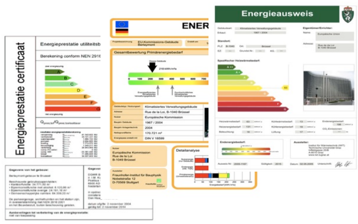

The 20-20-20 EU policy by 2020
100%
-20%
-20%
20%
8,5%
Greenhouse gas levels
Energy consumption
Renewables in energy mix


Comprehensive set of legislation to enhance energy efficiency
Revision in 2008
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
3/14


Energy Performance of Buildings Directive – EPBD (2002/91/EC)
Requirements - for Member States to specify and implement:
An integrated methodology to rate the energy performance of buildings
Minimum energy performance standards for new and for existing buildings that undergo major renovation
Energy performance certificates for buildings
Regular inspections of boilers and air-conditioning systems

EPBD – Energy Performance Certificate

Example for Member States' room for manoeuvre:



Directorate-General for Energy and Transport

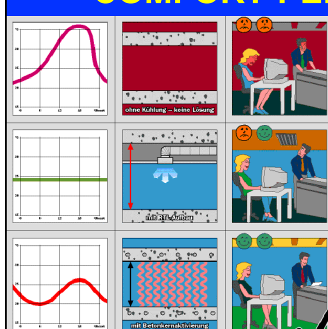
Achieving Excellence in Indoor Environmental Quality

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

Energy Efficient Technologies

- Indoor air quality
  - Pollution sources
  - Air distribution (contaminant removal) effectiveness
  - Personal ventilation
  - Air cleaning
- Thermal comfort
  - Low Temperature Heating- and High Temperature Cooling Systems
  - Thermo-Active-Building-Systems (TABS)
  - Drifting temperatures

COMFORT-PERFORMANCE



No cooling – decreased performance
Low energy costs
Low operation costs

Full Air-Conditioning
Constant temperature
Draught, Noise, SBS
High energy costs
High operation costs

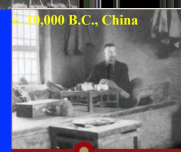
Thermo-Active-Building-Systems
Temperature ramps
Reasonable energy costs
Low operation costs

CONCEPTS OF RADIANT HEATING AND COOLING SYSTEMS

- **Heating - cooling panels**
- **Surface systems**
- **Embedded 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

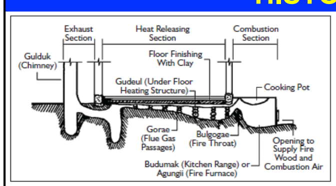
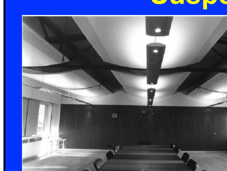


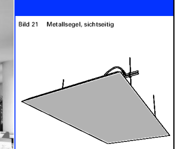
Figure 2: Structure of entirely ondol floored room.[9]

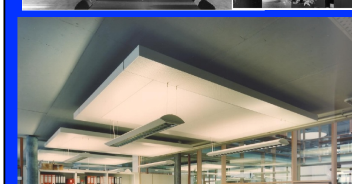
c. 1904, Liverpool Cathedral
heated with system based on the hypocaust principles

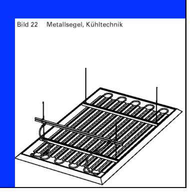
Hypocausts were used from the third century B.C. in ancient Europe.

Suspended cooled ceilings

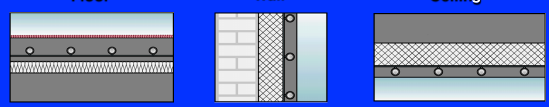




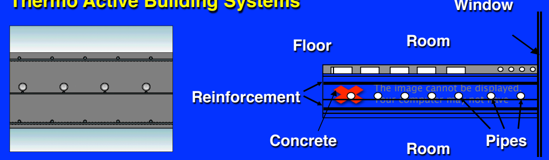




Radiant surface heating and cooling systems



Thermo Active Building Systems



Embedded piping systems

- Free use of space
- No cleaning
- Safety
- Comfort
- Energy

Low-Temperature heating High-Temperature Cooling

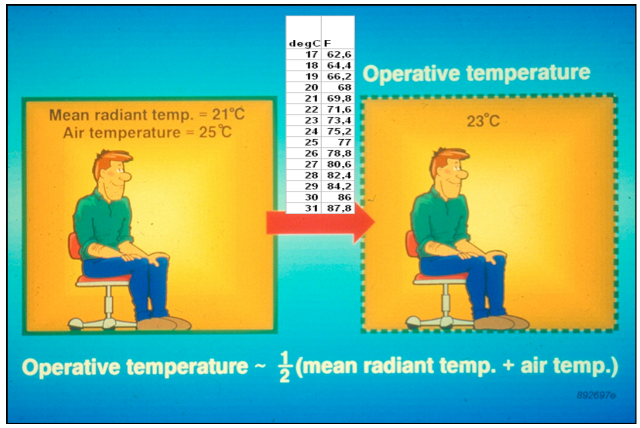
- Higher efficiency of boilers and chillers
- Lower distribution losses
- Better use of renewable energy sources
- Low energy consumption for circulation
- Future flexibility
- Low Exergy

THERMAL COMFORT

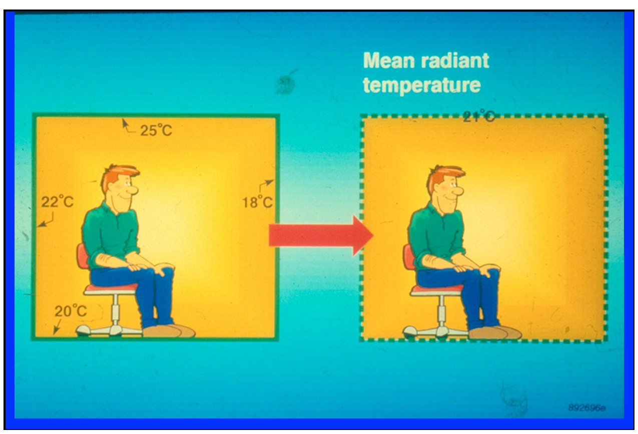
- $-0,5 < PMV < +0,5$; $PPD < 10$ %
- Spaces with sedentary work :
  - Summer clothing 0,5 clo
  - Winter clothing 1,0 clo
  - Activity level 1,2 met
- OPERATIVE TEMPERATURE
- WINTER 20 °C (68F)< t_o < 24 °C(75.2F)
- SUMMER 23 °C (73.4F) < t_o < 26 °C (78.8F).

OPERATIVE TEMPERATURE

- $t_o = (h_c t_a + h_r t_r)/(h_c + h_r)$
- $t_o = 0.5t_a + 0.5t_r$ (low air velocity)
    - » t_a = Air temperature
    - » t_r = Mean radiant temperature
    - » h_c = Convective heat exchange coefficient
    - » h_r = Radiative heat exchange coefficient



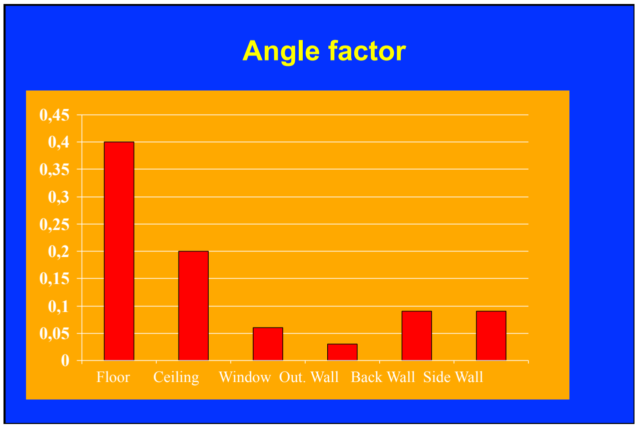
degC	F
17	62,6
18	64,4
19	66,2
20	68
21	69,8
22	71,6
23	73,4
24	75,2
25	77
26	78,8
27	80,6
28	82,4
29	84,2
30	86
31	87,8

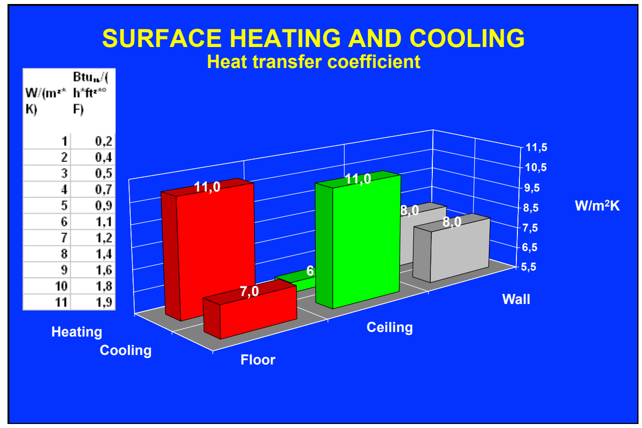


Mean Radiant Temperature

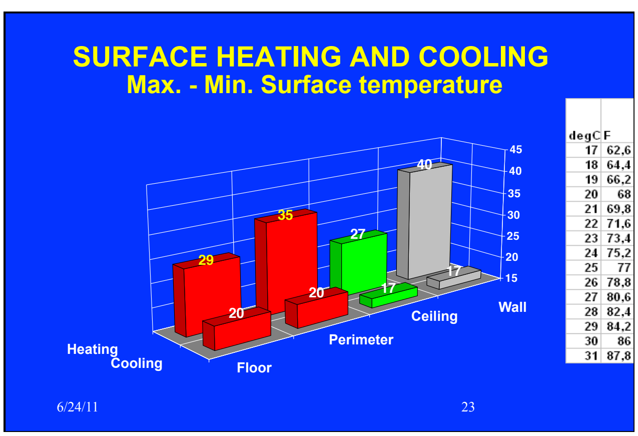
- $t_r = \Sigma F_{p\text{-}i}\ t_{si}$
    - $F_{p\text{-}i}$ = Angle factor from person to surface i
    - t_{si} = Surface temperature of surface i
    - $\Sigma F_{p\text{-}i} = 1$

Seite 5

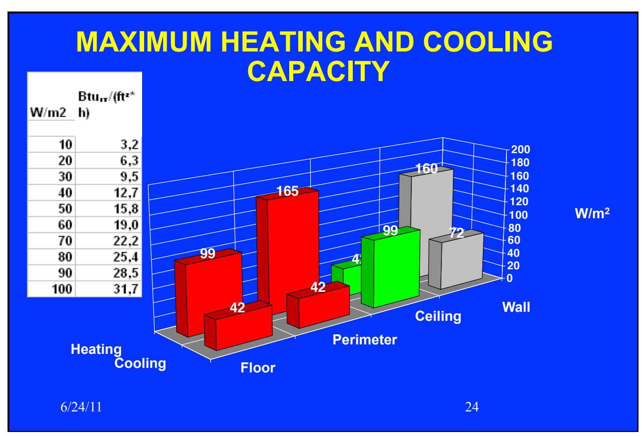




W/(m²*K)	Btu$_{IT}$/(h*ft²*°F)
1	0,2
2	0,4
3	0,5
4	0,7
5	0,9
6	1,1
7	1,2
8	1,4
9	1,6
10	1,8
11	1,9



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

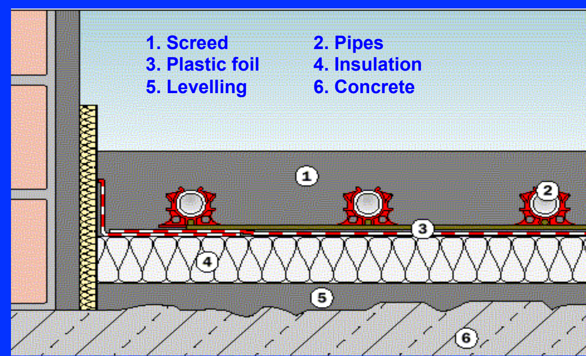


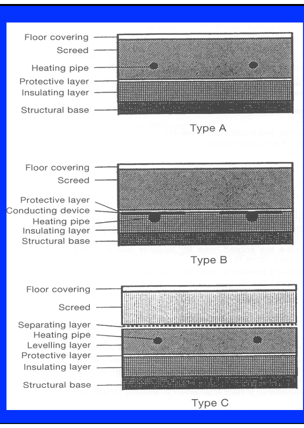
W/m2	Btu$_{IT}$/(ft²*h)
10	3,2
20	6,3
30	9,5
40	12,7
50	15,8
60	19,0
70	22,2
80	25,4
90	28,5
100	31,7

ISO/TC 205/WG 8
Radiant Heating & Cooling System

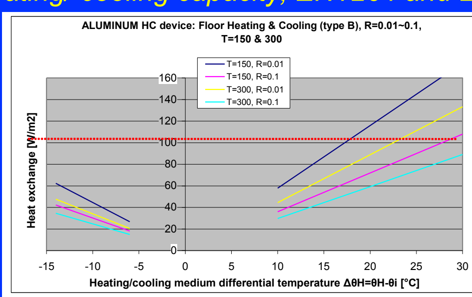
New standard

Part 1	Definition, symbols, and Comfort criteria	ISO/DIS 11855-1
Part 2	Heating and cooling capacity	ISO/DIS 11855-2
Part 3	Design and Dimensioning	ISO/DIS 11855-3 (July)
Part 4	Dynamic analysis	ISO/DIS 11855-4
Part 5	Installation and commissioning	ISO/CD 11855-5
Part 6	Operation and maintenance	ISO/CD 11855-6 (July)
Part 7	Electrical embedded heating system	





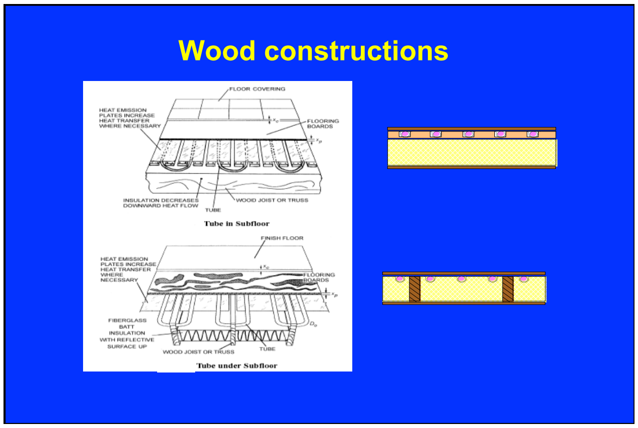
Heating/ cooling capacity, EN1264 and EN 15377

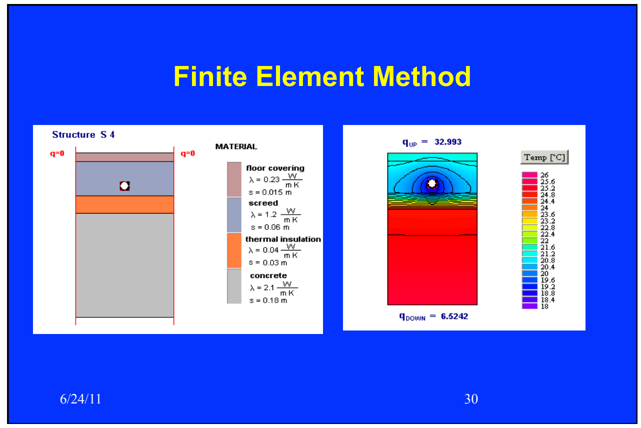


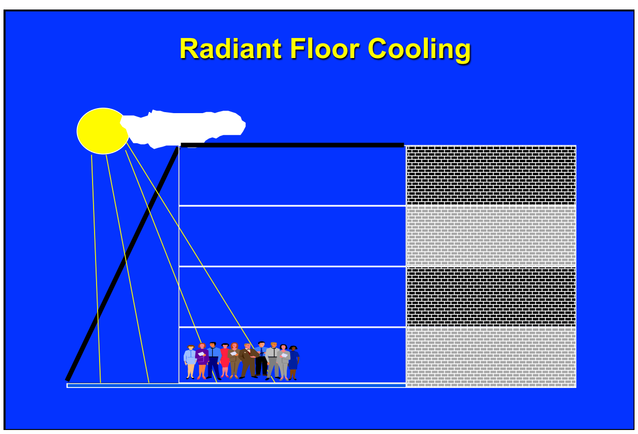
W/m2	Btu$_{IT}$/(ft²* h)
10	3,2
20	6,3
30	9,5
40	12,7
50	15,8
60	19,0
70	22,2
80	25,4
90	28,5
100	31,7

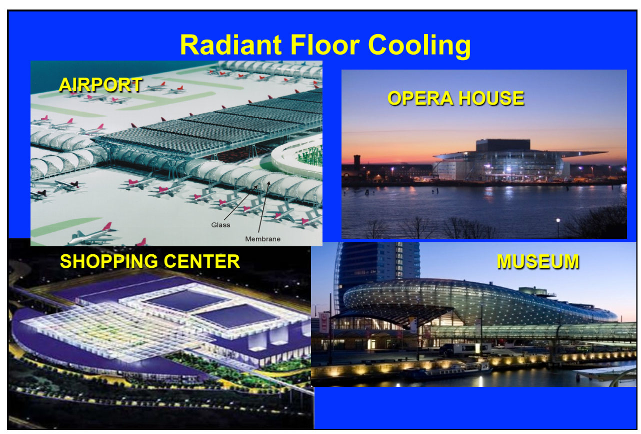
Figure 4.17 Heat exchange between the surface (with ceramic tiles, wooden parquets or carpet $R_{?B}$=0.1 and no covering $R_{?B}$=0) and the space when aluminium heat conductive device used

Seite 7


Wood constructions
FLOOR COVERING
HEAT EMISSION PLATES INCREASE HEAT TRANSFER WHERE NECESSARY
FLOORING BOARDS
INSULATION DECREASES DOWNWARD HEAT FLOW
TUBE
WOOD JOIST OR TRUSS
Tube in Subfloor
FINISH FLOOR
HEAT EMISSION PLATES INCREASE HEAT TRANSFER WHERE NECESSARY
FLOORING BOARDS
FIBERGLASS BATT INSULATION WITH REFLECTIVE SURFACE UP
WOOD JOIST OR TRUSS
TUBE
Tube under Subfloor

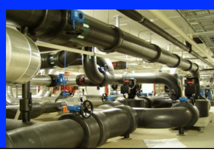

Finite Element Method
Structure S 4
q=0
q=0
MATERIAL
floor covering
λ = 0.23 W/mK
s = 0.015 m
screed
λ = 1.2 W/mK
s = 0.06 m
thermal insulation
λ = 0.04 W/mK
s = 0.03 m
concrete
λ = 2.1 W/mK
s = 0.18 m
q_UP = 32.993
Temp [°C]
26
25.6
25.2
24.8
24.4
24
23.6
23.2
22.8
22.4
22
21.6
21.2
20.8
20.4
20
19.6
19.2
18.8
18.4
18
q_DOWN = 6.5242
6/24/11
30


Radiant Floor Cooling


Radiant Floor Cooling
AIRPORT
Glass
Membrane
OPERA HOUSE
SHOPPING CENTER
MUSEUM

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



Slide 33

BBI airport, Berlin, Germany.

76,750 m² to be heated/cooled with floor system

- The in-city airports in Berlin will be closed and replaced by the new BBI
- In future, up to 6,500 persons will be starting or landing at the new airport in a typical hour.
- There will be a floor heating/cooling realized in 2010

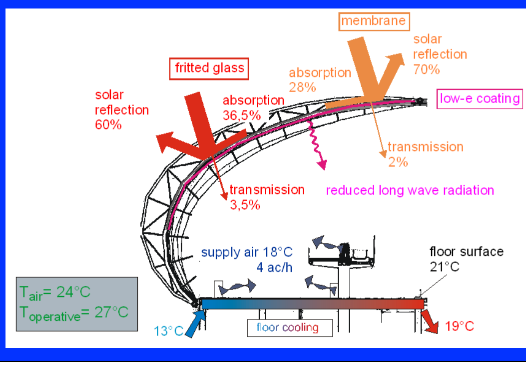
Airport Bangkok

HEAT LOADS

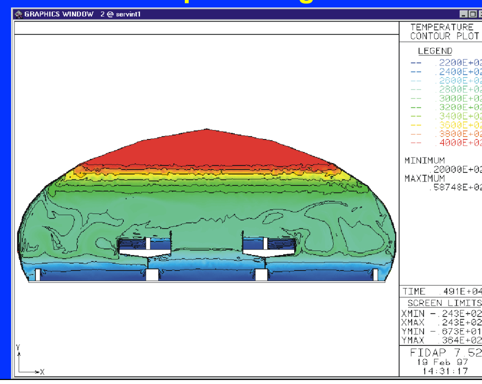
- Once the heat load to the space had been determined, the conditioning system was being developed.
- The loads for the concourse were 97 W/m2
- The conditioning systems to remove this heat from the space was divided as follows:
  - Radiant Floor 80 W/m2
  - Ventilation Air 17 W/m2

Seite 9

Airport Bangkok

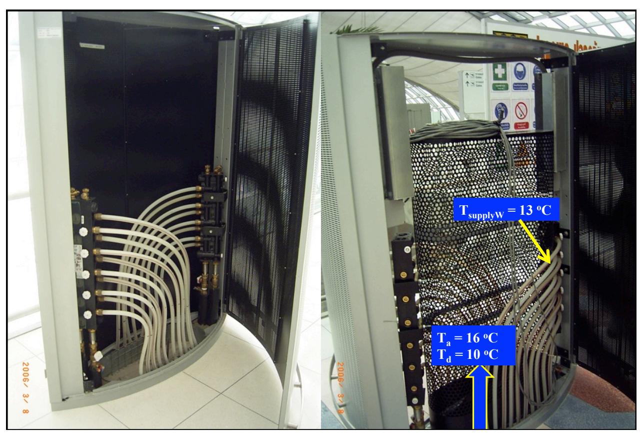


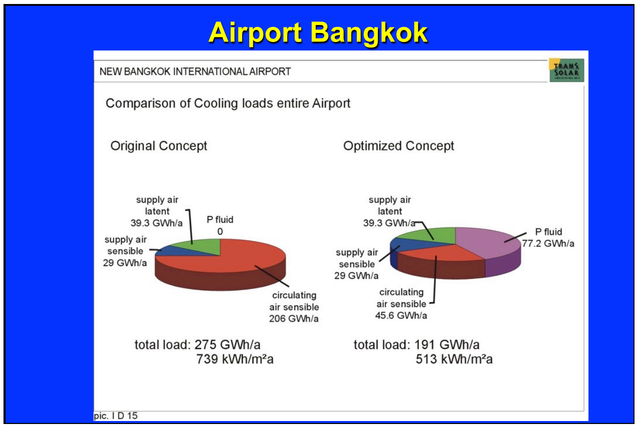
Airport Bangkok

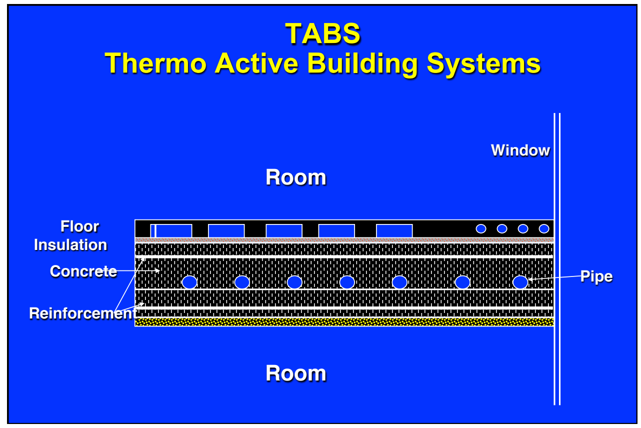


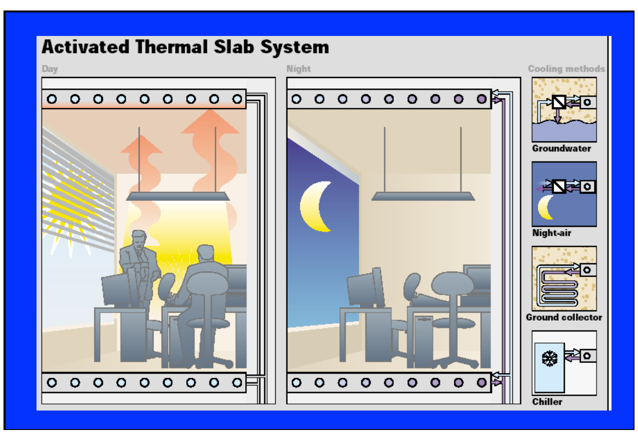
VENTILATION

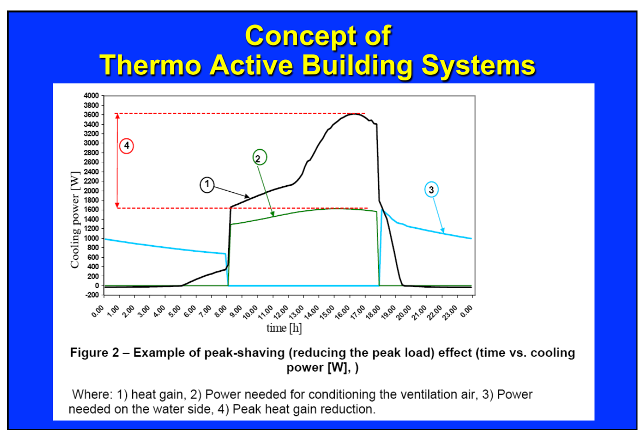
- The outdoor air AHU will supply variable outdoor air quantities at a constant temperature to the zone AHU's.
- The volume of outdoor air will be varied depending upon the CO_2 levels metered in each zone, down to a fixed minimum position
- Each zone AHU can supply air at 16 C to the space via the displacement diffusers

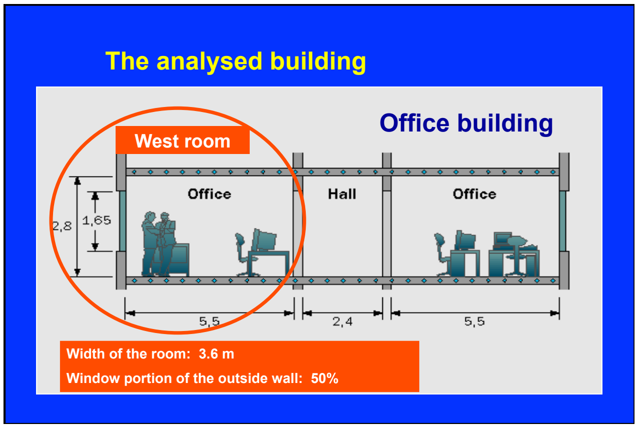


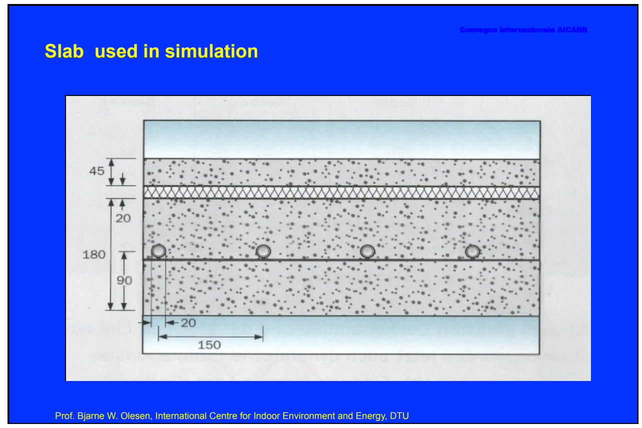

Airport Bangkok
NEW BANGKOK INTERNATIONAL AIRPORT
Comparison of Cooling loads entire Airport
Original Concept
Optimized Concept
supply air latent 39.3 GWh/a
P fluid 0
supply air sensible 29 GWh/a
circulating air sensible 206 GWh/a
supply air latent 39.3 GWh/a
P fluid 77.2 GWh/a
supply air sensible 29 GWh/a
circulating air sensible 45.6 GWh/a
total load: 275 GWh/a
739 kWh/m²a
total load: 191 GWh/a
513 kWh/m²a
pic. I D 15

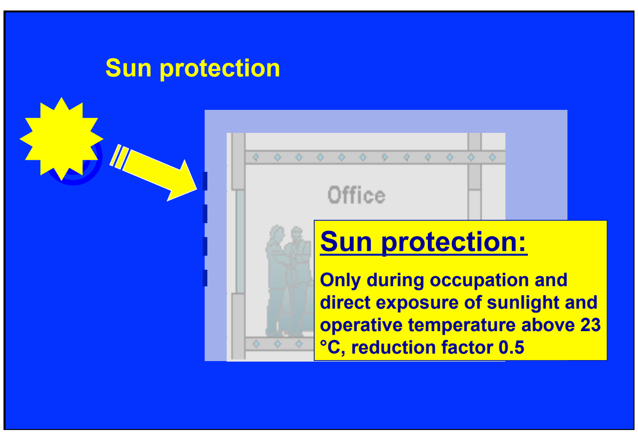

TABS
Thermo Active Building Systems
Window
Room
Floor
Insulation
Concrete
Pipe
Reinforcement
Room

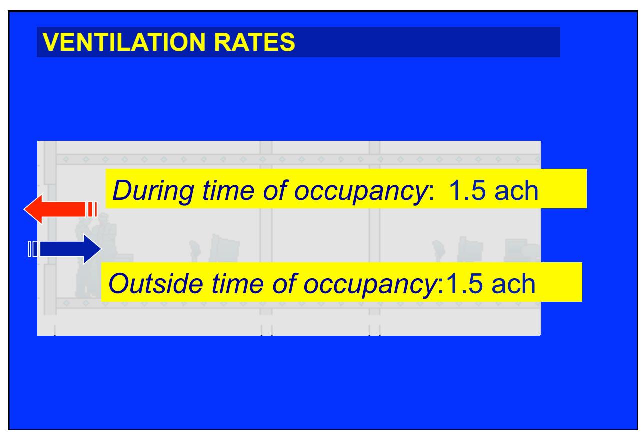

Activated Thermal Slab System
Day
Night
Cooling methods
Groundwater
Night-air
Ground collector
Chiller


Concept of
Thermo Active Building Systems
Cooling power [W]
time [h]
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.


The analysed building
Office building
West room
Office
Hall
Office
2,8
1,65
5,5
2,4
5,5
Width of the room: 3.6 m
Window portion of the outside wall: 50%


Slab used in simulation
45
20
180
90
20
150
Prof. Bjarne W. Olesen, International Centre for Indoor Environment and Energy, DTU


Sun protection
Office
Sun protection:
Only during occupation and direct exposure of sunlight and operative temperature above 23 °C, reduction factor 0.5


VENTILATION RATES
During time of occupancy: 1.5 ach
Outside time of occupancy:1.5 ach

CONTROL OF WATERTEMPERATURE

- Supply water temperature is a function of outside temperature according to the equation:

$t_{supply} = 0{,}52 * (20 - t_{external}) + 20 - 1{,}6 * (t_o - 22)$ °C (case 801)

- Average water temperature is a function of outside temperature according to:

$t_{average} = 0{,}52 * (20 - t_{external}) + 20 - 1{,}6 * (t_o - 22)$ °C (case 901)

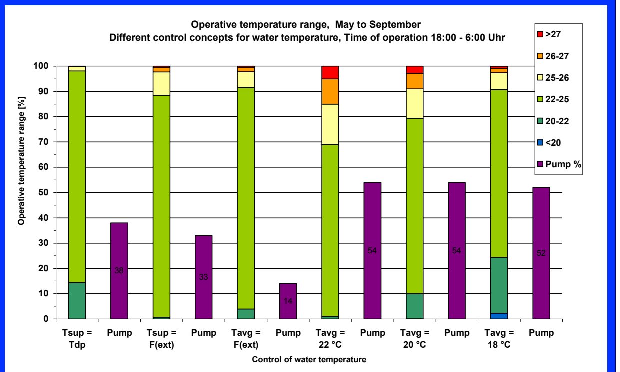
- Average water temperature is constant and equal to: 22°C in summer and 25°C in winter.
- Supply water temperature is a function of outside temperature according to the equation:

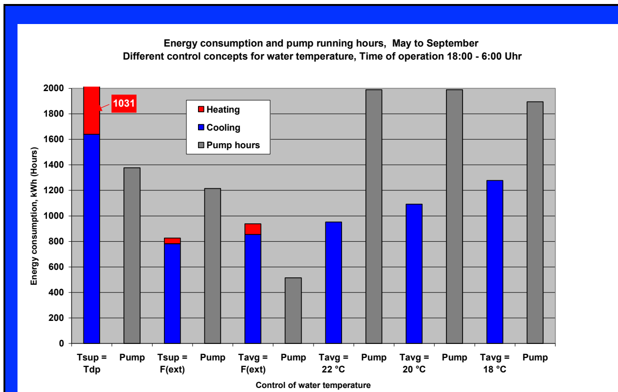
$t_{supply} = 0{,}35 * (18 - t_{external}) + 18$ °C summer (case 1401)

$t_{supply} = 0{,}45 * (18 - t_{external}) + 18$ °C winter (case 1401)

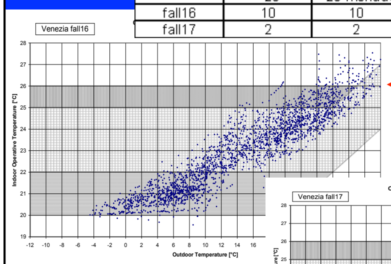
PERFORMANCE EVALUATION

- Range of operative temperature
- Pump running time
- Energy consumption

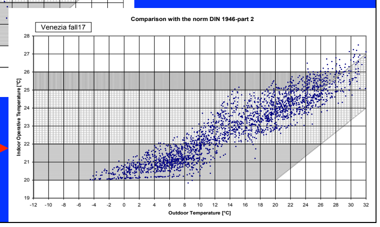




	<20	<20 monday	>26	>26 monday
fall16	10	10	84	34
fall17	2	2	53	10

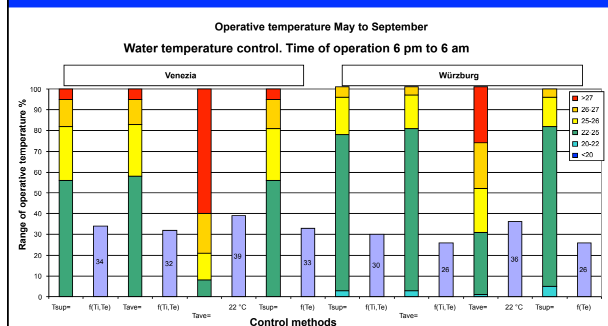


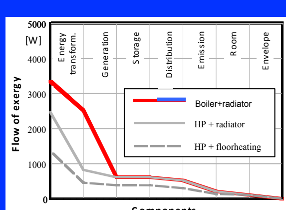
Circulation pump on at 18:00 Sunday

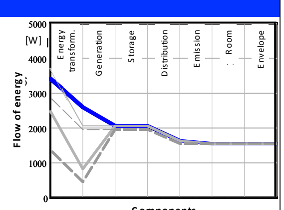


Circulation pump on 10:00 Sunday

CONTROL OF WATER TEMPERATURE SUMMER



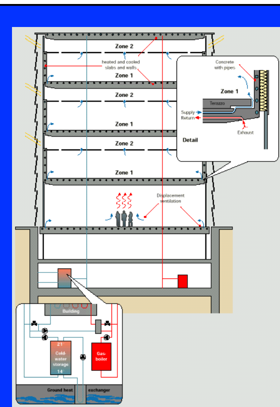




ART MUSEUM BREGENZ

ART MUSEUM IN BREGENZ

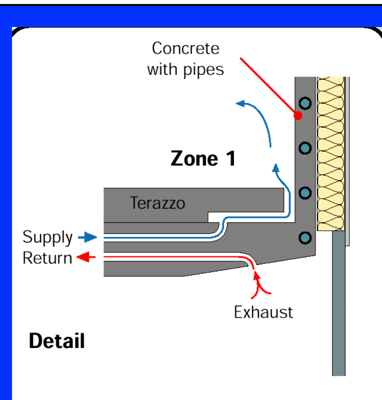
- Design requirements
  - Air temperature variations during a day within 4 K
  - Relative humidity variations less than 6 % during a day.
  - Seasonal variations between 48 and 58 %
  - Room temperature in winter 18 °C to 22 °C
  - Room temperature in summer 22 °C to 26 °C, occasional up to 28 °C
- Design load 250 persons pr. day, 2 hours
- Displacement ventilation < 0,2 h^{-1}
- Floor area 2.800 m² , 4 floors
- 28.000 m plastic pipes embedded in walls and floor slabs



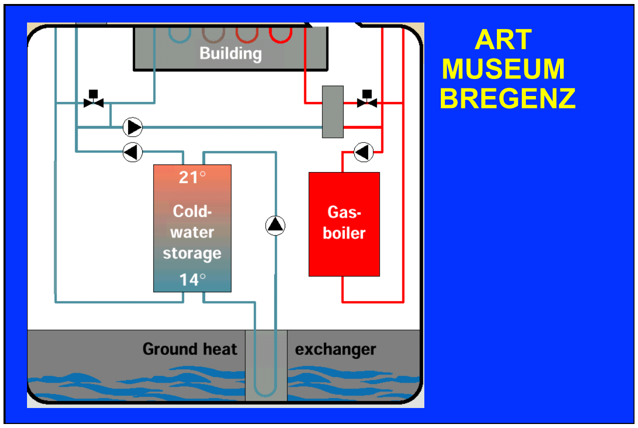
ART MUSEUM BREGENZ

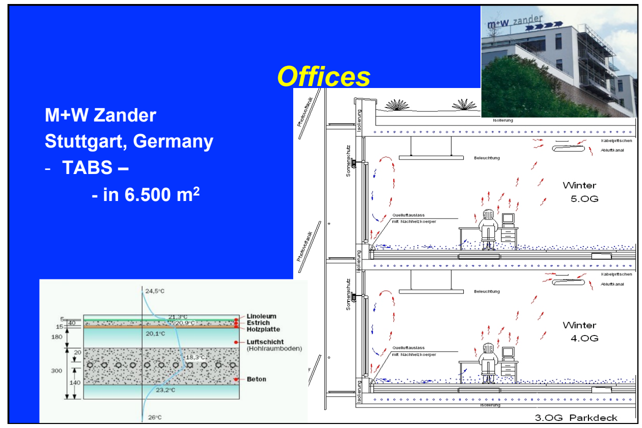
- 3.750 m² floor area
- 4.725 m² embedded pipes
- Condensing boiler
- Ventilation 750 m³/h per floor (first design was 25.000 m³/h

ART MUSEUM IN BREGENZ

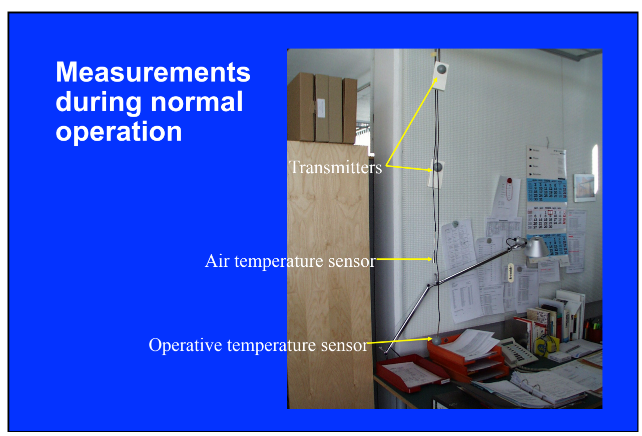


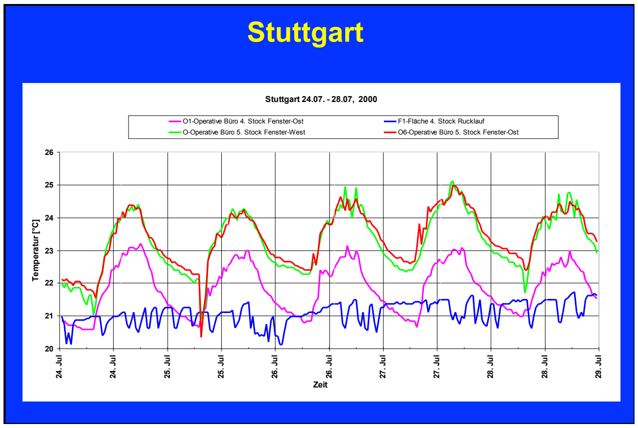
ART MUSEUM BREGENZ


ART
MUSEUM
BREGENZ
Building
21°
Cold-
water
storage
14°
Gas-
boiler
Ground heat
exchanger

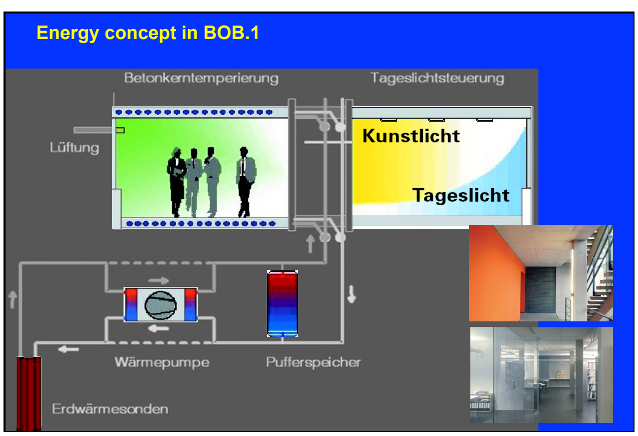

Offices
M+W Zander
Stuttgart, Germany
- TABS –
- in 6.500 m²
Winter
5.OG
Winter
4.OG
3.OG Parkdeck

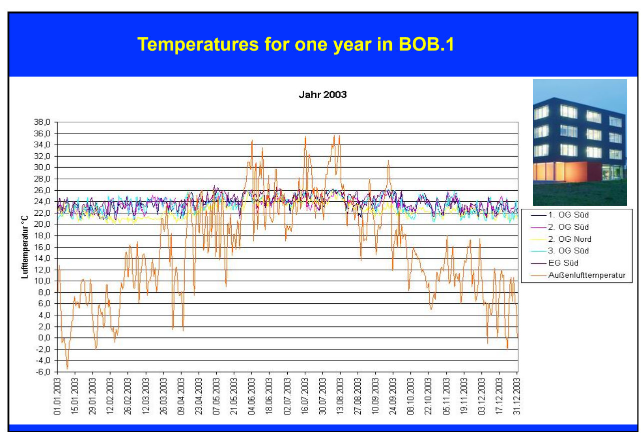

MW-Zander

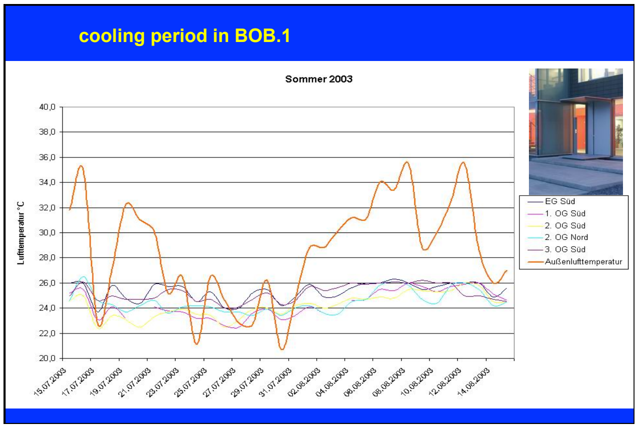

Measurements
during normal
operation
Transmitters
Air temperature sensor
Operative temperature sensor

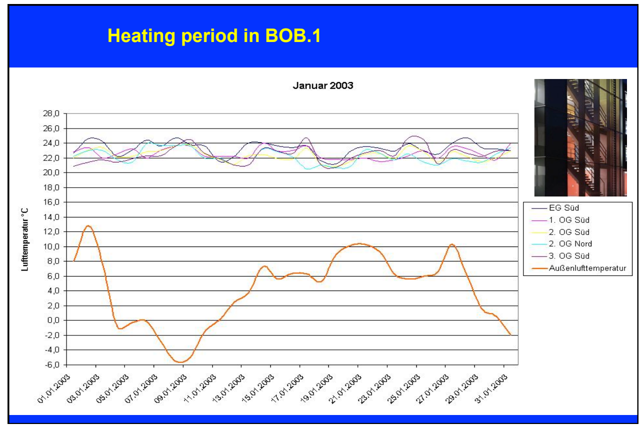

Stuttgart
Stuttgart 24.07. - 28.07, 2000
O1-Operative Büro 4. Stock Fenster-Ost
F1-Fläche 4. Stock Rucklauf
O-Operative Büro 5. Stock Fenster-West
O6-Operative Büro 5. Stock Fenster-Ost
Temperatur [°C]
Zeit

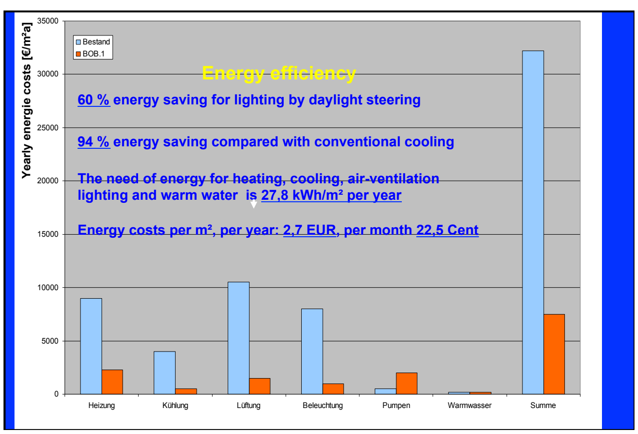

bob.1

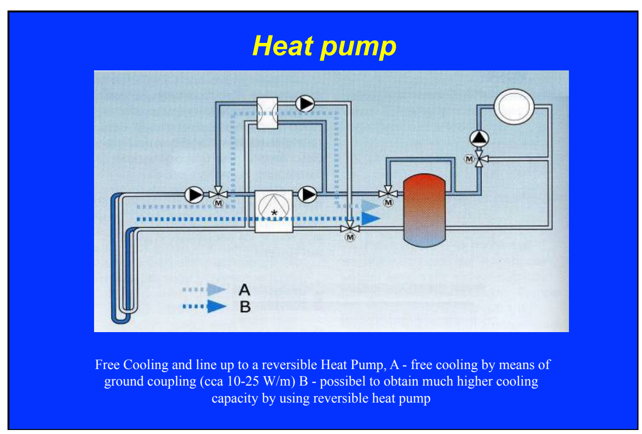

Energy concept in BOB.1
Betonkerntemperierung
Tageslichtsteuerung
Lüftung
Kunstlicht
Tageslicht
Wärmepumpe
Pufferspeicher
Erdwärmesonden


Temperatures for one year in BOB.1
Jahr 2003
Lufttemperatur °C
1. OG Süd
2. OG Süd
2. OG Nord
3. OG Süd
EG Süd
Außenlufttemperatur


cooling period in BOB.1
Sommer 2003
Lufttemperatur °C
EG Süd
1. OG Süd
2. OG Süd
2. OG Nord
3. OG Süd
Außenlufttemperatur

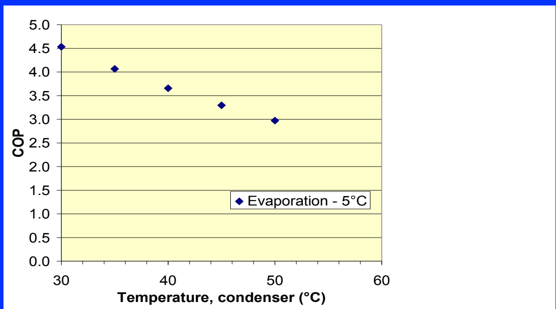

Heating period in BOB.1
Januar 2003
Lufttemperatur °C
EG Süd
1. OG Süd
2. OG Süd
2. OG Nord
3. OG Süd
Außenlufttemperatur


Yearly energie costs [€/m²a]
Bestand
BOB.1
Energy efficiency
60 % energy saving for lighting by daylight steering
94 % energy saving compared with conventional cooling
The need of energy for heating, cooling, air-ventilation lighting and warm water is 27,8 kWh/m² per year
Energy costs per m², per year: 2,7 EUR, per month 22,5 Cent
Heizung
Kühlung
Lüftung
Beleuchtung
Pumpen
Warmwasser
Summe

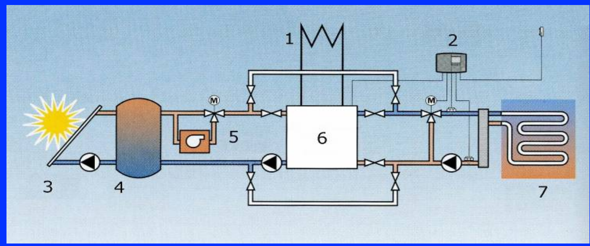

Heat pump
A
B
Free Cooling and line up to a reversible Heat Pump, A - free cooling by means of ground coupling (cca 10-25 W/m) B - possibel to obtain much higher cooling capacity by using reversible heat pump

Seite 18

Influence of condensing temperature on COP

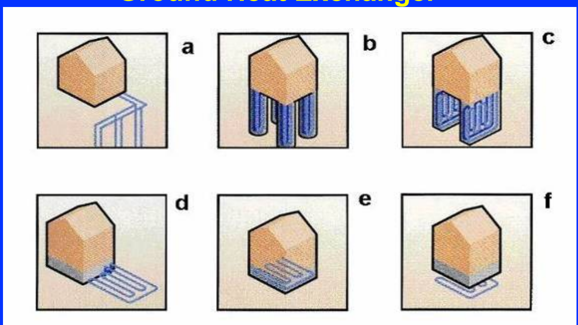


Absorption Heat Pump



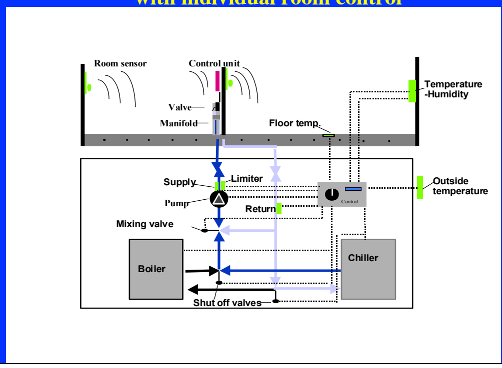
Cooling by using Absorption Heat Pump supported by Solar Heat, 1 - cooling tower, 2 - control system unit, 3 - Solar collector, 4 - buffer tank, 5 - additional heating, 6 – absorptive heat pump, 7 - floor heating system

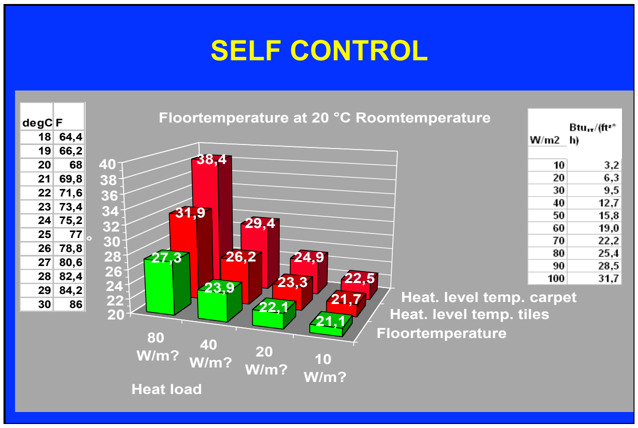
Ground Heat Exchanger



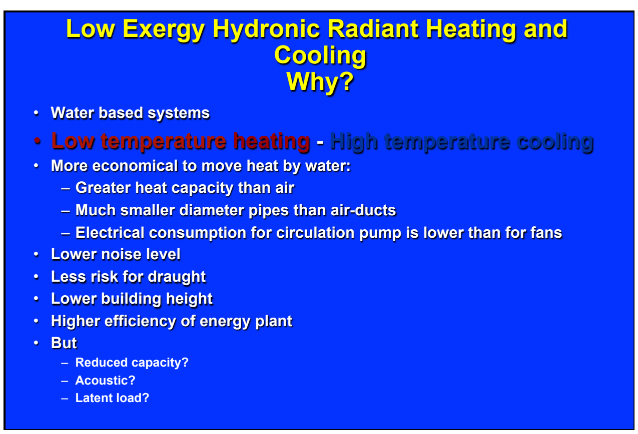
d - ground collector, e - plate floor cooler, f- soil cooler

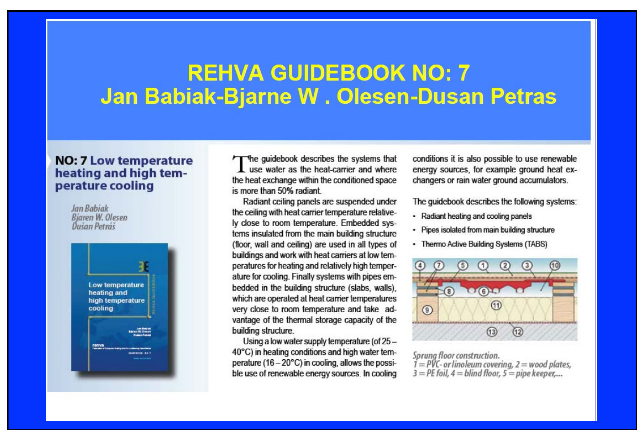
Control of a combined floor heating-cooling system with individual room control




SELF CONTROL
Floortemperature at 20 °C Roomtemperature
degC F
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
W/m2 Btu/(ft² 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
40 38 36 34 32 30 28 26 24 22 20
38,4
31,9
29,4
27,3
26,2
24,9
23,9
23,3
22,5
22,1
21,7
21,1
Heat. level temp. carpet
Heat. level temp. tiles
Floortemperature
80 W/m?
40 W/m?
20 W/m?
10 W/m?
Heat load


PRE-FABRICATION


Low Exergy Hydronic Radiant Heating and Cooling
Why?
• Water based systems
• Low temperature heating - High temperature cooling
• More economical to move heat by water:
– Greater heat capacity than air
– Much smaller diameter pipes than air-ducts
– Electrical consumption for circulation pump is lower than for fans
• Lower noise level
• Less risk for draught
• Lower building height
• Higher efficiency of energy plant
• But
– Reduced capacity?
– Acoustic?
– Latent load?


REHVA GUIDEBOOK NO: 7
Jan Babiak-Bjarne W . Olesen-Dusan Petras
NO: 7 Low temperature heating and high temperature cooling
Jan Babiak
Bjaren W. Olesen
Dušan Petráš
Low temperature heating and high temperature cooling
The guidebook describes the systems that use water as the heat-carrier and where the heat exchange within the conditioned space is more than 50% radiant.
Radiant ceiling panels are suspended under the ceiling with heat carrier temperature relatively close to room temperature. Embedded systems insulated from the main building structure (floor, wall and ceiling) are used in all types of buildings and work with heat carriers at low temperatures for heating and relatively high temperature for cooling. Finally systems with pipes embedded in the building structure (slabs, walls), which are operated at heat carrier temperatures very close to room temperature and take advantage of the thermal storage capacity of the building structure.
Using a low water supply temperature (of 25 – 40°C) in heating conditions and high water temperature (16 – 20°C) in cooling, allows the possible use of renewable energy sources. In cooling conditions it is also possible to use renewable energy sources, for example ground heat exchangers or rain water ground accumulators.
The guidebook describes the following systems:
• Radiant heating and cooling panels
• Pipes isolated from main building structure
• Thermo Active Building Systems (TABS)
Sprung floor construction.
1 = PVC- or linoleum covering, 2 = wood plates, 3 = PE foil, 4 = blind floor, 5 = pipe keeper,...


DTU
THANK YOU
International Centre for Indoor Environment And Energy
ICIEE