BASF
The Chemical Company

Soaking up the heat

Phase Change Materials in Construction

Ian Biggin
Director, Phase Energy Ltd.

RIBA · CPD ASSESSED MATERIAL

RIBA · CPD CORE CURRICULUM

Learning aims & objectives

- Gain a better understanding of what phase change materials (PCMs) are and what they aren't
- Appreciate what they can do and what they can't
- What products are available now
- How and where they could be used to store/release heat and modify building temperature (to give improved thermal comfort and energy efficiency)

Agenda

- Speaker introduction
- Introduction to BASF
- What are PCMs?
- How do they work in construction?
- Where to use PCMs?
- Benefits
- Problems & solutions
- Quality assurance
- Sustainability
- Case studies
- Summary & learning outcomes
- Contact details etc

Speaker introduction

- Ian Biggin – Phase Energy Ltd.
  - Chemist by profession, many years in senior technical and marketing roles in major companies
  - ~15 years working on PCMs; from raw materials to applications & testing
  - PE is a consultancy specialising in PCMs, including application development
  - PE provides support on PCMs to a number of clients, including BASF's UK technical support on PCMs

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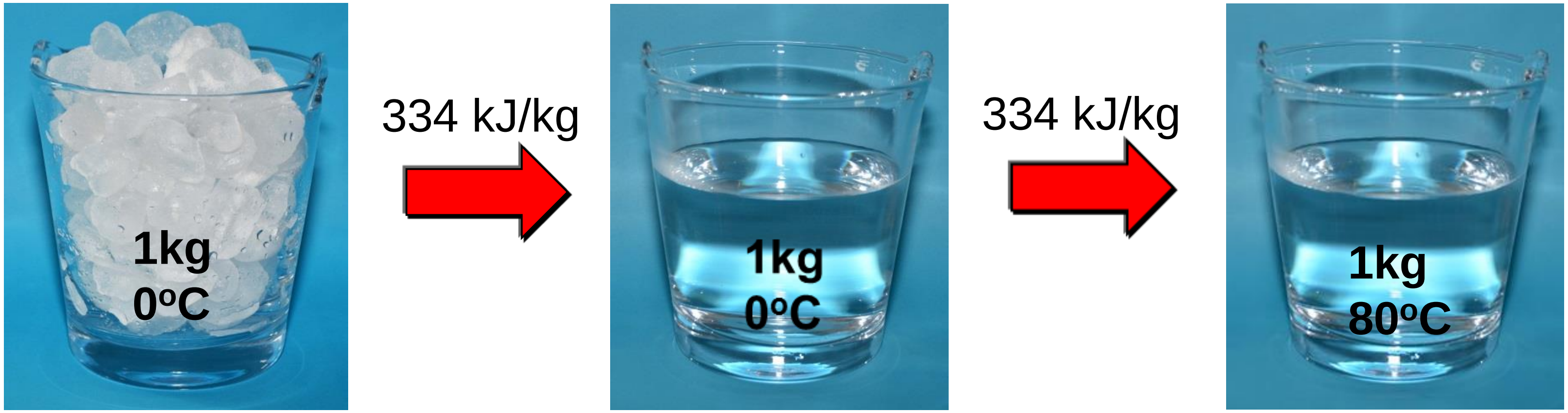
- 112,000 employees at end of 2015
- 6 "Verbund" sites
- About 380 production sites worldwide
- Sales of €70.4 billion in 2015
- €1.95 billion on R&D in 2015
- Produce Micronal® PCM microcapsules at Ludwigshafen site

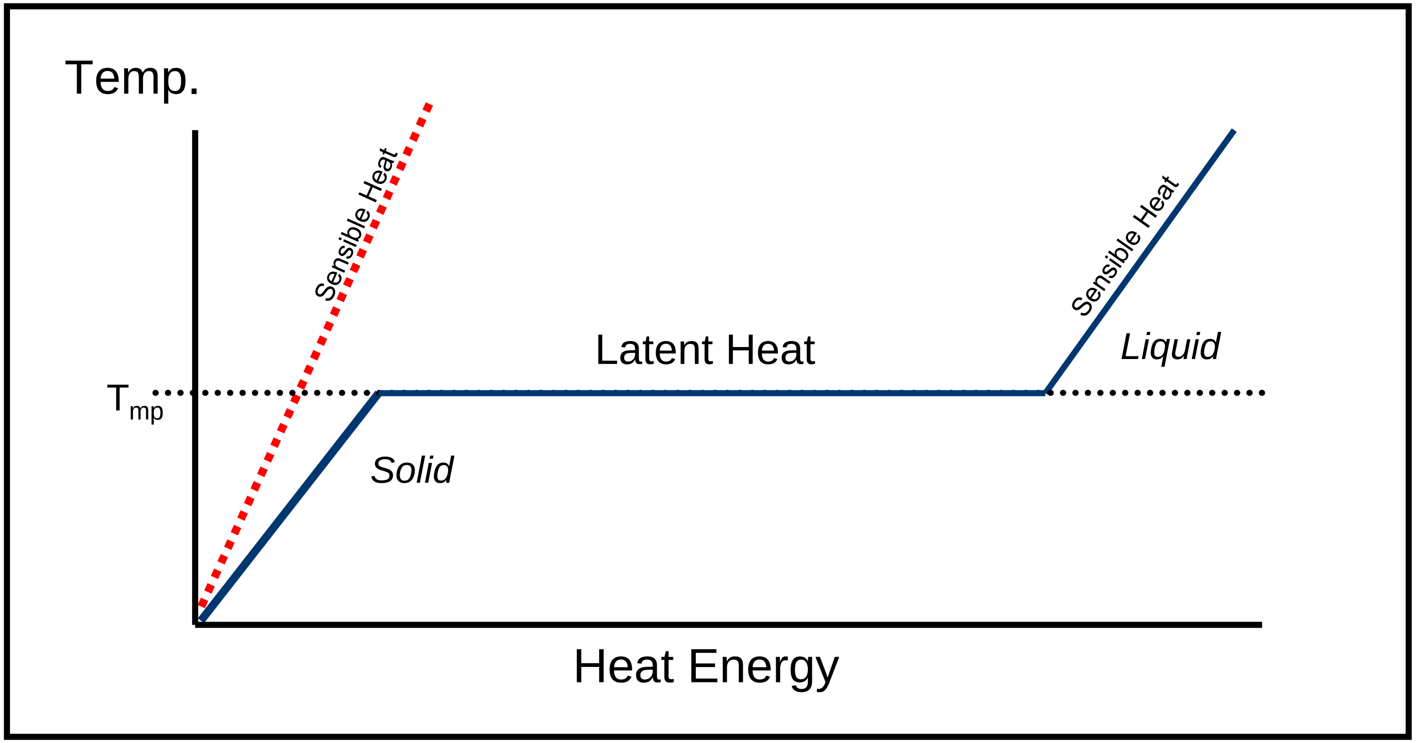
What are PCMs?

- PCMs are latent (hidden) heat storage materials i.e.:
  - They store or release large amounts of heat as they change phase (solid ↔ liquid)
  - They store or release heat without changing temperature



What are PCMs – "clever" thermal mass!

- Idealised graph



PCMs are thermal mass, NOT insulation!

What are PCMs?

- PCMs can be waxes or salt hydrates
  - Waxes can be petrochemical (paraffins) or bio-based (acids, alcohols, esters)
  - Salt hydrates e.g. $Na_2SO_4.10H_2O$
- Some properties of a good PCM:
  - Melt/freeze over a narrow temperature range (suitable for the proposed application e.g. between 20-24^{o}C)
  - Have a high enthalpy (thermal energy storage capacity)
  - Be suitable for the proposed application (e.g. longevity)
  - Must be cost effective

What are PCMs? - waxes

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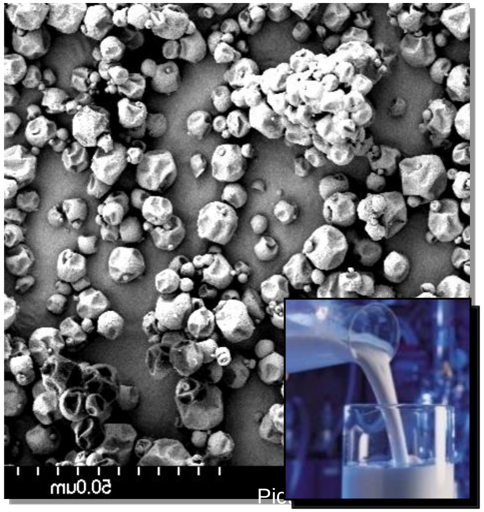
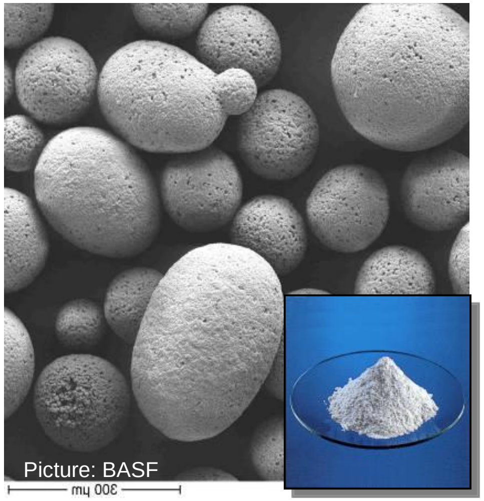
- Tend to be used in an encapsulated (trapped) form
  - Either micro or macroencapsulated
- Microencapsulated – tiny wax particles trapped in a tough polymer shell
  - Very tough; withstand sawing, drilling etc.
  - Often added to gypsum, clay panels etc.
- Macroencapsulated – in metal heat exchanger plates, absorbed into expanded graphite panels etc.





What are PCMs – salt hydrates

- Salt crystals (e.g. sodium sulphate, calcium chloride etc) which include molecules of water within their crystal structure
- When the salt hydrate reaches its melting point, the water molecules move away from the crystal structure and the solid crystals become a liquid
- When the liquid salt solution cools, the water molecules move back around the salt crystal structure and the liquid becomes a solid again

Comparison

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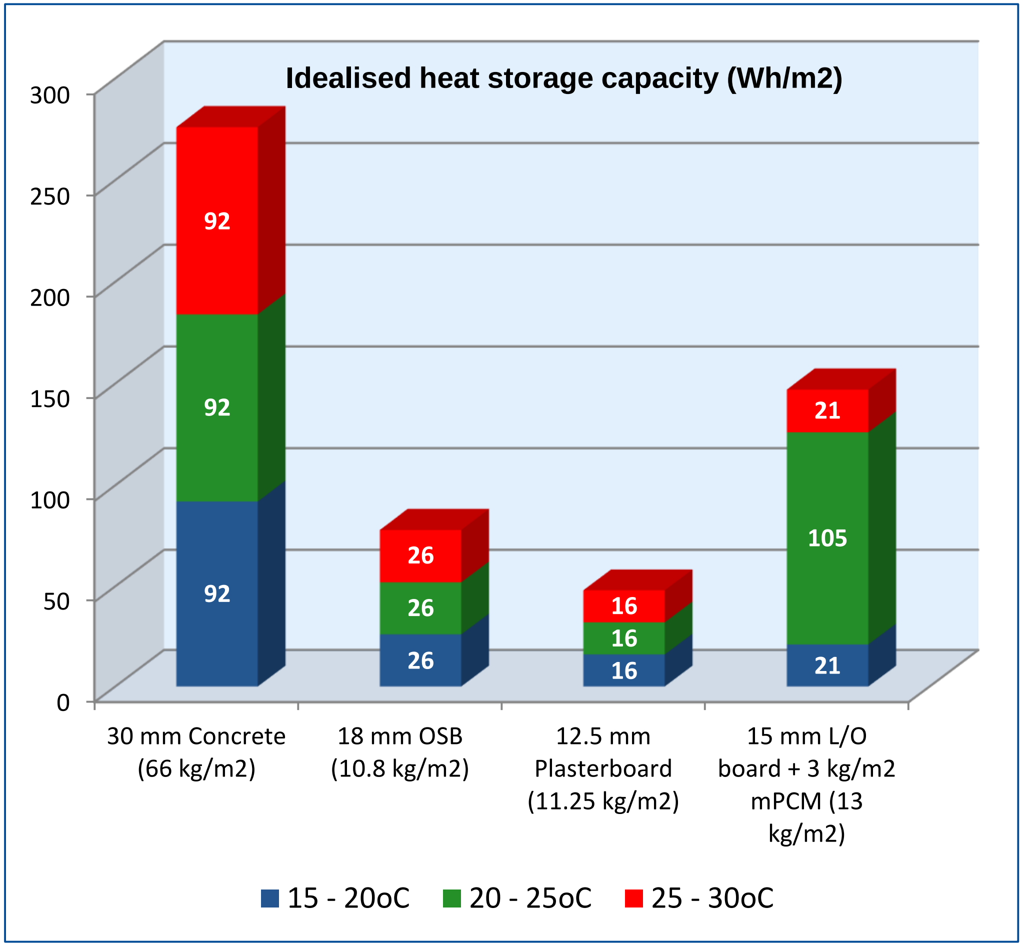
- Waxes
  - Generally stable with predictable properties (30+ years lifetime)
  - Cost varies (more expensive for speciality PCMs)
  - Usually used in sealed containers (micro/macro encapsulated)
  - Microencapsulated PCMs easily incorporated into wallboards, tiles etc.
- Salt hydrates
  - Usually formulated to achieve required thermal properties and deal with issues such as supercooling and separation (salts from water)
  - Generally don’t last as long as waxes
  - Can be corrosive and/or irritant
  - Utilised in sealed containers (vessels must be liquid & vapour tight)

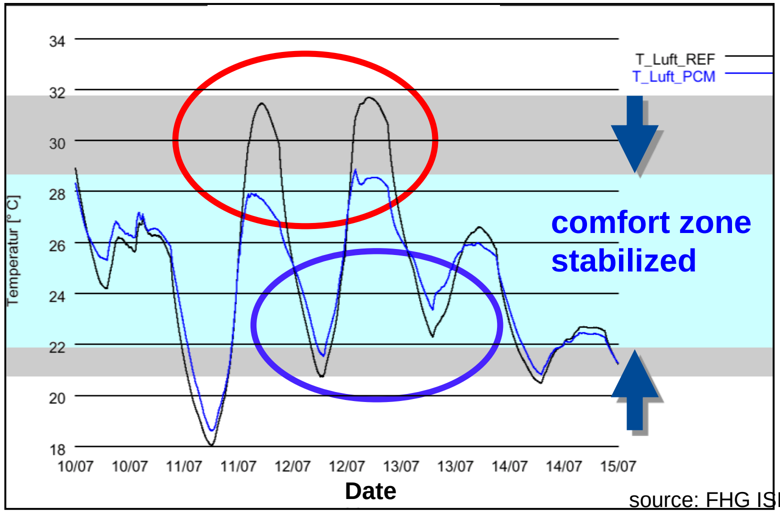
How do they work in construction?

- PCMs provide thermal mass
- Unlike concrete, brick etc. they provide most of their effect over a narrow temperature range
- Act like lightweight structure above and below their melt/freeze temperature range
- Act like a heavyweight structure around the "comfort range"
- Heat up and cool down quickly but buffer effectively in the comfort range

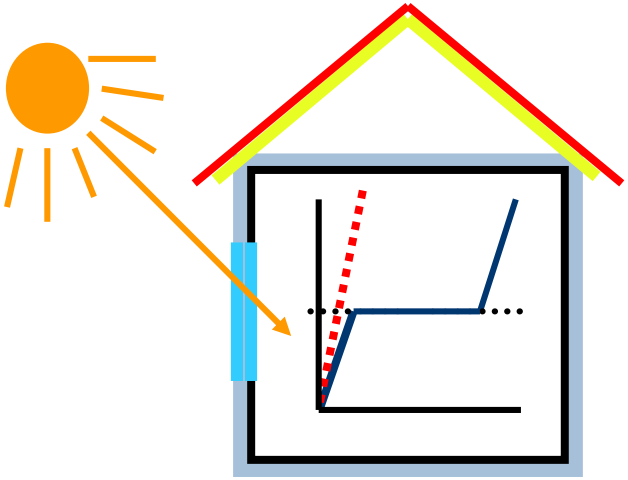


How do they work in construction?

Comparison Air Temperatures [°C]



source: FHG ISE



- PCM is trapping heat from room
- Recrystallization to recharge PCM

Rule of thumb:
≥3kg PCM/m² floor space

Where to use PCMs? - buildings

- Microencapsulated wax PCMs
  - Clay wallboards
  - Gypsum panels
  - Plasterboard
  - Ceiling tiles
  - PU foam panels
  - Gypsum plaster
  - Acoustic plaster

Where to use PCMs? - buildings

- Macroencapsulated wax or salt hydrate PCMs
  - In heat exchanger plates (e.g. for heat or coolth storage)
  - In foil packets, plastic or stainless steel balls etc.

Should they be used by themselves?

- PCMs, like sensible thermal mass, should be used in conjunction with other temperature control measures e.g.:
  - Insulation
  - Shading
  - Orientation
  - **Ventilation**
    - Ideally this should be night-time purge ventilation (3 – 5 ach) not just MVHR (0.3 - 0.5 ach)
    - The heat stored in any (e.g. PCMs, concrete etc.) thermal mass should be released overnight

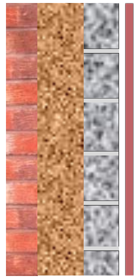
Getting it wrong in Westminster

- Single aspect apartments
- No cross ventilation
- Night purge ventilation difficult
  - Security
  - External noise
  - Pollution etc.
- Any internal thermal mass often decoupled from room air (e.g. use of drywall), or doesn't cool
- Average, overnight bedroom temp. 27–29^{o}C (Sept. 2006); average external temp. 15-18^{o}C

Courtesy Westminster City Council

Where to use PCMs?

- For any thermal mass to be effective it should be in contact with room air

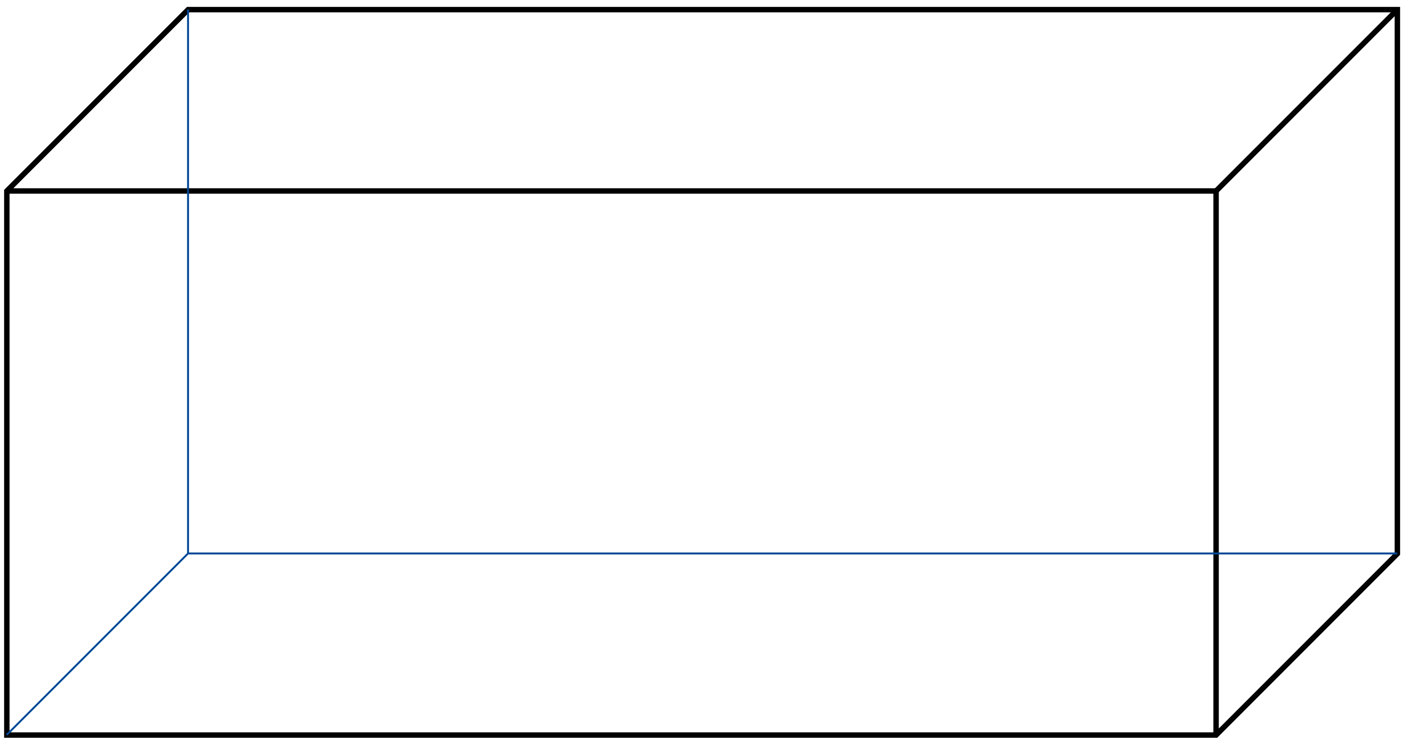


Wall construction	U-value W/m²K	Admittance W/m²K	Kappa value kJ/m²K
Plaster 13 mm Brick 100 mm Brick 100 mm	2	4.26	169
Plasterboard 13mm Mineral wool (quilt) 150 mm Plaster 13 mm Brick 100 mm Brick 100 mm	0.24	0.73	9
Drywall 13 mm Cavity 10 mm Aerated block 100 mm Cavity 150 mm (Mineral wool) Brick 100 mm	0.19	1.86	9

Values are estimates based on the Arup/Concrete Centre software

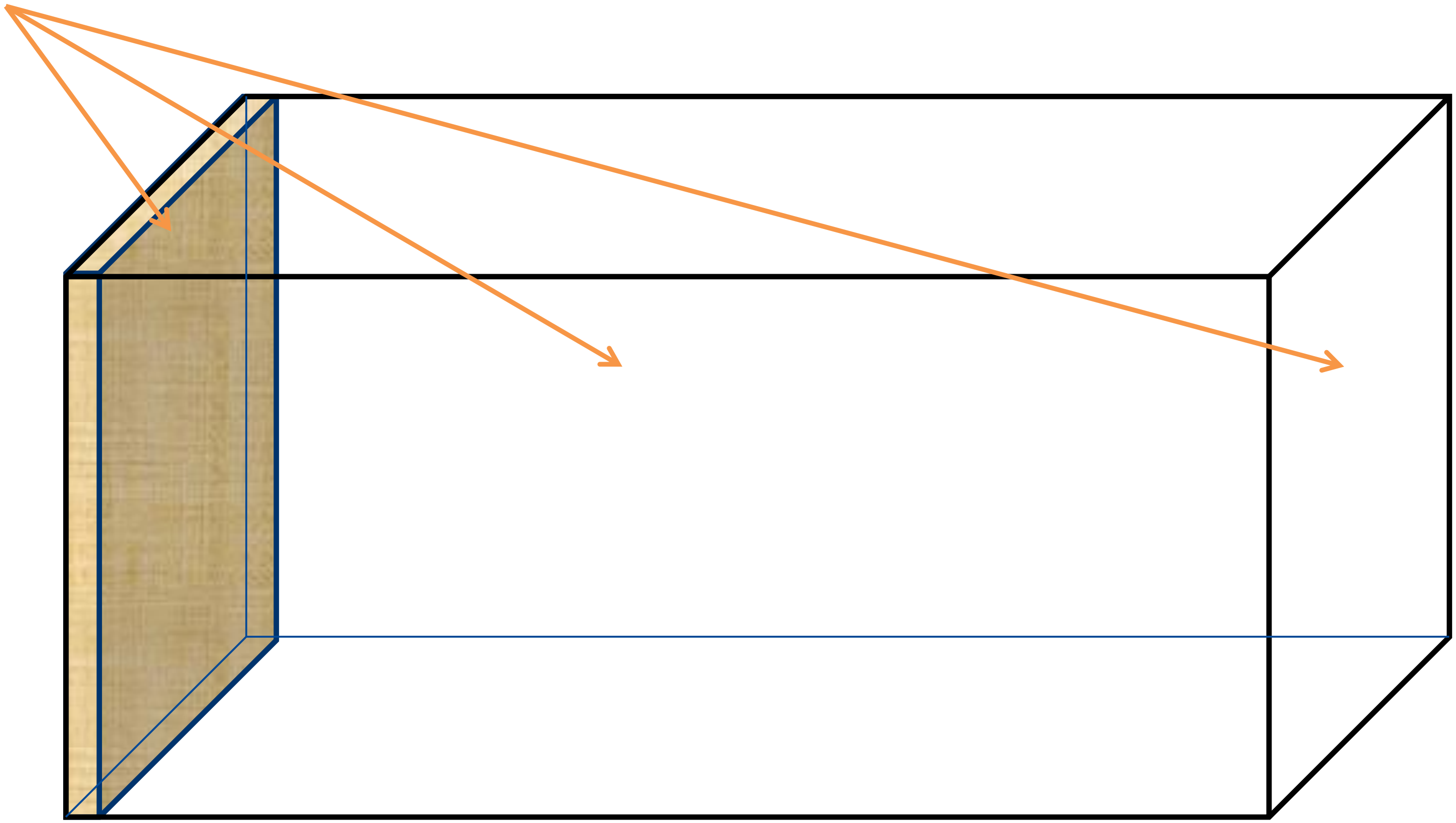
Where to use PCMs in buildings?

- Various options



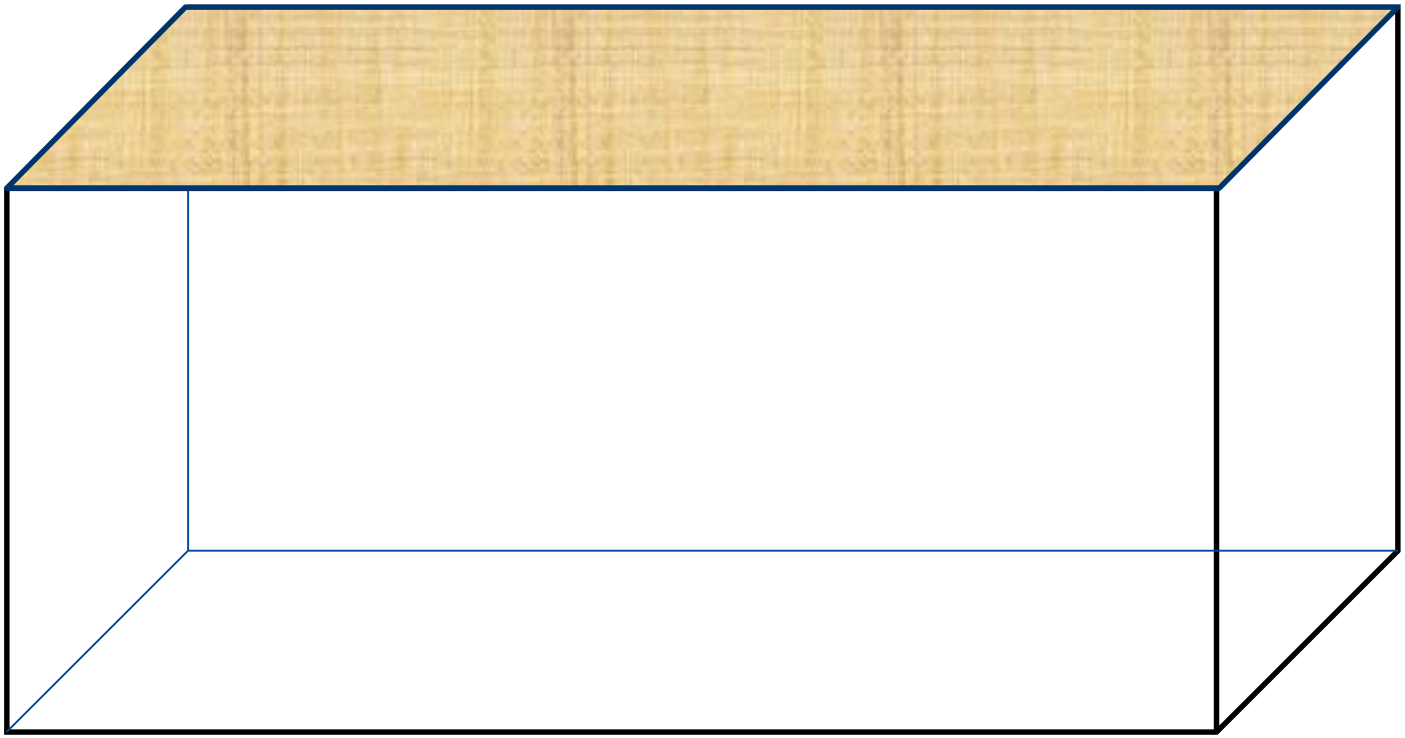
Where to use PCMs in buildings?

- Walls



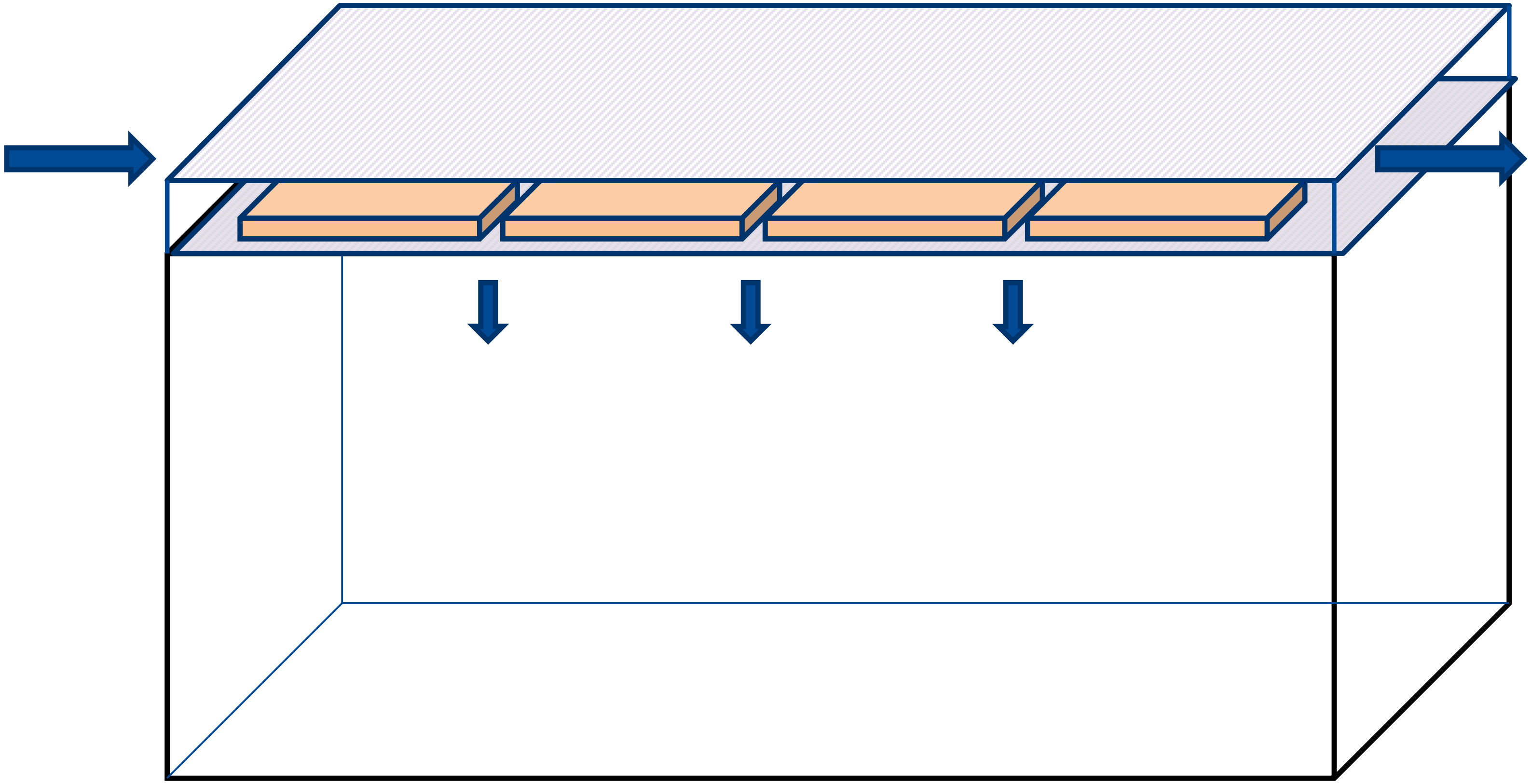
Where to use PCMs in buildings?

- Ceilings – e.g. plasterboard or ceiling tiles with plenum



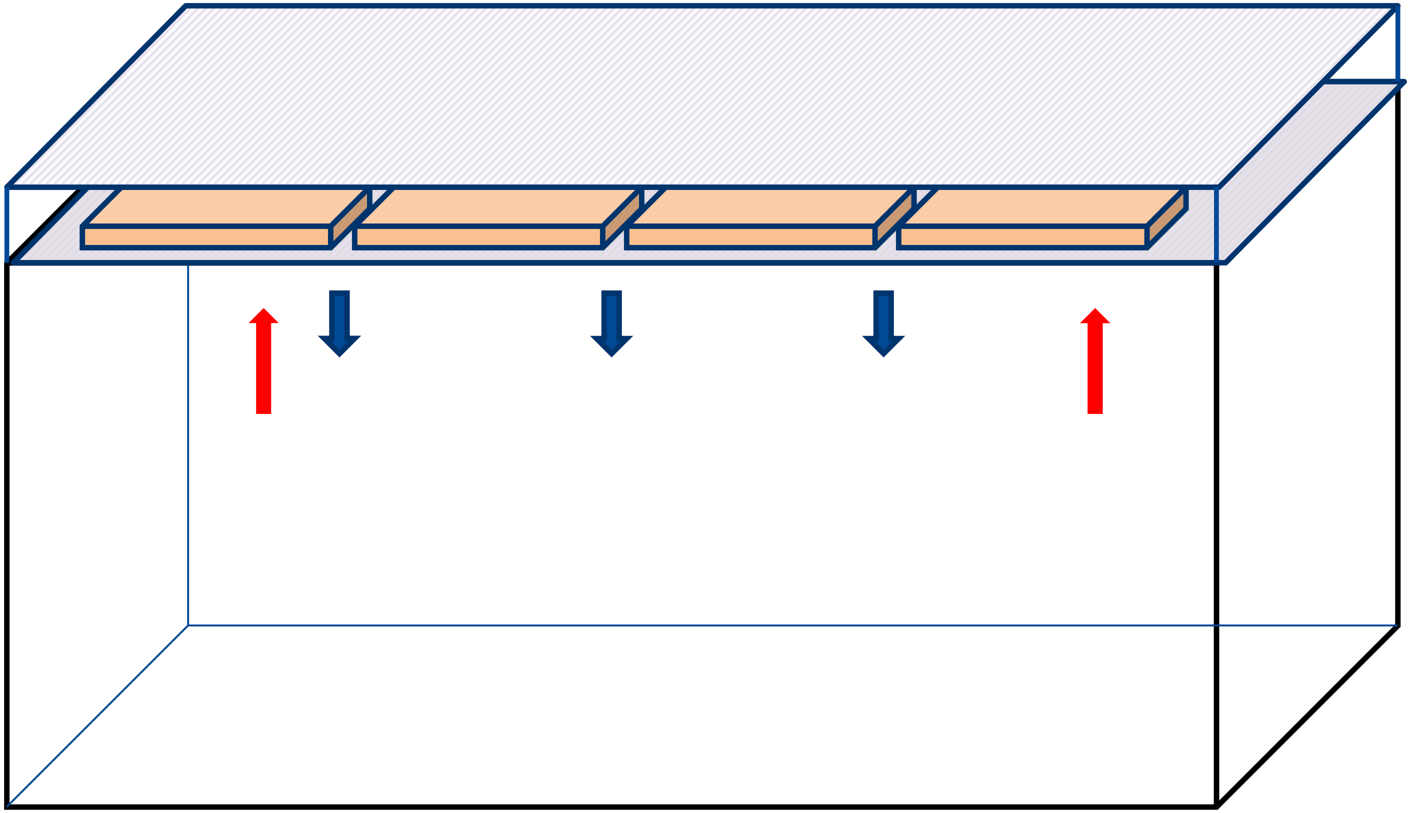
Where to use PCMs in buildings?

- Via PCM heat exchanger plates (night)

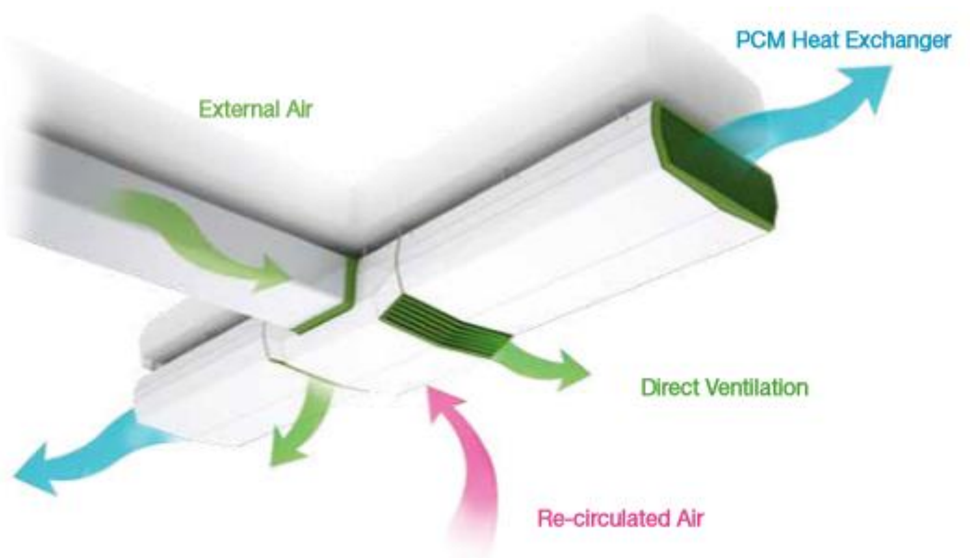


Where to use PCMs in buildings?

- Via PCM heat exchanger plates (day)



Cool storage



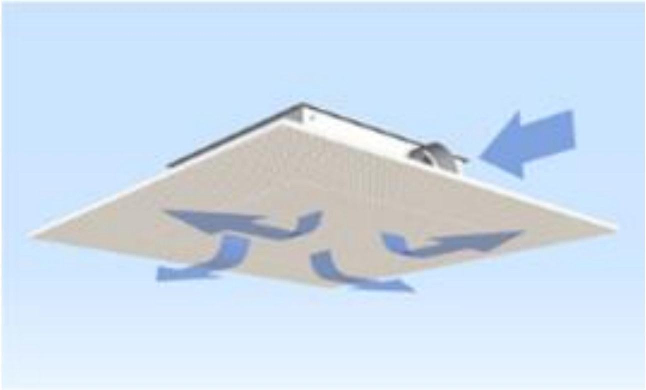
Courtesy of Monodraught

Courtesy of Actimass

Removing stored heat from thermal mass

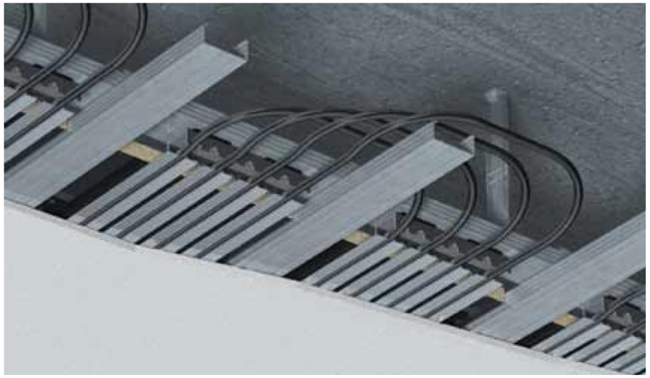
- Heat stored in any thermal mass (PCM, concrete etc.) should be removed, usually at night

- Ventilation (image courtesy of LTG)



- Use of water cooling

(Image courtesy of Emco)



Where to use PCMs?

- Wherever thermal mass would be beneficial (e.g. lightweight construction, refurbishment)
- Where heat/coolth needs to be stored for use at a different time (or place) e.g.:
  - Solar heat acquired during the day stored and used at night
  - Heat from ASHPs stored for use during peak electricity periods
  - Night-time coolth stored and used during daytime periods in e.g. ventilation systems
  - Heat/coolth from off-peak electricity stored and used later
  - Waste heat from industrial processes for office etc. heating

PCMs act as thermal batteries, storing and releasing heat

Benefits – why use PCMs?

- Provide “intelligent” thermal mass
  - Maximum effect over the chosen temperature range (acts like lightweight structure above and below chosen temperature range; heavyweight structure within that range)
- Choice of melting points available (e.g. 23ºC, 25ºC)
- Ideal for lightweight structures where provision of thermal mass is difficult
- Replace thermal mass where existing concrete etc has been decoupled from the room air (e.g. due to IWI, use of drywall, suspended ceiling etc)
- Use only in the most appropriate places within a building (e.g. near heat sources!)
- Some products (e.g. ceiling tiles) can be taken with you if you move

Problems and solutions

- Fire (waxes) – overcome by correct design of wallboard, tile etc (products must pass relevant flammability tests)
- Stability/longevity of salt hydrate systems (including packaging)
- Cost effectiveness
  - But provide potential overall cost benefits
- Lack of approved thermal modelling software (DSM)
  - PCM module in Design Builder (Level 5 due soon, also NRGsim work)
  - Currently there are no regulations which apply specifically to PCMs (other than those which relate to their chemical H&S status)
  - Any PCM-based product must pass all the relevant tests for that product type (e.g. wallboard, ceiling tiles etc.)

Quality assurance

- QA company in Germany, RAL
  - Standardised procedures for qualifying PCM performance and durability
  - Quality criteria include:
    - Latent heat storage capacity
    - Melt/freeze cycling stability (will it last for 30+ years?)
    - Thermal conductivity
  - To qualify for Class A label the PCM must withstand 10,000 melt/freeze cycles without significant change in enthalpy (heat energy storage)

Sustainability – microencapsulated wax

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- Production of 1kg mPCM generates <1.8 kg CO_2.
- Basic figure for PCM quantity in a room is 3 kg per m² floor space.
- 10 m² of a product (with 3 kg/m² mPCM) can store up to 1 kWh energy.
- Inclusion of mPCM in 10 m² of a building product

  causes 54 kg additional CO_2 , compared to standard building product.

- The mPCM will perform constantly over 30 years and more (RAL approval).
- By storing 1 kWh of cold using night ventilation during 100 days per year over thirty years, 10 m² of PCM (30kg) will save 3 MWh of A/C-energy treatment (thermal).
- If this cooling energy were instead supplied by a split unit, this would require at least 1 MWh of electrical energy (COP ~ 3).
- The production of 1 MWh of electrical energy generates approximately **570 kg CO_2.**

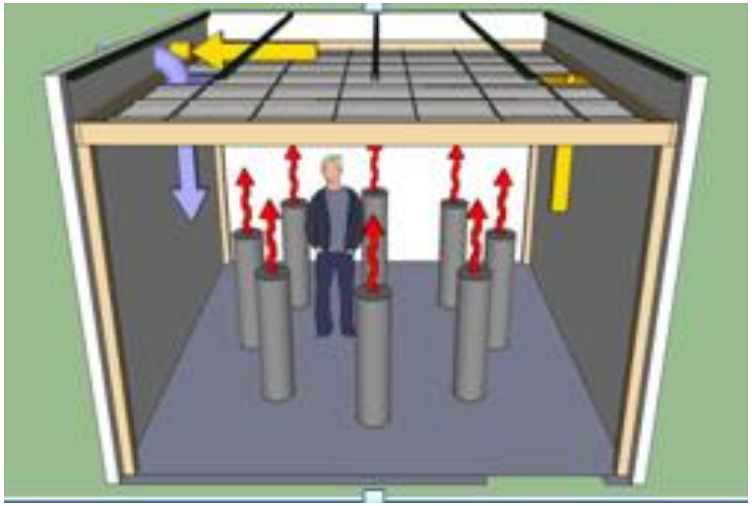
Ratio of CO_2 avoidance = 1:10

Case study - BSRIA

Test Conditions
Structure - Insulated Thermal Test Chamber

HVAC System:
1. Displacement ventilation;
2. Overhead air;
3. Overhead air ducted return

Location:	**BSRIA** , Bracknell, UK
Room Size:	16 m^2
Ceiling Coverage - mPCM tiles:	0, 30, 57 %
Thermal Storage:	0, 662, 1,260Wh
Applied Cooling Load:	30, 60 W/m^2
Air Circulation Rate:	2.5, 4.1, 11.1 $l/s\ m^2$
Purge Temperature:	14, 18 ^0C



Displacement Ventilation System
- 662Wh of thermal storage delayed the operation of the air conditioner by 1:20 hours with a 30 W/m^2 load
- 1,260Wh delayed this by 4:27 hours.
- The PCM tiles typically reduced temperature variations on the ceiling to +/- 1ºC.

Courtesy of Armstrong

Case study – office, Central London

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Test Conditions

Structure – Midrise masonry building

HVAC System: Split system, ventilation fan

Location: London, UK

Room Size: 47.5 m^2

Ceiling Coverage (mPCM tiles): 60%

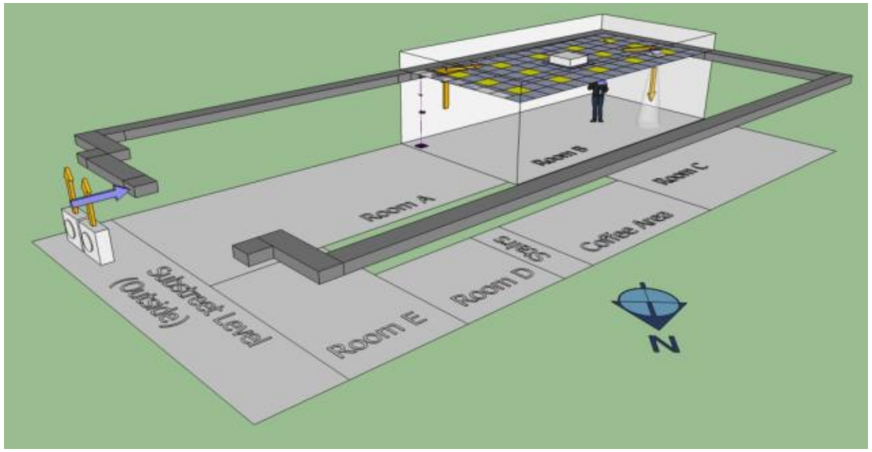
Thermal Storage: 3,900 Wh

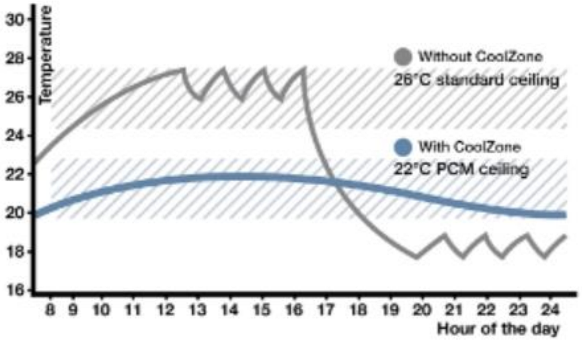
Applied Cooling Load: Up to 55 W/m^2

Air Circulation Rate: Up to 13 $l/s\ m^2$

Purge Temperature: Varies, based on night time outside air temperature

Energy Savings: 20 – 70% (depending on conditions)





Courtesy of Armstrong

Summary & learning outcomes

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- PCMs are an “intelligent” type of thermal mass
- They are not a type of insulation (but they will work well in combination)
- They allow structures to warm up and cool down quickly but buffer the temperature within a “comfort temperature range”
- Like all thermal mass, they absorb heat but this should be released overnight using cool night air (purge ventilation), water (e.g. capillary mats) or chilled air (via off-peak electricity)
- They should be part of a well-designed, system-based approach to thermal management
- They can also be effective at storing heat/cold for ASHPs, solar thermal etc

Contacts

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Micronal® PCM app (iOS and Android)

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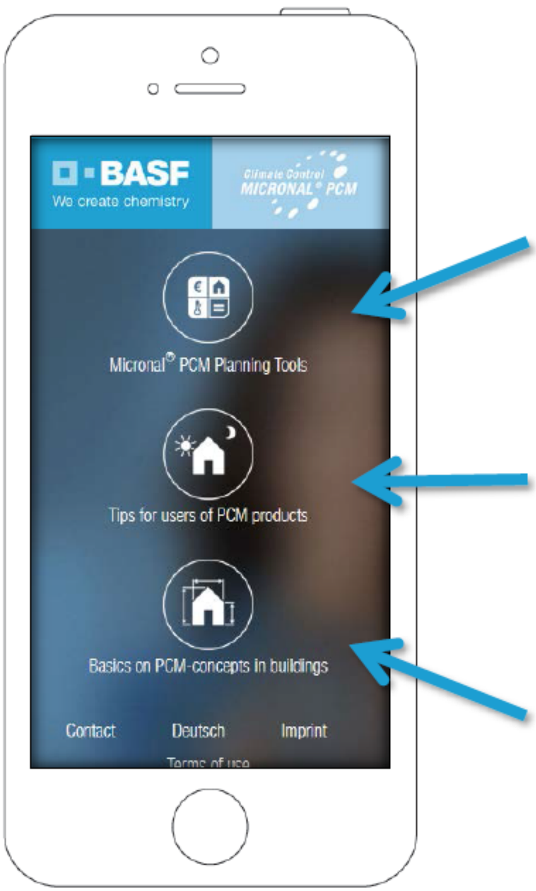

Basic Functions:

- Tools for architects, planners, producers
  PCM-calculator, material data, equivalent thickness
- PCM tips for builders and developers
  and weather depending cooling times
- Basics of PCM application:
  products, standards, links, tips on planning with PCM

Micronal® PCM App

- ❑ iOS and Android devices + desktop version
- ❑ Based on tool developed by Arup
- ❑ Doesn't model but "looks up" data from TRNSYS simulations
- ❑ Calculates "equivalent thickness" (of concrete etc.)
- ❑ User settings e.g.
  - Climate zone (northern Europe = Manchester)
  - Room type: office, classroom, dwelling
  - Fixed floor area e.g. office 16.9m^2
  - Fixed constructions e.g. floor, ceiling, walls, windows etc.
  - Orientation, window area (external gains)
  - Ventilation (night purge, mechanical, chilled ceiling)
  - Strategy: standard versus PCM + night cooling
  - Cooling load, cooling energy, energy cost

Micronal® PCM in Public Buildings School in Luxemburg, Diekirch

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Good thermal comfort in container lightweight construction without active cooling.

ISE
Fraunhofer Institut Solare Energiesysteme

- New school building for the state of Luxembourg, town of Diekirch
- Construction: structural work steel container
- Interior work: dry construction and PCM
- Purely passive temperature management at 23°C on walls and ceilings using Knauf PCM SmartBoard®.
- Implementation: ALHO Systembau GmbH, Morsbach
- Monitoring: Fraunhofer Institute for Solar Energy Technology (ISE) in Freiburg

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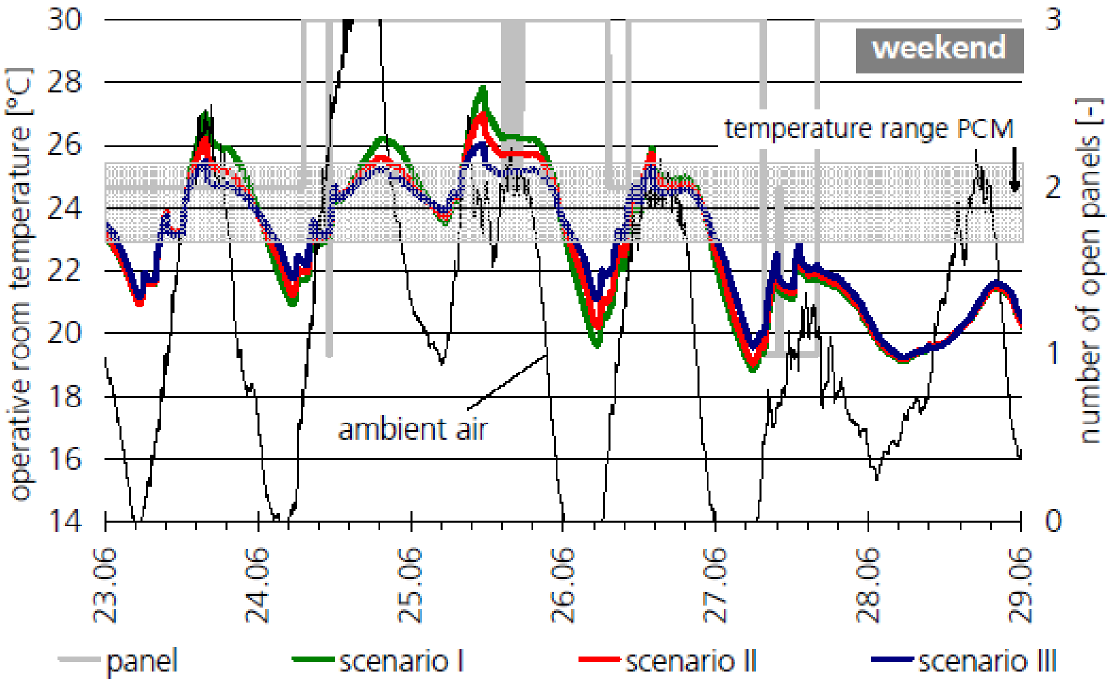
Simulation study: development of temperatures



scenario I: room without PCM

scenario II: room with PCM only on the ceiling panels

scenario III: room with PCM in interior and exterior walls and the ceiling

- comparison of hourly operative room temperature
- small difference between scenario I and II: smart board in ceiling with 40m² constitutes just a small increase of thermal storage
- significant effect with scenario III

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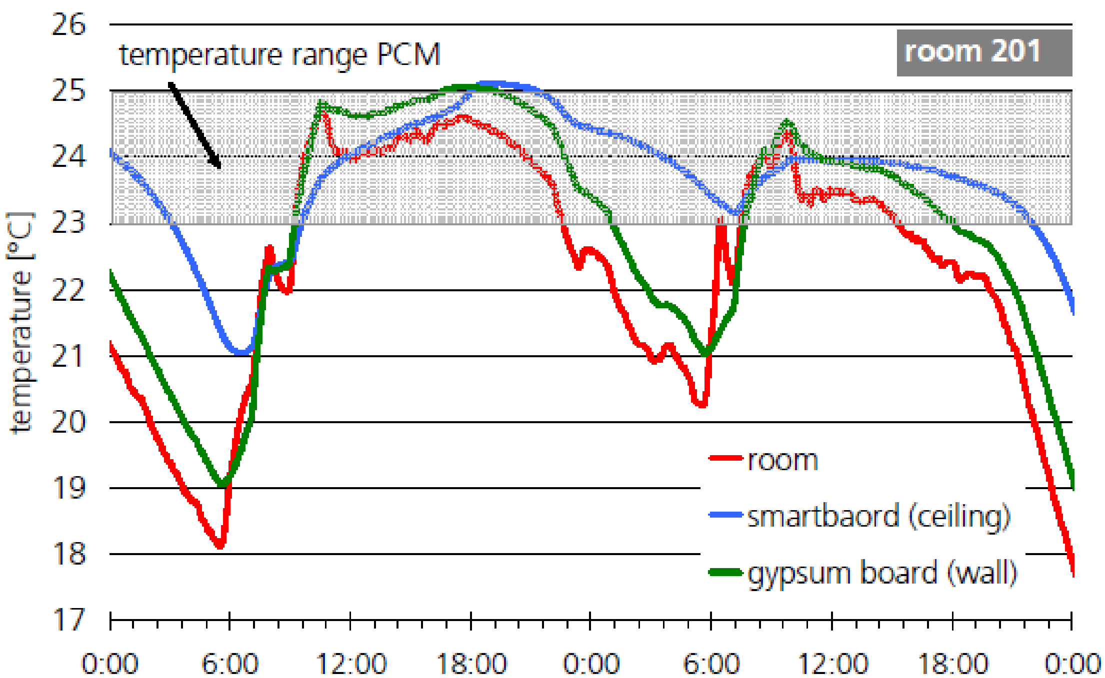
Evaluation monitoring: phase change materials I



- smartboard 23 in walls and ceilings
- temperature range of phase change 23 to 25°C
- within the temperature range of the phase change:
  → ceiling with attenuated daily amplitude
  → delayed temperature increase and decrease of smartboard

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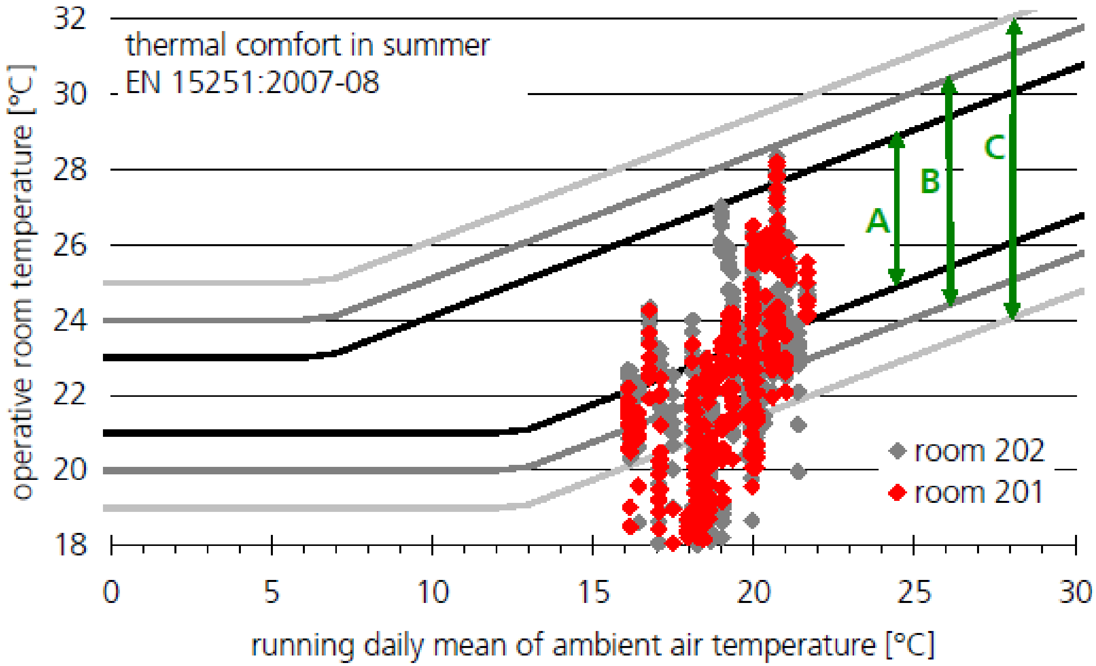
Evaluation monitoring: thermal comfort II



- European Guideline DIN EN 15251:2007-08
- hourly room temperature during 7 am and 4 pm
- 3 comfort classes A, B and C according to user satisfaction
- comfort class A: very satisfied occupants
- few exceedance of comfort limit

Micronal® PCM in Building Materials & Systems
Temperature Management in Buildings
Reference Building Measurements

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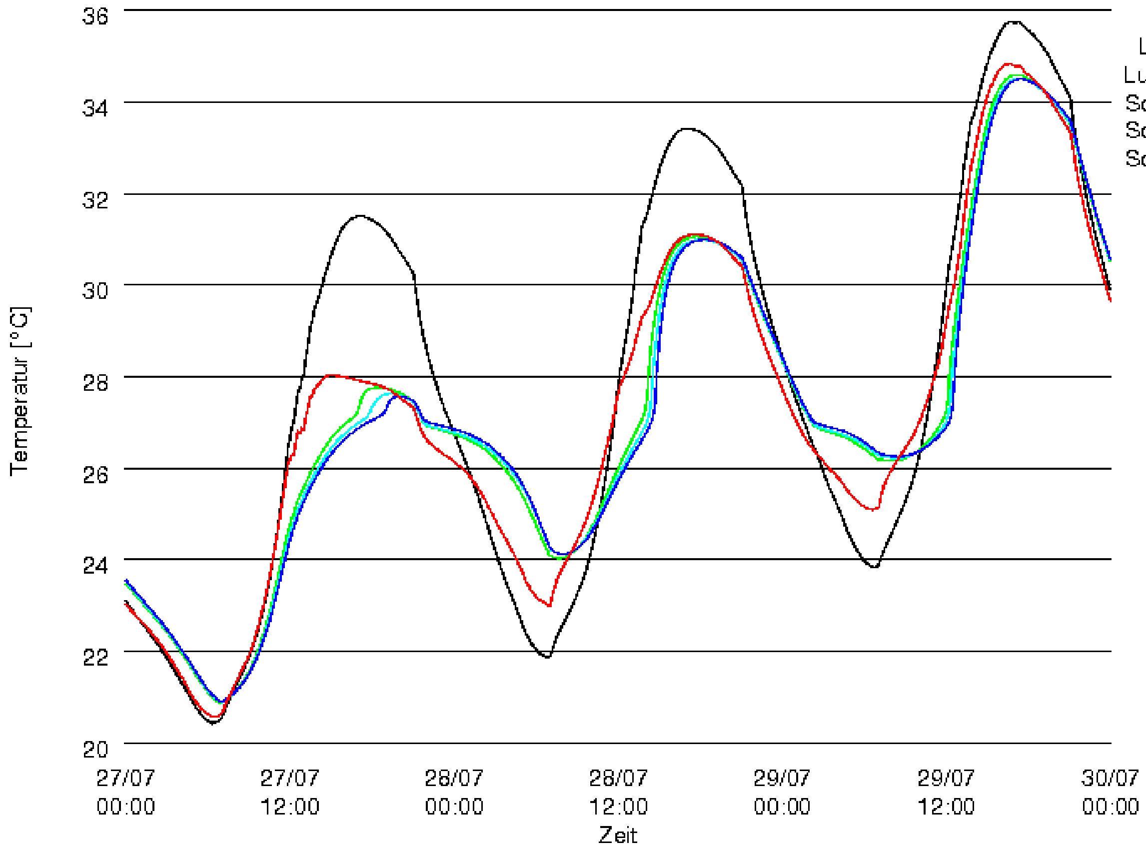
- Comparison between room with and without PCM-modified ceiling



→ thermal mass only helps if temperature cyles suffice

Active:
PCM-system in larger objects

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- **Strong energy impact on modern buildings need temperature control**
- **Technology change: From air conditioning units to cooling tower + groundwater cooling**
- **Active concept: Recooling with water**
  - **Concrete core activation**
  - **Capillary mats in PCM plaster**

Picture: MFS

Example for modern glas architecture:
Print Media Academie, Heidelberg

Micronal® PCM in Building Materials & Systems
First Commercialized Object Realizing
Active Cooling Concept: Gotzkowskistrasse, Berlin

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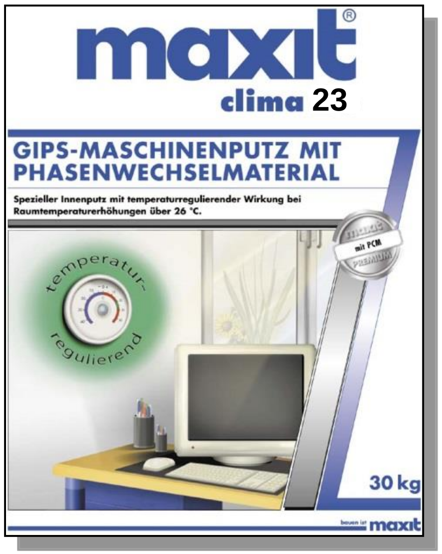
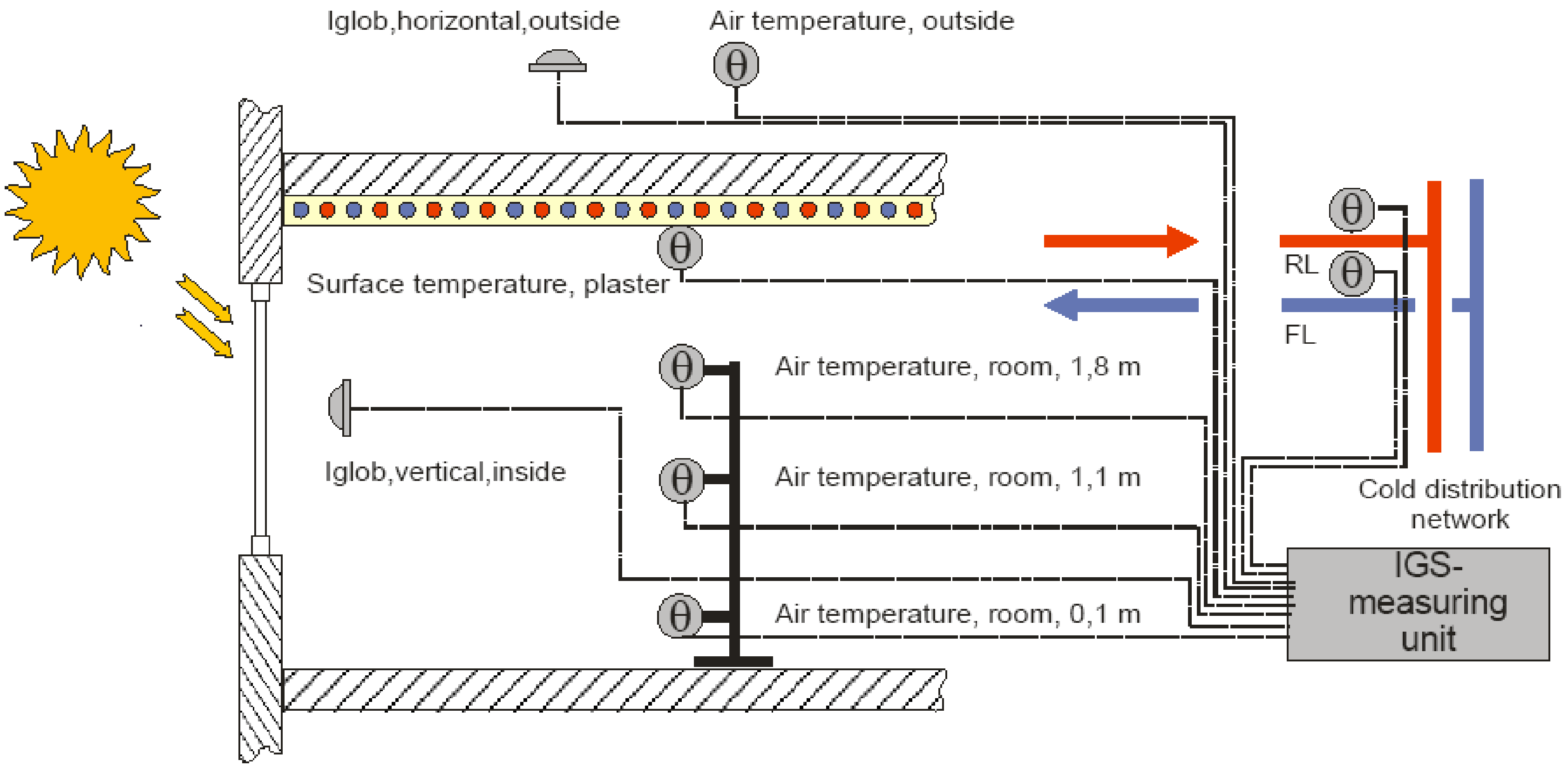


- **Refurbished object:**
  Gotzkowskistraße, Berlin, D
- **Active control plus PCM with 1,100 m² "maxit clima" – plasters**
- **7 t Micronal® 23°C processed**

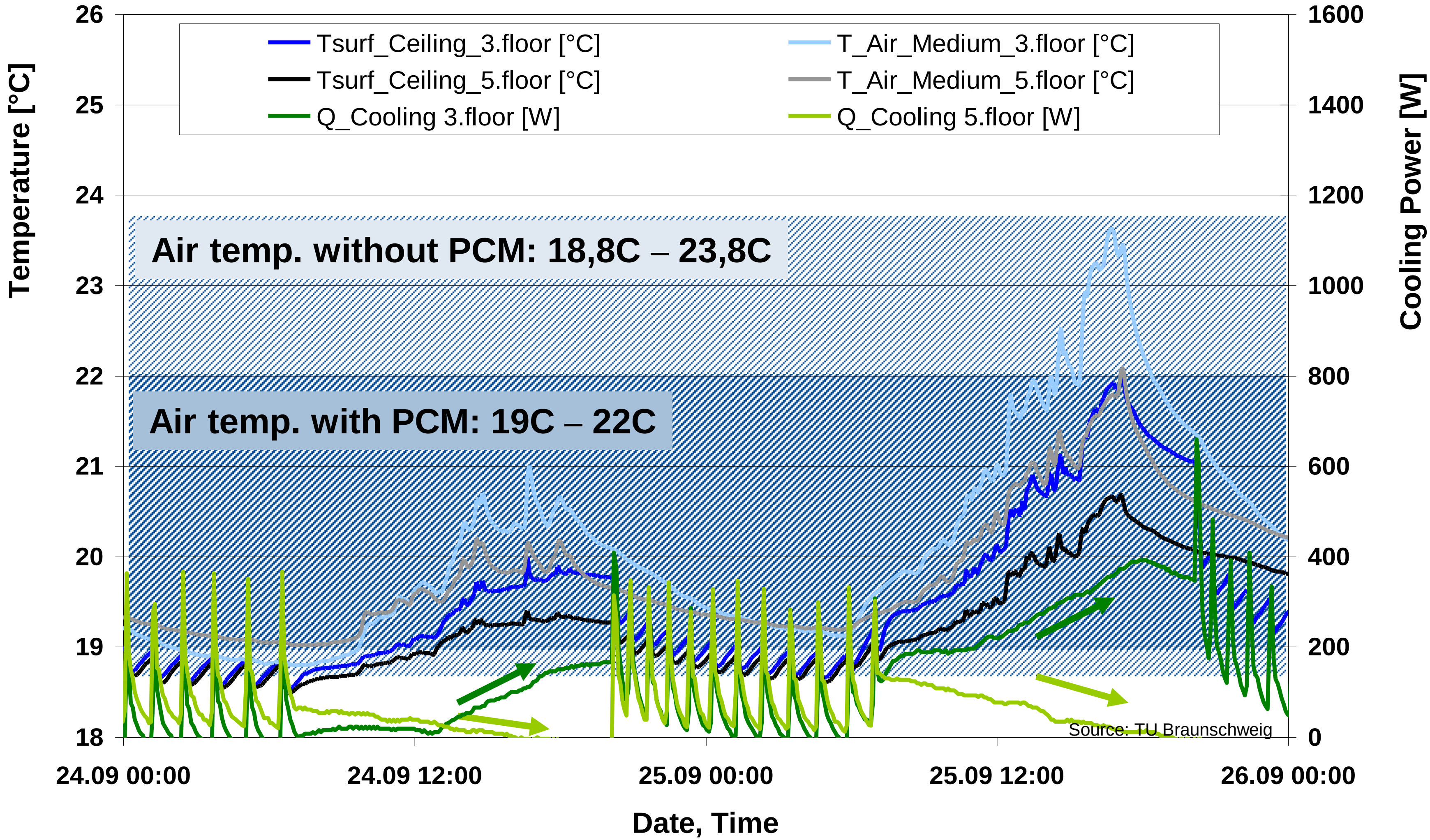
Foto: MFS

Micronal® PCM in Building Materials & Systems
Measurement Systems
Gotzkowskistrasse, Berlin



Measurement equipment in the test rooms

Micronal® PCM in Building Materials & Systems
PCM-Plaster (5th floor) vs. Plaster (3rd floor)
Gotzkowski Street, Berlin



Micronal® PCM in Building Materials & Systems
SmartBoard™ as System Component
Active Cooling Ceiling by Ilkazell, Zwickau

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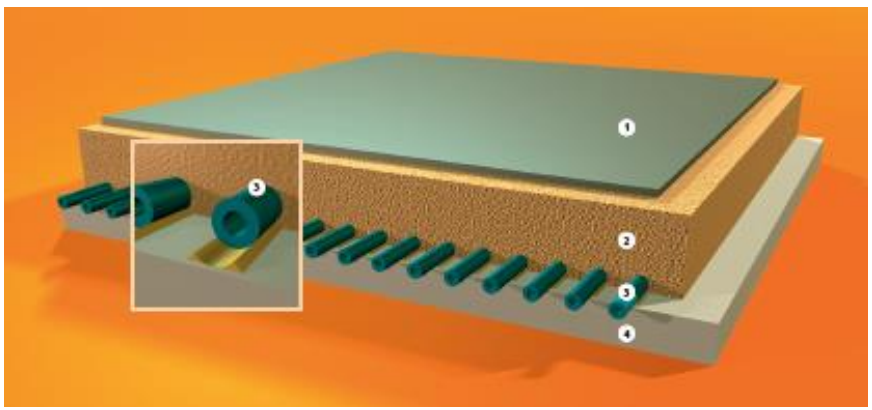

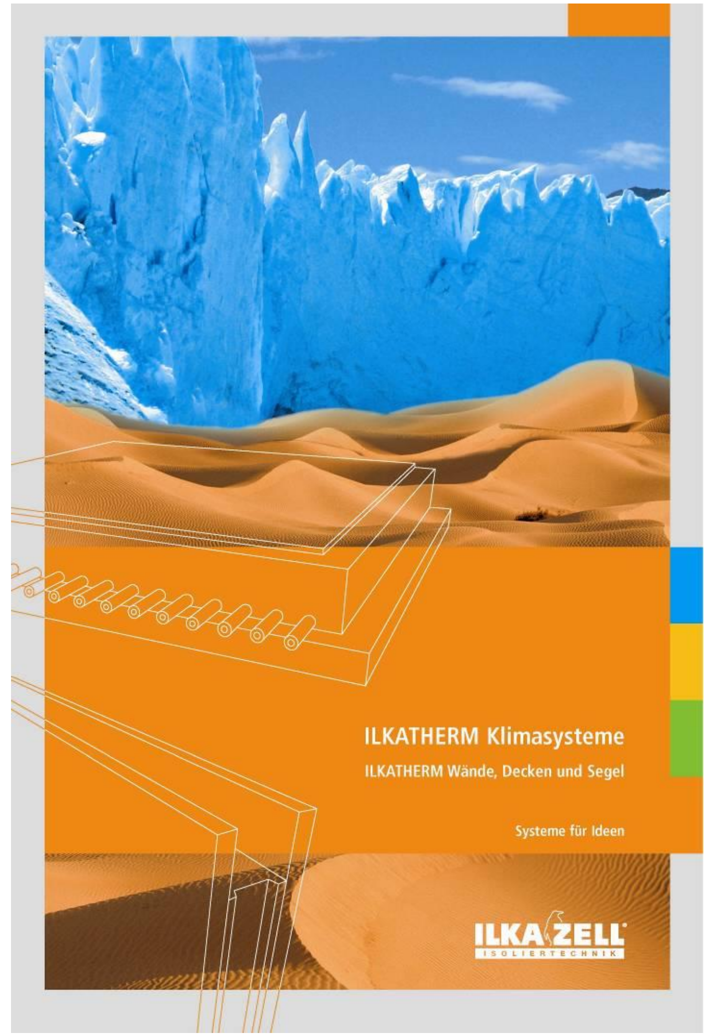

Micronal® PCM in Building Materials & Systems
Office Renovation and Expansion
in Karlsruhe, Germany

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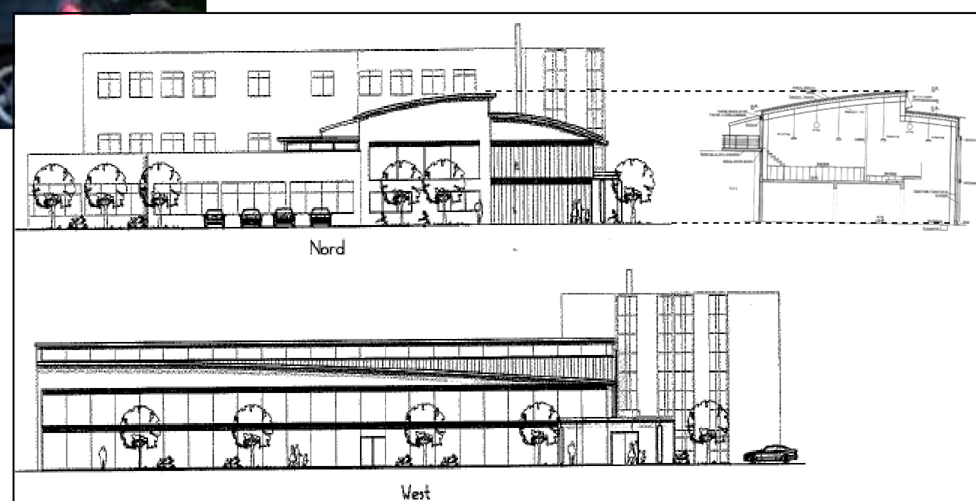
- **Facade in Zero-Energy quality**
- **Extended daylight using**
- **High climatic and illumination comfort**
- **Pilot application of new technologies (LowEx)**

ENGELHARDT & BAUER

Printing Company in Karlsruhe

Germany. Approx. 900m²



Micronal® PCM in Building Materials & Systems
Office Renovation & Expansion in Karlsruhe
Regenerative cooling concept with chilled ceiling

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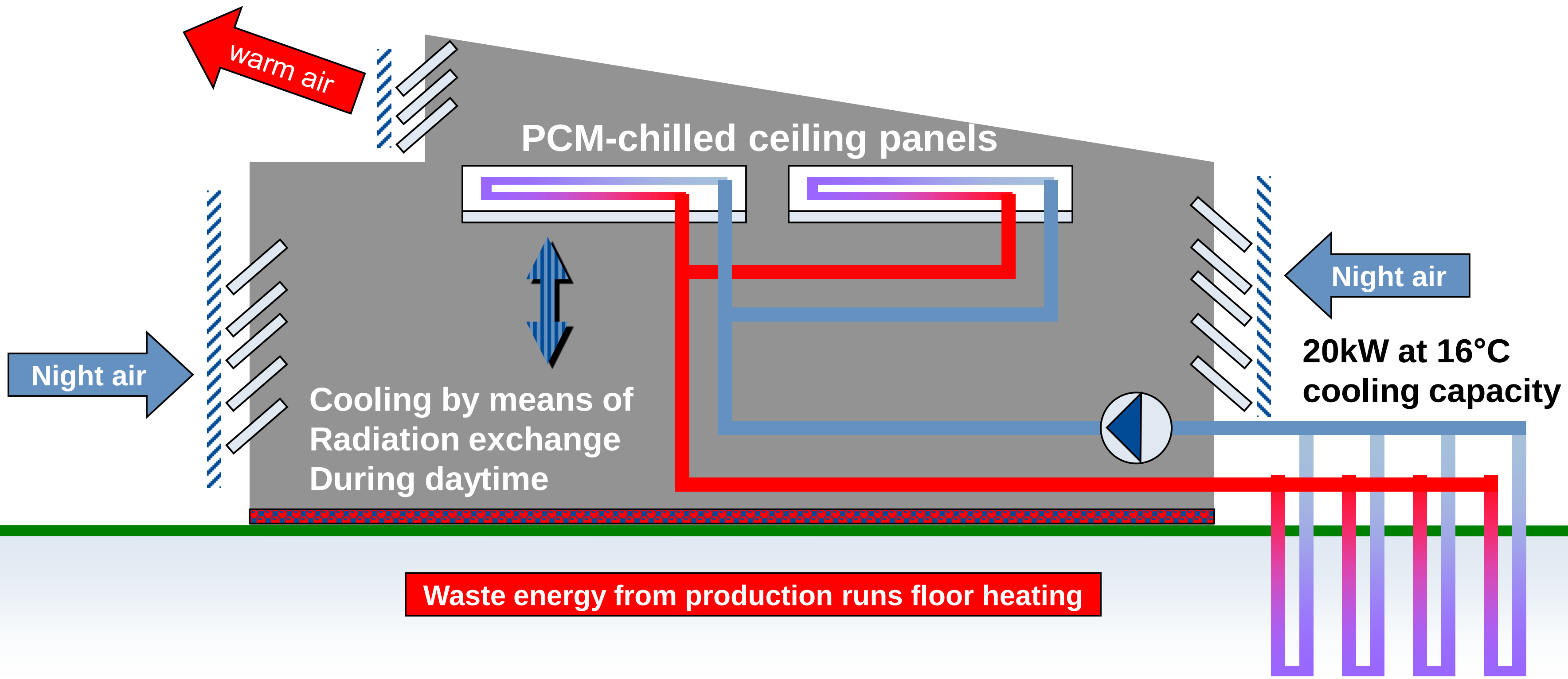
- Cooling by means of small dimensioned ground heat exchanger
  - Valuable solution for temperature control based on naturally available cooling source.
- No heat exchanger between ground cooling source and chilled ceiling
  - Minimized technical efforts, reduced running and maintenance costs.



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Office Renovation & Expansion in Karlsruhe
Chilled Ceiling Keeps Working Area Cool

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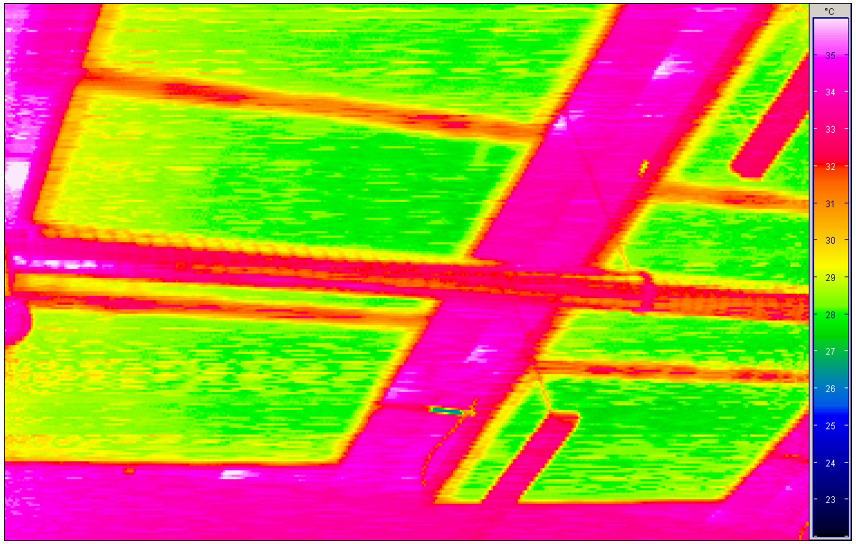
The Chemical Company

Chilled ceiling as suspended panels



IR-radiation thermo graphic picture

- **Before renovation**
  - **Specific electrical consumption in office area:** **80 kWh/(m²a)**
  - **Specific heat consumption per year:** **160 kWh/(m²a)**
- **After renovation (calculated)**
  - **New primary energy consumption:** **54 kWh/(m²a)**
  - **Heat consumption 21 kWh/m²a; covered by waste heat from production**
  - **Removing of all existing chillers, installation of regenerative chilled ceiling**