Thermal Storage: Residential and Commercial Buildings

IEA Committee on Energy Research and Technology
Strategic and Cross-Cutting Workshop
Energy Storage Issues and Opportunities

Prof. Dr. Luisa F. Cabeza
Dr. Albert Castell

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- Introduction
  - Human comfort requirements
  - Demand for heating and cooling
- Heating and cooling of buildings
  - Applications for space heating
  - Applications for space cooling
  - Applications for domestic hot water
- Conclusions

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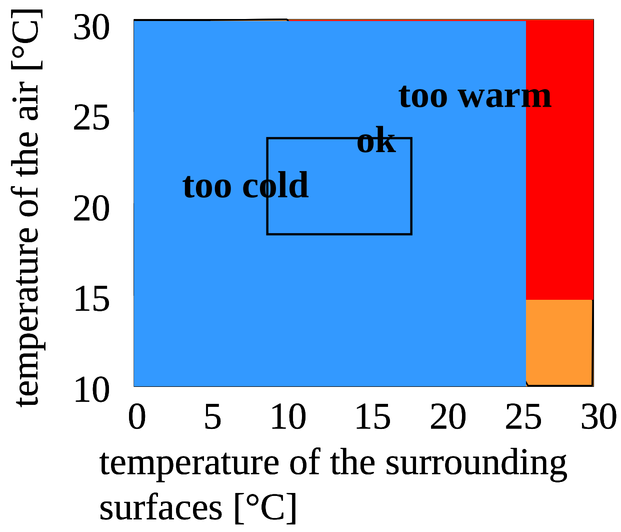
Human comfort requirements

- Temperature
  - air temperature: 22°C to 26°C
  - thermal radiation (surface temperatures):
  - changes < 5°C vertically, < 10°C horizontally
- Relative humidity
  - 30% - 70% ok, 50% best
- Air velocity
  - velocity < 9m/min in winter, <15m/min in summer,
  - minimum air movement for moisture removal!



Demand for heating and cooling

- Space heating and cooling
  - With air as heat transfer medium
  - With water as heat transfer medium
- Domestic hot water
  - Drinking water regulations
  - High power requirement, 1 L/min with heating from 20 °C to 40 °C means 1.25 kW of heating power!
  - Competition to hot water storage with direct discharge

  ⇒ very difficult!

Demand for heating and cooling

shape of the building

reduction of heat loss

- small surface to volume ratio
- small number of added parts
- multiple unit buildings

orientation of the building

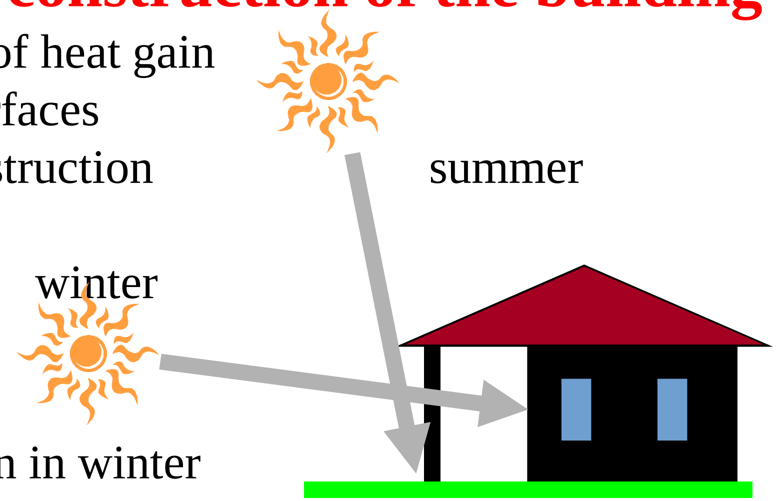
reduction of heat loss

- small surface to the wind (convection heat loss)
- large area to the south (solar gain)
- sleeping rooms in the northern part of the building

outside construction of the building

reduction of heat gain

- white surfaces
- roof construction



outdoor design conditions

outside plants

reduced solar gain in summer

increased solar gain in winter

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Applications for space heating

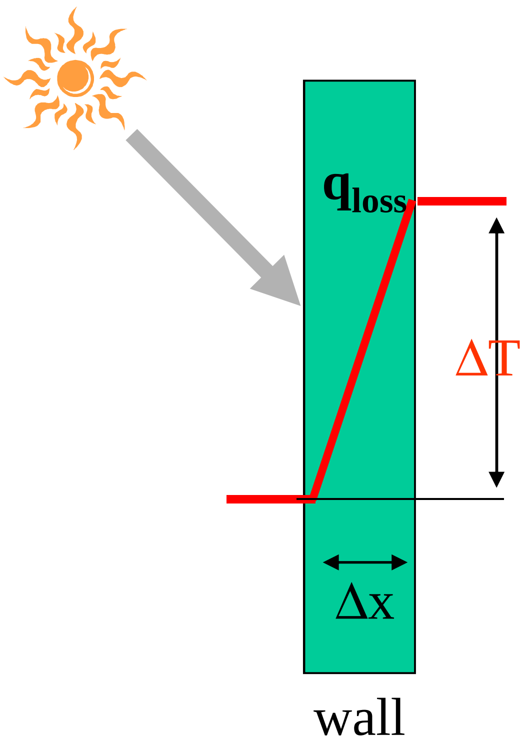
- General consideration for systems with heating from a warm surface
  - Heating power $q=A \cdot \alpha \cdot \Delta T$
  - Temperature difference ΔT

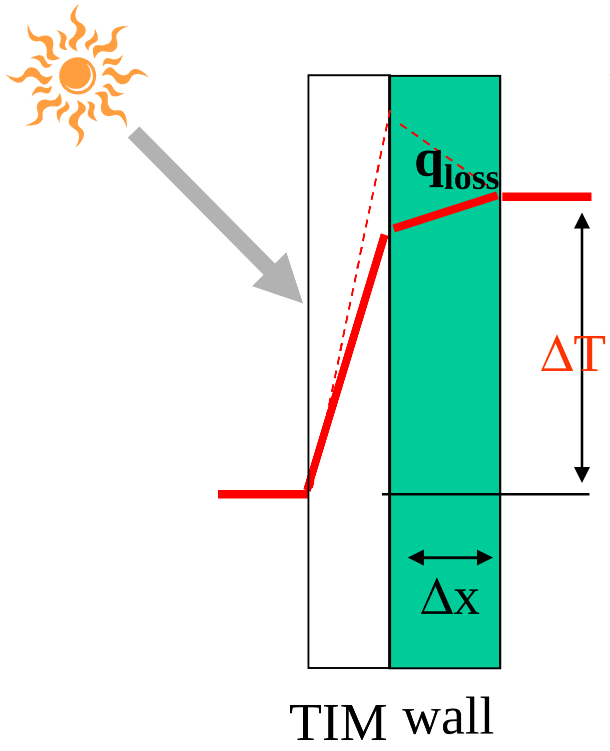
    can be increased, but at the expense of reduced efficiency in many cases
    - ΔT = 10 to 20 °C for low temperature heating over large surfaces
    - ΔT = 20 to 40 °C for regular heating systems with heating units
  - Heat transfer coefficient α
    - Wall heating α = 3 to 6 W/m^2K
    - Floor heating α = 6 to 10 W/m^2K
    - No heating from ceiling
  - The encapsulation is also need as heat exchanger in hot water systems!

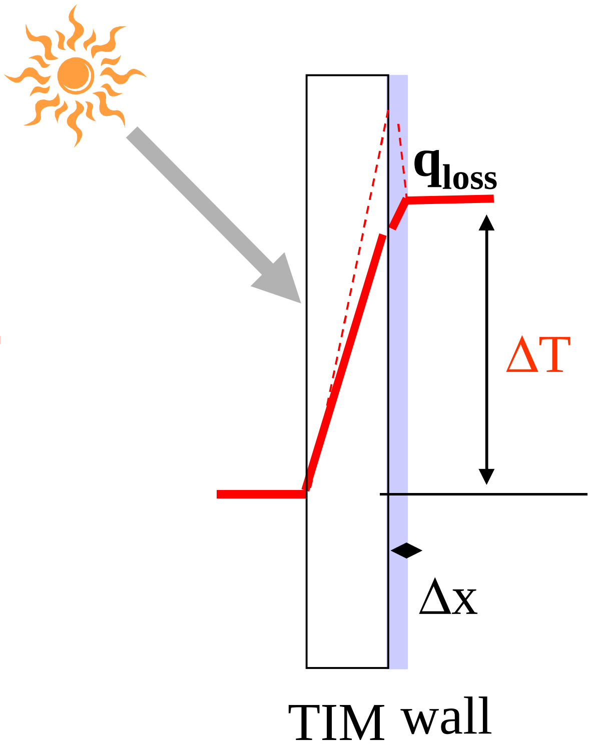
Applications for space heating

- Façade elements for heating, cooling and illumination

Ordinary wall	Wall with Transparent Insulation	PCM element with Transparent Insulation

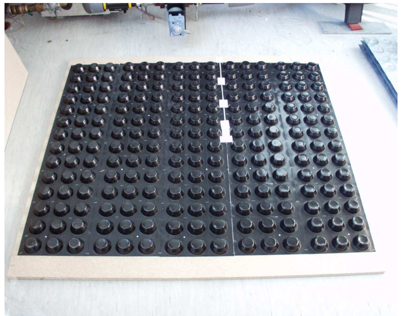




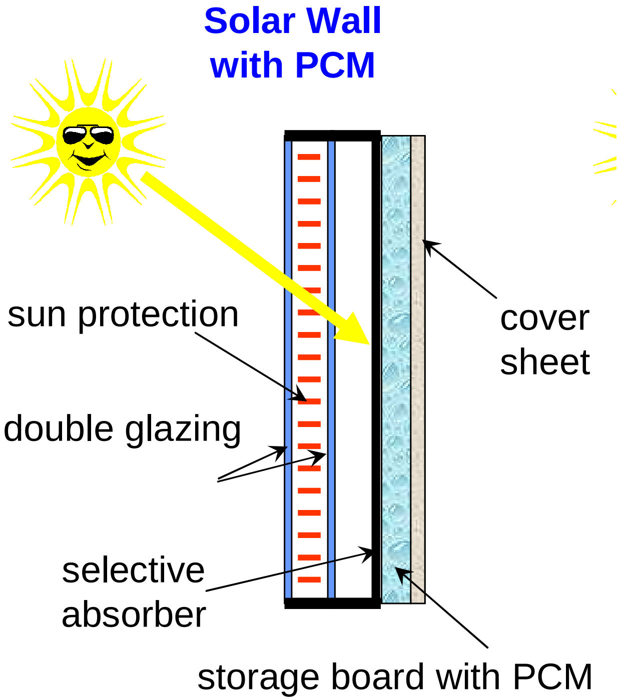


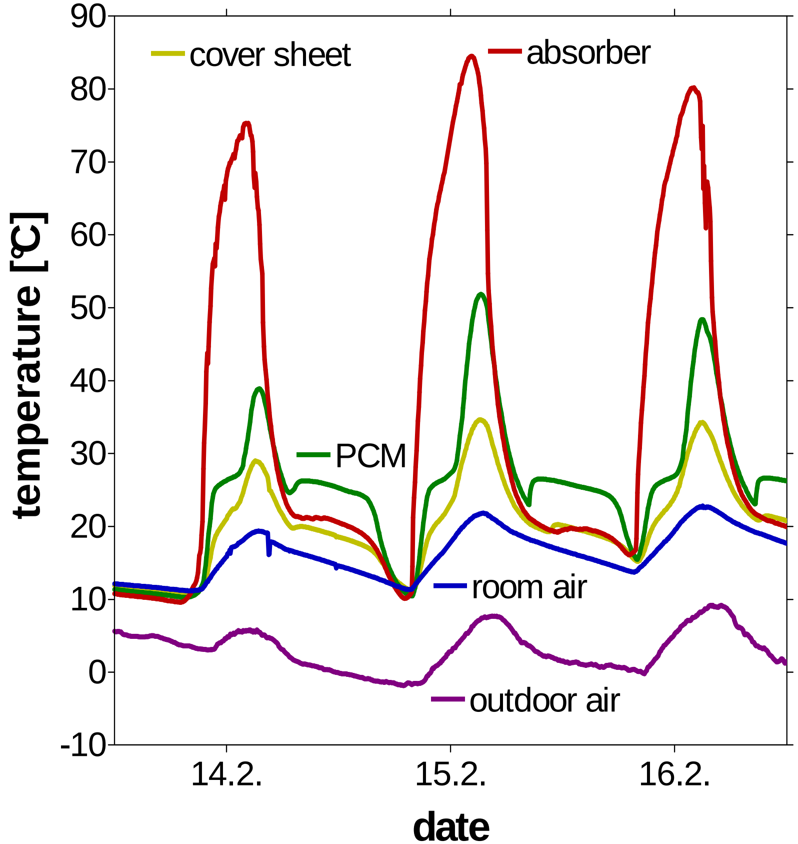
Applications for space heating

- Solar wall with PCM



Arnold, ZAE (LP-PCM)

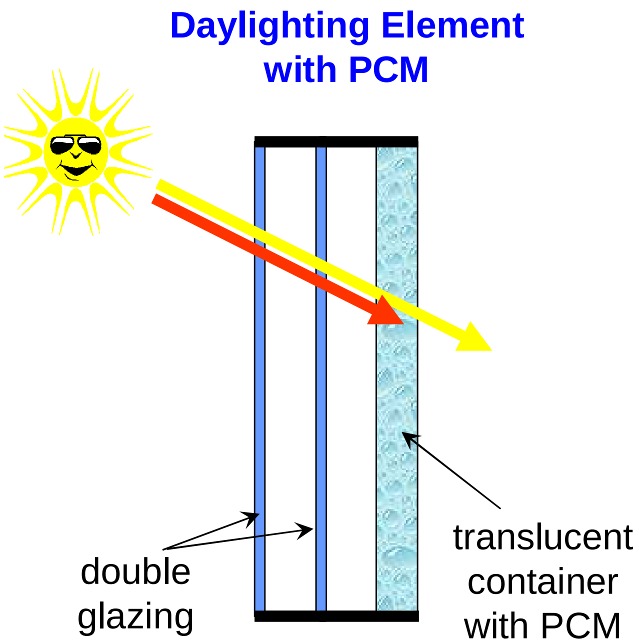


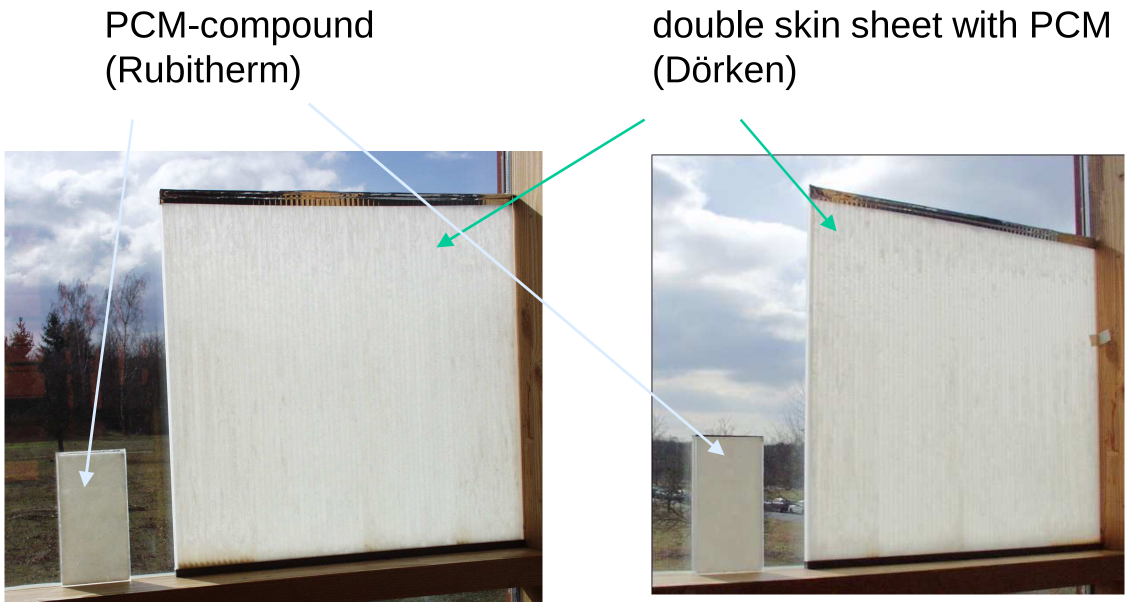


Applications for space heating

- Daylighting element with PCM

Arnold, ZAE (LP-PCM)





PCM solid

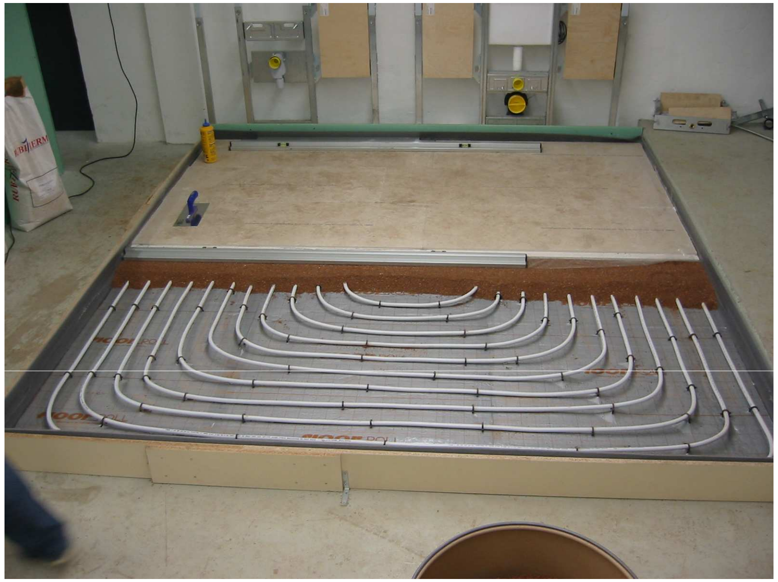
PCM liquid

- ➢ homogenous and diffuse illumination
- ➢ moderate heat gains in daytime
- ➢ reduced heat losses at night
- ➢ more comfortable indoor temperatures

Applications for space heating

- Floor heating systems

Rubitherm:
- High storage capacity (0,5 kWh/m^2)
- Energy consumption reduced up to 35% compared with conventional heating systems
- No time necessary for drying after installation



Sumika Plastech (Japan) Electrical floor heating system with PCM

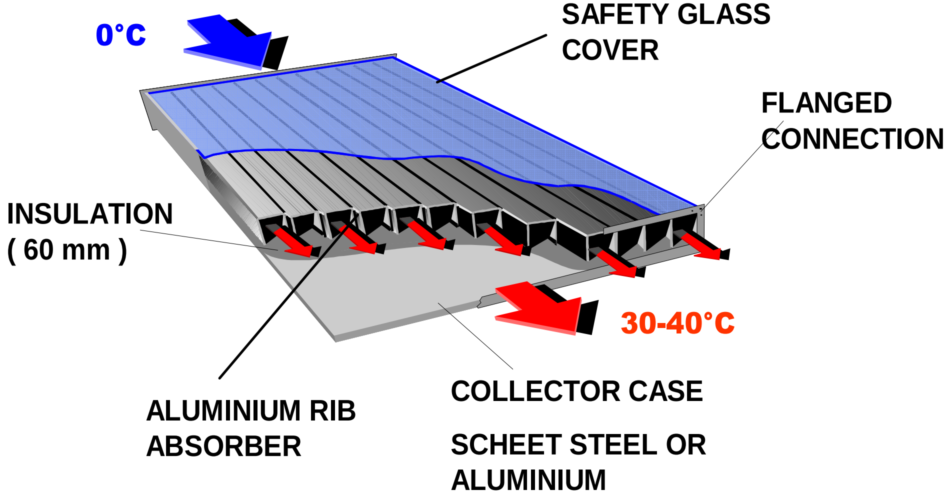
Applications for space heating

- General consideration for systems with heating by supplying hot air
  - Heating power $q=\rho\cdot cp\cdot\Delta T\cdot\Delta V/\Delta t$
  - ΔT can be easily, but at the expense of reduced efficiency in many cases
  - Heat capacity of air $\rho\cdot cp \cong 1$ J/LK (water has approx. 4kJ/LK)
  - Volume flow $\Delta V/\Delta t$ creates noise and can lead to uncomforted feeling if the air moves too fast
  - Compared to systems with hot water:
    - Leakage is no problem
    - The necessary encapsulation of the PCM is no disadvantage in this case as systems with hot water also need a heat exchanger!

Applications for space heating

- PCM to buffer temperature variations in solar-air-systems
  - Solar-air systems are well suited for heating the fresh air circulated into buildings in an energy-efficient manner

Grammer, ZAE (LP-PCM)



  - Problem: Temporal difference between heat demand and solar heat availability
  - Possible solution: Heat storage with PCM

Applications for space heating

- PCM was tested in four different solar-air system prototypes collector absorber
  - ventilation pipes (double pipe with PCM in the partition)
  - hypocaust (hot-air floor heating with a PCM layer as heat storage)
  - storage block (hot-air storage connected to the collector)

    $\Rightarrow$ appears to be the most promising application
- A prototype has been in operation at Grammar
  - charged via 20 m^2 collector
  - air flow 180 - 300 m^3/h
  - approx. 4.1 kWh latent heat storage capacity

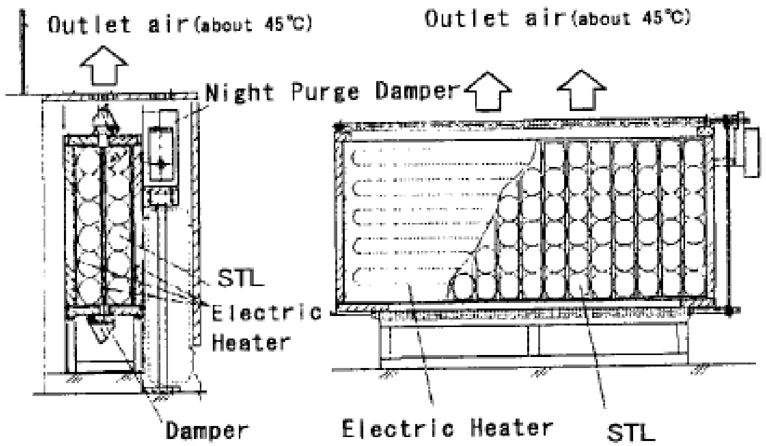
Applications for space heating

- Storage for heating with hot water
  - for regular heating systems with heating units T = 40 to 60 °C
  - NaOAc·3H_2O-graphite-compound for high density storage with good heat transfer
  - currently more than 1300 cycles tested, no performance loss observed

Bosch, SGL, Behr, Merck, ZAE (LP-PCM)

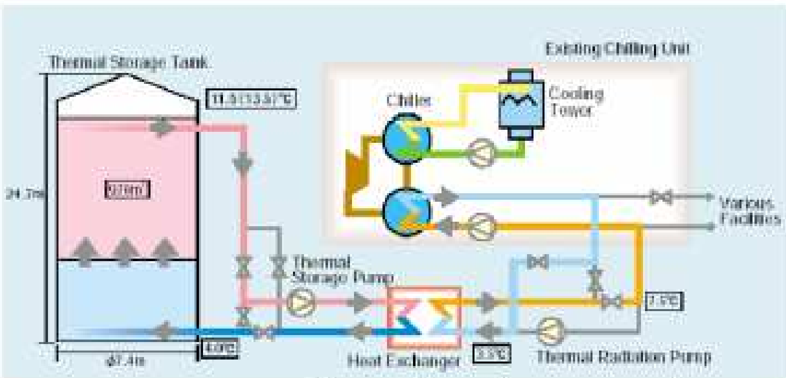
Applications for space heating

- Takasaki City hall (Japan)
  - A new city hall had been completed in February 1998
  - The building was equipped with heating apparatuses using PCM, which was called Thermal Storage Counter (TSC)
    - One TSC unit had 396 capsules containing PCM whose melting temperature was 55 ºC
    - The capsules were heated up during night using discounted nighttime electric tariff
    - The stored heat was discharged during daytime by both convection and radiation

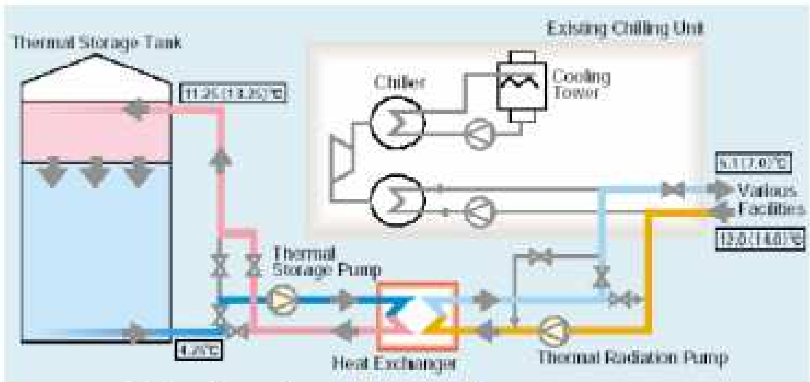


Applications for space heating

- Narita airport (Japan)
  - Micro encapsulated PCM was used for thermal energy storage system in Narita international airport
  - The refrigerants in heating and cooling plant should be changed from CFC 11 to HCFC 123 due to abandon of HFC
  - The encapsulated PCM was adopted to compensate deterioration of cooling capacity by replacing refrigerants



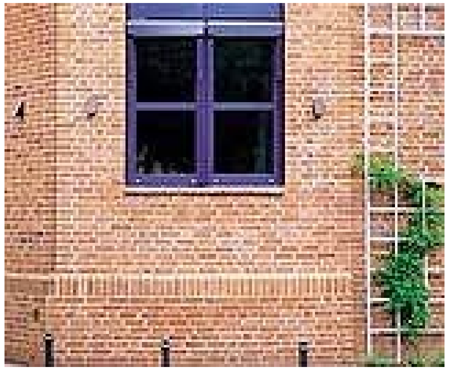
The night time operation

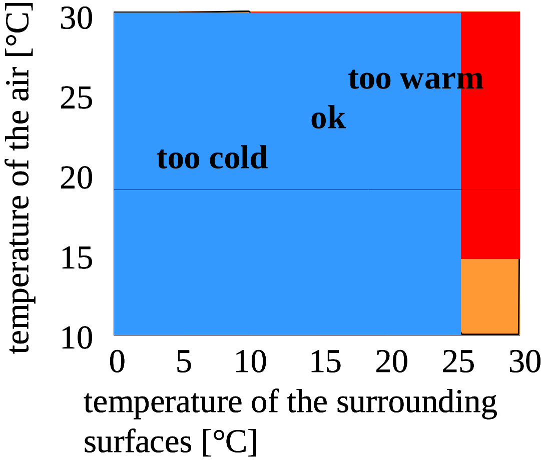


The day time operation

Applications for space cooling

- The Problem
  - Stone walls
    - Good heat storage
    - Buffer temperature changes
    - Storage of night cold
      by ventilation at night

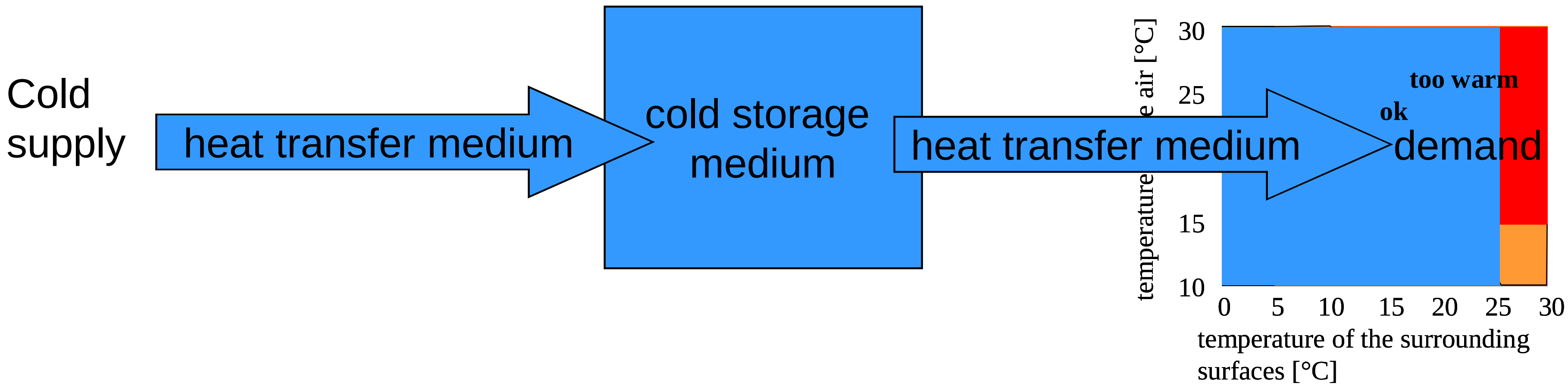




  - Today often lightweight construction
    - Flexibility and visual effects
    - Little heat storage
    - Very bad indoor climate!

Applications for space cooling

- Selection of the PCM



– The lower the temperature of the melting point of the storage

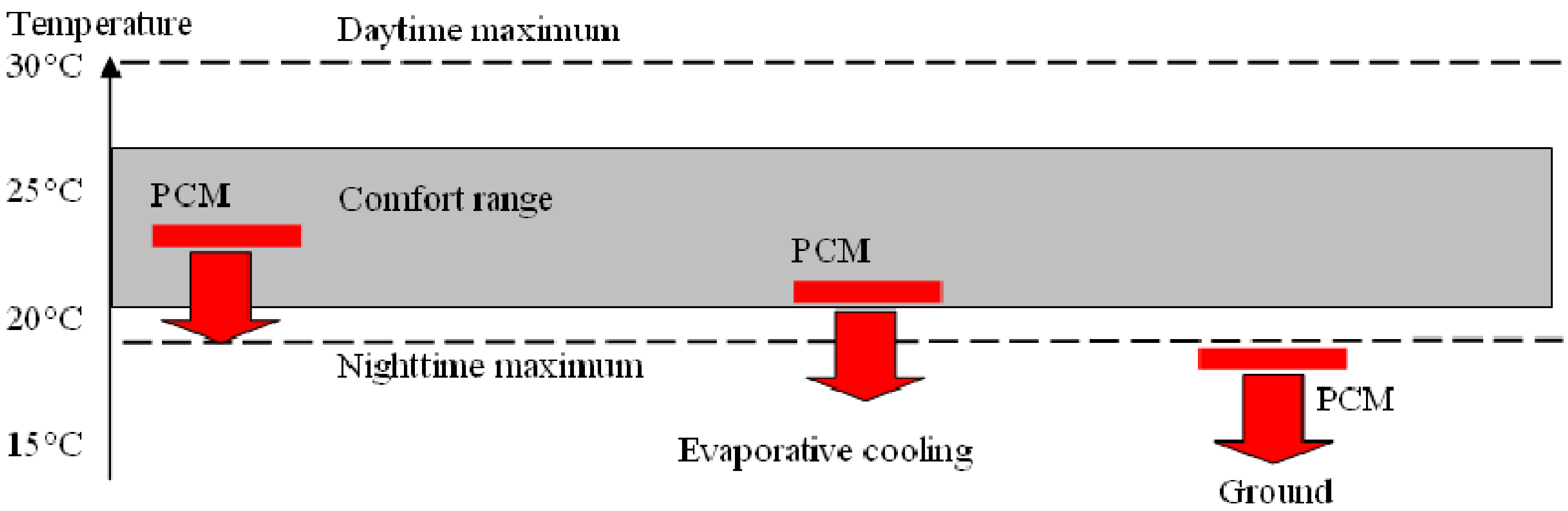
⇒ the higher the cooling power

⇒ the more difficulties arise searching a suitable cold source

- "natural" sources
  - Cold night air, in Germany usually below 22 °C
  - Evaporative cooling, depends on humidity, maybe down to 12 °C
  - Ground water, maybe down to 10°C
- "artificial" sources, chillers go down to below 0 °C

Applications for space cooling

- Strategies for natural cold sources:
  - Availability of cold source?
  - Cold source temperature?
  - Investment cost?



Applications for space cooling

- Examples using natural cold sources can be divided into
  - Passive systems:

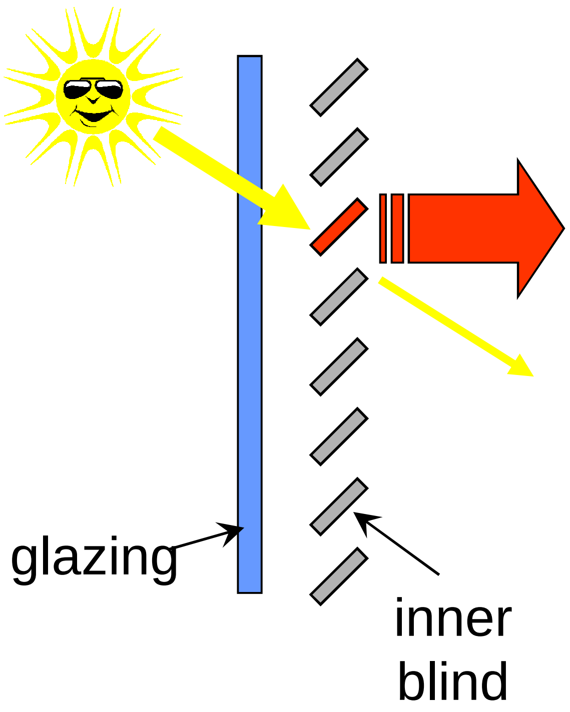
    building materials or building components

    increase of thermal mass of the building
  - Active systems:

    intermediate storage to use cold from the night or other cheap cold sources and actively moving the heat transfer medium

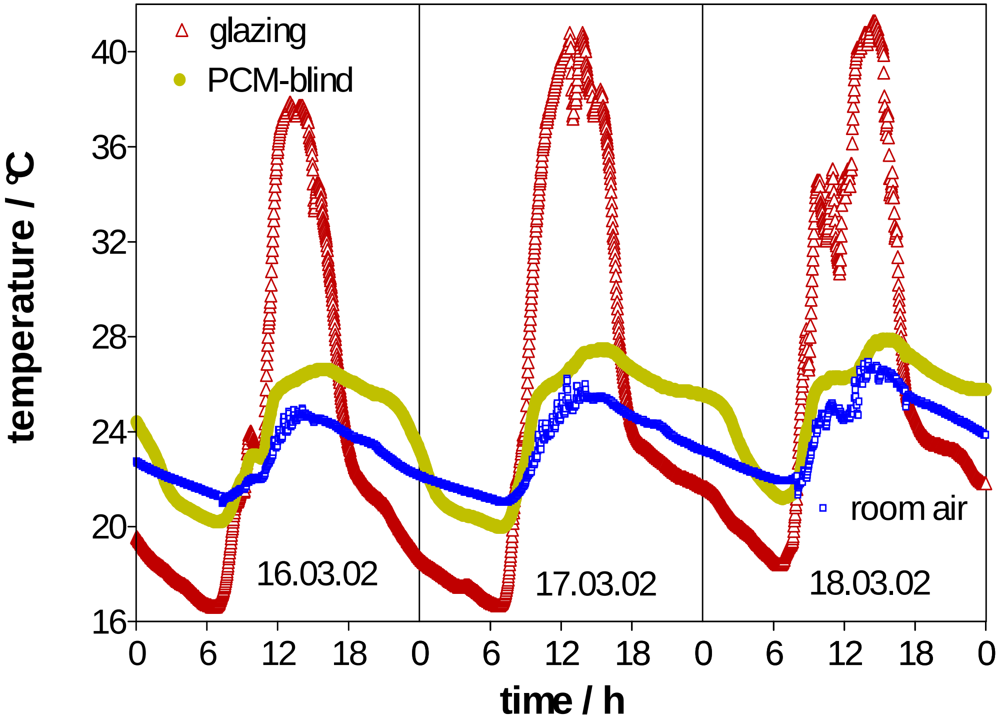
- Shading-PCM compound system
  - External blinds are susceptible to strong winds
  - Internal blinds release absorbed solar heat
    into the room!
    ⇒Idea: reduce and delay temperature rise
    through PCM in the blind

Warema, ZAE (LP-PCM)



- Experimental results from a horizontal blind

horizontal blinds with PCM



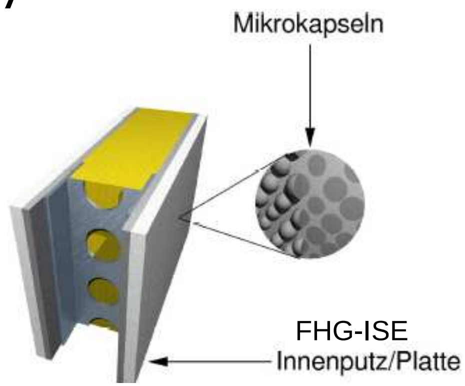
Applications for space cooling

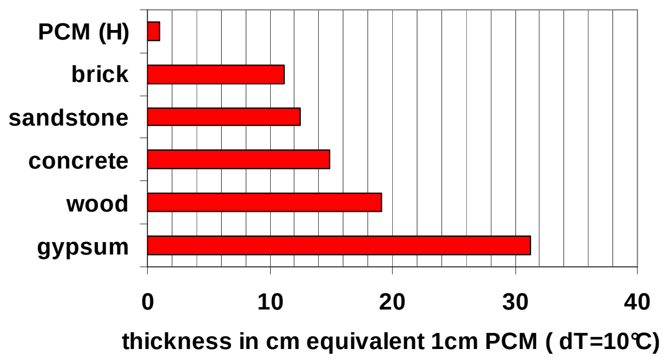
- Sun shading system with PCM developed and tested in laboratory scale
  - experimental and simulation results were very promising:
  - significant decrease in max. blind temperature by ≈ 10 – 15°C
  - significant decrease in operative temperature of the room by ≈ 3°C
  - time shift heat gains from noon to evening

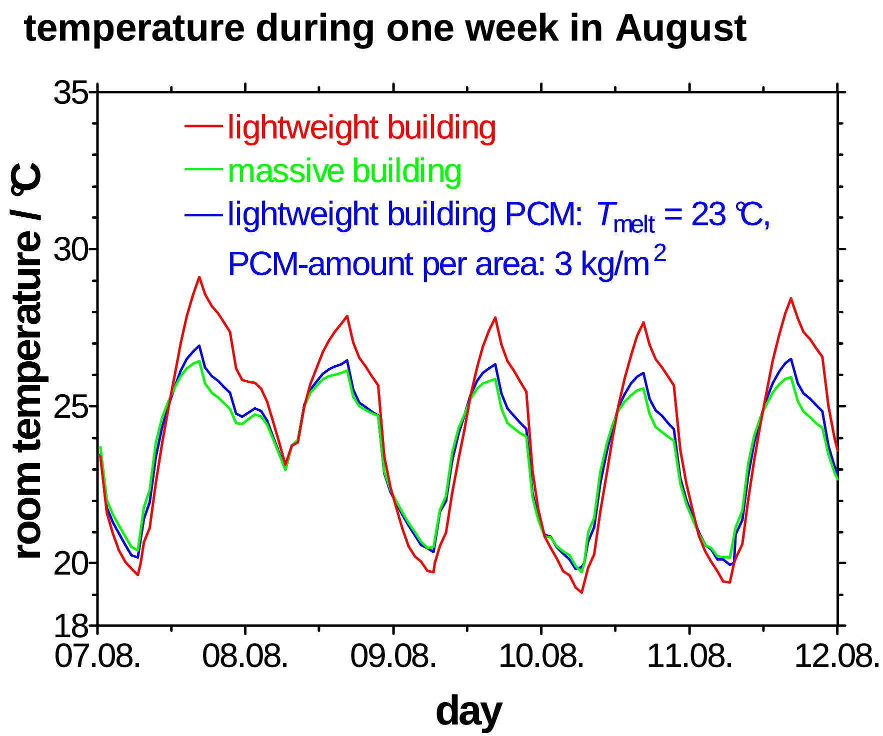
    ⇒ improved thermal comfort during working hours
- New demonstration project for PCM-systems will start mid 2005:
  - development of Sunshading system with PCM to prototype stage
  - test of system performance in various demonstration buildings under realistic conditions

Applications for space cooling

- Microencapsulated PCM in building materials
  - Strategy:





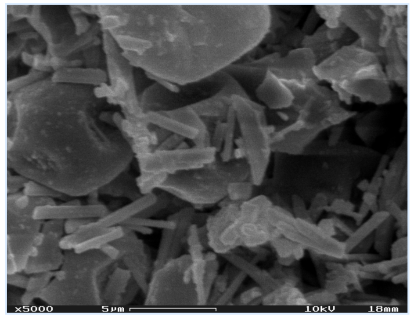


Peak shaving: temperature peaks during summer can be reduced by the use of PCM

Applications for space cooling

- Gypsum plaster boards with micro-encapsulated paraffin

Knauf, ZAE (LP-PCM)
35 wt.-% micro-encapsulated paraffin integrated into plaster board during conventional production process;



handling as without PCM

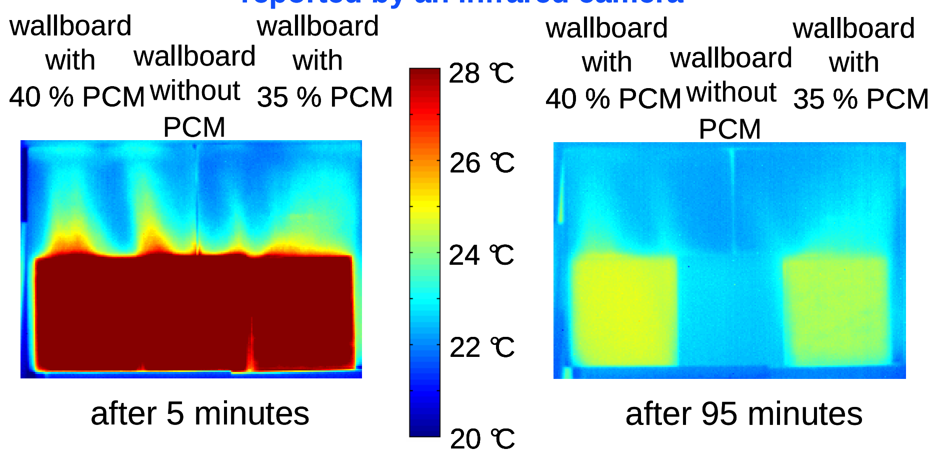
Technical data:

enthalpy: ΔH =366 kJ/m²,
= 35 J/g
cp= 1.2 J/(gK),

flammability:

B2 (classified in DIN 4102 part 1)

Cooling down of several gypsum plaster boards reported by an infrared camera



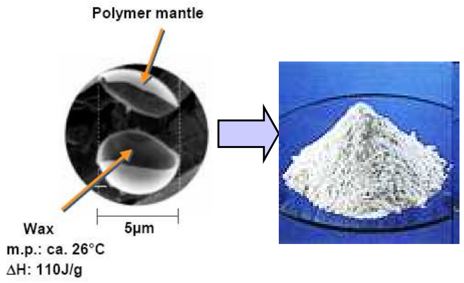
Installations: ZAE test room, Fh Rosenheim, Bundesgartenschau 2005 in Munich

Applications for space cooling

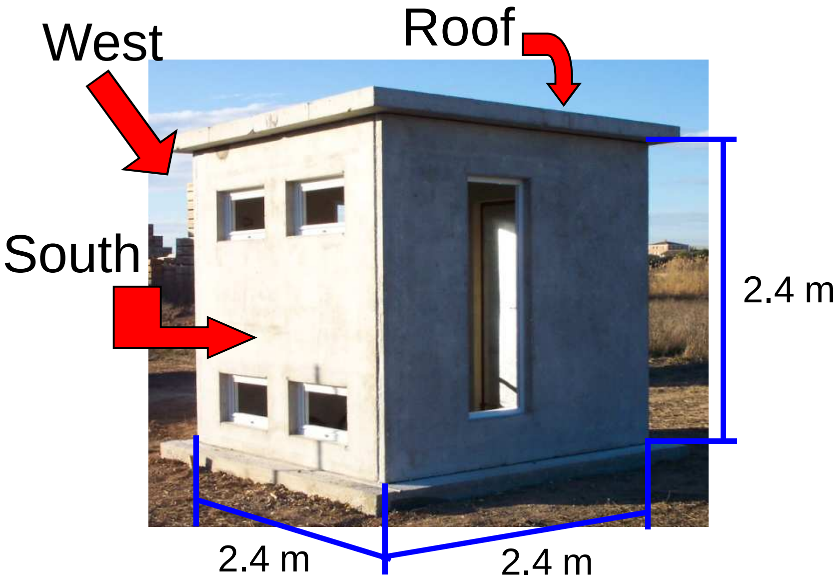
- Plaster with micro-encapsulated paraffin
  - Maxit, FhG-ISE
    - 2000 „3-liter house“ – LUWOGE Ludwigshafen
    - 2001 test room at IBP Holzkirchen
    - 2002 office in the new ISE building
    - 2002 – 2003 1st commercial building in Offenburg
    - 2003 test room in the façade test stand at the ISE
    - 2003 administrative building maxit in Breisach

Applications for space cooling

- Concrete
  - **Concrete:** No insulation
  - **Concrete + Micronal:** 5% in weight of microencapsulated PCM



Micronal	
Melting point (ºC)	26
Heat Storage Capacity (kJ/kg)	110



Micronal		
Mass of PCM per	wall (kg)	83
	floor area (kg/m^2)	43.2
Percentage referred to	structural material (%)	5
	wall (%)	5

Applications for space cooling

- Conventional brick:
  - **Reference:** No insulation
  - **Polyurethane:** 5 cm of PU
  - **RT27+PU:** CSM panels (RT-27) and 5 cm of polyurethane

Paraffin RT-27	
Melting point (ºC)	28
Congealing point (ºC)	26
Heat Storage Capacity (kJ/kg)	179
Heat conductivity (W/m·K)	0.2

Reference

Polyurethane

RT27+PU

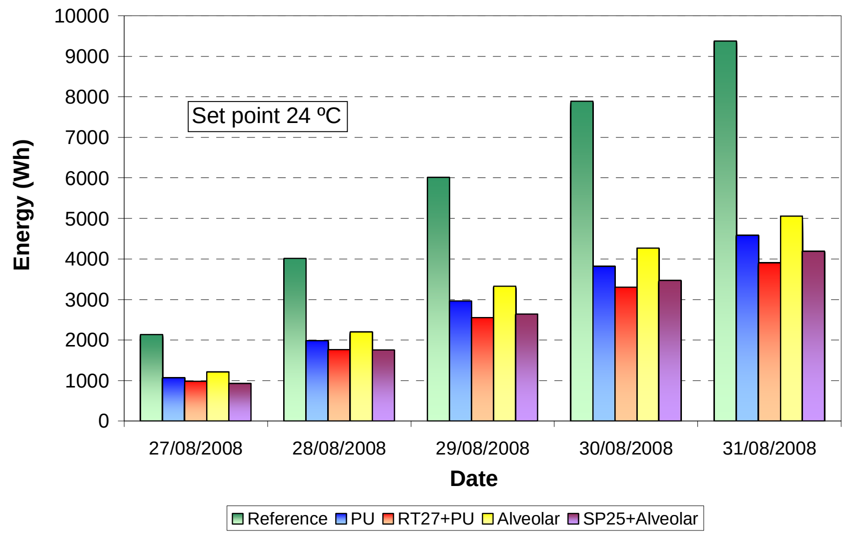
Hydrated salt SP-25 A8	
Melting point (ºC)	26
Congealing point (ºC)	25
Heat Storage Capacity (kJ/kg)	180
Heat conductivity (W/m·K)	0.6

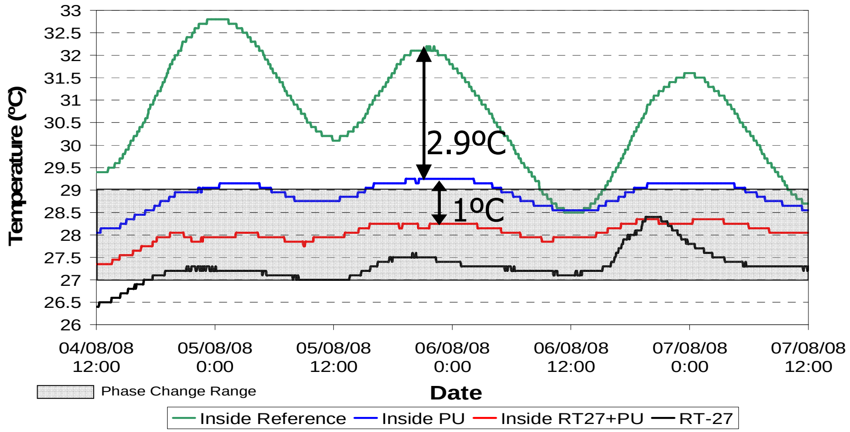
- Alveolar brick:
  - **Alveolar:** No insulation
  - **SP25+Alveolar:** CSM panels (SP-25 A8) inside the cubicle

Alveolar

SP25+Alveolar

Applications for space cooling



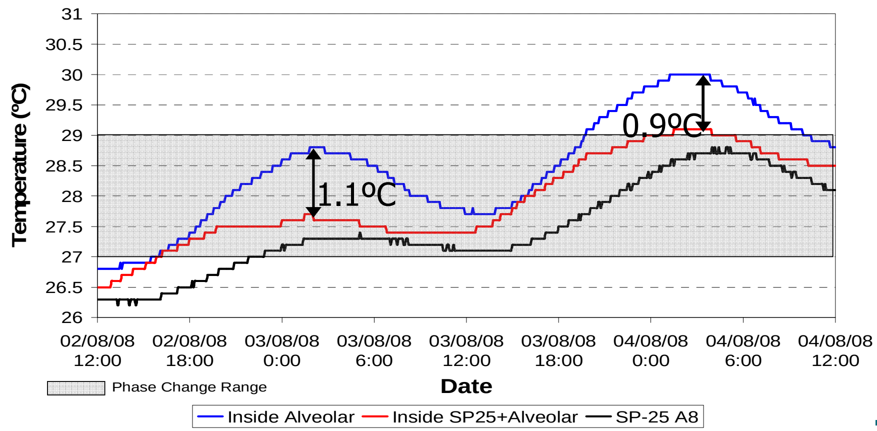


Summer period – 04/08/08 to 07/08/08

CONVENTIONAL BRICK

ALVEOLAR BRICK

Summer period – 02/08/08 to 04/08/08



Applications for space cooling

- PCM-plaster with capillary sheets connected to ground water
  - Increased thermal storage capacity
  - Use of “more reliable” cold sources like groundwater (natural) or cold production
  - Energy used to move heat transfer medium=fluid and maybe for cold production

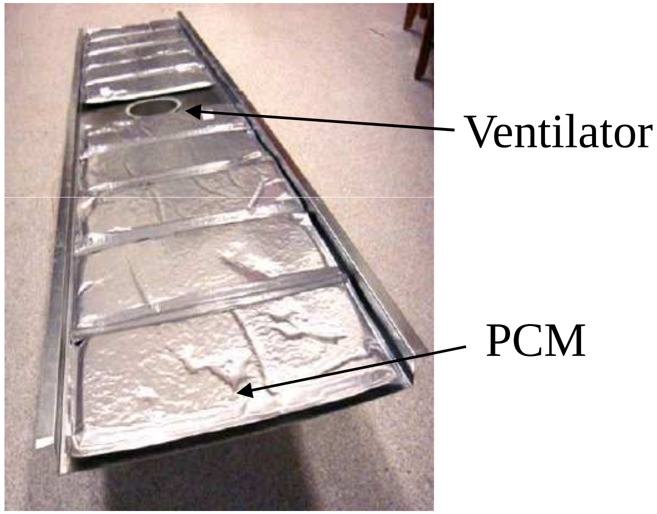
Berlin, Gotzkowskystraße
1.100 m² plaster on capillary sheets installed

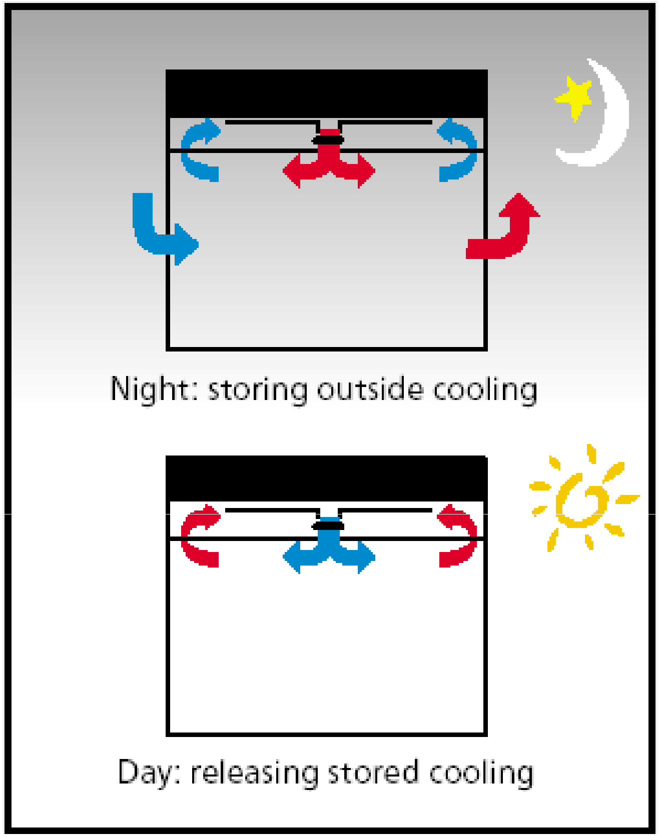
Maxit

Applications for space cooling

- Free cooling systems in the ceiling

Climator CoolDeck installed in Stevenage Borough Council's offices





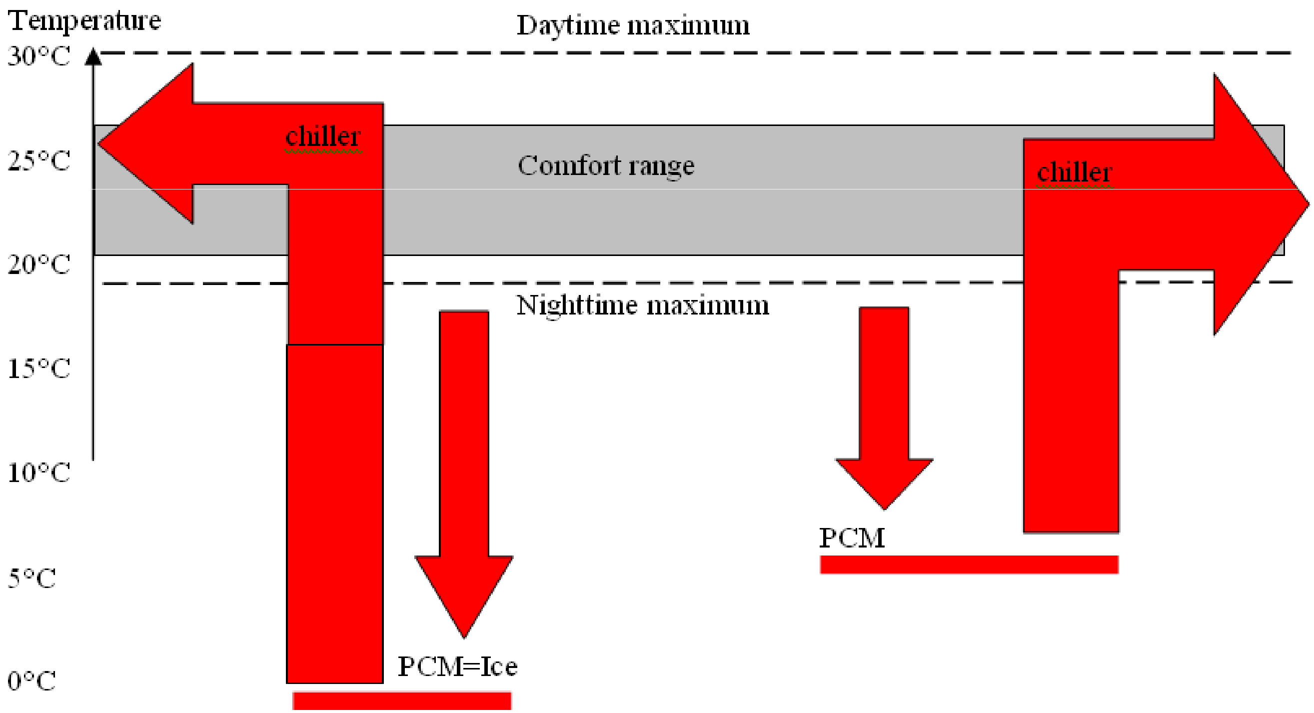
Observations:
- Reduction of 3-4°C in internal temperatures
- Installed at a fraction reduced cost alternative
- Energy consumption is low (cooling / fan energy) ~20

Applications for space cooling

- Free cooling systems in the wall
  - Example:

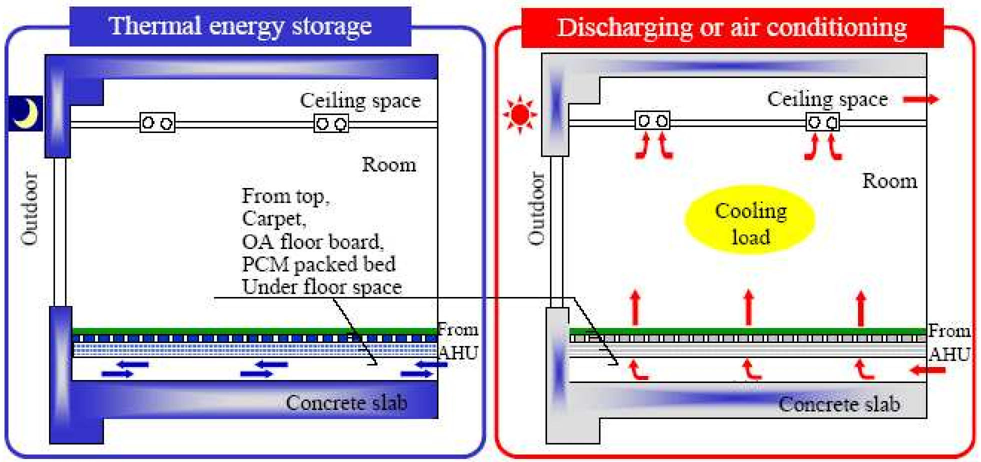
Applications for space cooling

- Strategies for artificial cold sources:
  - Ice or other PCM → Chiller efficiency
  - Compression-, Ammonia-, LiBr-Chiller → investment cost



Applications for space cooling

- Development of Supply Air Conditioning System Utilized Granulated Phase Change Materials (Japan)
  - In this system, latent heat is stored in PCM that is embedded directly below OA floor boards in the form of granules with several millimeters in diameter
  - The feature of the system is that heat exchange occurs through direct contact between the granular PCM and air serving as the heat medium



Applications for space cooling

- Clathrate Hydrate Slurry (Japan)
  - A new material was developed, Tetra n-butyle ammonium salt, which composed hydrate at atmospheric pressure and had latent heat in 5 to 12 ºC
  - The slurry was fluid and could be pumped as heat transfer medium
  - The material was expected to reduce pumping power consumption, which was relatively large in HVAC system
  - The performance of system was demonstrated in a real scale experimental facility, which had area of 1,700 m^2 for air conditioning

Applications for space cooling

- Phase change material slurries and their commercial applications (Germany)
  - Slurries have similar general fluid properties and they offer the advantage of high latent heat storage capacity at a narrow temperature band corresponding to the phase change temperature
  - They require smaller storage capacity and reduce pumping costs
  - Simulations show the potential in saving energy for pumping the heat transfer fluid
    - A well dimensioned application could save up to 50% of electricity that is necessary for conveying the same amount of heat of a water system

Applications for domestic hot water

- PCM in stratified water tanks (Spain)
  - The idea was to include a PCM module at the top of the water tank to increase its energy density and to improve its performance
  - Various PCMs with melting temperatures around 55ºC were tested (RT54, fatty acids, and sodium acetate)
  - Experiments showed that the addition of only about 6% of volume of PCM increase the density energy of the tank by about 40%, and that water was kept at usage temperature a longer period of time

Innovació concurrent GREA

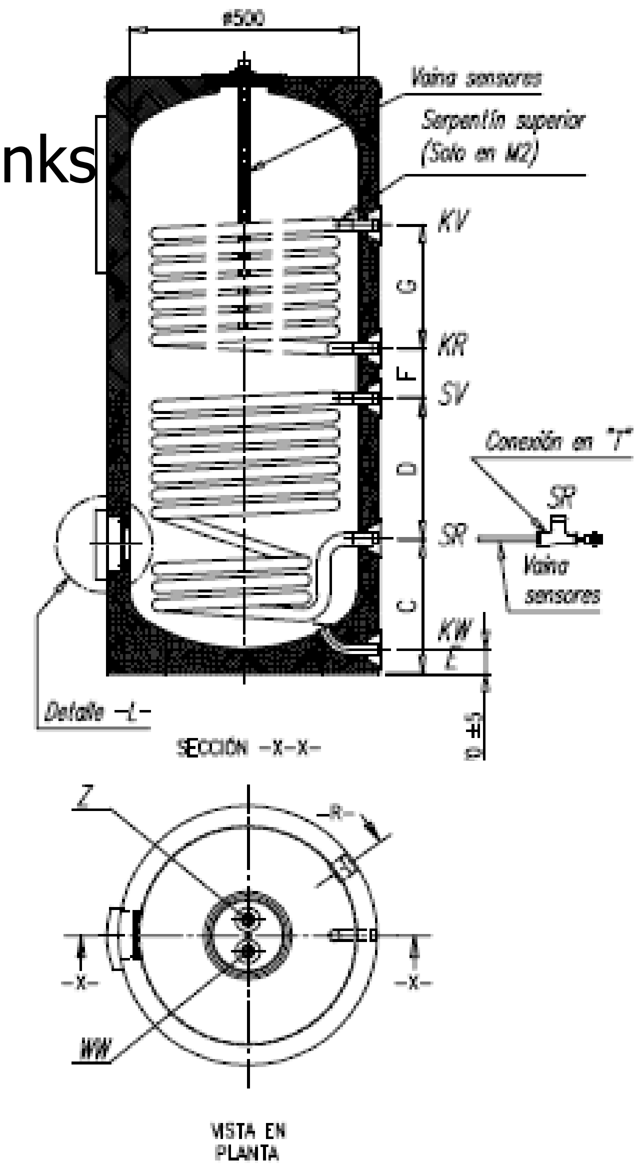
Applications for domestic hot water

- PCM in stratified water tanks (Spain)

  Description of the installation. Storage tanks
  - 2 storage water tanks of 287 L
  - 1685 mm high and 620 mm of diameter
    - Internal coil heat exchanger for the solar loop
    - One tank with an upper coil heat exchanger

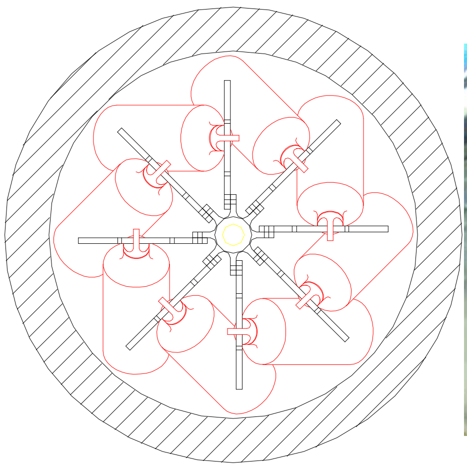
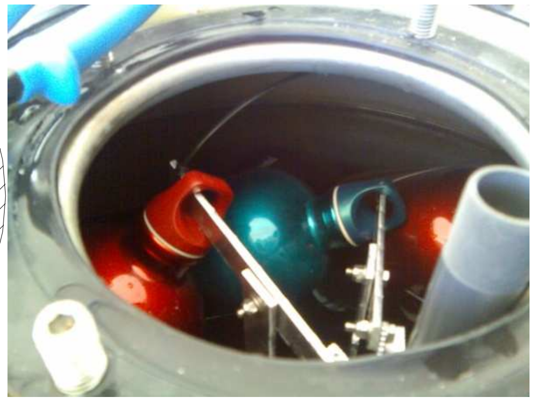
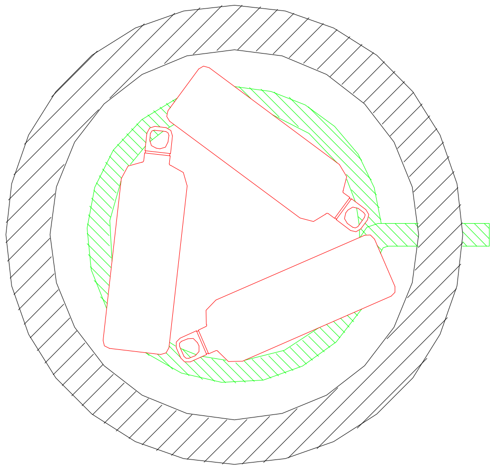
Upper coil heat exchanger		Lower coil heat exchanger	
Heat exchanger surface	Volume	Heat exchanger surface	Volume
1.1 m^2	9.62 L	1.4 m^2	12.24 L

A	B	C	D	F	G	H
1685	Ø685	345	355	130	400	760



Applications for domestic hot water

- PCM in stratified water tanks (Spain)
  Description of the installation. PCM configuration
  - PCM used: composite PCM-graphite
  - 2 different PCM configurations tested:
    - 9.21 kg of PCM in 8 aluminium modules
    - PCM located in the upper coil heat exchanger and 3 aluminium modules
      - Total amount of 8.05 kg → experimental density of PCM in the coil of 0.5 kg/L

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Conclusions

- Many different systems have been tested for PCM application in buildings to reduce energy consumption
  - PCM in building envelopes presents a huge potential
  - Under floor heating systems with PCM present good results
  - Heating systems using both air and water have been tested
  - Domestic hot water systems to increase thermal storage capacity

Conclusions

- Incorporating PCM in building envelopes
  - Temperature peaks can be reduced
  - Energy savings can be achieved

- Incorporating PCM in under floor heating systems
  - Energy savings can be achieved

- Incorporating PCM in active free cooling systems
  - Temperature peaks can be reduced

- Incorporating PCM in domestic hot water systems
  - The energy storage capacity can be increased