The PCMs4Buildings Project - Thermal Energy Storage PCM-based Systems for Building Applications

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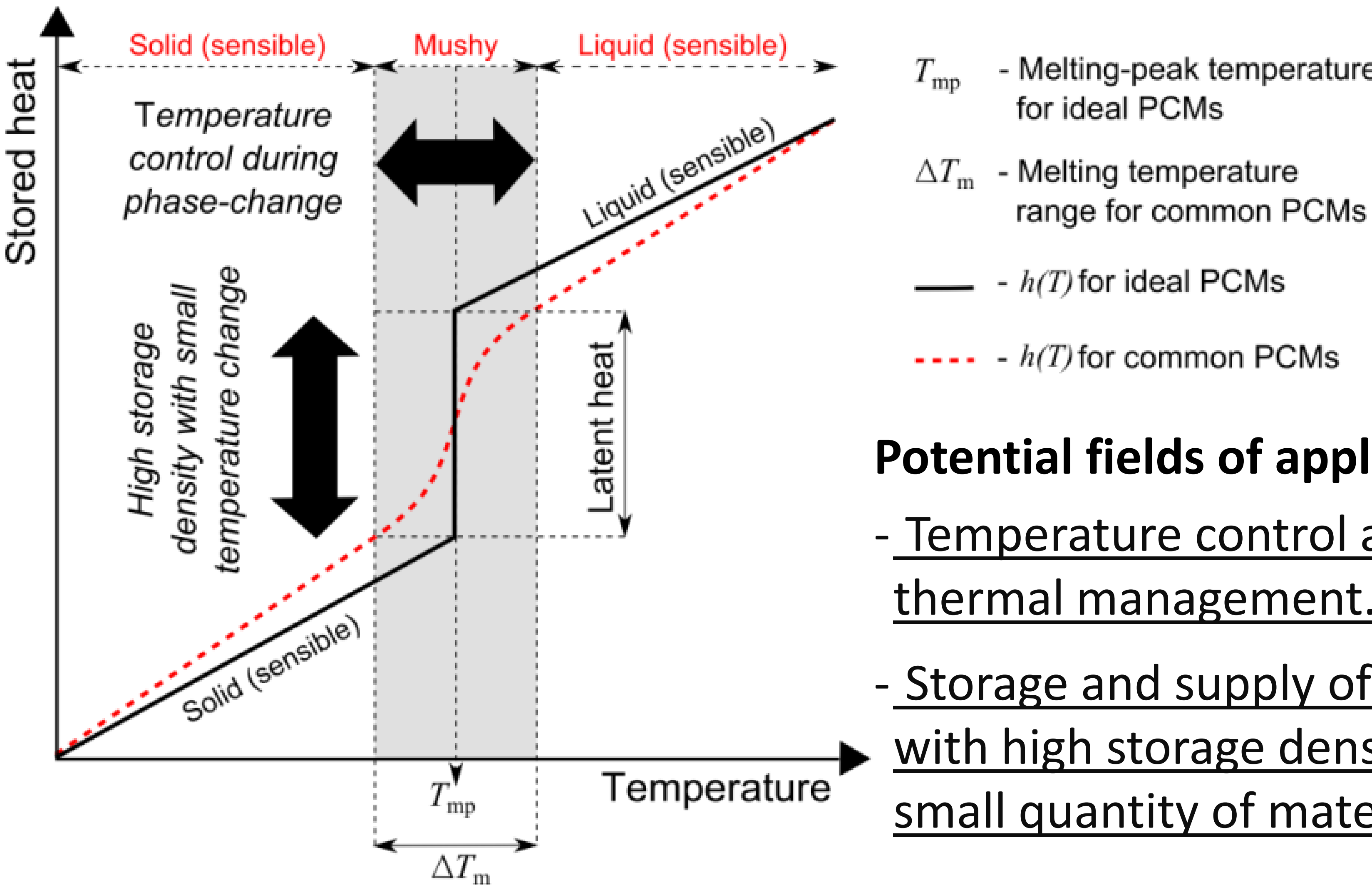
Framework

PCMs How do they work?



Potential fields of application:

- Temperature control and thermal management.

- Storage and supply of heat with high storage density in a small quantity of material.

Major goals

➡ **<u>To develop a holistic and chain-strategic methodology to evaluate the thermal performance of new PCM-based systems for buildings</u>:**

(i) thermophysical characterization of different PCMs;

(ii) experimental and numerical evaluation of the heat transfer with solid-liquid phase change processes;

(iii) evaluation of the thermal performance of new prototypes designed during the implementation of the research plan.

➡ **To contribute to the dissemination of the technology, and ultimately, to the reduction of the environmental impact of the Built Environment, setting the world on a more sustainable path, as required by the 2030 Agenda.**

Research Team

Consultants and Industrial partners

Department of Mechanical Engineering (DEM)

Department of Chemical Engineering (DEQ)

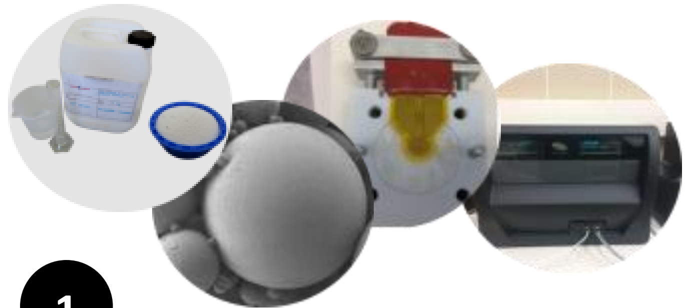
PCMs4Buildings

Department of Civil Engineering (DEC)

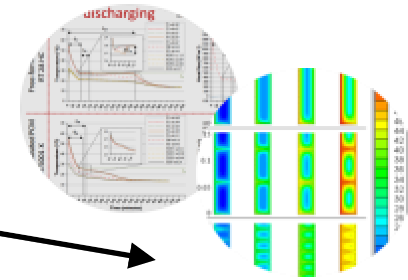
Universidade de Coimbra

http://www.adai.pt/pcms4buildings

Main tasks



1 Thermophysical characterization of PCMs



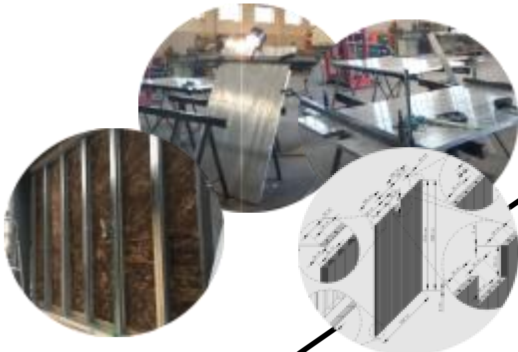
2 Numerical modeling and CFD evaluation

3 Tests in the small-scale experimental setup

PCMs4Buildings

TASKS

Systems with PCM-filled rectangular cavities for the storage of solar thermal energy for buildings

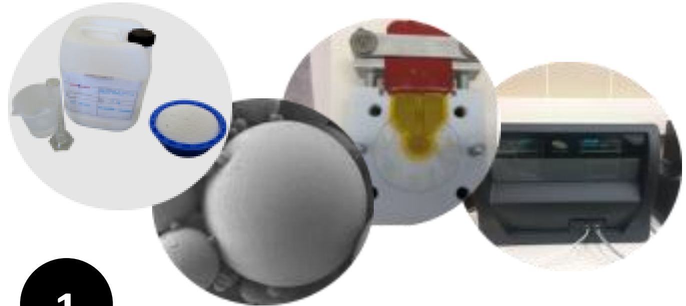


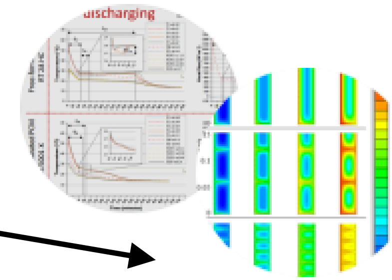
5 Definition of full-scale prototypes

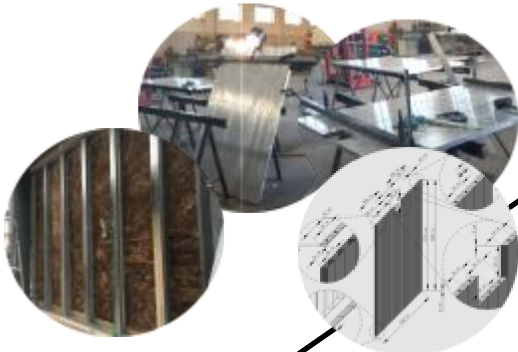
4 Tests in the Guarded Hot Box setup and other real-scale experimental apparatus

6 Dissemination, technical seminars and workshops

Main tasks







1 Thermophysical characterization of PCMs

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Systems with PCM-filled rectangular cavities for the storage of solar thermal energy for buildings

❶ Thermophysical characterization of PCMs

Main challenges:

- To carried out a reliable thermophysical characterization of commercial PCM-based products since data provided by manufacturers are often lacking or uncertain;
- To overcome some of the problems of using conventional equipment and techniques to measure the main thermophysical properties of different kinds of PCMs.

Commercial paraffin-based PCMs evaluated:

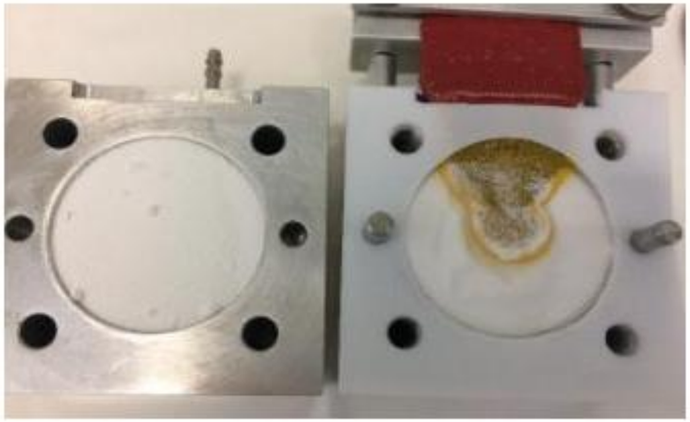
PCM	Form	Melting-peak temperature [°C]	Manufacturer
PCM 18	Bulk	18	Microtek laboratories
PCM 24	Bulk	24	Microtek laboratories
PCM 28	Bulk	28	Microtek laboratories
RT 22 HC	Bulk	22	Rubitherm
RT 25 HC	Bulk	25	Rubitherm
RT 28 HC	Bulk	28	Rubitherm
MPCM 18D	Microencapsulated	18	Microtek Laboratories
MPCM 24D	Microencapsulated	24	Microtek Laboratories
MPCM 28D	Microencapsulated	28	Microtek Laboratories
Micronal® DS 5001 X	Microencapsulated	26	BASF
Alba®balance 25	PCM-enhanced plasterboard	25	Saint-Gobain

❶ Thermophysical characterization of PCMs

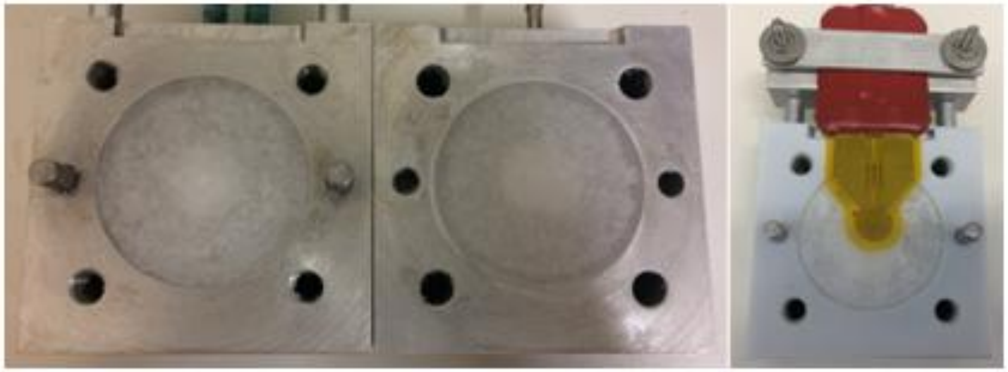
Measurements:

➡ **Thermal conductivity of both solid and liquid phases - *k*(*T*)**

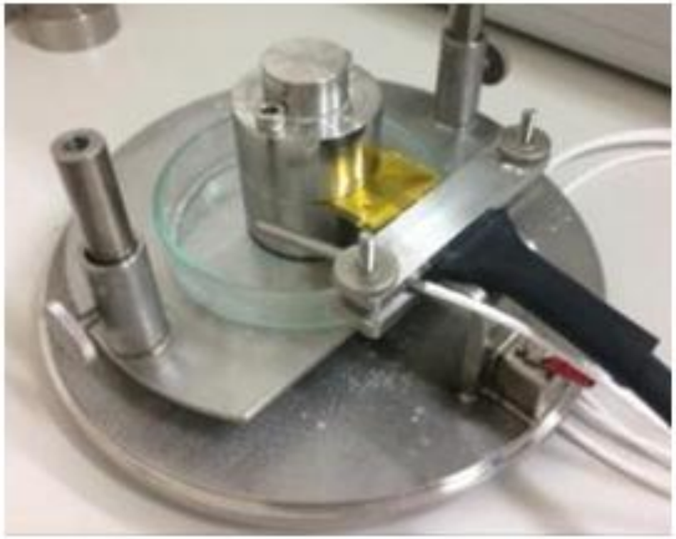
Transient Plane Source (TPS) method - Hot Disk TPS 2500 S equipment in the 0–50 ºC range, with 5 ºC intervals.



Liquid sample holder full with the DS 5001 X.



Liquid sample holder full with the RT 22 HC.



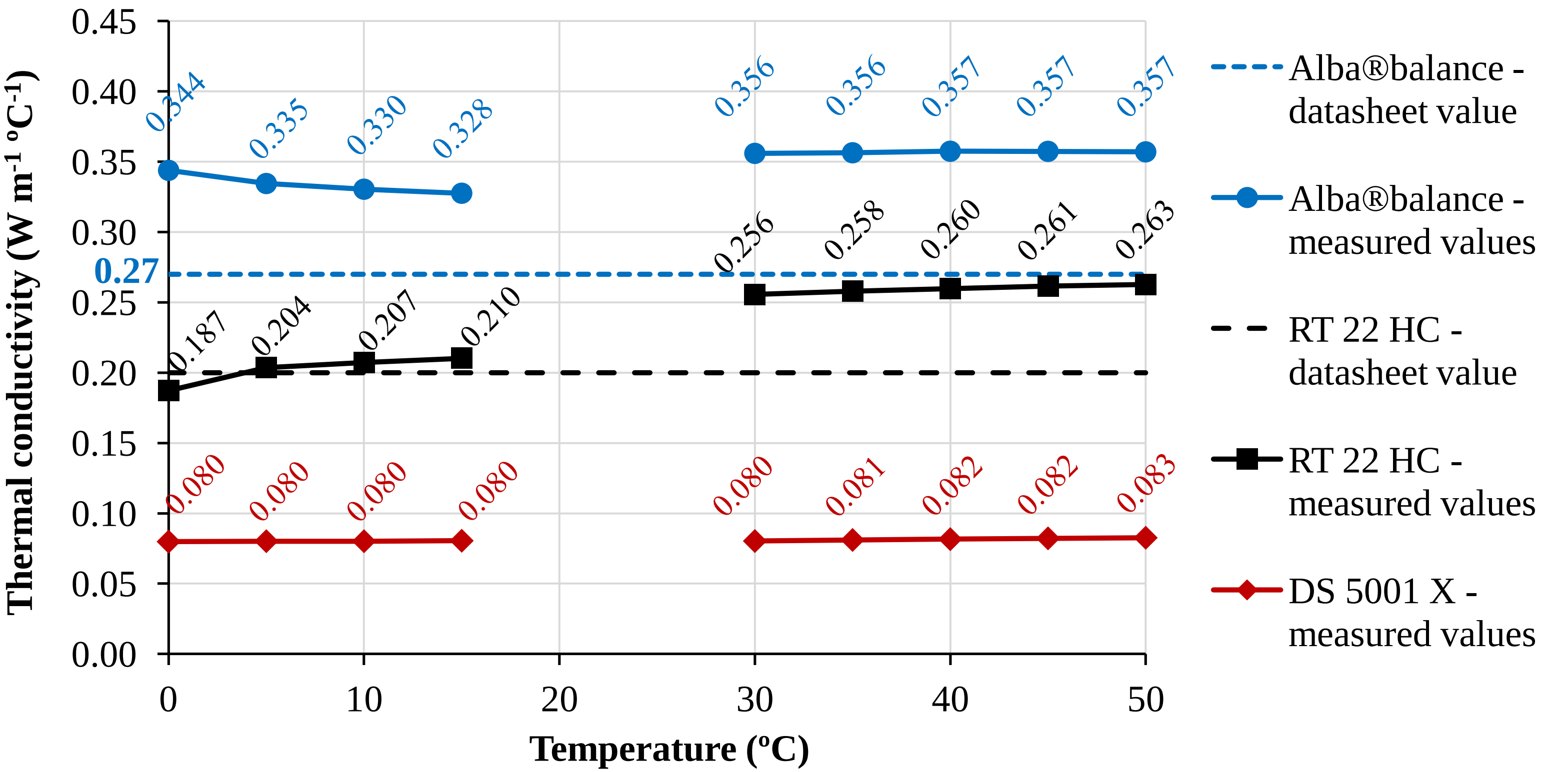
Powder sample holder full with the DS 5001 X.

1 Thermophysical characterization of PCMs

Measurements:

➡ Thermal conductivity of both solid and liquid phases - *k*(*T*)

Variation of thermal conductivity with temperature evolution of 3 different PCM-based products. The dashed lines indicate the thermal conductivity given by the manufacturers.

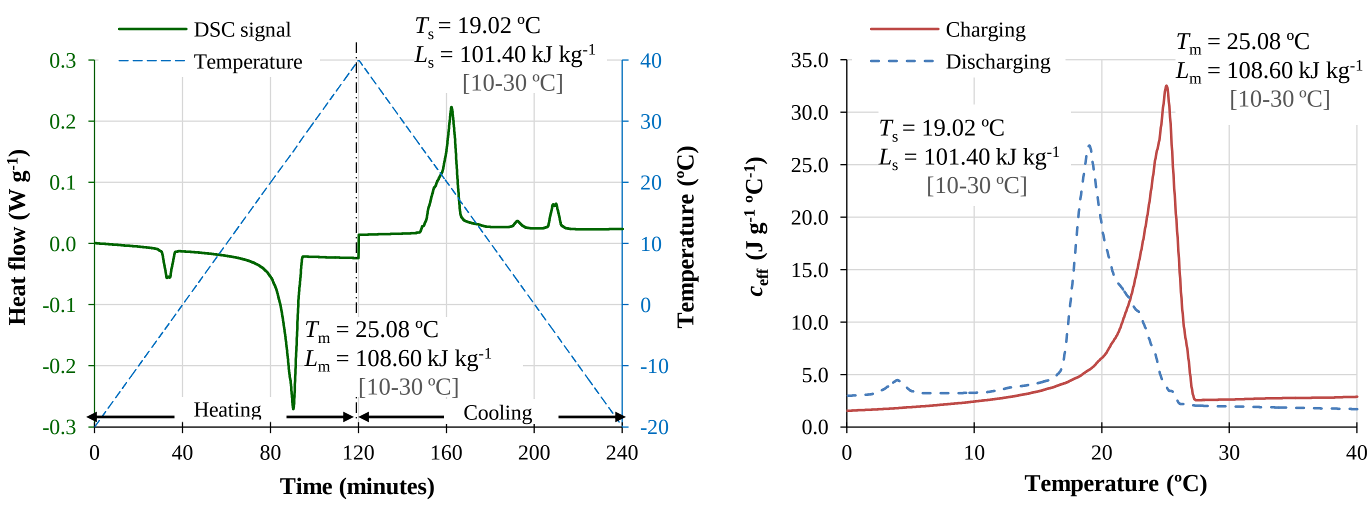


❶ Thermophysical characterization of PCMs

Measurements:

- **Melting and solidification peak temperatures - T_m / T_s**
- **Latent heat of fusion and solidification - L_m / L_s**
- **Specific heat of both solid and liquid phases – $c_{p,m}$ / $c_{p,s}$**
- **Effective specific heat curves - $c_{eff}(T)$**

Q100 Modulated Differential Scanning Calorimetry (MDSC) equipment from TA Instruments - underlying heating/cooling rates of 0.5 ºC min^{-1}, in the temperature range of –20 ºC to 40 ºC.



DSC and effective specific heat curves for the 7.40 mg sample of the Micronal® DS 5001 X.

❶ Thermophysical characterization of PCMs

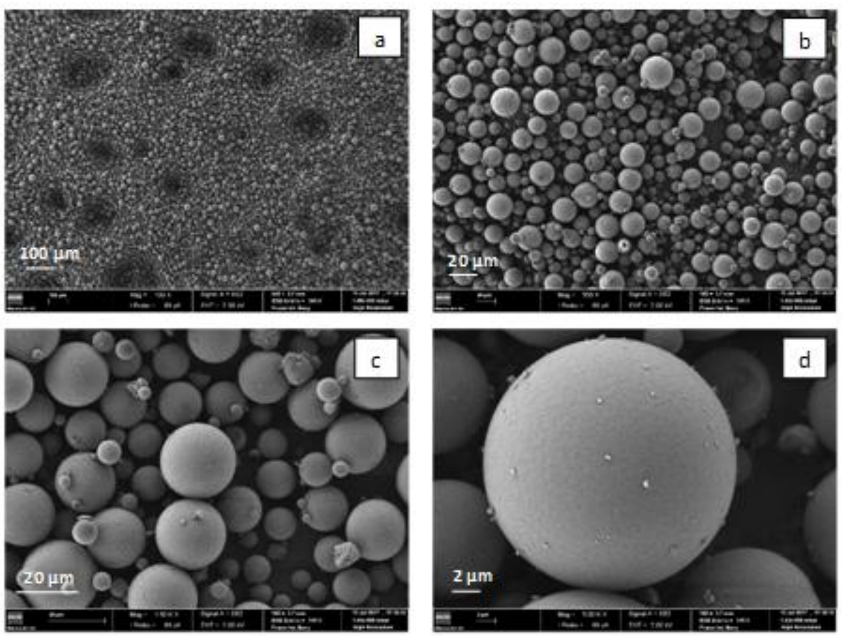
Measurements:

➡ **Volumetric mass density - ρ_m / ρ_s**

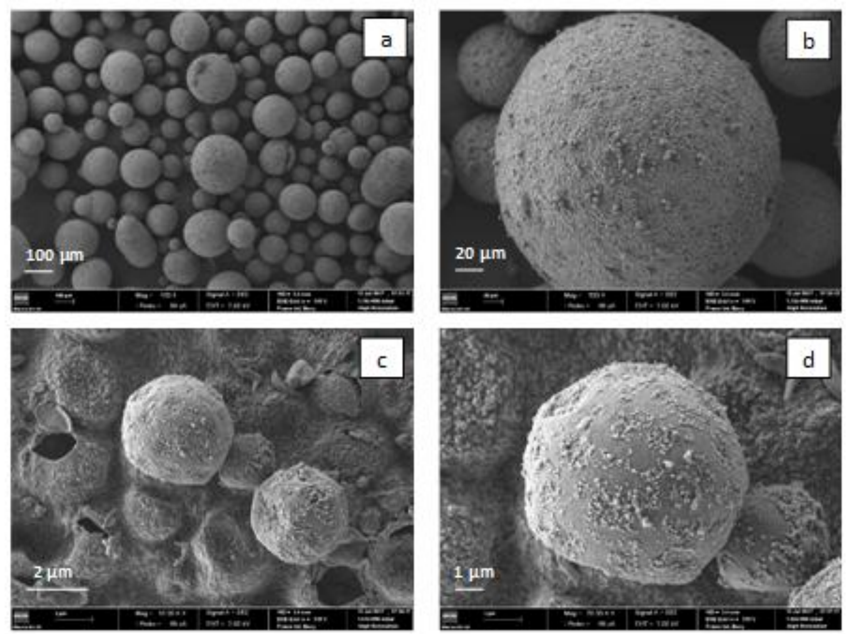
➡ **Thermogravimetric analysis (TGA)**

➡ **Microstructure**

scanning electron microscope (SEM)

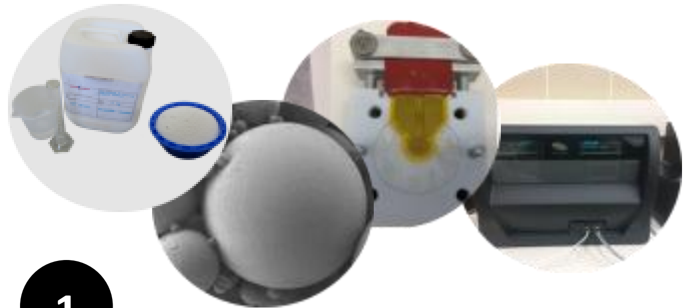


MPCM 18D



Micronal® DS 5001 X

Main tasks



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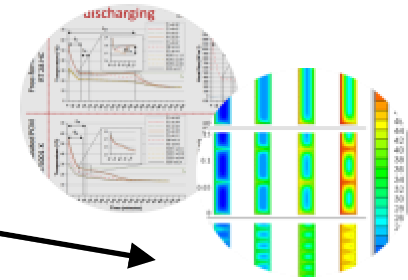

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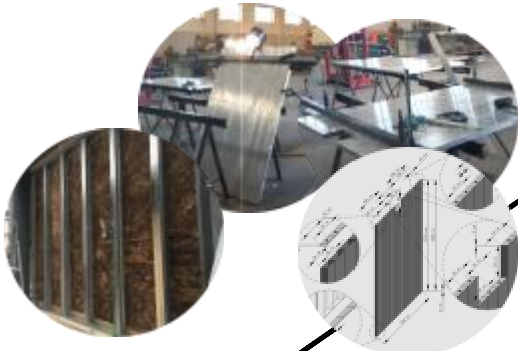


5 Definition of full-scale prototypes

4 Tests in the Guarded Hot Box setup and other real-scale experimental apparatus

6 Dissemination, technical seminars and workshops

❷ Numerical modeling and CFD evaluation

➡ Heat transfer with solid-liquid phase-change of microencapsulated PCMs - purely diffusive transient model.

➡ Heat transfer with solid-liquid phase-change of free-form PCMs (ongoing) – adjective/diffusive transient model.

- natural convection
- volume variation
- hysteresis

❷ Numerical modeling and CFD evaluation

➡ Heat transfer with solid-liquid phase-change of microencapsulated PCMs - <u>purely diffusive transient model.</u>

Six numerical approaches

- Effective heat capacity (EHC) method → ANSYS CFX®
- Additional heat source (AHS) method → ANSYS CFX®
- Enthalpy-porosity (H-P) method → ANSYS FLUENT®

EHC method → Four different ways to specify the variation of the effective specific heat with temperature, $c_{eff}(T)$

❷ Numerical modeling and CFD evaluation

➡ Heat transfer with solid-liquid phase-change of microencapsulated PCMs - <u>purely diffusive transient model.</u>

Six numerical approaches

- Effective heat capacity (EHC) method
- Additional heat source (AHS) method
- Enthalpy-porosity (H-P) method

Four different ways to specify the variation of the effective specific heat with temperature, $c_{\mathrm{eff}}(T)$

***T*-based procedure** – *T* is the only dependent variable and the solid-liquid interface position is tracked explicitly.

Enthalpy-based procedure – the liquid fraction is computed based on the enthalpy balance.

❷ Numerical modeling and CFD evaluation

➡ Heat transfer with solid-liquid phase-change of microencapsulated PCMs - <u>purely diffusive transient model.</u>

Six numerical approaches

- **Effective heat capacity (EHC) method**
- Additional heat source (AHS) method
- Enthalpy-porosity (H-P) method

Introduces the concept of an equivalent heat capacity, and models the effect of latent heat by inflating the sensible heat capacity in the phase-change temperature range.

Four different ways to specify the variation of the effective specific heat with temperature, $c_{\mathrm{eff}}(T)$

❷ Numerical modeling and CFD evaluation

➡ Heat transfer with solid-liquid phase-change of microencapsulated PCMs - <u>purely diffusive transient model.</u>

Six numerical approaches

- Effective heat capacity (EHC) method
- **Additional heat source (AHS) method**
- Enthalpy-porosity (H-P) method

The latent heat is treated as an internal heat source.

Four different ways to specify the variation of the effective specific heat with temperature, $c_{eff}(T)$

❷ Numerical modeling and CFD evaluation

➡ Heat transfer with solid-liquid phase-change of microencapsulated PCMs - <u>purely diffusive transient model.</u>

Six numerical approaches

- Effective heat capacity (EHC) method
- Additional heat source (AHS) method
- **Enthalpy-porosity (H-P) method**

The latent heat is directly described by the enthalpy changes.

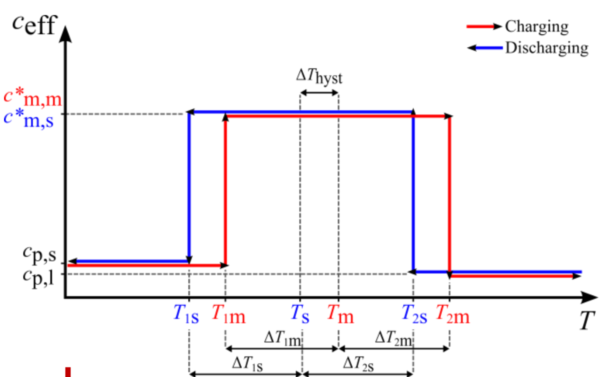
Four different ways to specify the variation of the effective specific heat with temperature, $c_{eff}(T)$

❷ Numerical modeling and CFD evaluation

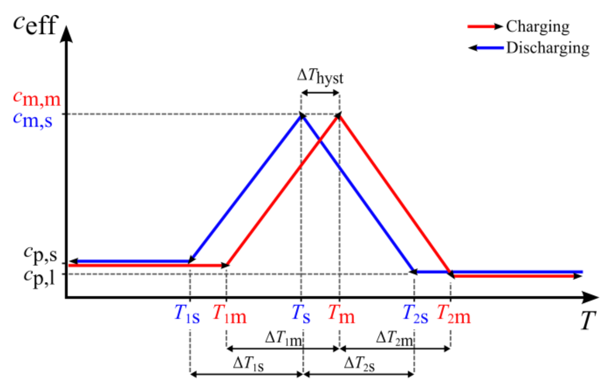
➡ Effective heat capacity (EHC) method

3 artificial curves:

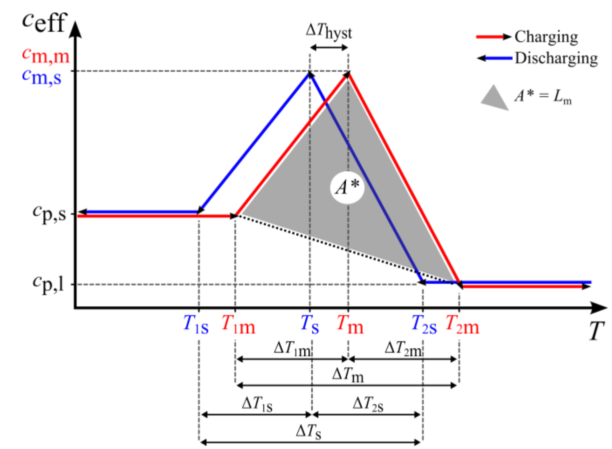
Rectangular profile



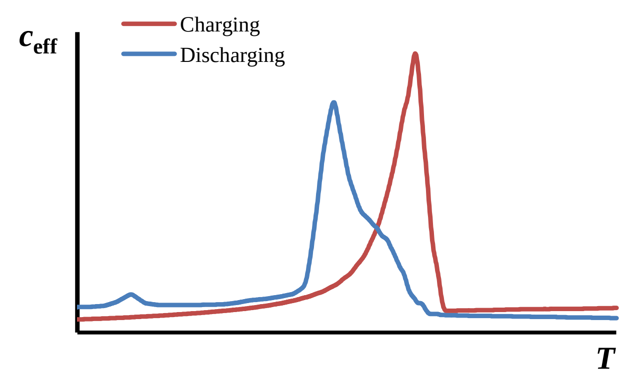
Triangular profile



Self-adjusted triangular profile

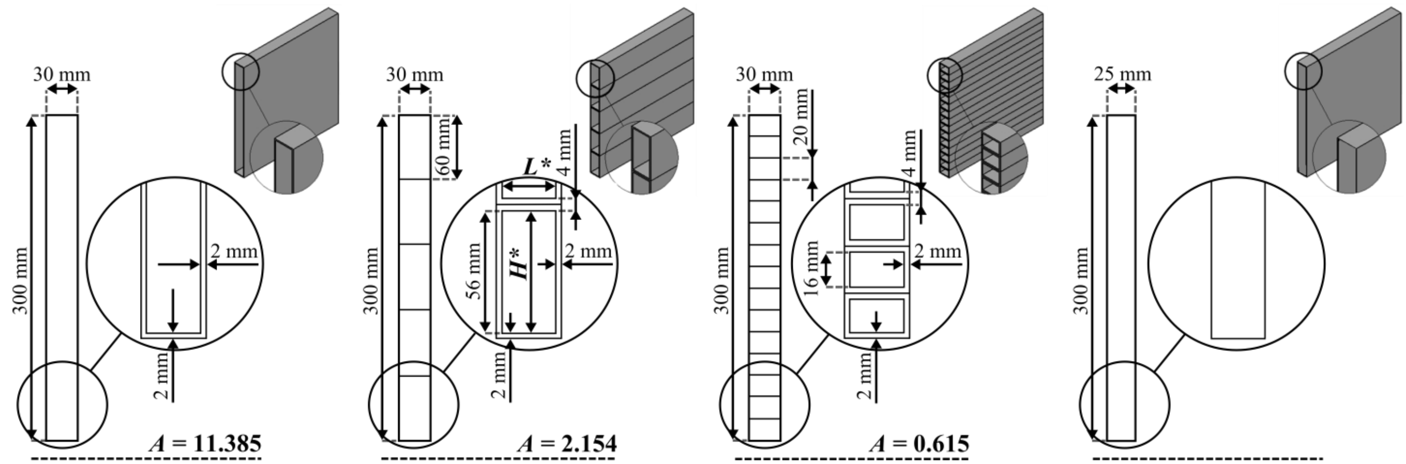


$c_{eff}(T)$ curve obtained experimentally:

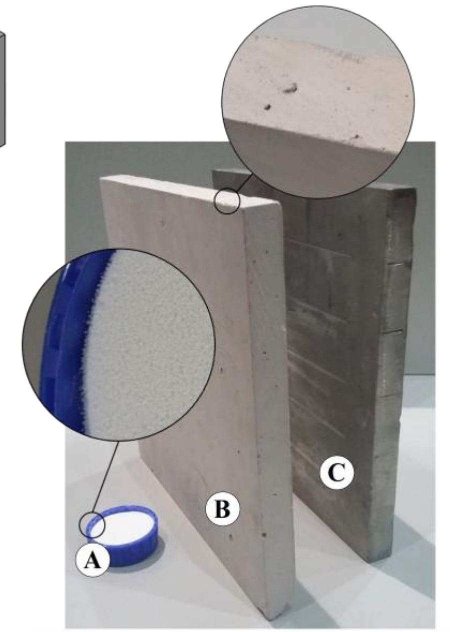


Four different ways to specify the variation of the effective specific heat with temperature, $c_{eff}(T)$

❷ Numerical modeling and CFD evaluation

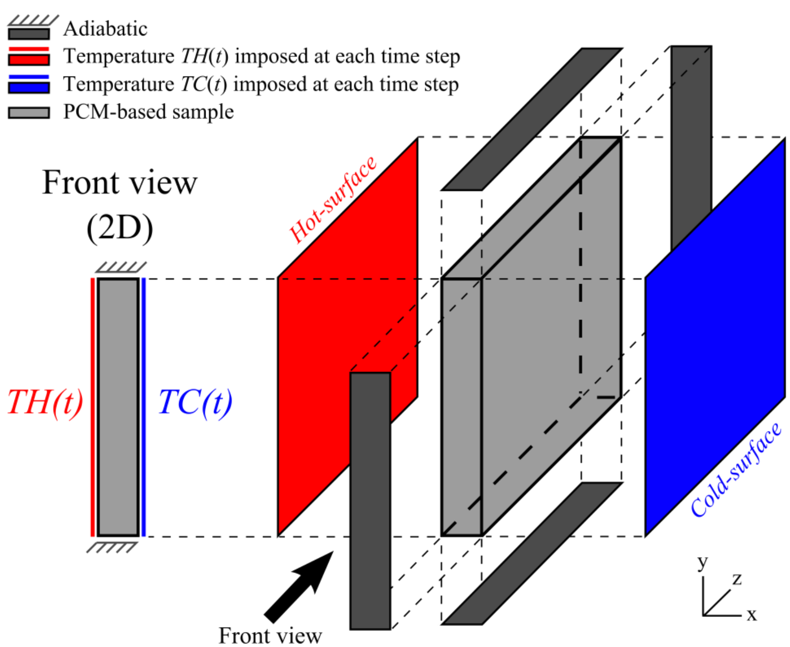


4 geometries of the PCM-based sample (physical domain)



2 kinds of PCM-based samples

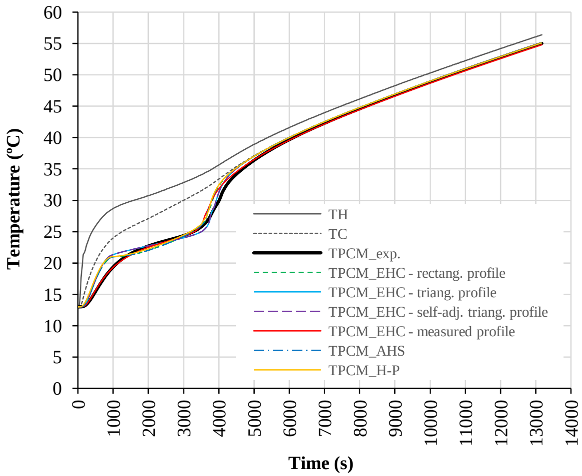
(A) Microencapsulated PCM Micronal® DS 5001 X
(B) PCM-plasterboard Alba®balance
(C) Aluminium container of the TES unit



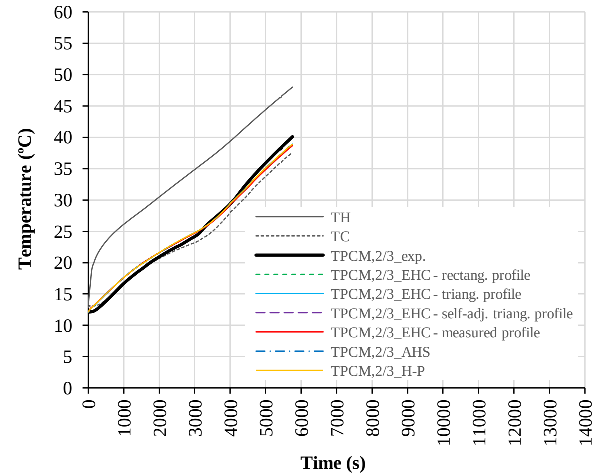
3D numerical domain with the imposed boundary conditions

❷ Numerical modeling and CFD evaluation

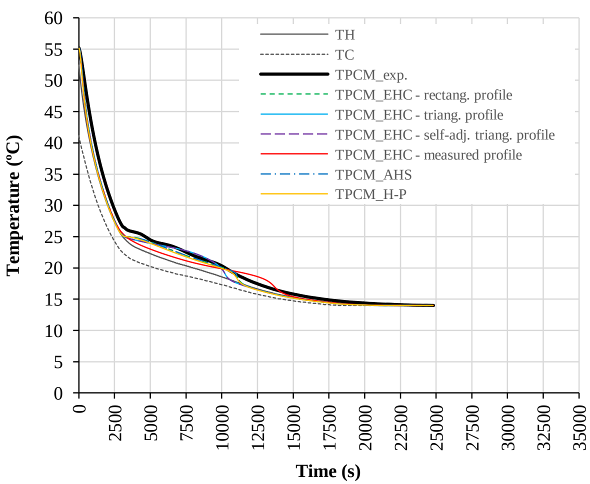
➡ Main results



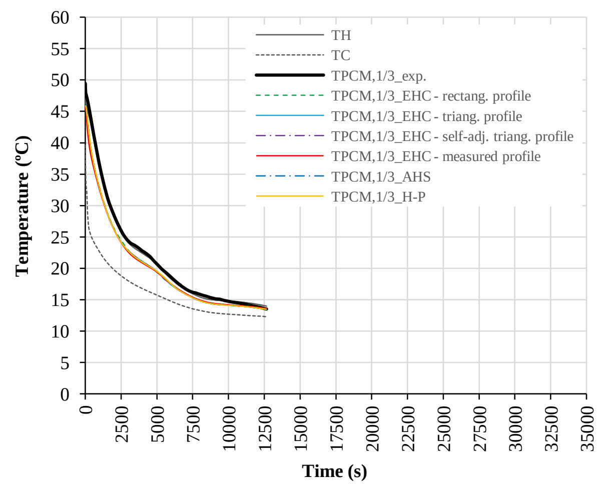
15-cavities TES unit – Charging



PCM-enhanced plasterboard – Charging



15-cavities TES unit – Discharging

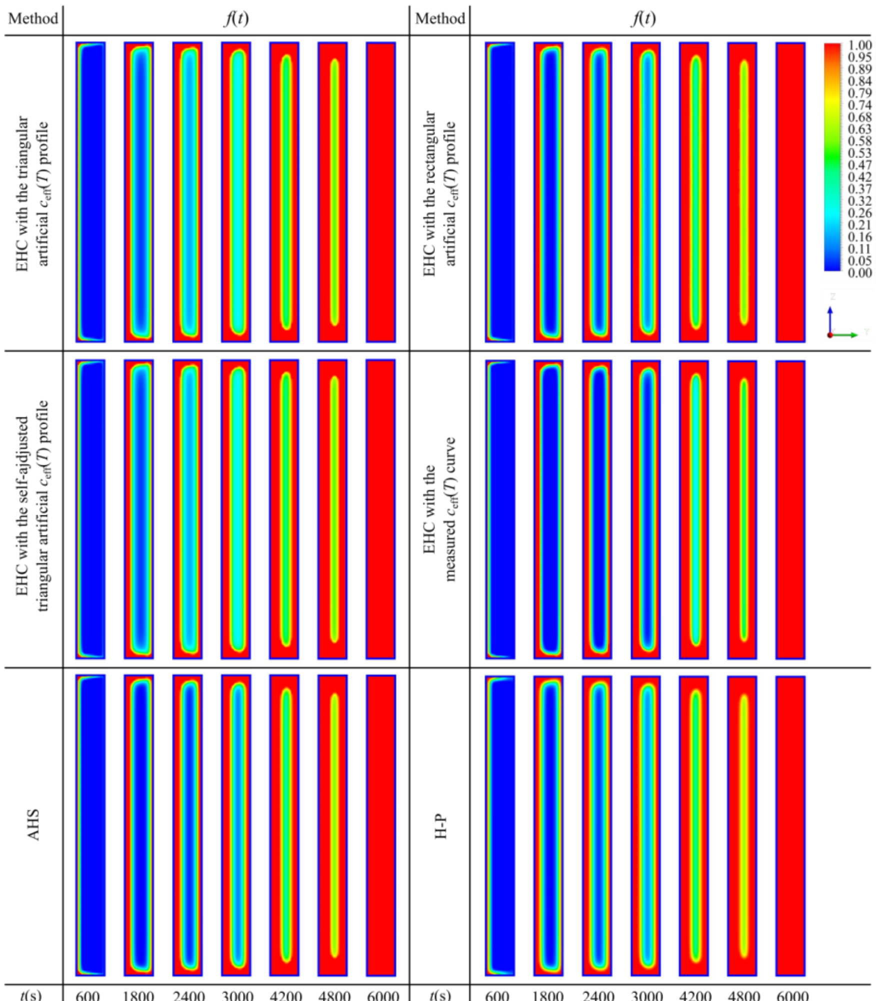


PCM-enhanced plasterboard – Discharging

❷ Numerical modeling and CFD evaluation

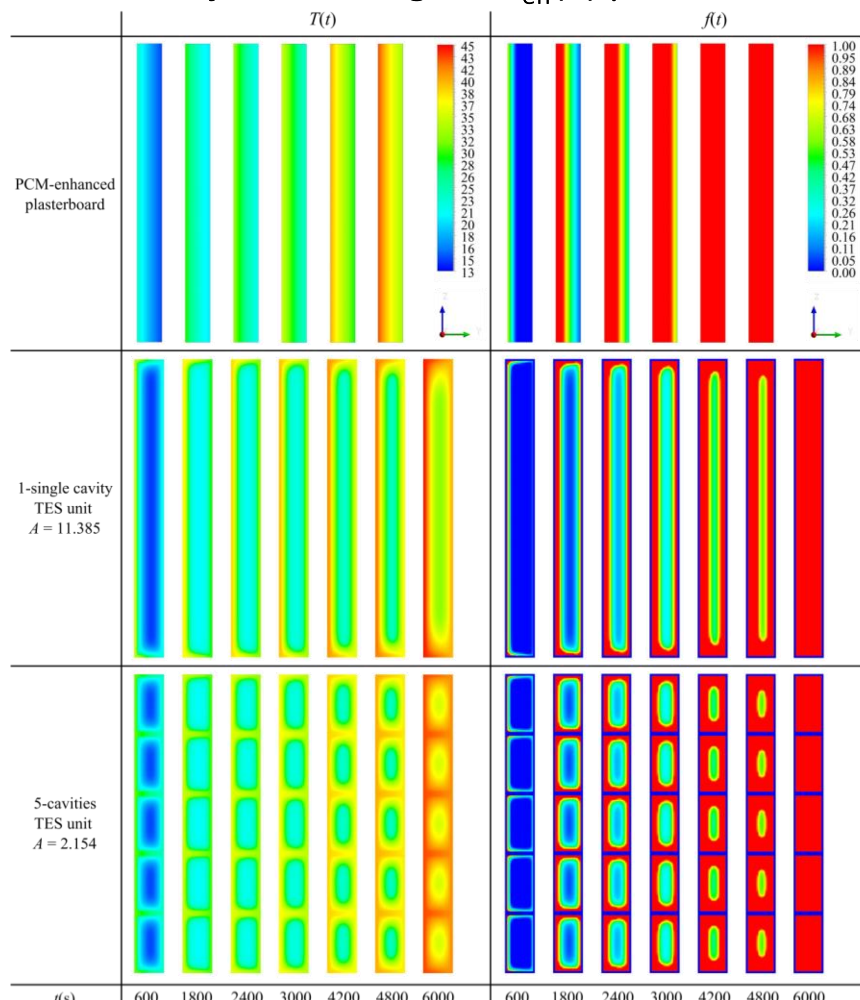
➡ Main results

$f(t)$ - charging of the 1-single cavity TES for the different numerical approaches.

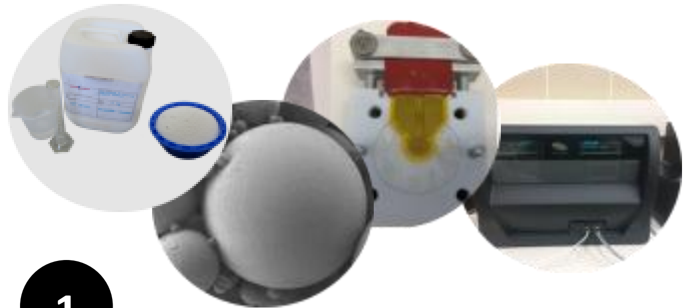


Field-distributions of $T(t)$ and $f(t)$

$T(t)$ and $f(t)$ - charging of some domains considering the EHC method with the self-adjusted triangular $c_{eff}(T)$ profile.



Main tasks



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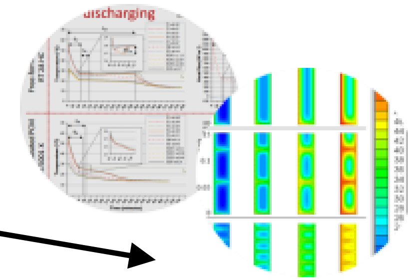

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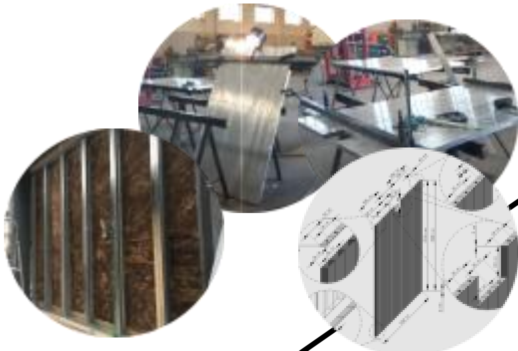

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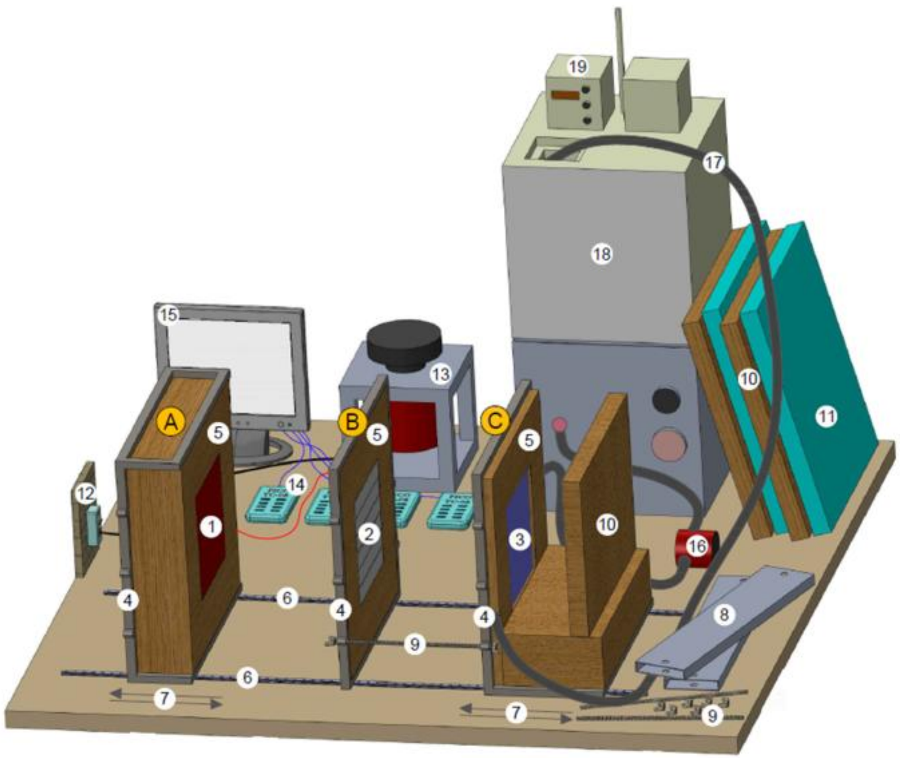
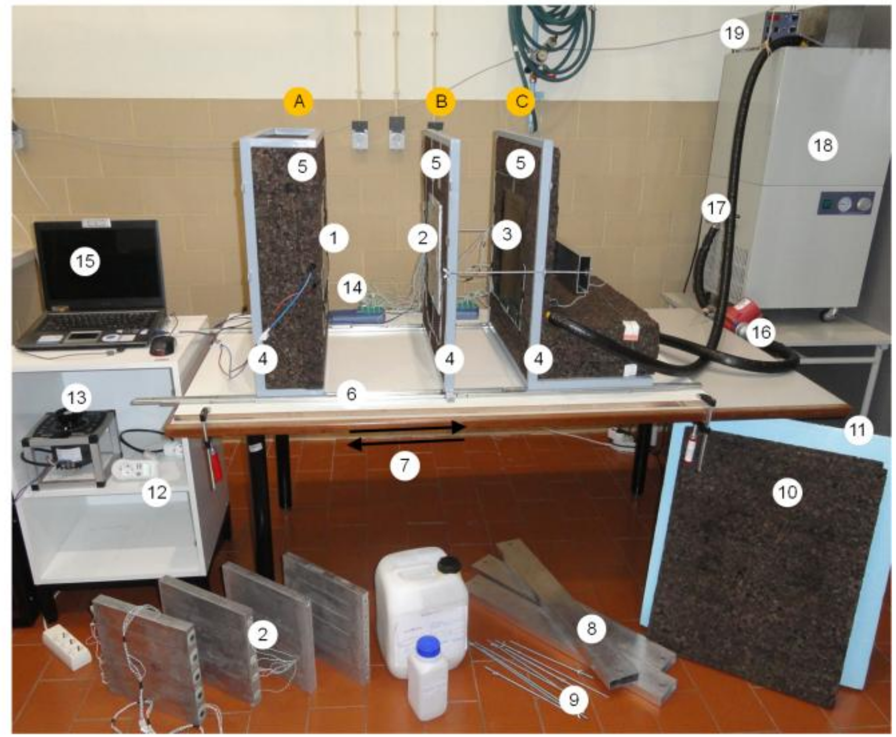
6 Dissemination, technical seminars and workshops

❸ Tests in the small-scale experimental setup





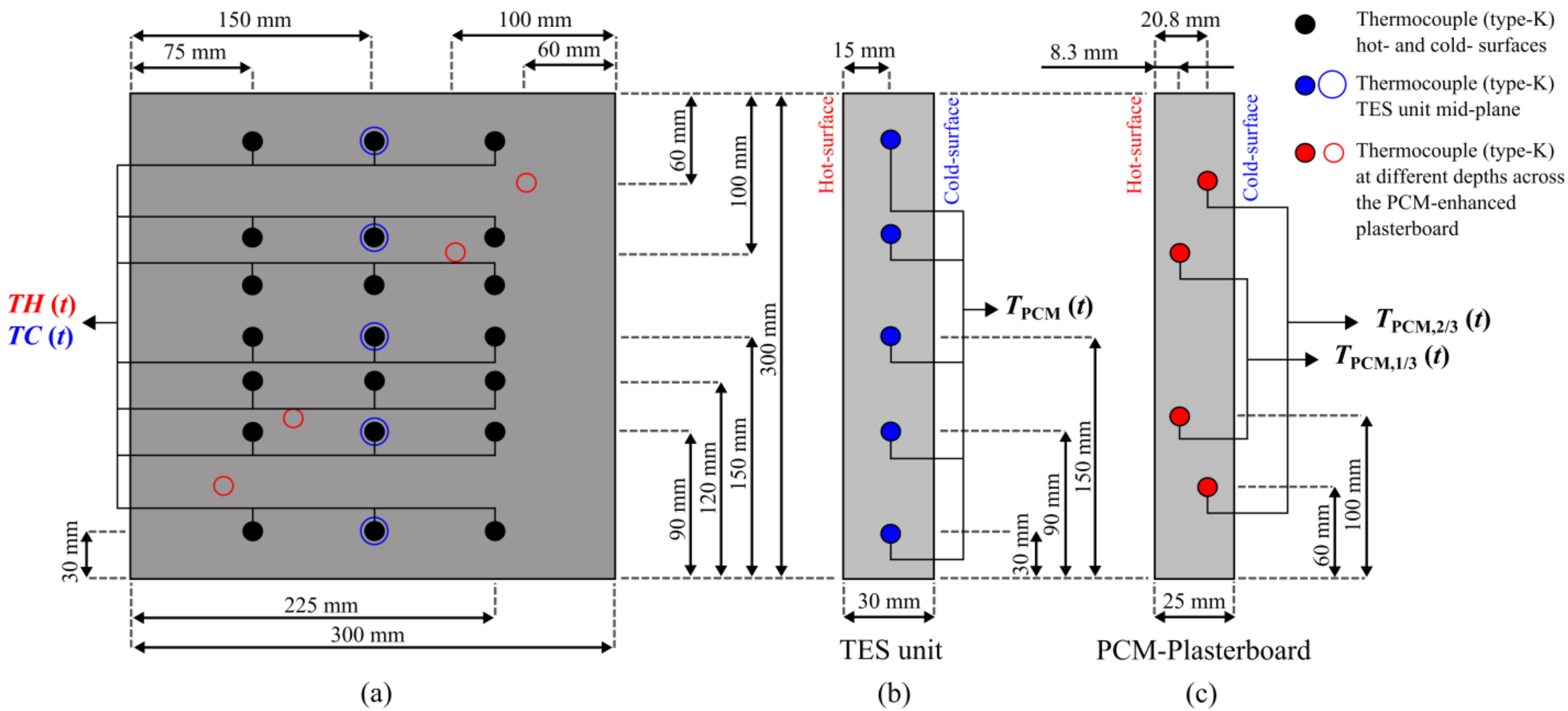
A - Movable heating module

B - Fixed test module

C - Movable cooling module

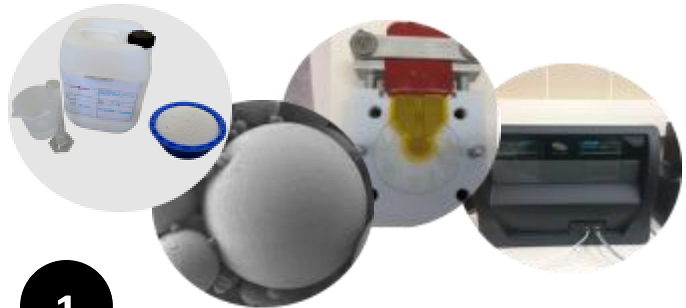
① - Hot-plate
② - Aluminium test-sample filled with PCM
③ - Cold-plate
④ - Rigid iron skeleton of the modules
⑤ - Thermal insulation boundary - cork
⑥ - Rails for linear motion
⑦ - Linear motion of the heating/cooling modules
⑧ - Accessories for compressing and joining the modules
⑨ - Threaded rods and nuts for the junction of the modules
⑩ - Movable thermal insulation layer - cork
⑪ - Movable thermal insulation layer - XPS
⑫ - Digital wattmeter
⑬ - Variac
⑭ - Pico® USB TC-08 thermocouple data logger
⑮ - PicoLog® data acquisition program
⑯ - Circulator pump *Grundfos* UPE 25-60
⑰ - Water circulation - insulated flow
⑱ - Water bath *Heto Lab Equipment* DBT KB21
⑲ - HetoTherm DBT 200 thermostat

❸ Tests in the small-scale experimental setup

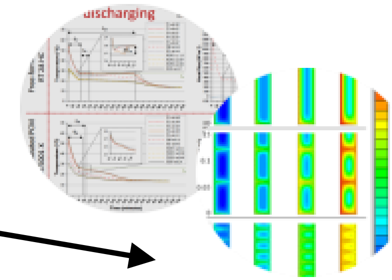


Sketch of the distribution of the K-type thermocouples (a) on the cold- and hot-surfaces of the test-samples; (b) on the mid-plane section of the TES unit; (c) within the PCM-enhanced plasterboard at different depths.

Main tasks

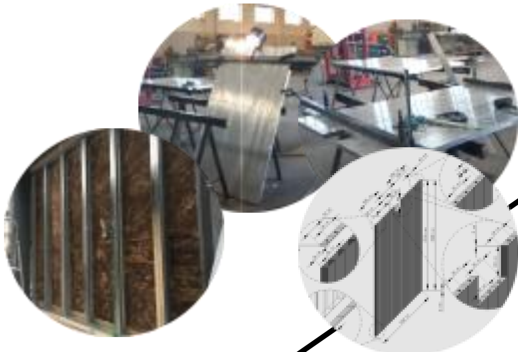


1 **Thermophysical characterization of PCMs**



2 **Numerical modeling and CFD evaluation**

3 **Tests in the small-scale experimental setup**



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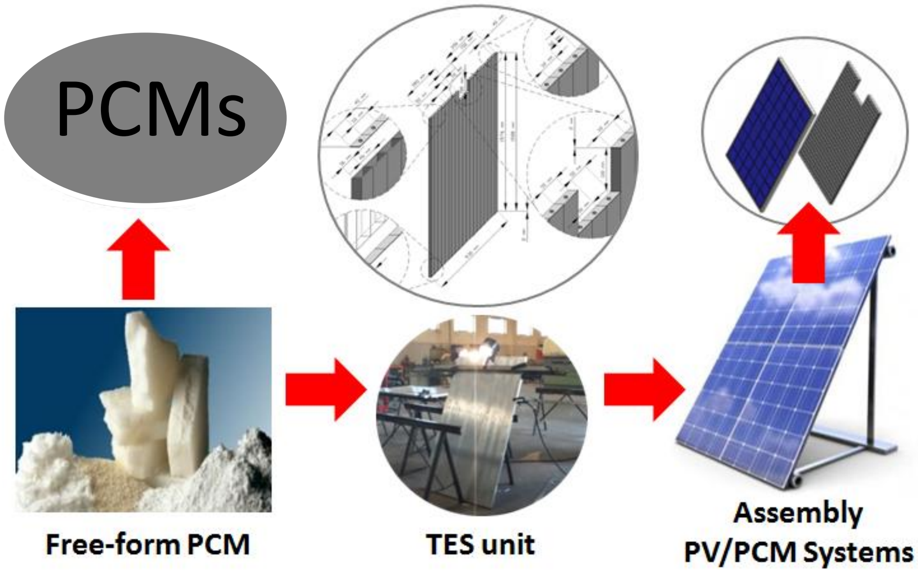
6 **Dissemination, technical seminars and workshops**

❺ Definition of full-scale prototypes

PV/PCM systems



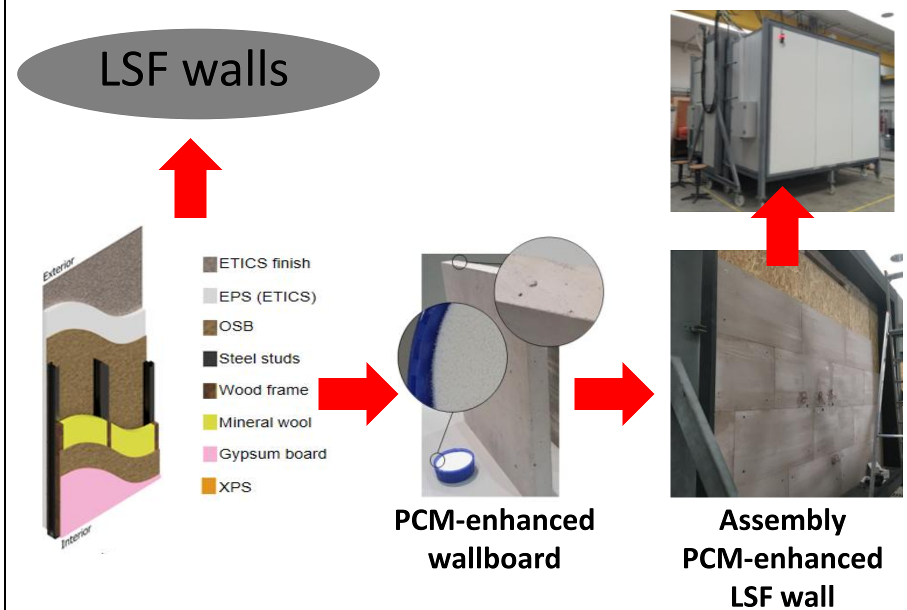
Problem:

High operating temperatures reduce the performance of commercial polycrystalline silicon photovoltaic (PV) devices by reducing the efficiency of solar to electrical energy conversion in the PV cells.

Research question:

Can movable PCM-filled TES units be used to improve the energy efficiency of polycrystalline silicon PV panels ?

LSF systems with PCMs



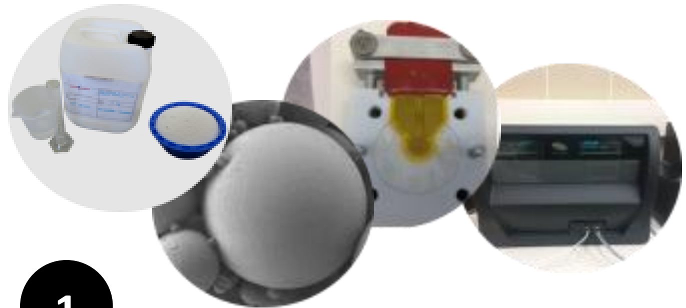
Problem:

LSF construction may show lower thermal mass which can result in several comfort-related problems, larger temperature fluctuations and higher energy demand for heating and cooling.

Research question:

Can PCM-based solutions be used to improve the thermal performance of LSF construction ?

Main tasks



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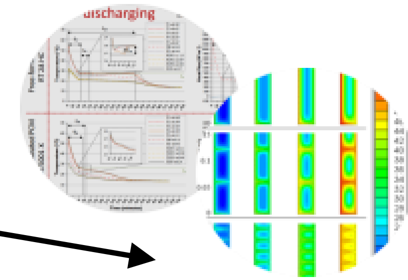
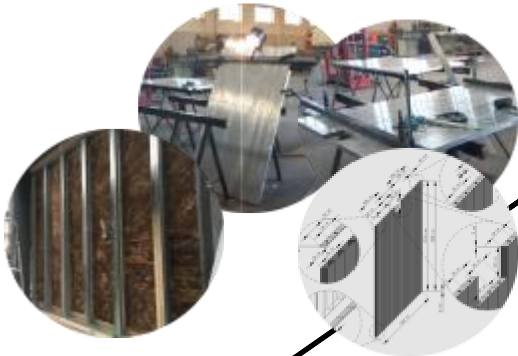


2 **Numerical modeling and CFD evaluation**



5 **Definition of full-scale prototypes**

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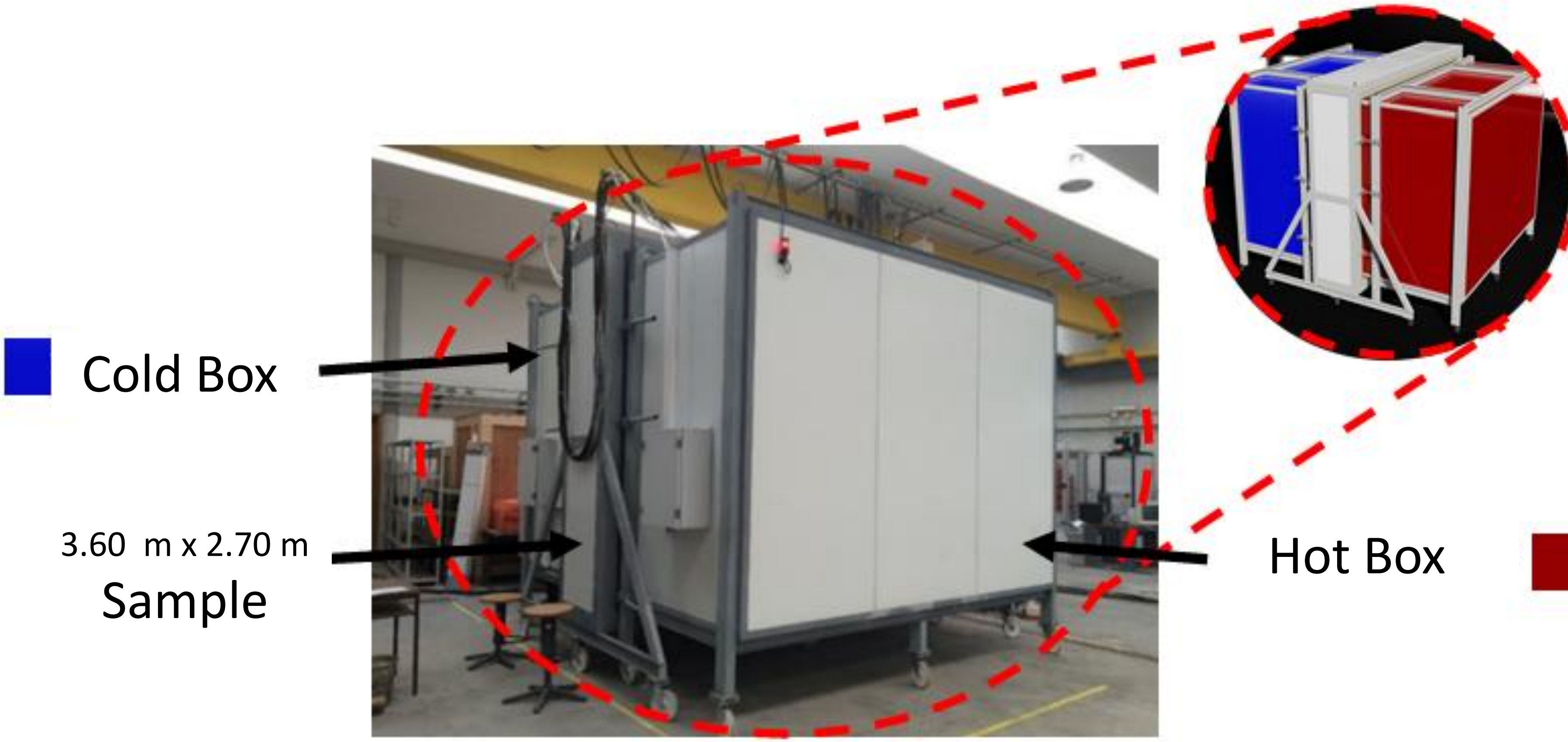
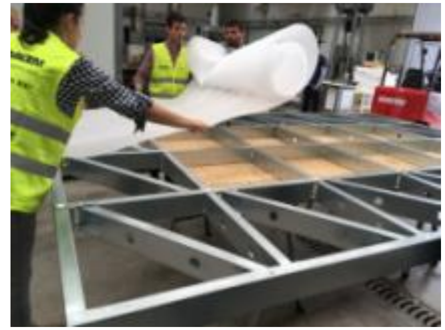
6 **Dissemination, technical seminars and workshops**

❹ Tests in the Guarded Hot Box setup and other real-scale experimental apparatus

➡ LSF walls with PCMs – Guarded Hot Box (ongoing)



Assembly of the LSF walls with PCMs



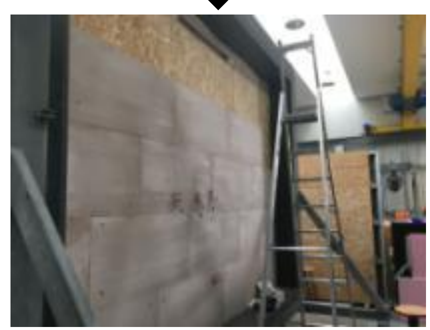
B(A)[a]
Balthazar
Aroso
arquitectos

URBIMAGEM

Assembly of the
LSF Wall - LSF System B(A)[a]

Placo

Alba®balance 25



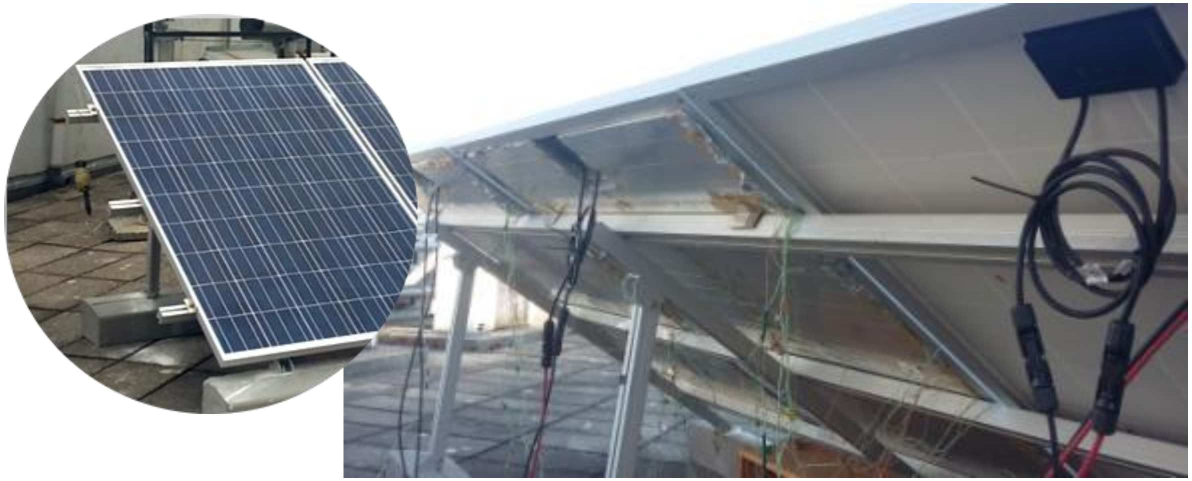
LSF wall + PCM-enhanced plasterboard

Evaluation of the thermal performance in transient conditions

❹ Tests in the Guarded Hot Box setup and other real-scale experimental apparatus

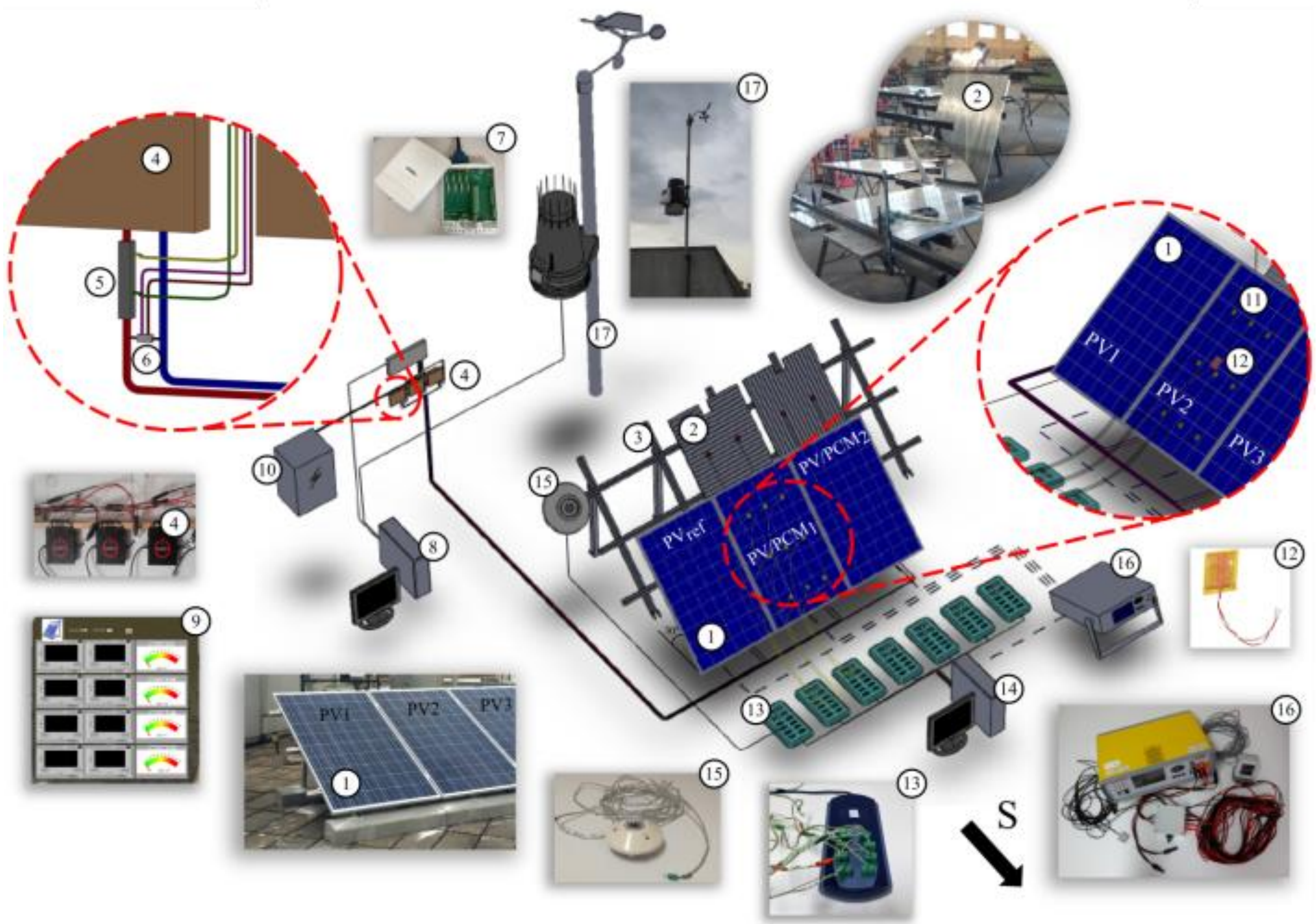
➡ PV/PCM systems – outdoor apparatus (ongoing)

Goal: To carry out an experimental parametric study to evaluate the influence of different configurations of the TES unit (horizontally and vertically oriented cavities) and the impact of different phase-change temperature ranges of the PCM.



➡ Assembly of the PV/PCM systems

➡ Experimental apparatus



(1) *Risen* RSM60-6-250P PV modules
(2) TES units filled with the PCM
(3) Support system
(4) DC/AC microinverter *BeOn*
(5) Shunt resistor
(6) Voltage divider
(7) *National Instruments*™ SCC-68 I/O connector block
(8) Computer for data acquisition
(9) *LabView*™ program interface - current, voltage and power monitoring/recording
(10) Main service panel
(11) Thermocouples (K-type)
(12) *Omega*™ flexible heat flux sensor HFS-4
(13) *Pico*® USB TC-08 thermocouple data logger
(14) *PicoLog*® data acquisition program
(15) *Kipp&Zonen* CM11 pyranometer
(16) PVPM2540C mobile peak power and *I-V*-curve measurement device for PV modules
(17) *Davis Instruments* Vantage Pro2™ weather station

Monitoring data:

- Time evolution of temperature and heat flux on the surfaces of both the PV panels and the TES units to be compared with each other;
- Time evolution of current and voltage of each PV module to determine the power output of each PV and the solar conversion efficiency;
- Time evolution of the weather conditions.

Location: *Coimbra, Portugal.*

The PCMs4Buildings Project - Thermal Energy Storage PCM-based Systems for Building Applications

Thank you!

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Cofinanciado por: