Analytical and Experimental Modelling of Energy Storage in Phase Change Materials for Natural Cooling of Buildings

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Summary

- Introduction
- Product overview
- Model development and Test procedures
- Implementation
- Case Study

Energy Potential of Phase Change

WATER

Sensible heat - 4.2 J/g/°C

MELTING / FREEZING

Latent heat - 334 J/g

ICE

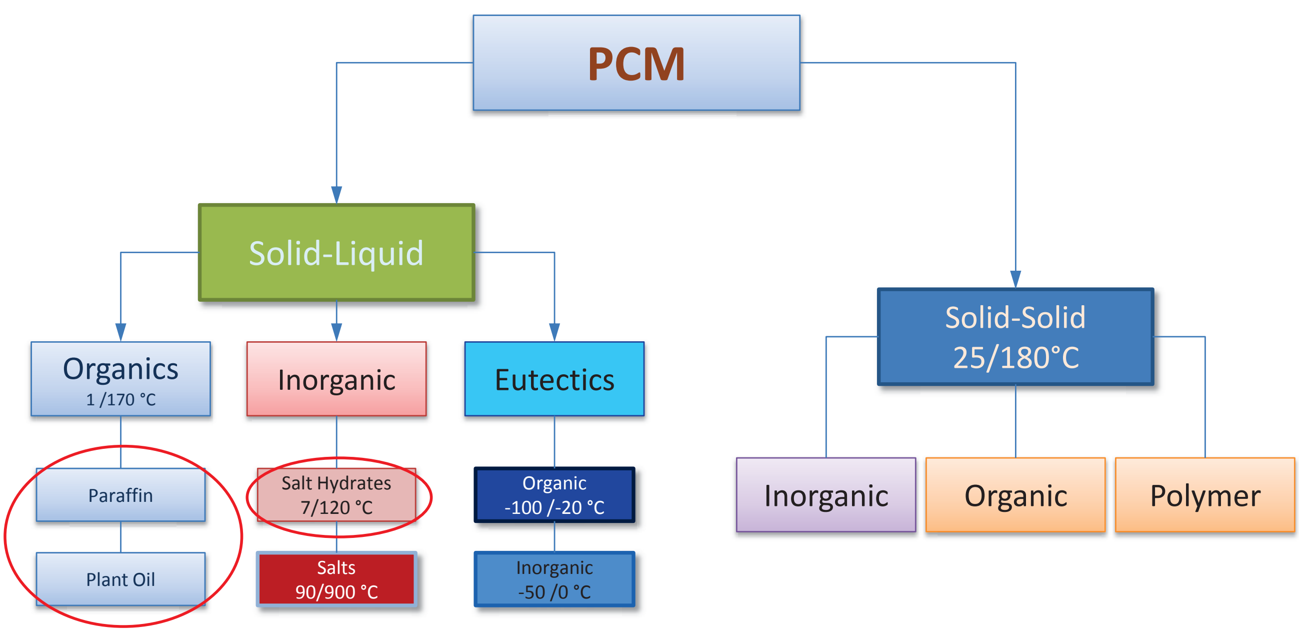
Sensible heat - 2.1 J/g/°C

125g of ice will cool down 1L of water by 10°C

$$Q_{water} = 4.2\ J/g°C \times 1000g \times 10\ °C = 42000\ J$$

$$Q_{Latent} = 334\ J/g \times 125g = 41750\ J$$

PCM Classification



PCM Properties

ORGANICS:

Advantages:
- Stable
- Encapsulation
- Energy dense

Disadvantages:
- Expensive
- Flammable
- Thermal conductivity

SALT HYDRATES:

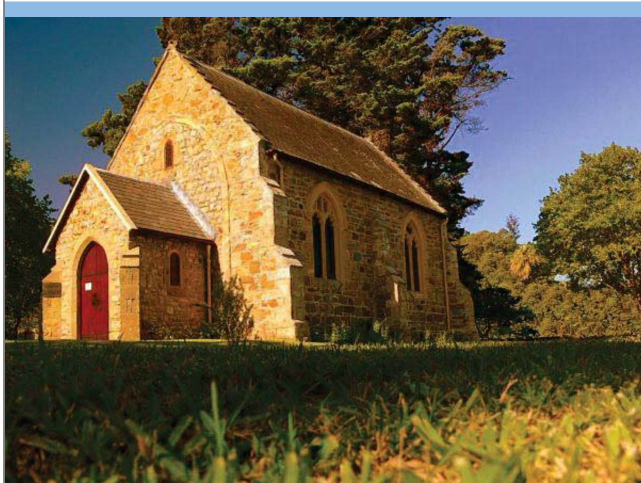
Advantages:
- Cost
- Sustainable

Disadvantages:
- Corrosive (plastic & metals)
- Thermal conductivity
- Segregation

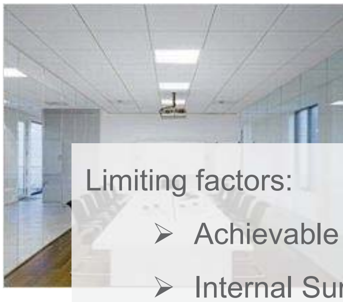
Intelligent thermal mass

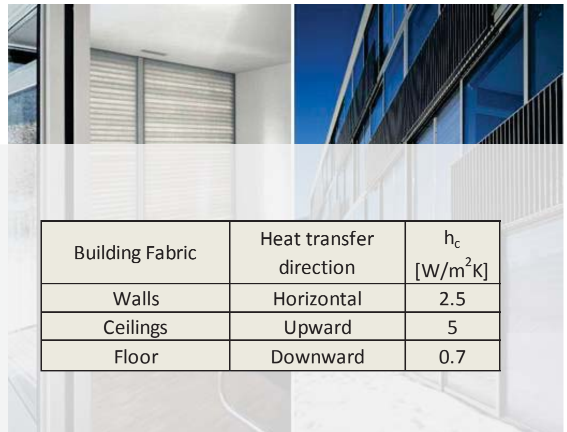
- Easy to retrofit, intelligent thermal mass
- Dissipates heat built up

Melt / Freeze 1Kg of PCM ≈ **Heat / Cool 200Kg of Concrete by 1°C**



Passive thermal mass products

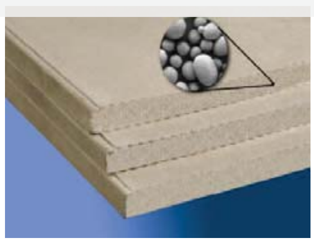


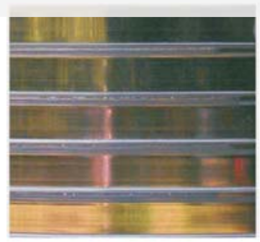


Limiting factors:

- Achievable Heat Transfer Rates
- Internal Surface Area
- Temperature difference
- TIME
- Control Strategy

Building Fabric	Heat transfer direction	h_c [W/m^{2}K]
Walls	Horizontal	2.5
Ceilings	Upward	5
Floor	Downward	0.7





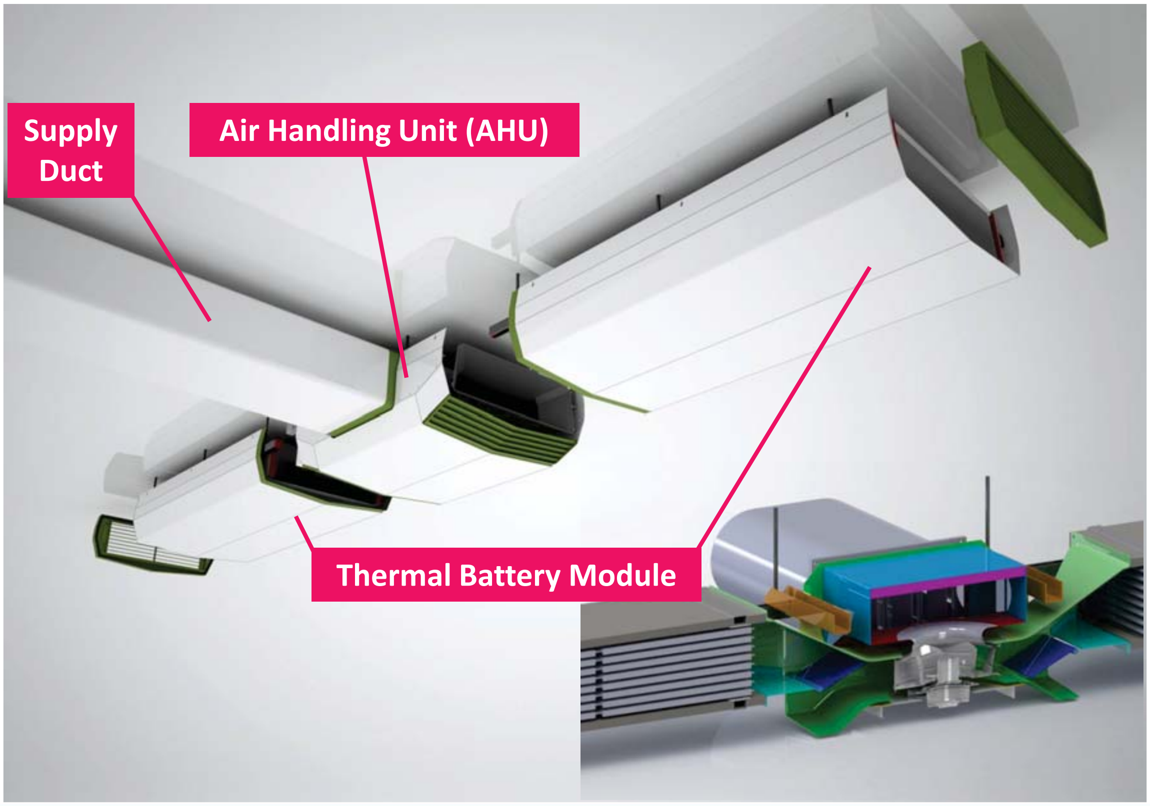
GLASSXcrystal in its liquid state

GLASSXcrystal in its crystal state

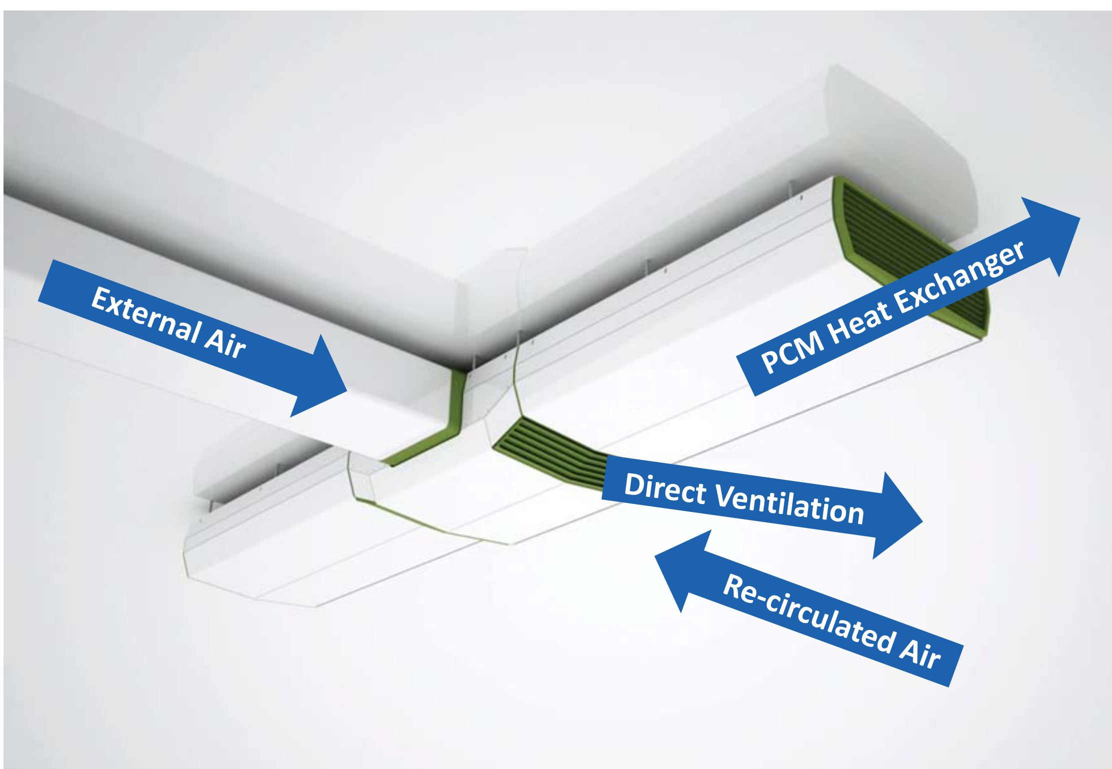
Coolphase

Product Summary

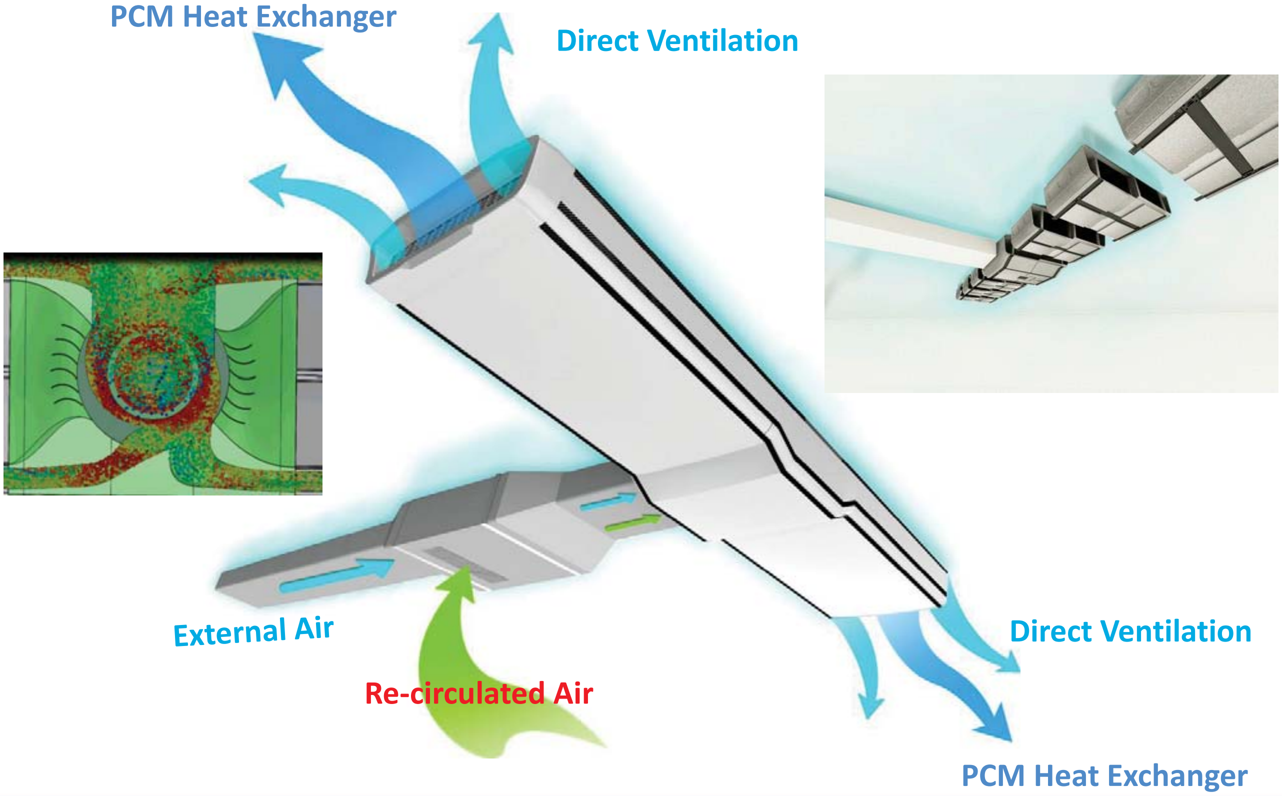
Ventilation and Storage Concept



How it works - CP Delta (2011-2012)

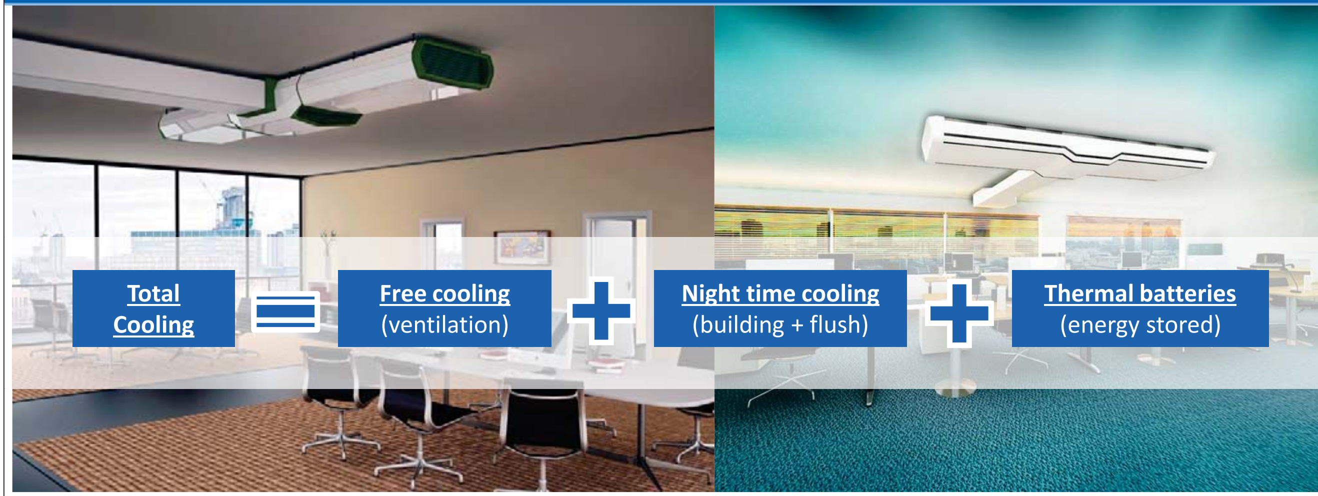


How it works - CP Nova (Current)



Ceiling Void Installation

Performance criteria



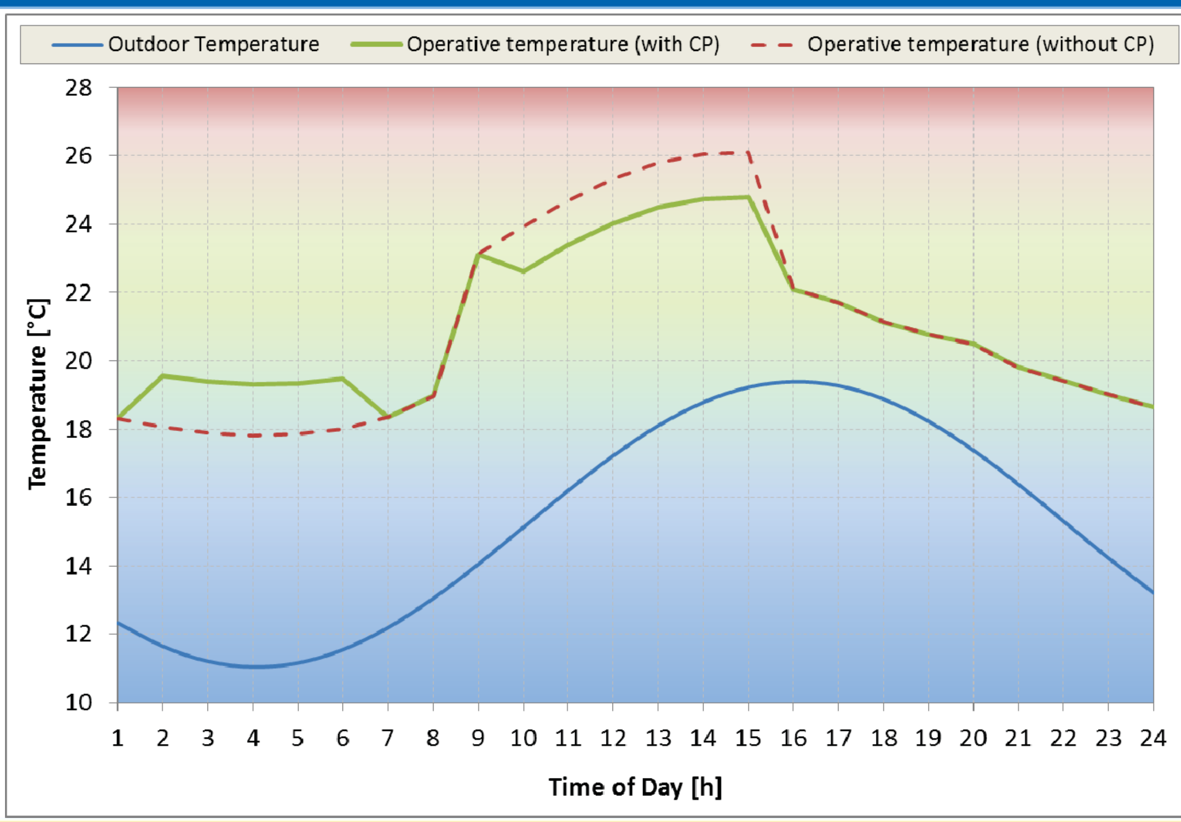
Delta Unit (2011-2012):

- Normal ventilation rate – **100 to 250** l/s
- Maximum ventilation rate - **350** l/s
- Typical energy usage – **30W to 120W**
- Thermal energy storage - **8 KWh**

Nova Unit (Current):

- Normal ventilation rate – **100 to 260** l/s
- Maximum ventilation rate - **320** l/s
- Typical energy usage – **7W to 80W**
- Thermal energy storage – 6, **8, 10 KWh**

CP Operation Schedule (CIBSE Admittance Model)



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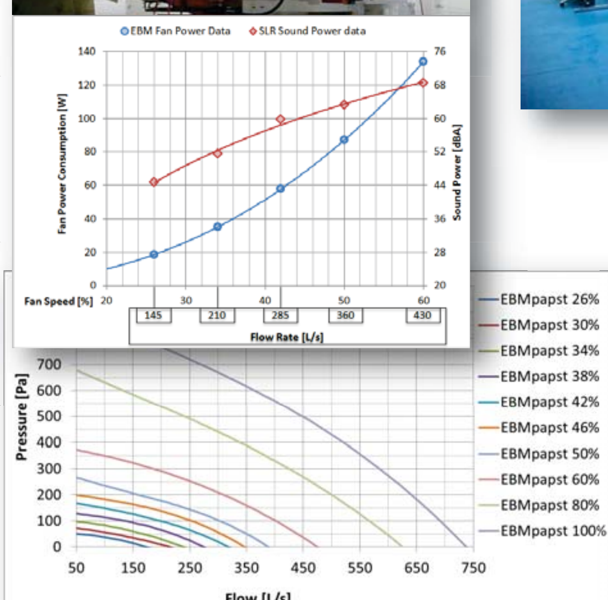
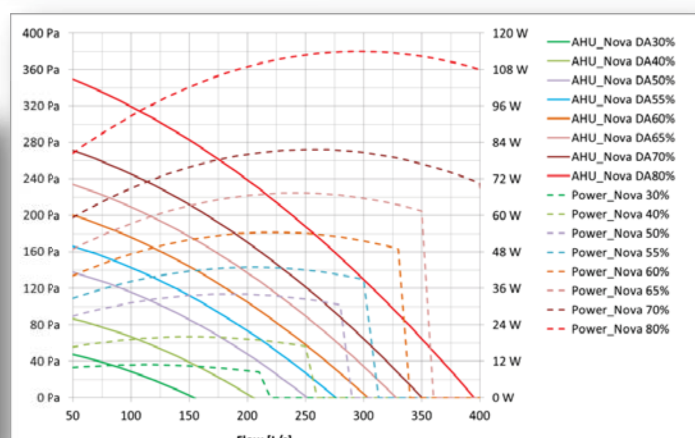
Cool phase

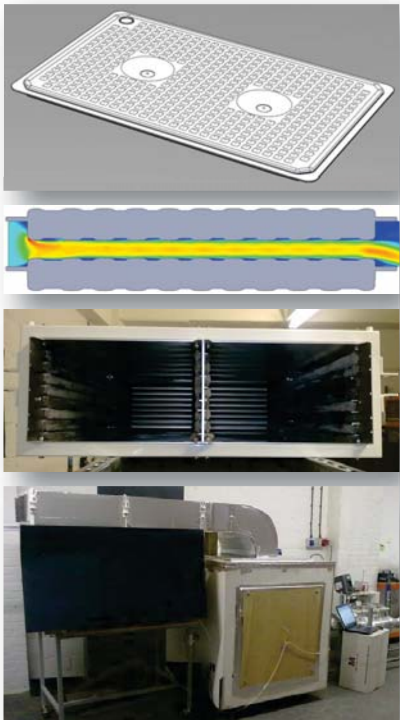
Testing & Modelling

EBMpapst – AHU Independent tests



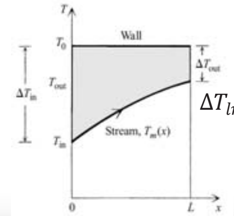


Heat Transfer Modelling

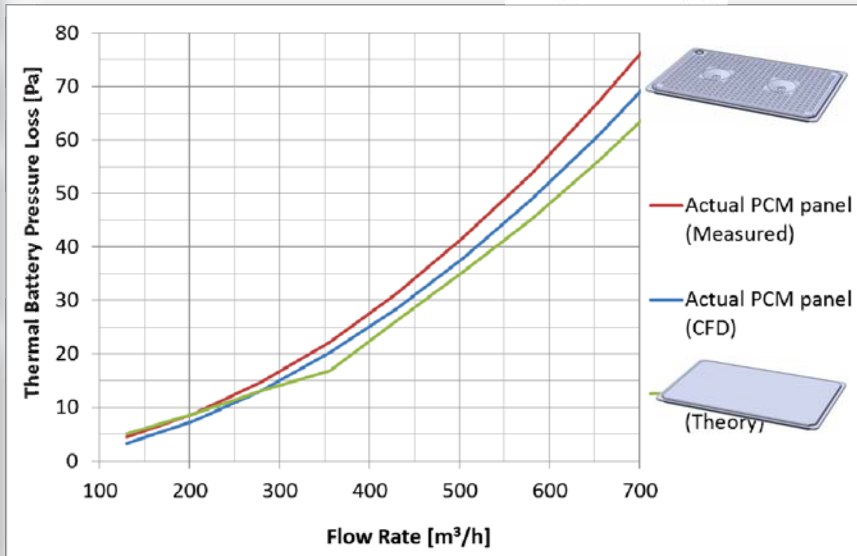


$$Q_h = h \cdot A_w \cdot \Delta T_{lm}$$

$$Q_h = \dot{m} \cdot c_p \cdot (T_{out} - T_{in})$$

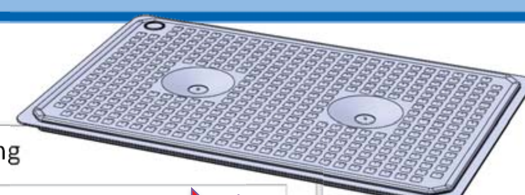


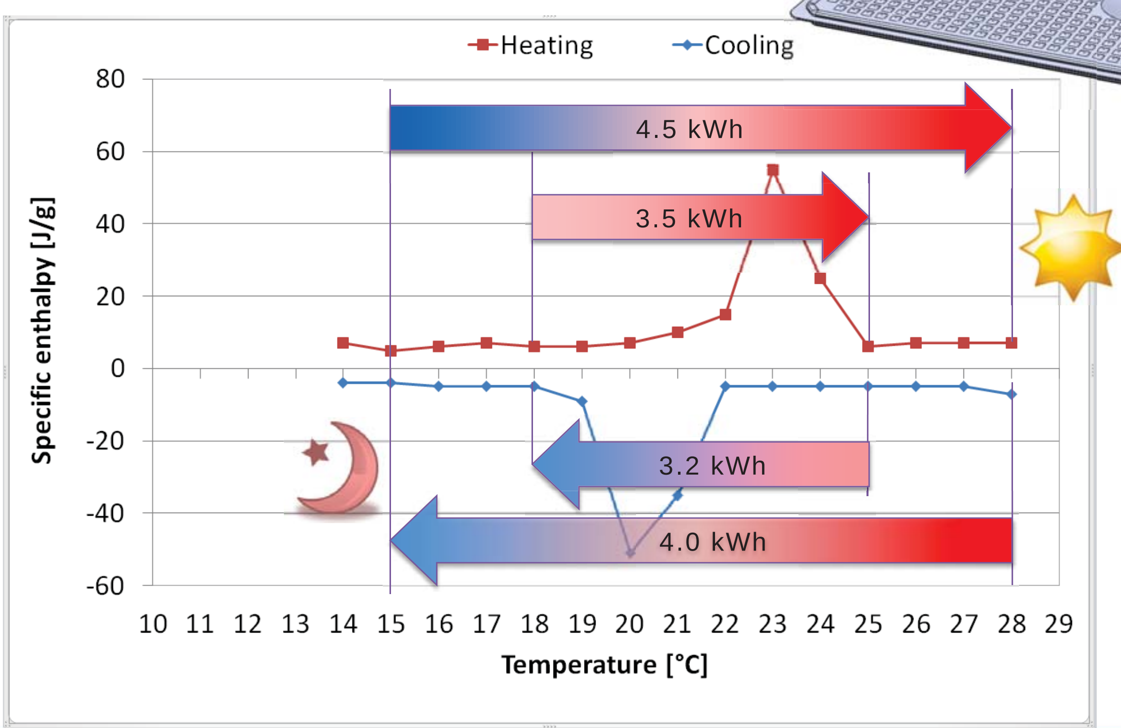
$$\Delta T_{lm} = \frac{\Delta T_{in} - \Delta T_o}{\ln \frac{\Delta T_{in}}{\Delta T_o}}$$



PCM Panel

- PCM characteristics (SP22A17)





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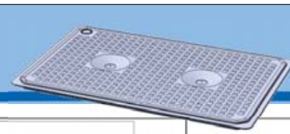
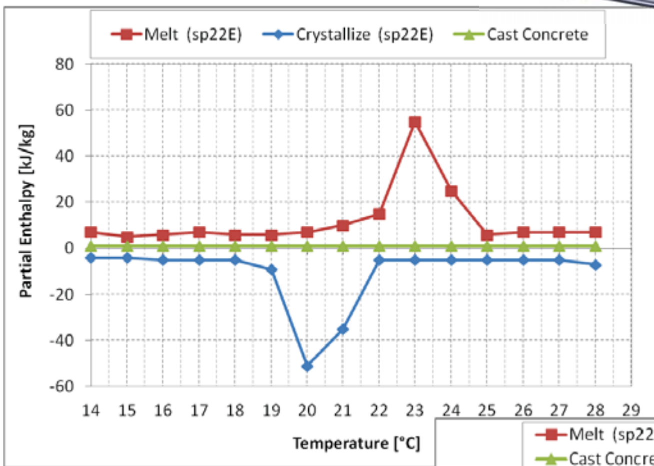
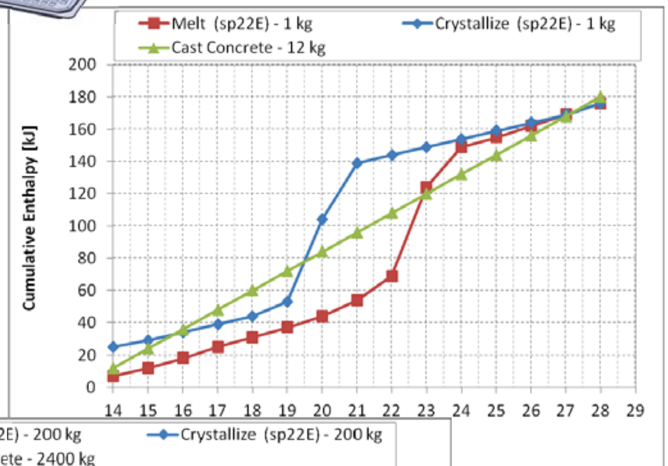
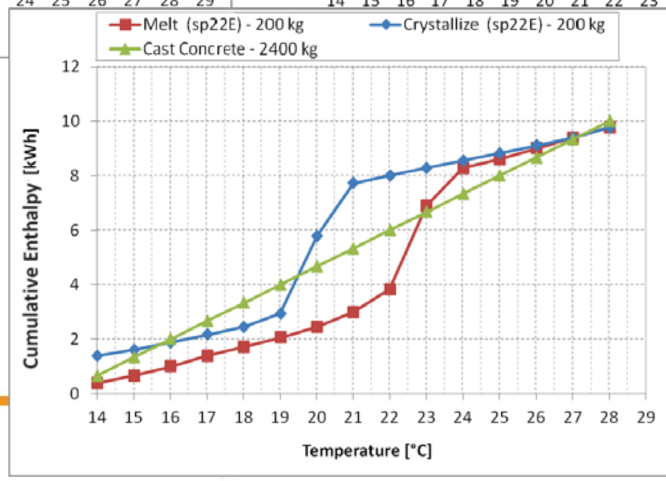
PCM characteristics



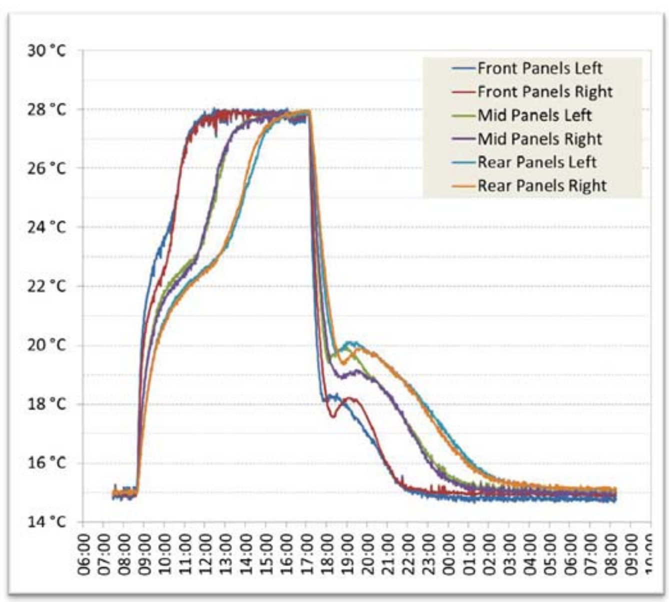






TB Performance Testing – Full Scale

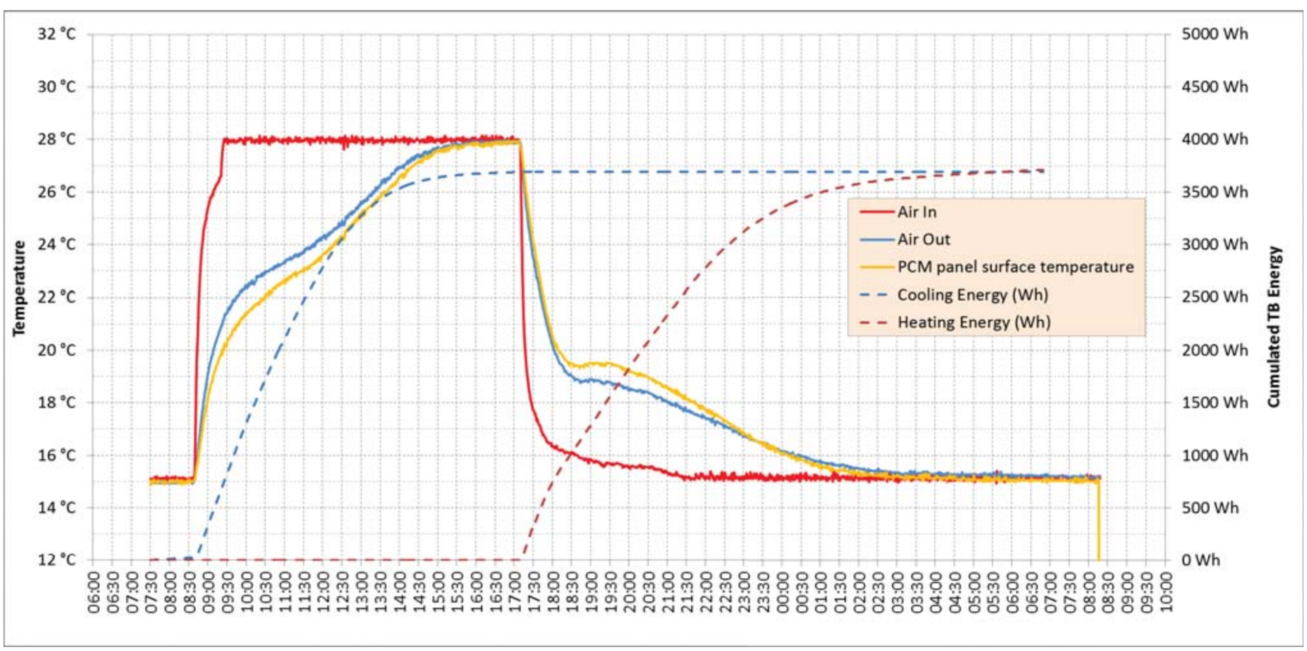
- TB cooled to 15°C at night and exposed to constant temperature of 28°C



TB Performance Testing – Full Scale

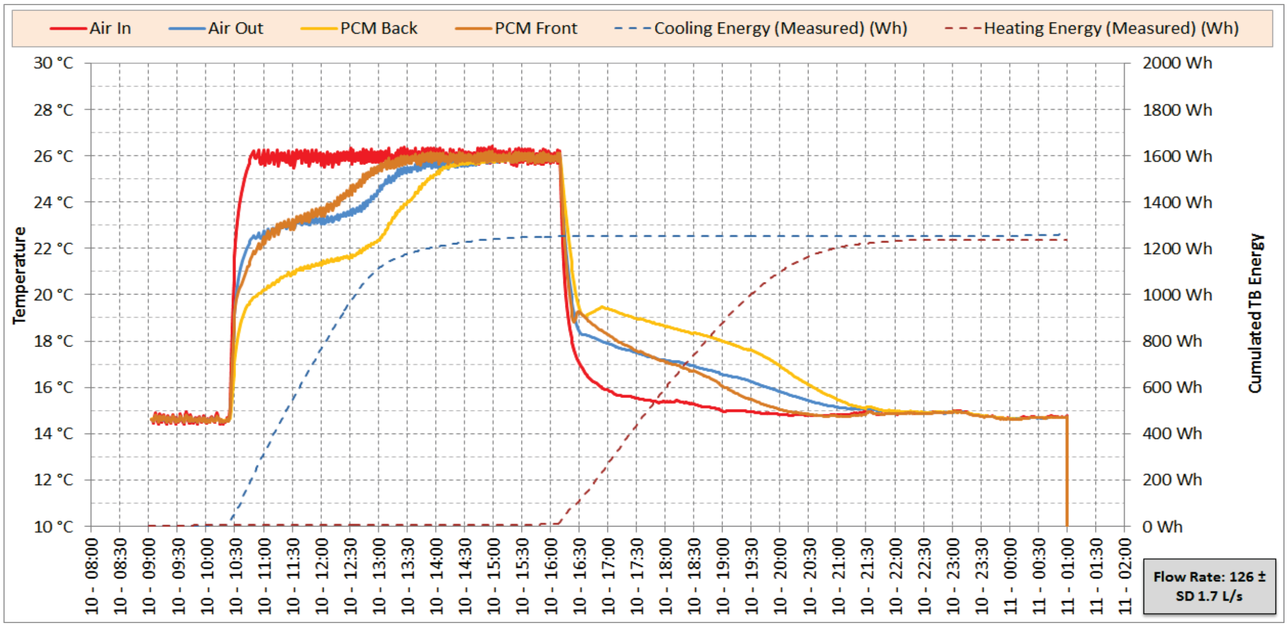
- Measurement Setup
  - Controlled airflow and supply air temperature (15°C-28°C)
  - Temperature sensors upstream and downstream of the TB
  - Surface temperature measured on 6 panels (front & back edges)

TB Performance Testing – Full Scale



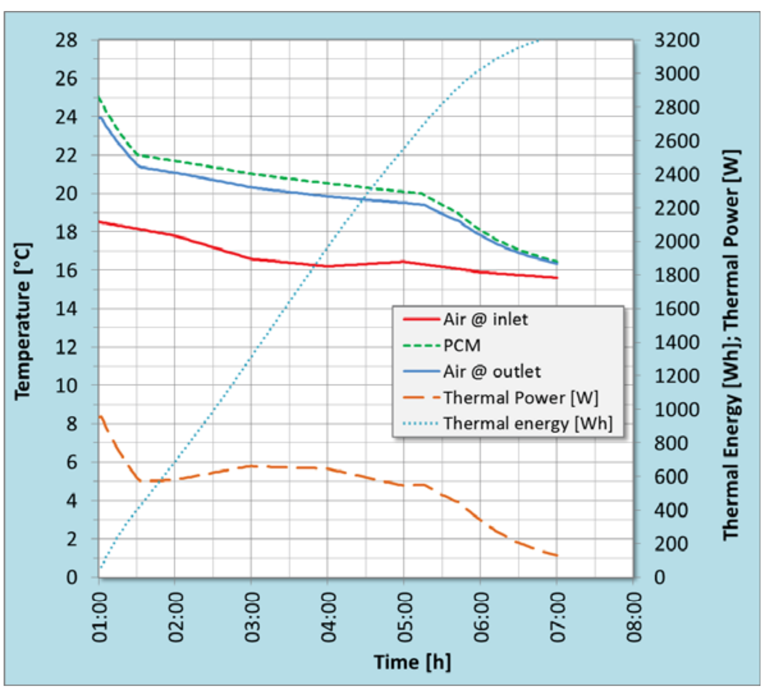
TB Performance Testing – Full Scale

- Delivered performance of 1 battery module (15°C - 26°C temperature range)



TB Charging model (Excel tool)

- TB night charging (01:00 – 06:00; 5h) (warm night London):



- AHU: Charging Mode
- Fan speed: 50% (288 L/s)
- Flow rate: 144 L/s /TB

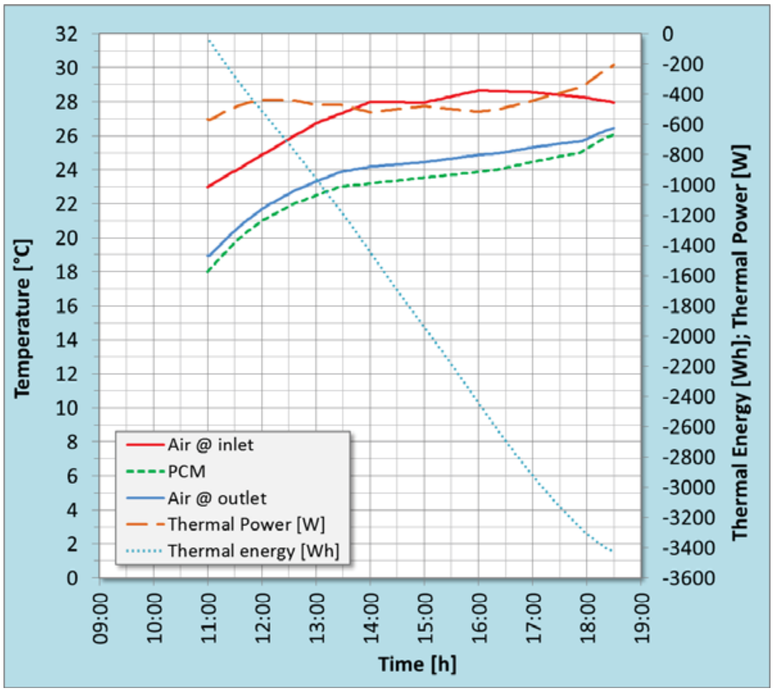
- PCM temperature: 25°C → 18°C
- Thermal Energy: 3015 Wh

- Thermal Power:
  - Start: **952 W**
  - End: 340 W
  - Average: 603 W over 5h

- Power Consumption:
  5h x 87.3W = 436.5 Wh

TB Discharge Model (Excel Tool)

➢ TB discharge (11:00 – 17:30; 6.5h) (hot day London)



- AHU: Cooling Mode
- Fan speed: 42% (230 L/s)
- Flow rate: 115 L/s /TB

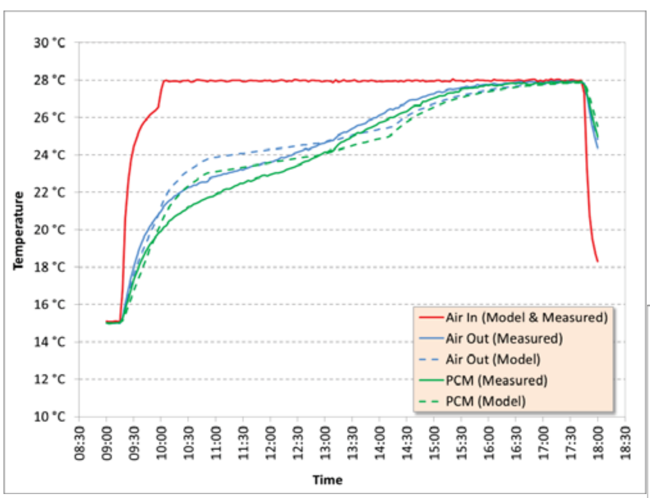
- PCM temperature: 18°C → 25°C
- Thermal Energy: -3127 Wh

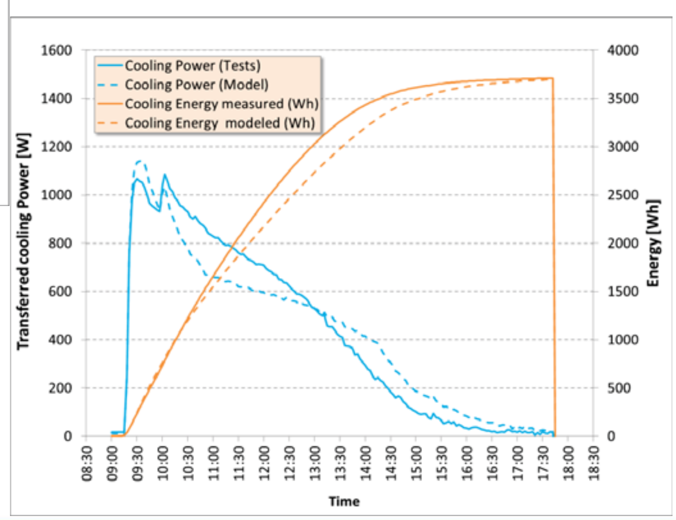
- Thermal Power:
  - Start: **-563 W**
  - End: -392 W
  - Average: -481 W over 6.5h

- Power Consumption:
  6.5h x 57.9W = 376.4 Wh

- EER=(2x3127)/813=7.7

TB Performance Testing vs Model





IES Implementation

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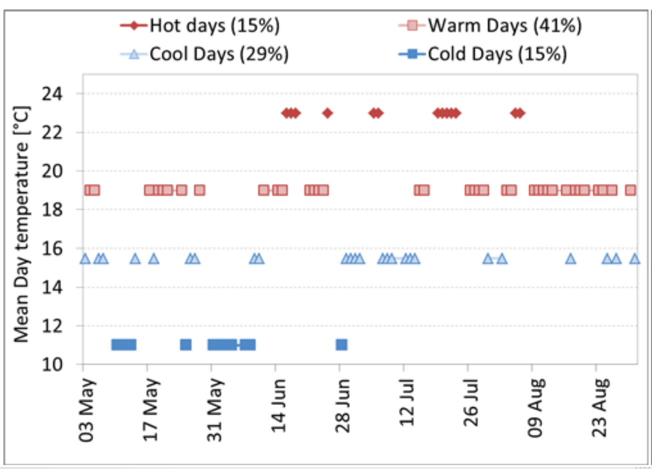
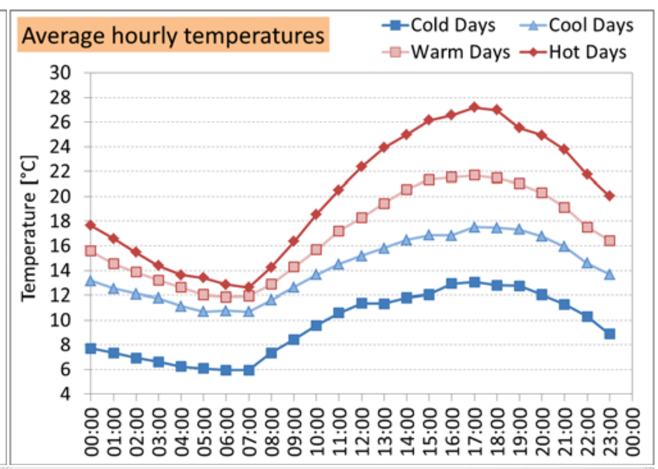
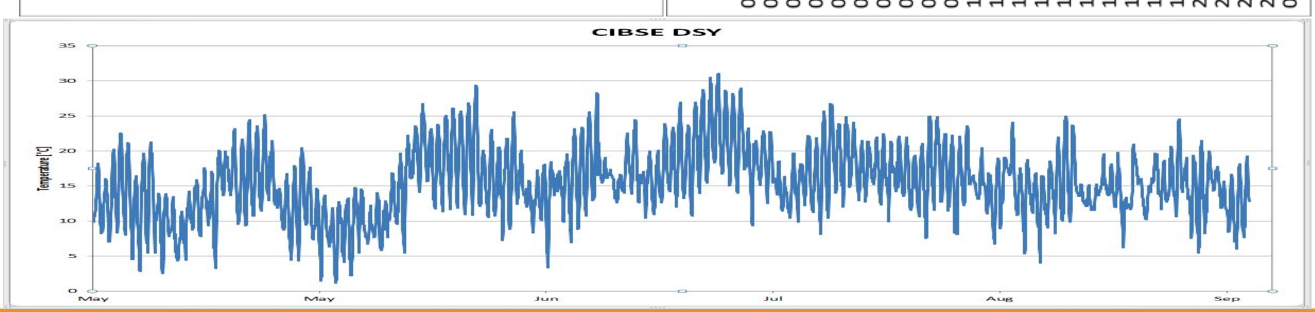
Temperature profile and frequency

- Weather analysis (Excel tool)

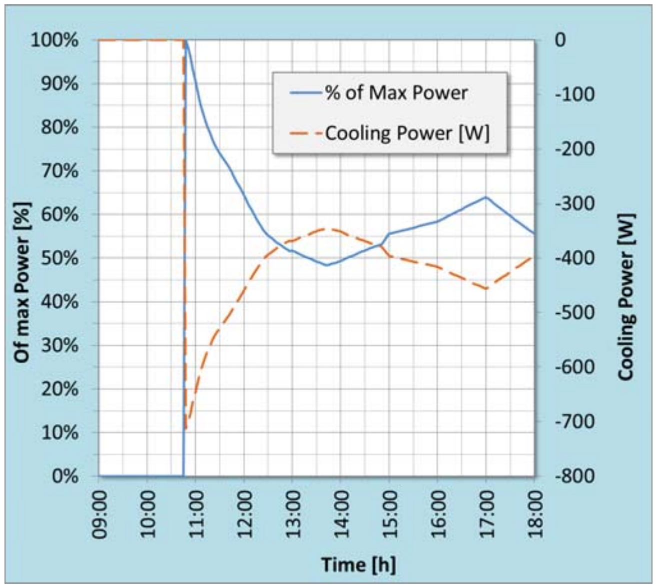






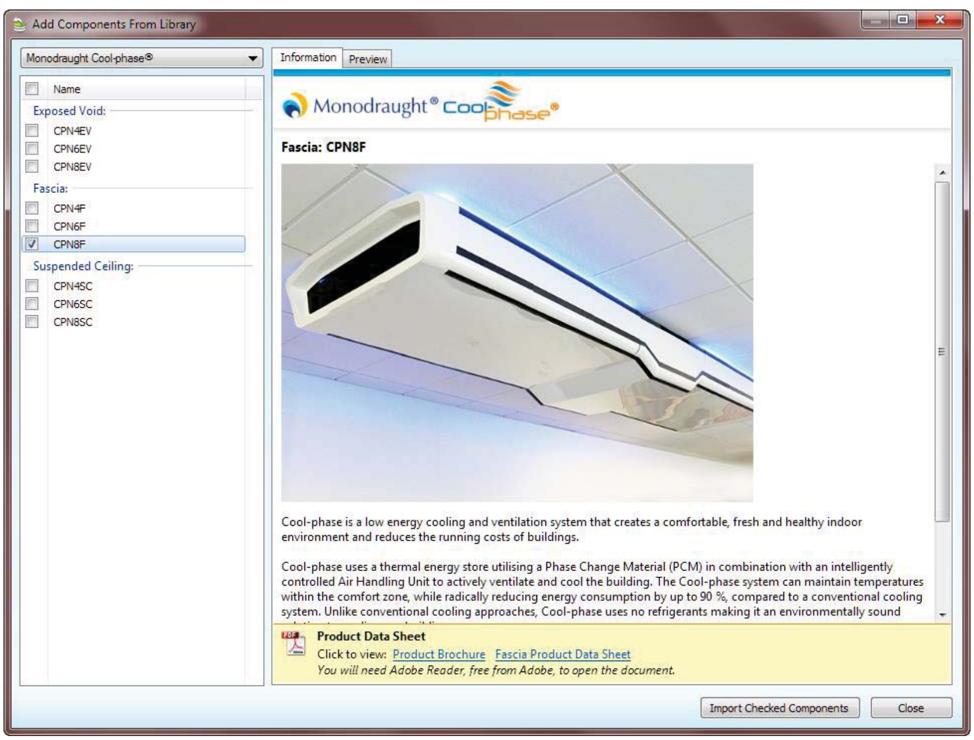
TB Discharge Profile (IES)

Fresh Air mode

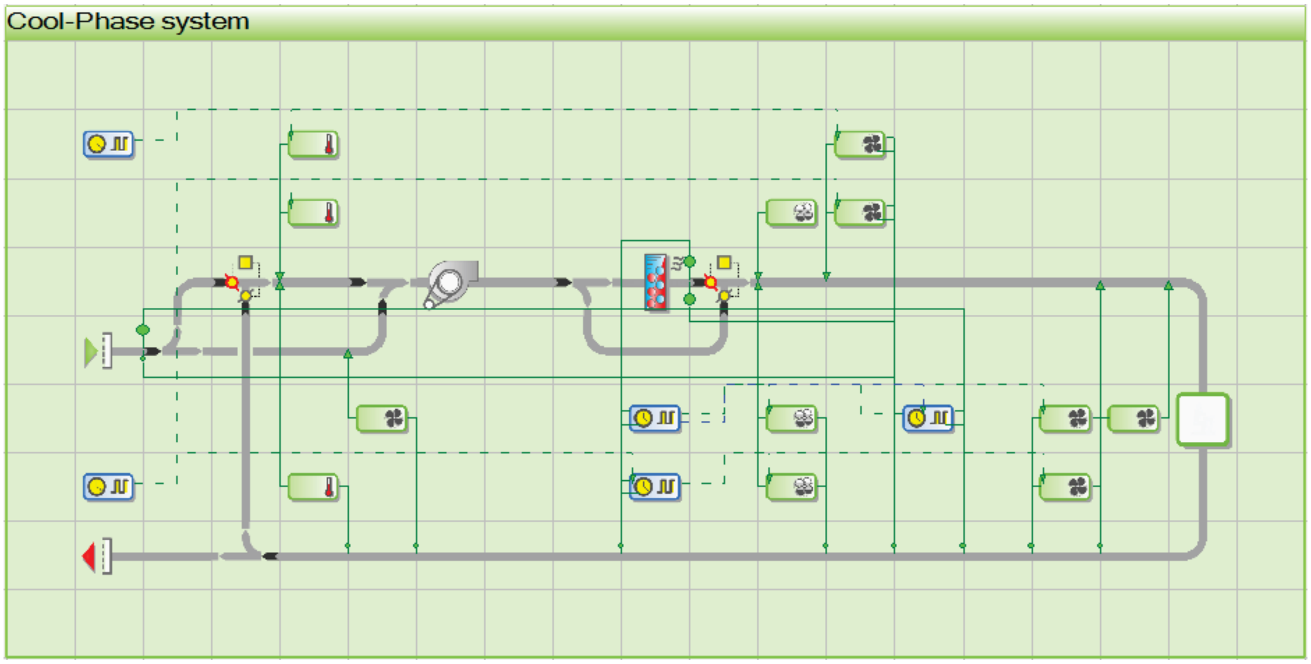


- Thermal Power:
  - **Start: -713 W (IES input)**
  - **Thermal Profile 0-100%**

IES Component Tool



IES Integration – as ApacheHVAC



Case Study

Notre Dame School Building (London)

Case study – Notre Dame School Building (London)

About the Case Study:

Two COOL-PHASE systems were installed in an IT classroom in April 2011. The classroom (approx. 70 m²) has high internal heat gains with 30 PCs and an overhead projector, while partly shaded windows on two sides (NW & SE) create solar gains.

Two control rooms were chosen in order to provide a comparison to the performance of the COOL-PHASE systems; the first was another IT classroom with 30 PCs and an overhead projector, resulting in similar internal heat gains. Due to external gains from SW facing windows, there was higher external heat loading than the classroom where COOL-PHASE was installed. This classroom had a Split Air Conditioning (AC) system already installed to provide cooling.

The second control room was a Geography classroom with much lower internal and external heat loading. This classroom had a single PC and overhead projector. The room was chosen as it was located next to the room with the COOL-PHASE systems and would provide a baseline to compare performance to.

- All rooms prior to the install used manually operated windows to provide natural ventilation.
- Data logging equipment was installed in each of these classrooms.
- Temperature and CO_2 levels were monitored every minute. The data loggers were installed in February 2011 during the Spring term so that the two environments could be compared before the COOL-PHASE® low energy cooling and ventilation systems were installed.
- To verify the data logger readings, the temperature was recorded with a hand held digital meter in 8 locations around the room.
- The resulting temperature gradient was measured and used to identify any local hot or cold spots within the room.

Case study – Notre Dame School Building (London)

Before and After

Temperatures and CO_2 levels were monitored during the Spring term prior to the install to enable the two IT classrooms to be compared.

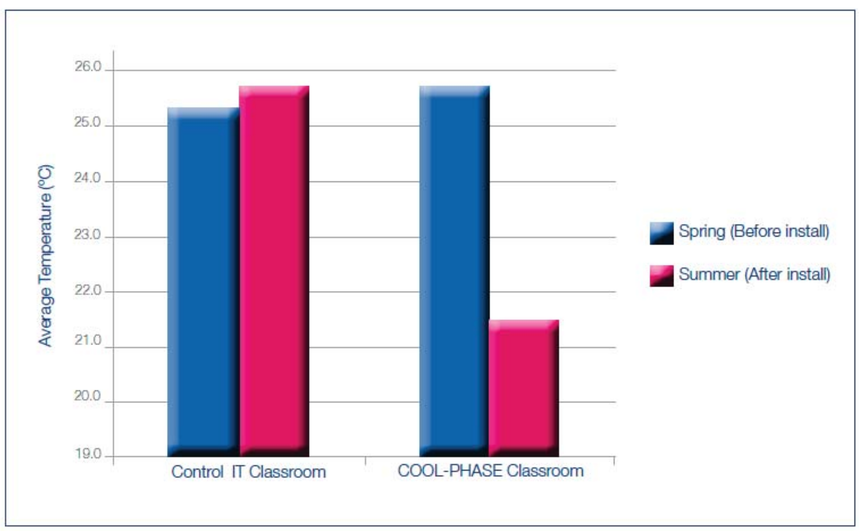
The average temperature in both environments during the Spring term are very similar. This shows both rooms have very similar internal heat loading.

The results show that the average temperatures increased in the control room slightly between the Spring and Summer term as can be expected due to warmer weather.

However the room with the COOL-PHASE system has not replicated these trends and instead has seen a significant reduction in the average temperatures before and after the install.

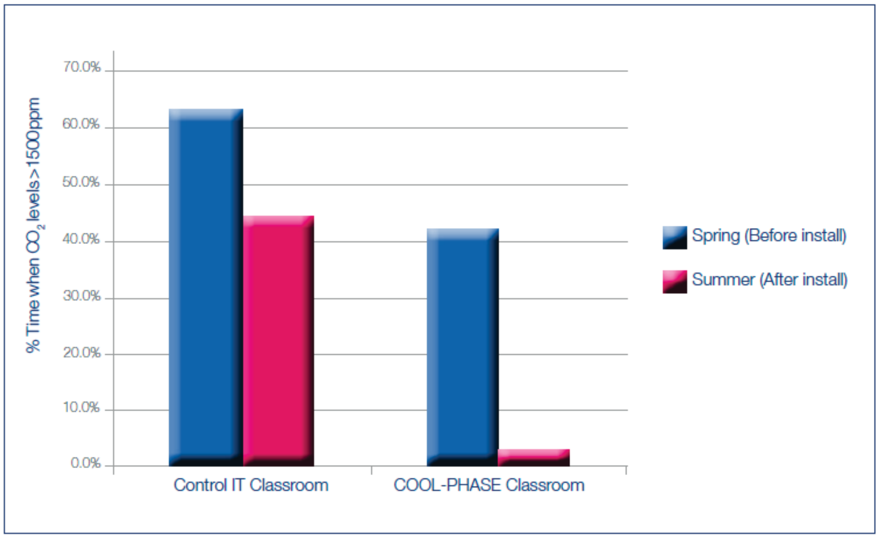
The external heat loading in the control IT classroom is higher than the room where COOL-PHASE is installed and this would become a more significant factor in the Summer term, however the AC system should be able to overcome the total heat loading.

Despite the differences between the rooms, it is clear that the COOL-PHASE system has had a significant impact on average temperatures.



Comparison of the temperature before and after the install

Case study – Notre Dame School Building (London)



Comparison of the CO_2 levels before and after the install

A similar pattern can be seen for the CO_2 levels. The results show that the control IT classroom had worse ventilation than the classroom where COOL-PHASE was installed.

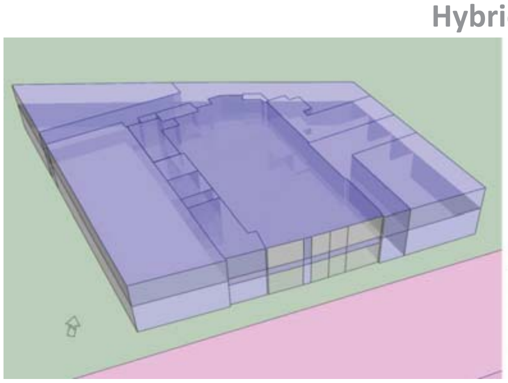
This can be expected as the control classroom only had windows on one side; whereas the room where the COOL-PHASE systems were installed has windows on two opposite sides of the room allowing cross ventilation.

An improvement in air quality between the Spring and Summer term can be explained by the windows being opened more frequently.

However the results before and after the install of the COOL-PHASE system shows a very significant reduction in the number of hours where the CO_2 levels exceed 1500 ppm.

Cool-phase

Hybrid operation with VRF



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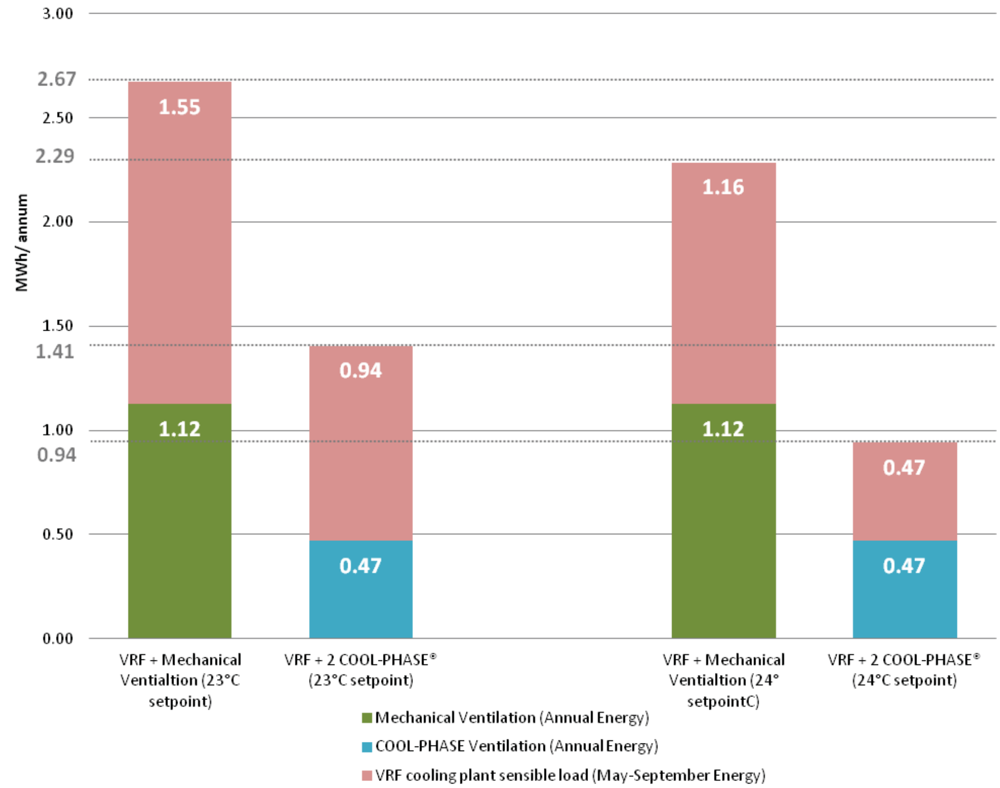
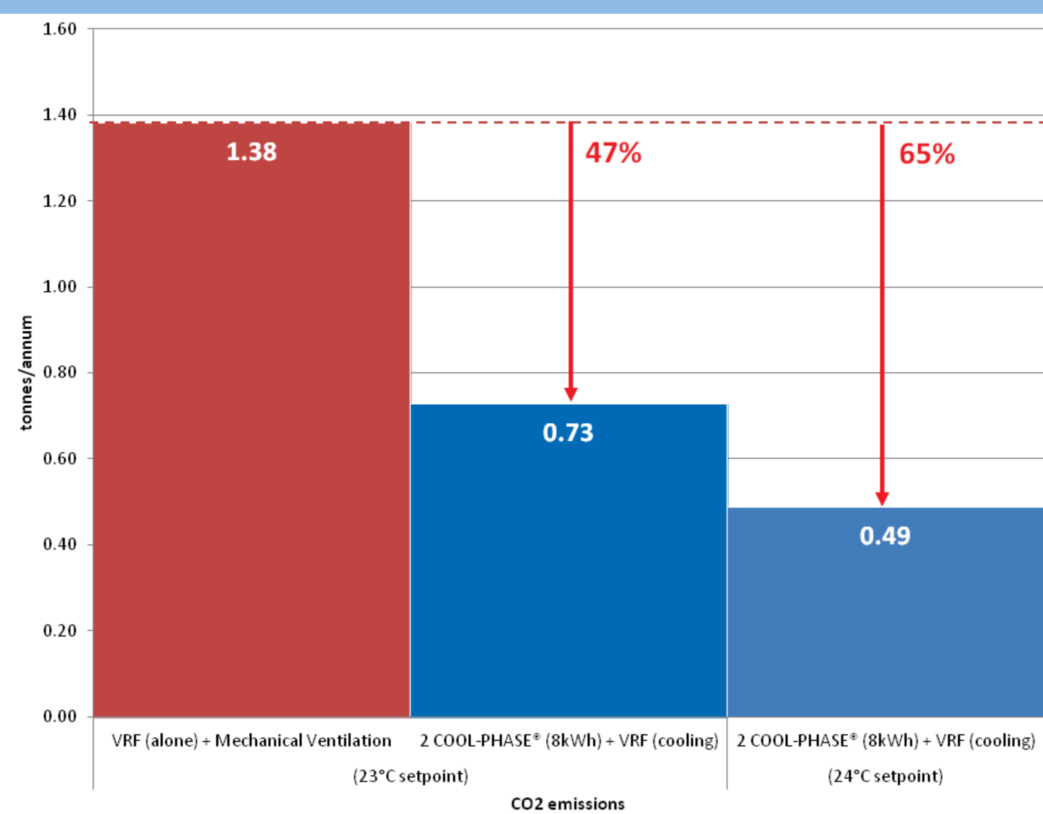
Hybrid operation with VRF



Hybrid operation with VRF



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