International Building Physics Conference

IABP – International Association of Building Physics

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Toronto, Ontario, Canada

Thermal energy storage frontiers

Prof. Luisa F. Cabeza

Dr. Emiliano Borri

Universitat de Lleida

Biography of the speakers

Luisa F. Cabeza

- Born in Barcelona, Spain in 1967
- PhD in industrial engineering from University Ramon Llull (Spain)
- Post-doctoral researcher at the Eastern Regional Research Center (ARS, USDA) in Philadelphia
- Full professor @University of Lleida
- Coordinator of the research group GREiA

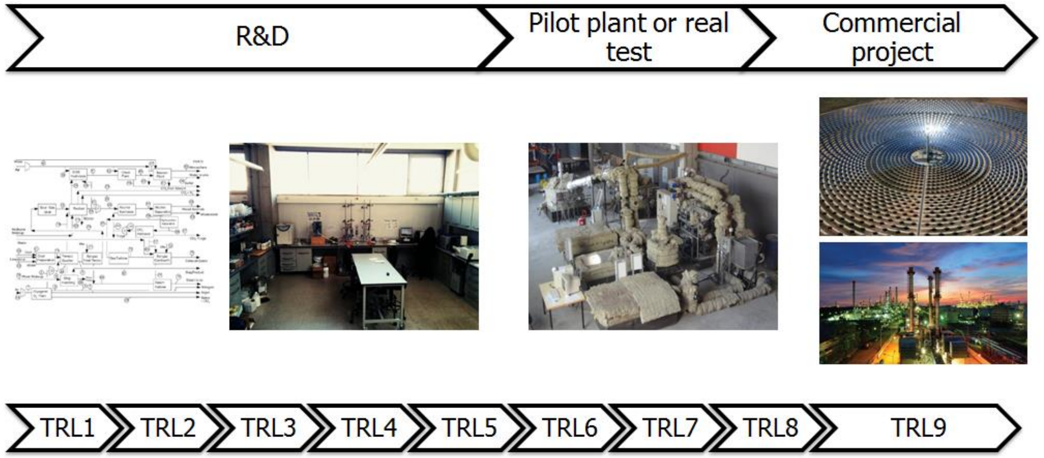
Emiliano Borri

- Born in San Severino Marche, Italy in 1989
- PhD in industrial engineering from Università Politecnica delle Marche (Italy)
- Since 2019 he is a post-doctoral researcher at the GREiA research group University of Lleida

GREiA research group

GREiA research group

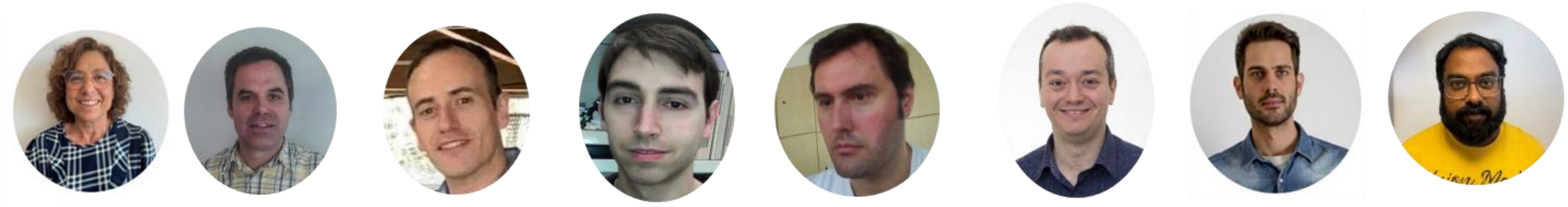
- Vision
  - Being a reference group of engineering at an international level, always linked to the University of Lleida
- Mission
  - To propose solutions to the industry in the fields of sustainability, energy engineering and control, through research, technology transfer and training



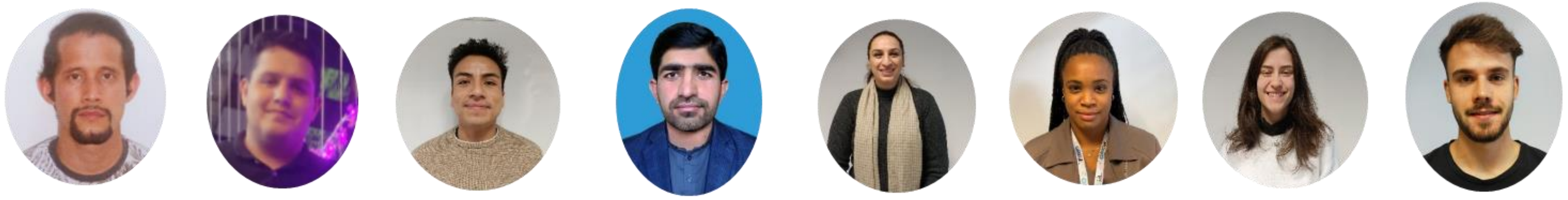
- Objectives
  - To improve existing knowledge through research and innovation
  - To help increase the competitiveness of companies through collaborations, whether for the design of new products or as a technology consultancy

GREiA research group

Luisa F. Cabeza | Joao Marques-Silva | Cèsar Fernández | Josep M. Morera | Josep Ramon Castro | Carles Mateu | Teresa Alsinet | Ramon Béjar



Esther Bartolí | Jordi Planes | Josep Argelich | Santi Martinez | Gabriel Zsembinszki | Marc Escribà-Gelonch | Emiliano Borri | Saranprabhu MK



Pablo Tagle | Edgar Rojas | Rodrigo Martinez | Waqar Ahmed | Nadiya Mehraj | Daylen Font | Sara Risco | Sergi Dueso

GREiA research group

Energy

- Energy engineering
  - **Evaluation and study of thermal energy storage**
  - Characterization and development of materials
  - Evaluation and improvement of heat exchange
  - Laboratory and experimental pilot plants
- Industrial and construction design
  - Sustainable construction
  - Green facades and roofs
  - Dynamic structures and structural stress studies
- Energy sustainability
  - Life cycle analysis (LCA) and life cycle cost analysis (LCC) of materials and processes
  - Development of numerical models to analyse and optimize energy efficiency in buildings and industrial processes

Artificial intelligence

- Designing control solutions for efficient energy usage using AI approaches
- AI powered search for optimal designs and materials for energy storage
- Resolution of computationally difficult problems by programming restrictions and reasoning
- Design, implementation and evaluation of very efficient algorithms to find solutions to problems that are modelled in different languages

Chemical engineering

- Use of animal and vegetable waste to apply circular economy in industrial processes
- To provide sustainable manufacturing processes

Contents

- Introduction to thermal energy storage (TES)
- TES technologies
- TES applications
- Innovation potential according to roadmaps
- Research trends and gaps in academic literature

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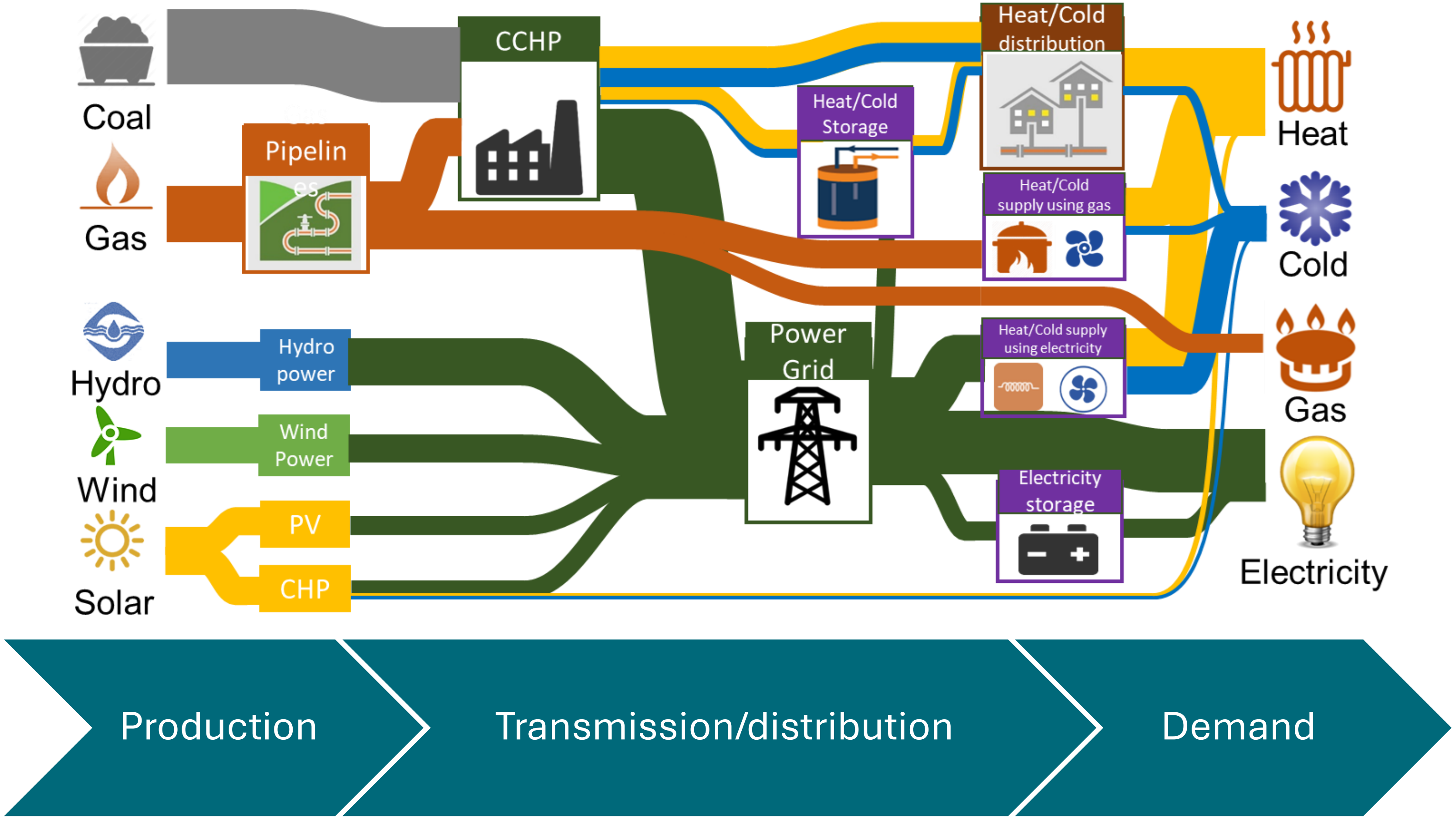
The energy system



http://www.ningzhang.net/MES.html

The energy system

- According to the IEA, electricity demand grew 5% in 2021 with almost half the increase met by fossil fuels, notably coal, threatening to push CO2 emissions from the power sector to record levels in 2022
- Renewables are expanding quickly but not enough to satisfy a strong rebound in global electricity demand this year, resulting in a sharp rise in the use of coal power that risks pushing carbon dioxide emissions from the electricity sector to record levels next year
- The production and use of energy account for more than 75% of the EU greenhouse gas emissions
- Decarbonising the EU energy system is therefore critical to reach our 2030 climate objectives and the EU long-term strategy of achieving carbon neutrality by 2050

The energy system

- The European Green Deal focuses on 3 key principles for the clean energy transition, which will help reduce greenhouse gas emissions and enhance the quality of life of our citizens:
  1. Ensuring a secure and affordable EU energy supply
  2. Developing a fully integrated, interconnected and digitalised EU energy market
  3. Prioritising energy efficiency, improving the energy performance of our buildings and developing a power sector based largely on renewable sources

The energy transition

https://rmi.org/energy-transition-in-2022/

The energy transition

The main disadvantage of renewable energies is that they are discontinuous

→

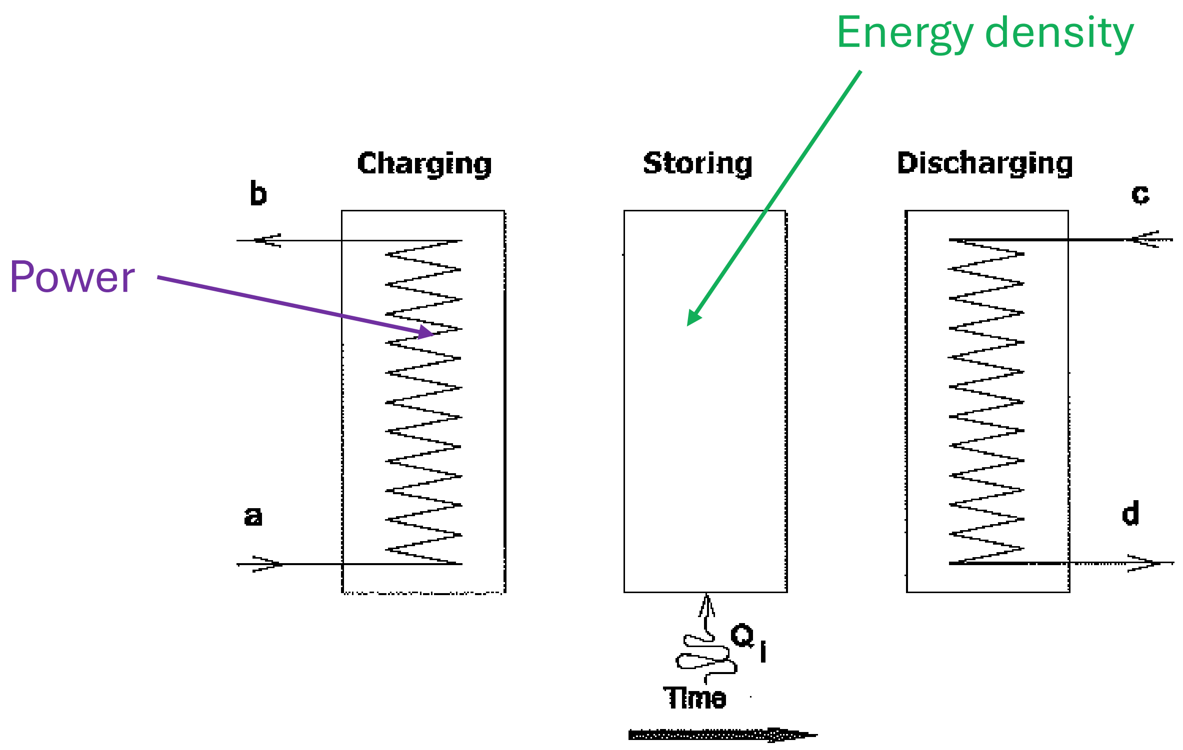
We need energy storage, including **thermal energy storage**

The energy system

- Thermal energy storage (TES):
  - Operate with a goal of storing energy for later use as heating or cooling capacity
  - Individual TES technologies operate in the generation and end-use steps of the energy system and can be grouped by storage temperature: low, medium, high
  - Is well suited for an array of applications including seasonal storage on the supply-side and demand management services on the demand-side portion of the energy system

Basic principle of TES

- Energy is supplied to a storage system for removal and use at a later time
- A complete storage process involves at least three steps: charging, storing and discharging
- What mainly varies is the scale of the storage and the storage method used
- Seasonal storage requires immense storage capacity



Benefit of TES

- Some of the benefits of are:
  - To reduce the energy demand for heating and cooling of buildings through passive TES solutions
  - To enhance the integration of clean energy sources used for the production of electrical or thermal power tackling the problem related to their intermittency
  - To increase the generation capacity and the flexibility of energy systems reducing or shifting the peak load operation to take advantage of off-peak times when electricity is cheaper

Benefit of TES

- Main barriers to TES deployment
  - Lack of technology readiness in some of the TES technologies
  - Lack of knowledge and awareness on the benefit of TES
  - Uncertainty about the future of energy system (risk on investments on TES)
  - Conflicting policies and planning due to limited vision across different energy vectors (i.e., heating/cooling and power)

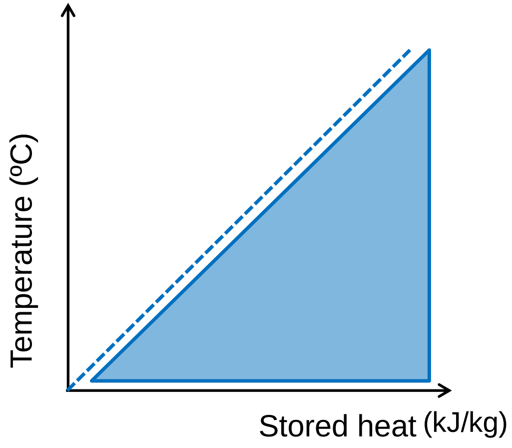
Contents

- Introduction to thermal energy storage (TES)
- TES technologies
- TES applications
- Sustainability and social aspects

TES technologies

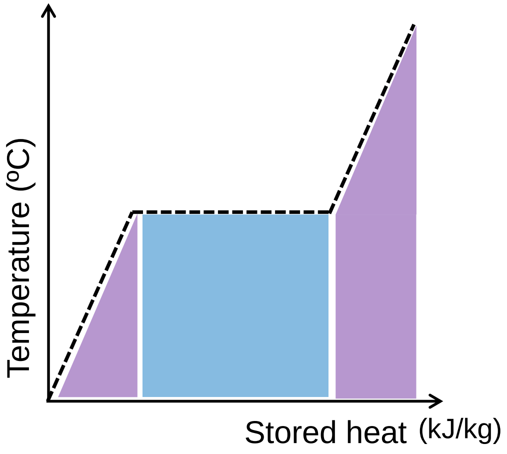
Sensible

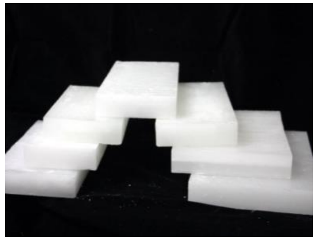
$$Q_{sensible} = \int_{T_1}^{T_2} C_p \cdot dT$$



Latent

$$Q_{latent} = \int_{T_1}^{T_{pc}} C_{p,s} \cdot dT + \Delta H_{pc} + \int_{T_{pc}}^{T_2} C_{p,l} \cdot dT$$

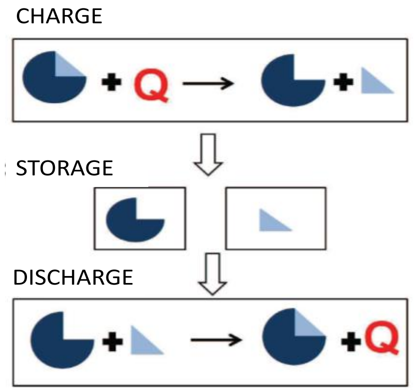




Thermochemical

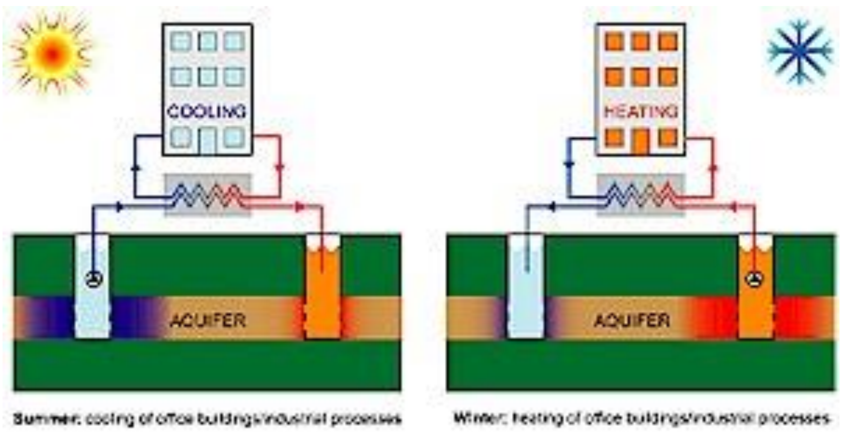
Sorption & chemical reactions

$$A_{(s)} \underset{\text{heat release, exothermic reaction}}{\overset{\text{heat storage, endothermic reaction}}{\rightleftharpoons}} B_{(s)} + C_{(g)}$$



Sensible TES

- Underground thermal energy storage (UTES) systems
  - Pump heated or cooled water underground for later use as a heating or cooling resource
  - Include aquifer and borehole thermal energy storage systems, where this water is pumped into (and out of) either an existing aquifers or man-made boreholes
- Pit storage systems
  - Use shallow pits, which are dug and filled with a storage medium (frequently gravel and water) and covered with a layer of insulating materials
  - Water is pumped into and out of these pits to provide a heating or cooling resource

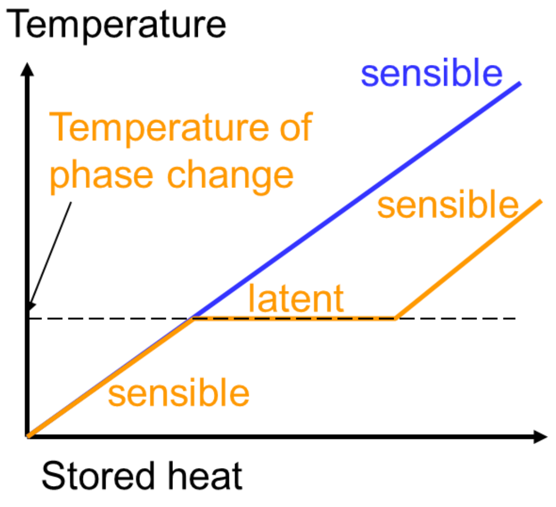


Sensible TES

- Solid media storage systems
  - Store energy in a solid material for later use in heating or cooling
  - In many countries, electric heaters include solid media storage (e.g., bricks or concrete) to assist in regulating heat demand
- Molten salts
  - Are solid at room temperature and atmospheric pressure, but undergo a phase change when heated
  - They are frequently used to store heat in CSP facilities for subsequent use in generating electricity
- Hot- and cold-water storage in tanks
  - Can be used to meet heating or cooling demand
  - A common example of hot water storage can be found in domestic hot water heaters, which frequently include storage in the form of insulated water tanks

Latent TES

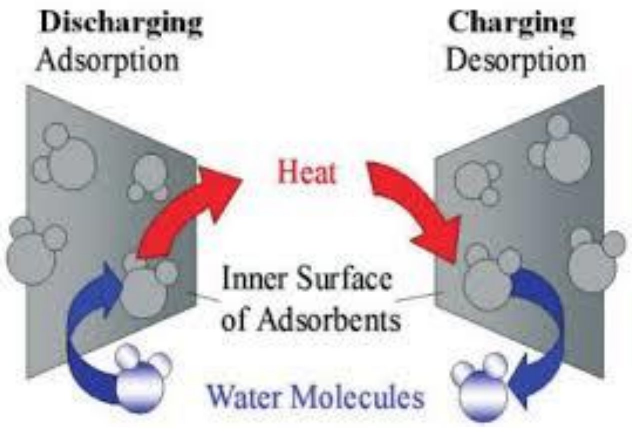
- Heat storage as latent heat
  - PCM can store about 3 to 4 times more heat per volume than is stored as sensible heat in solids or liquids
  - Materials with useful phase change are called latent heat storage materials or = phase change material (PCM)

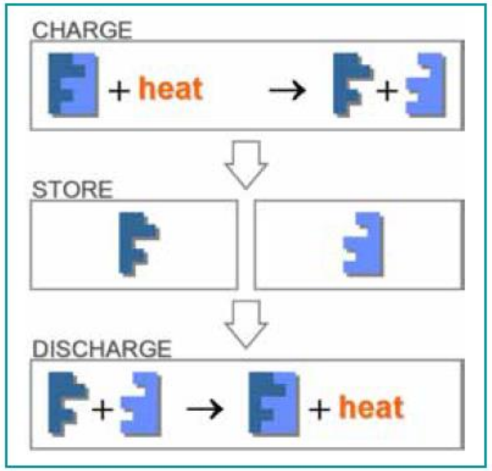


- Ice storage
  - It is a form of latent heat storage, where energy is stored in a material that undergoes a phase change as
    it stores and releases energy

Thermochemical TES

- Uses reversible chemical reactions to store thermal energy in the form of chemical compounds
- This energy can be discharged at different temperatures, dependent on the properties of the thermochemical reaction





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TES applications

- Building applications
  - Passive systems in the envelope
  - Active systems in the envelope (ventilated façade)
  - DHW solar energy with PCM in water tank
- High temperature applications
  - Solar cooling
  - Industrial waste heat recovery
  - Storage in CSP
- Other applications
  - General containers
  - Beverages
  - Catering
  - Blood products
  - Electronic devices

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Building applications

- To increase the thermal inertia of the building
  - PCM in concrete, gypsum plaster wallboard, ceilings
  - Microencapsulated, macroencapsulated
- Practical assessment of the influence of PCM integrated in building structures and their influence on thermal stability of indoor environment
- In order to assess the impact of the solutions adopted, monitoring is necessary

Building applications

- University of Lleida
  - Different cubicles were built using different Mediterranean typical constructive solutions. Internal dimensions are 2.4 x 2.4 x 2.4 meters
  - The important temperature oscillations during day and night make it very suitable for the PCM operation (melting during the day and solidifying during the night)
  - The PCMs tested were designed for cooling applications
  - Reference cubicle without insulation and without PCM
  - Experimental cubicle without insulation and with microencapsulated PCM

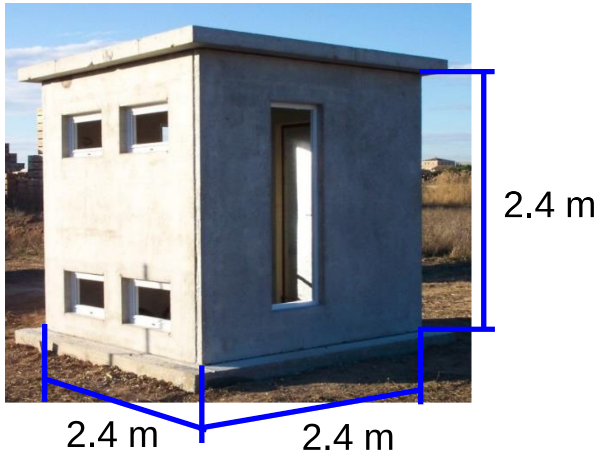
Building applications

- Different constructive solutions:
  - Concrete
    - No insulation
    - w/wo microencapsulated PCM
  - Conventional brick
    - No insulation
    - Different insulation materials
    - Insulation and macroencapsulated PCM
  - Alveolar brick
    - No insulation
    - w/wo macroencapsulated PCM

- Monitoring of internal, walls and ambient temperatures; heat fluxes and energy consumptions
- South, West and Roof wall contain PCM

Building applications

- Concrete envelope with microencapsulated PCM
- PCM MICRONAL®PCM (BASF)
  - 26ºC melting temperature
  - Phase change enthalpy of 110 kJ/kg
  - Each panel incorporates around 5% in weight
- No insulation
- Windows → south, east and west walls



Cabeza, L. F., Castellon, C., Nogués, M., Medrano, M., Leppers, R., Zubillaga, O. Use of microencapsulated PCM in concrete walls for energy savings. Energy and buildings 39 (2007) 113-119

Building applications

- Brick cubicles
  - Reference cubicle (Reference): This cubicle has no insulation
  - Polyurethane cubicle (PU): 5 cm of spray foam polyurethane as insulation
  - PCM cubicle (RT27+PU): 5 cm of spray foam polyurethane as insulation and an additional layer of PCM
  - CSM panels containing RT-27 paraffin are located between the perforated bricks and the polyurethane

Building applications

- Alveolar brick cubicles
  - Reference cubicle (Alveolar): The alveolar brick has a special design which provides both thermal and acoustic insulation. No additional insulation was used in this cubicle
  - PCM cubicle (SP25+Alveolar): Several CSM panels containing SP-25 A8 hydrate salt are located inside the cubicle, between the alveolar brick and the plaster

Building applications

- Brick envelope with macroencapsulated PCM
  - Conventional brick:
    - Reference: No insulation
    - Polyurethane: 5 cm of polyurethane
    - RT27+PU: CSM panels (RT-27) and 5 cm of polyurethane
  - Alveolar brick:
    - Alveolar: No insulation
    - SP25+Alveolar: CSM panels (SP-25 A8) inside the cubicle

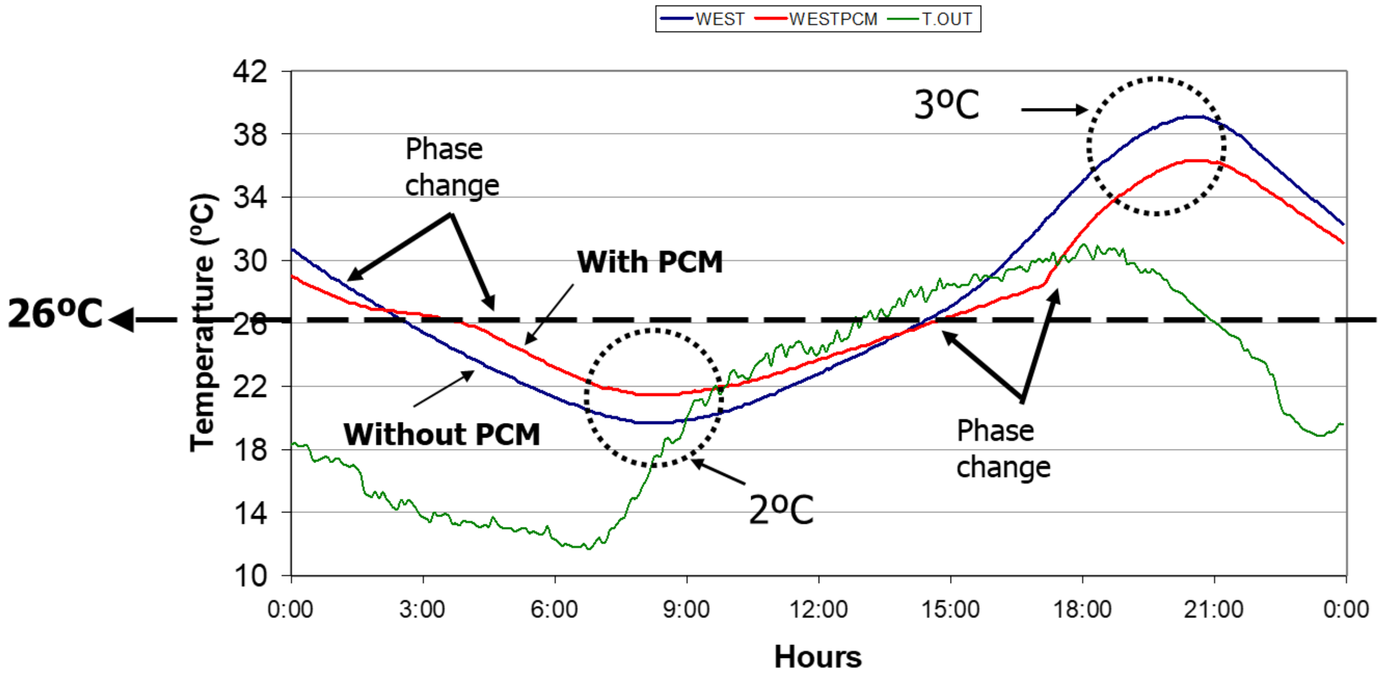
Paraffin RT-27	
Melting point (ºC)	28
Congealing point (ºC)	26
Heat Storage Capacity (kJ/kg)	179
Heat conductivity (W/m·K)	0.2

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

Castell, A., Martorell, I., Medrano, M., Pérez, G., Cabeza, L. F.. Experimental study of using PCM in brick constructive solutions for passive cooling. Energy and buildings 42 (2010) 534-540.

Building applications

- Concrete envelope with microencapsulated PCM
  - Outdoors temperature and temperatures of the west wall, July 2005



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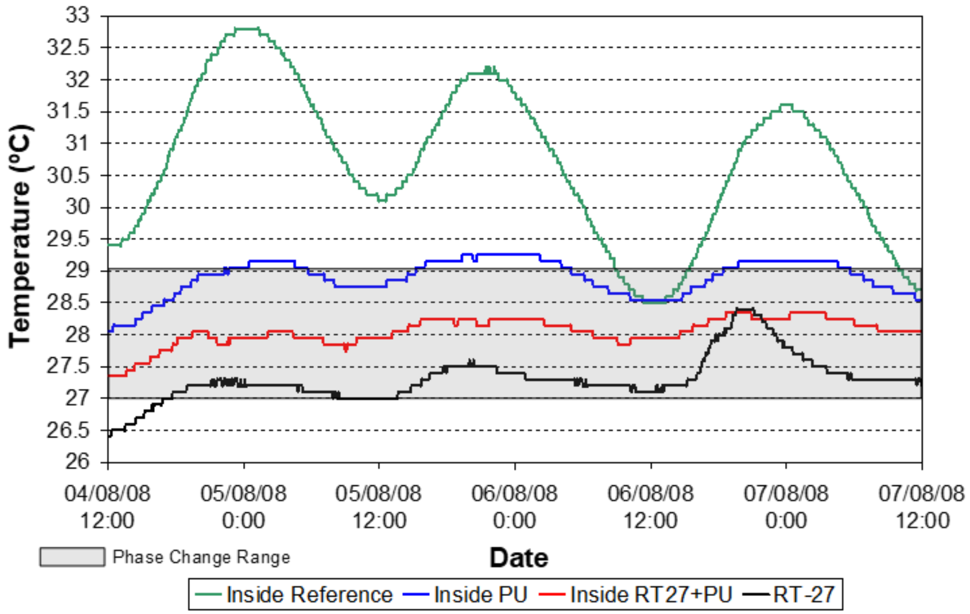
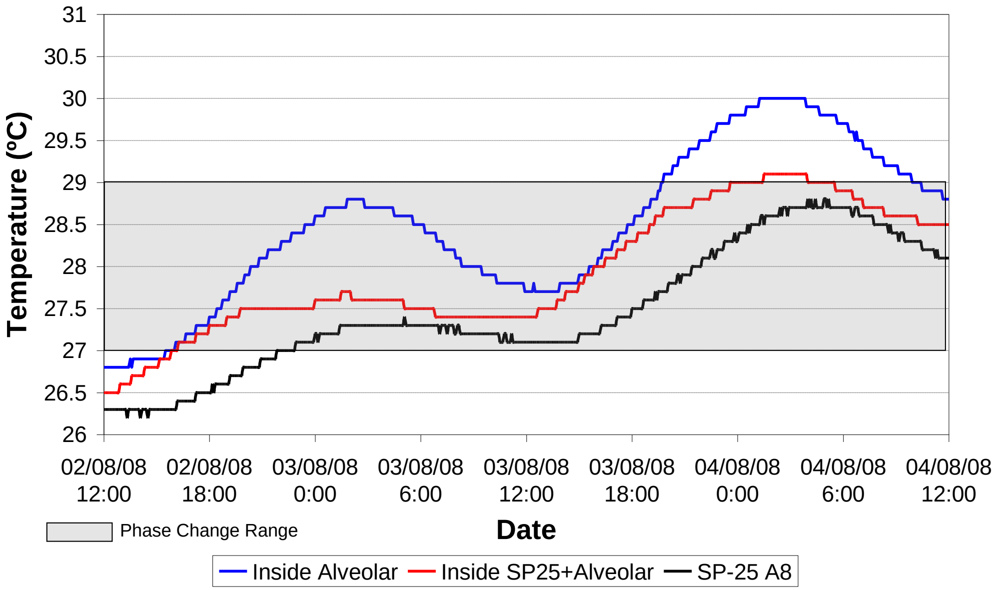
Building applications

- Brick envelope with macroencapsulated PCM (free floating experiments)



conventional brick

Summer period – 04/08/08 to 07/08/08



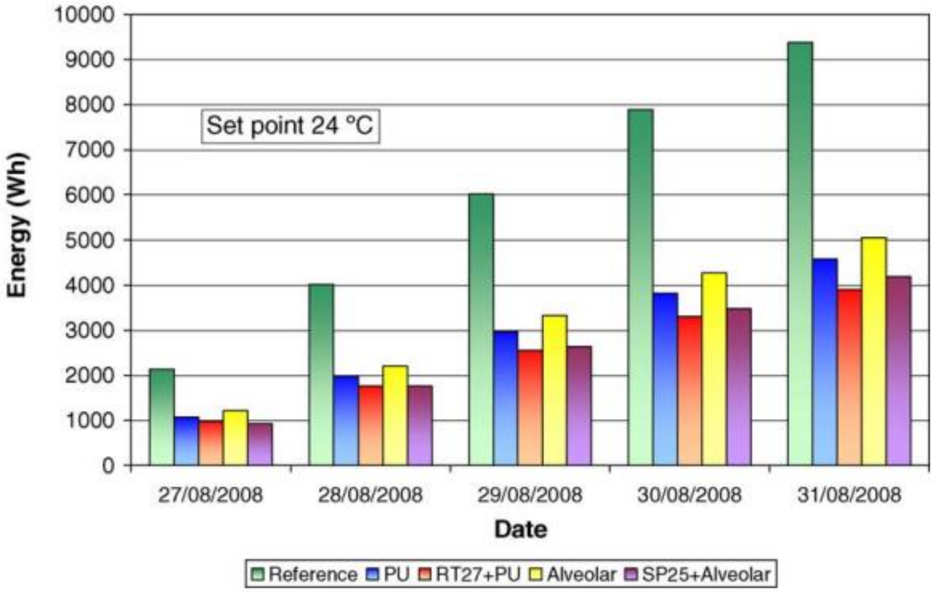
alveolar brick

Summer period – 02/08/08 to 04/08/08

Castell, A., Martorell, I., Medrano, M., Pérez, G., Cabeza, L. F.. Experimental study of using PCM in brick constructive solutions for passive cooling. Energy and buildings 42 (2010) 534-540.

Building applications

- Brick envelope with macroencapsulated PCM (free floating experiments)



Accumulated energy consumption and savings for the different cubicles.

	Energy consumption[a] (Wh)	Energy savings[b] (Wh)	Energy savings[b] (%)	Improvement[c] (%)
Reference	9376	0	0	–
PU	4583	4793	51.12	0
RT27 + PU	3907	5469	58.33	14.75
Alveolar	5053	4323	46.11	0
SP25 + Alveolar	4188	5188	55.33	17.12

[a] Set point of 24 °C during 5 days.
[b] Referred to the Reference cubicle.
[c] Referred to the cubicle with analogue constructive solution and without PCM.

CO_2 emissions to the atmosphere due to the energy consumption of the cubicle.

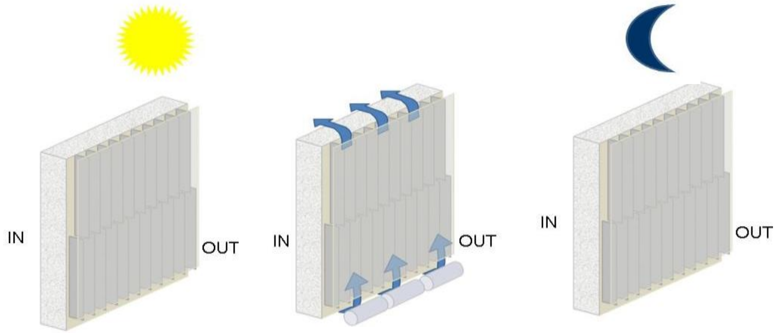
	Energy consumption[a] (kWh/year/m²)	CO_2 emissions (kg/year/m²)	CO_2 savings[b] (kg/year/m²)	CO_2 improvement[c] (kg/year/m²)
Reference	29.3	16.8	0.0	
PU	14.3	8.2	8.6	0.0
RT27 + PU	12.2	7.0	9.8	1.2
Alveolar	15.8	9.1	7.7	0.0
SP25 + Alveolar	13.1	7.5	9.3	1.6

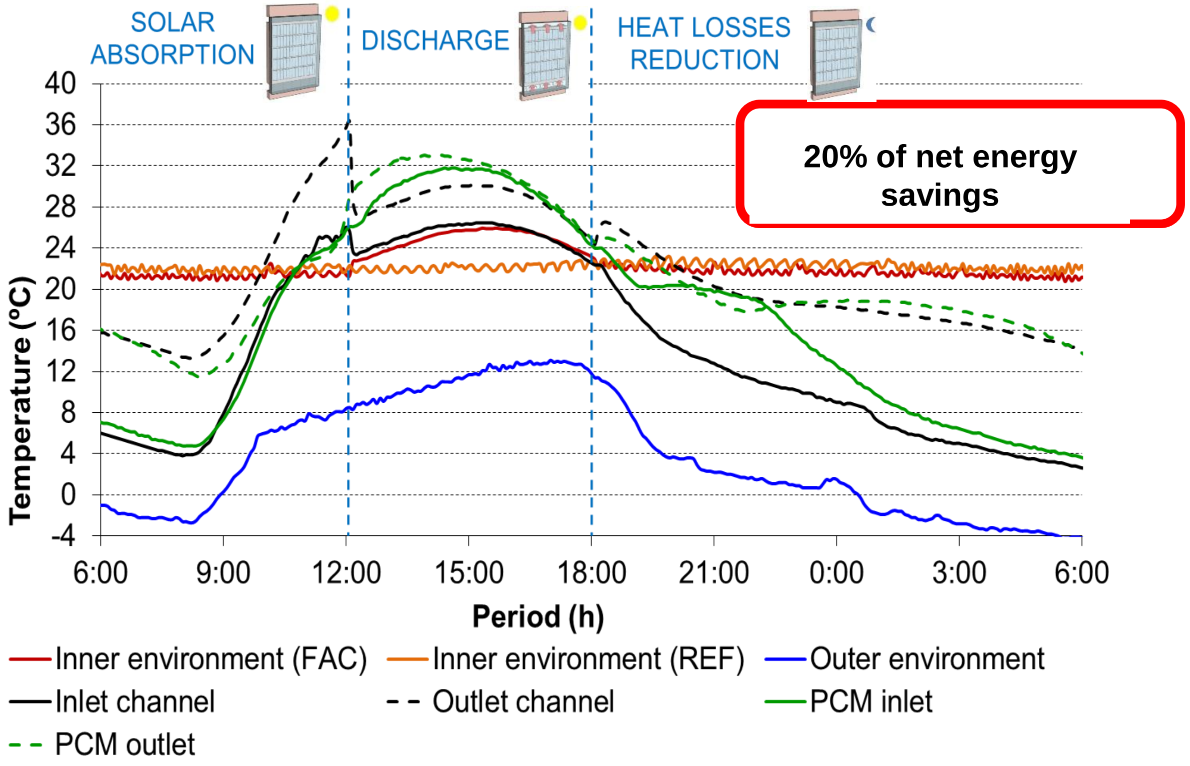
[a] Set point of 24 °C during 90 days per year (cooling demand).
[b] Referred to the Reference cubicle.
[c] Referred to the cubicle with analogue constructive solution and without PCM.

Castell, A., Martorell, I., Medrano, M., Pérez, G., Cabeza, L. F.. Experimental study of using PCM in brick constructive solutions for passive cooling. Energy and buildings 42 (2010) 534-540.

Building applications

- Ventilated Double Skin Facade with PCM

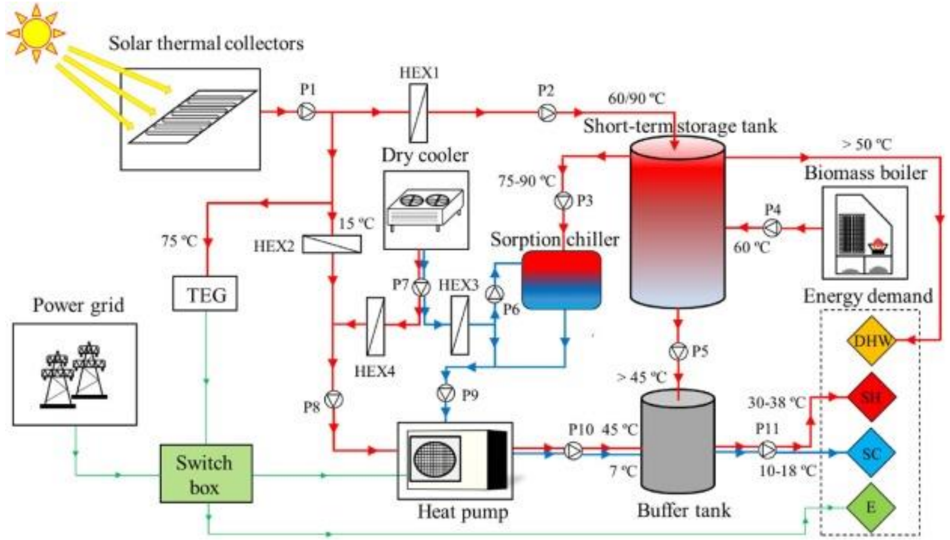


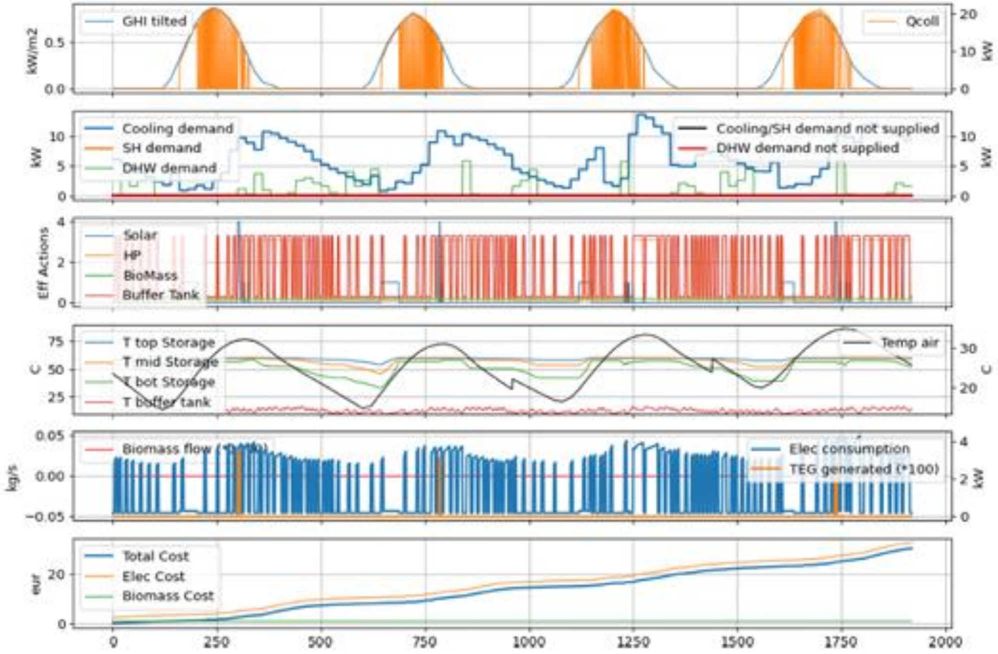


De Gracia, A., Navarro, L., Castell, A., Ruiz-Pardo, Á., Alvárez, S., Cabeza, L. F.. Experimental study of a ventilated facade with PCM during winter period. Energy and Buildings 58 (2013) 324-332.

Building applications

- Control shows to have a big importance in managing active TES but can we do better?
  - Artificial intelligence has a lot of potential to minimize the energy consumption of HVAC especially when energy storage is integrated





This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 814945 (SolBio-Rev)

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TES applications

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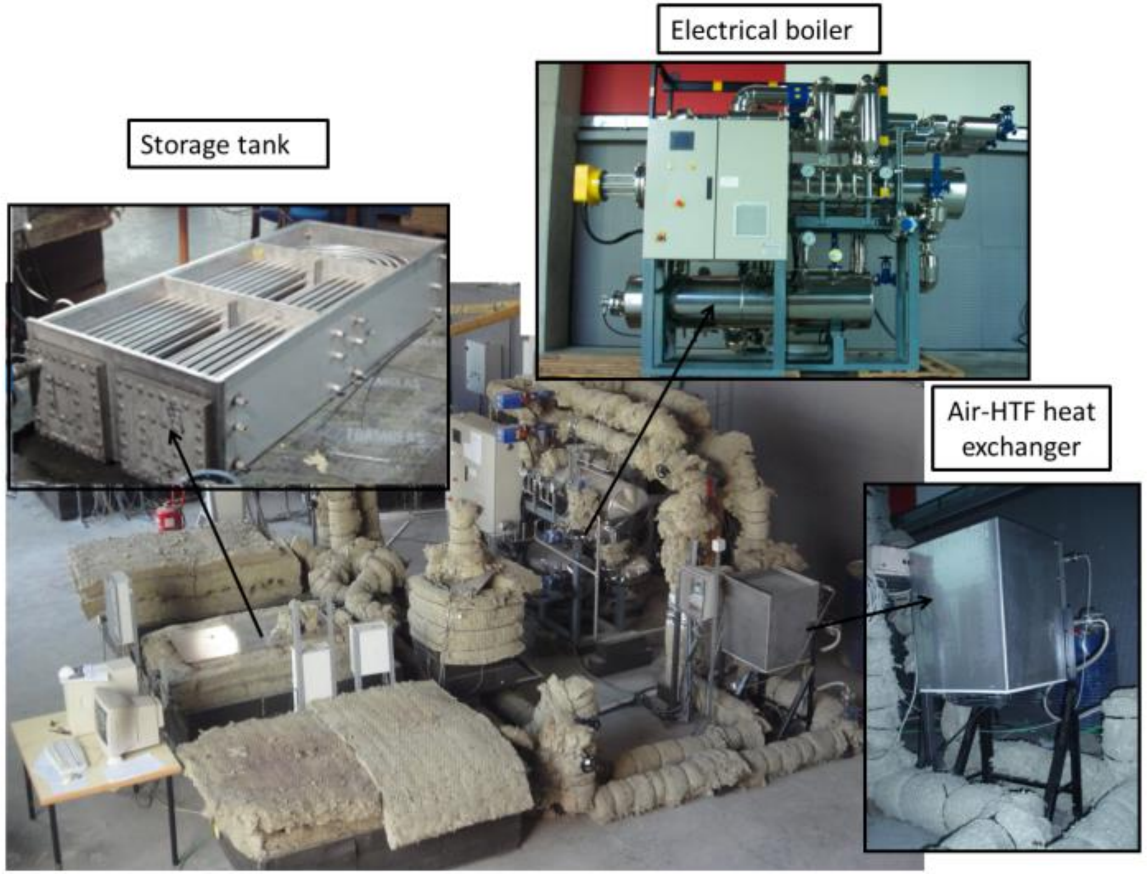
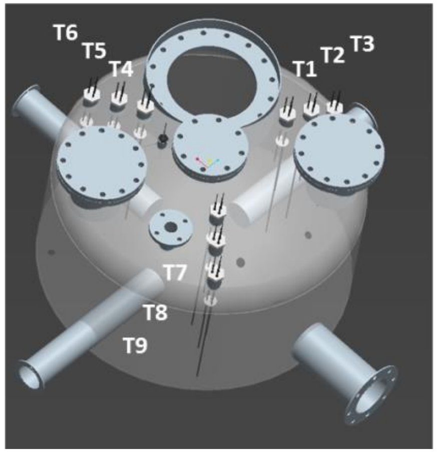
High temperature applications

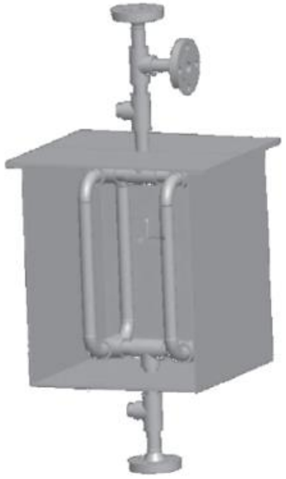
- The high temperature pilot plant was designed and built by the GREiA research group in 2009
- This facility allows the research on:
  - Thermophysical properties of new TES and HTF
  - Thermal behaviour of storage tank container materials
  - Validation of numerical models

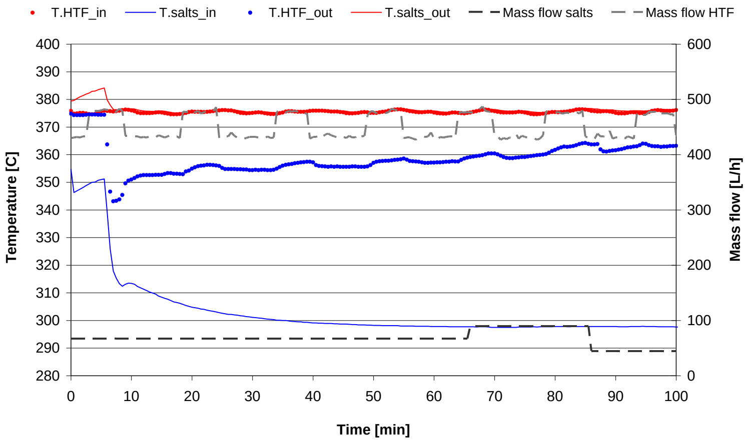


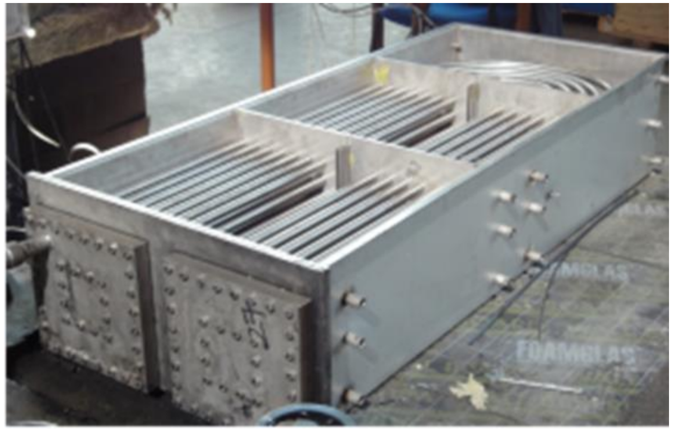
High temperature applications

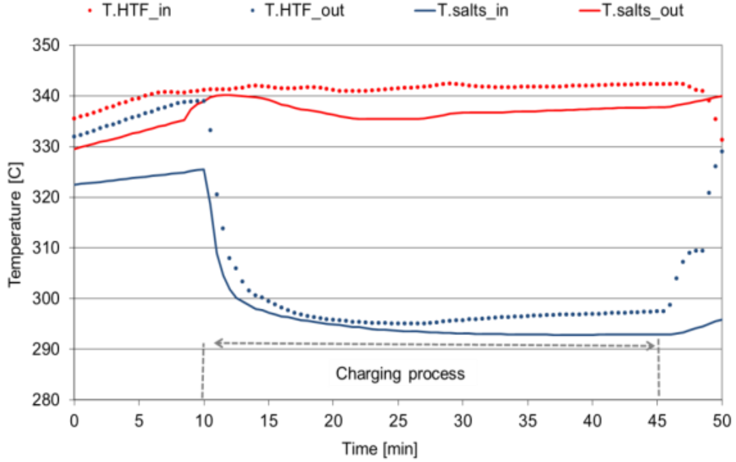
- TES materials tested:
  - D-mannnitol
  - Hydroquinone
  - RT58
  - Bischofite
  - NaCl
  - Water
- HTF used:
  - Therminol VP1
  - Syltherm 800







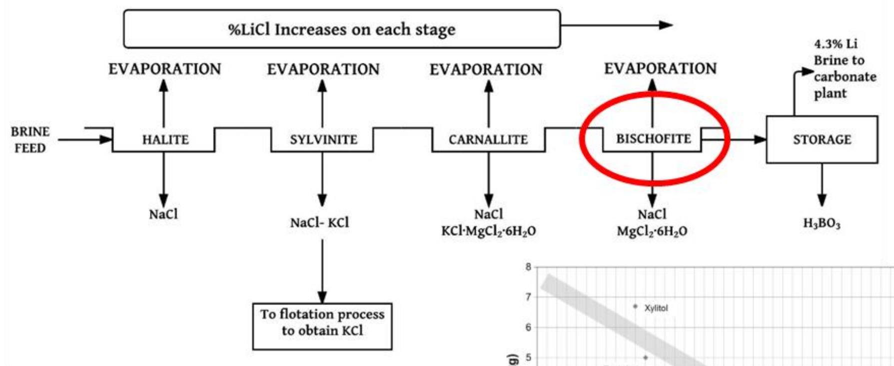


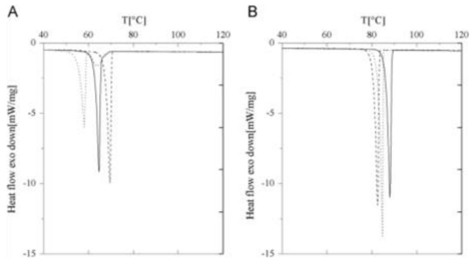


Peiró, G., Prieto, C., Gasia, J., Jové, A., Miró, L., Cabeza, L. F. Two-tank molten salts thermal energy storage system for solar power plants at pilot plant scale: Lessons learnt and recommendations for its design, start-up and operation. Renewable energy 121 (2018) 236-248.

High temperature applications

- Investigating potential use of by-products from the non-metallic industry as TES material: example from Chile (2014-15)





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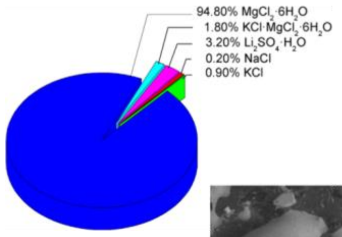
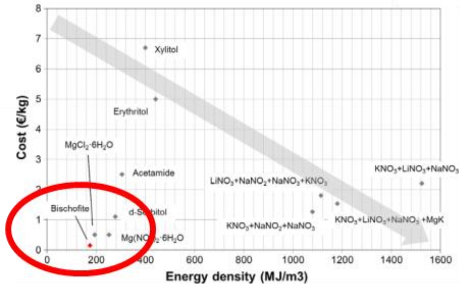
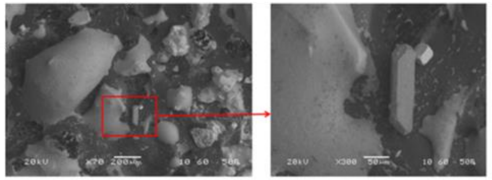
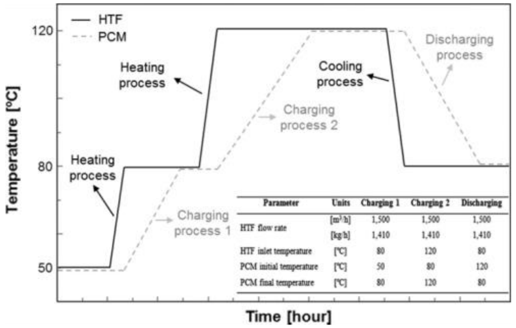






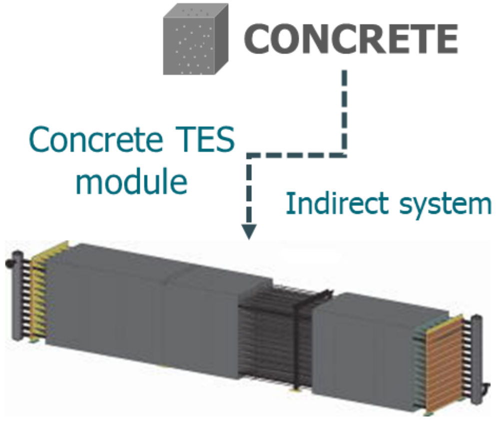


Parameter	Units	Charging 1	Charging 2	Discharging
HTF flow rate	[m³/h]	1,500	1,500	1,500
	[kg/h]	1,410	1,410	1,410
HTF inlet temperature	[°C]	80	120	80
PCM initial temperature	[°C]	50	80	120
PCM final temperature	[°C]	80	120	80

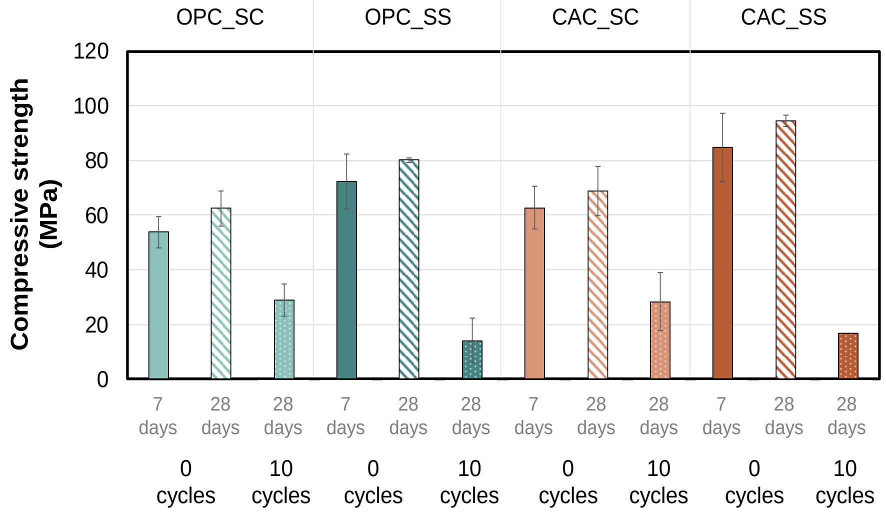
High temperature applications

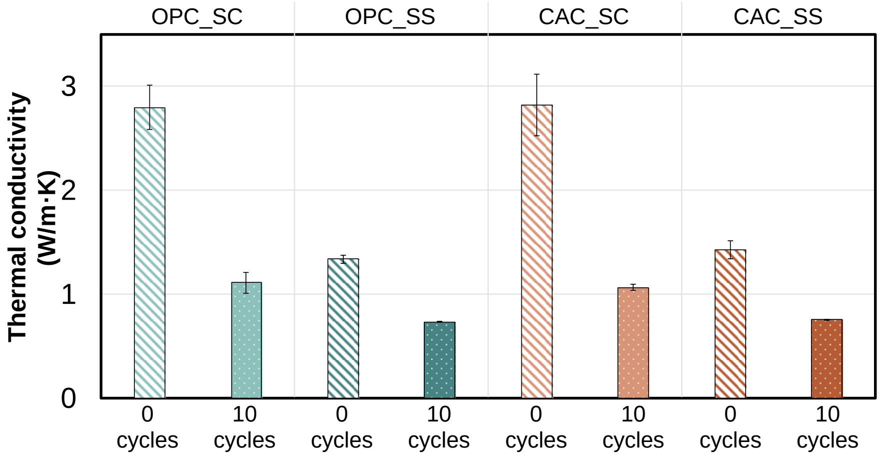
Aggregate granulometry

2100 kg/m³



Boquera, L., Castro, J.R., Fernandez, A.G., Navarro, A., Pisello, A.L., Cabeza, L.F. Thermo-mechanical stability of concrete containing steel slag as aggregate after high temperature thermal cycles Solar Energy 239 (2022) 59–73





CSP-ERA.NET is supported by the European Commission within the EU Framework Programme for Research and Innovation Horizon 2020 (Cofund ERA-NET Action, N° 838311). This study receives funding from the Ministerio de Ciencia e Innovación - Agencia Estatal de Investigación (MCIN/AEI/10.13039/501100011033) through the PCI2020-120695-2 project and the European Union "NextGenerationEU"/PRTR

TES applications

- Building applications
  - Passive systems in the envelope
  - Active systems in the envelope (ventilated façade)
  - DHW solar energy with PCM in water tank
- High temperature applications
  - Solar cooling
  - Industrial waste heat recovery
  - Storage in CSP
- Other applications
  - General containers
  - Beverages
  - Catering
  - Blood products
  - Electronic devices

General containers containing a PCM

All-Purpose delivery transporters

Transport of blood

Soft container by Sofrigam

PVC Packet with TEAP PCM

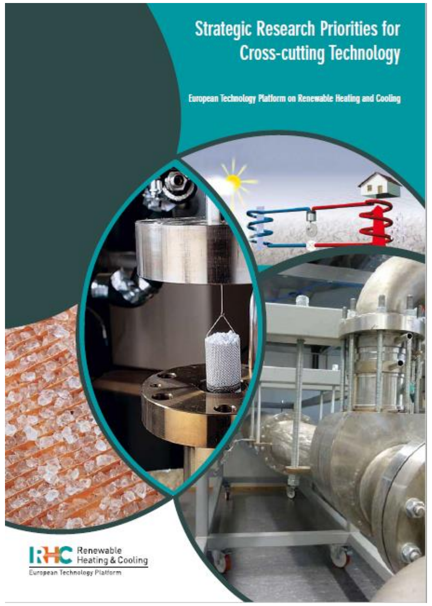
Top view of battery jacket

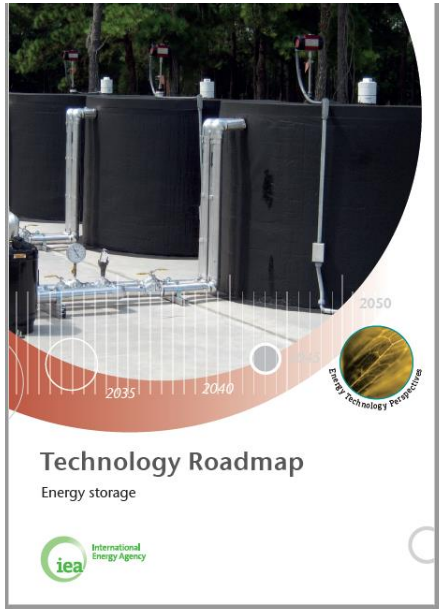
Laptop cooler

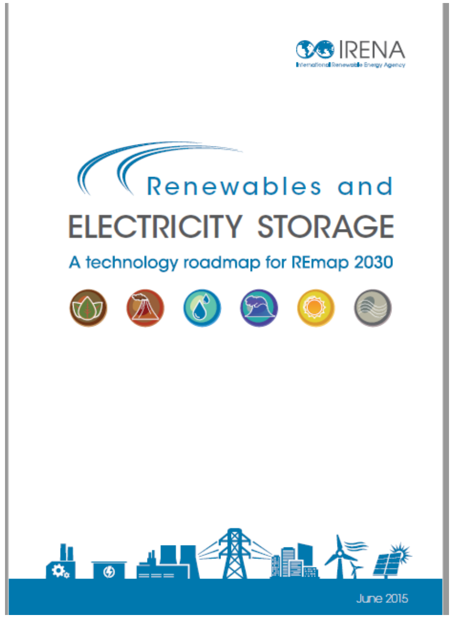
Contents

TES roadmaps

- In recent years different TES roadmap were published to define the technology trends in a market perspective establishing technologic and economic targets and to support policy-makers







Innovation potential for short term (5 years) according to IRENA

- Power
  - Next generation of molten-salt with increasing temperature range and performance
  - Pilots for solid-state TES (i.e. concrete) and novel stand alone molten salt thermal batteries
- Industry
  - Cost reductions and enhancements in integration and control of existing water TES
- Cold chain
  - Material and operational improvements, as well as better integration, could increase efficiencies and lower costs in use of ice and other PCM systems
  - Linking of cold chain assets across sectors could deliver synergies

Innovation potential for short term (5 years) according to IRENA

- District heating and cooling
  - Improvements in integration and management of water TES could significantly reduce costs and expand deployment opportunities
- Buildings
  - PCM thermal batteries combined with energy management systems are being trialled to demonstrate use of off-peak power to decarbonise heat/cooling and save consumers money
  - A development in materials to improve thermal properties and corrosion resistance in tank and solid state TES technologies could improve efficiency, and enhanced innovations in integration and control systems will improve cost effectiveness

Innovation potential for medium term (5-10 years) according to IRENA

- Power
  - LAES; A-CAES and solid state will enhance the use of TES for renewable and an alternative for CSP plants
- Industry
  - Solid state technology to provide a low-cost TES for both electricity and industrial process
  - High-temperature PCMs and salt hydration storage (thermochemical) can increase the energy density
- Cold chain
  - Next generation PCMs for storage at sub-zero temperatures and passive cooling
- District heating and cooling
  - Ongoing research and demonstration of PCMs for use in cooling are expected to drive wider deployment.
- Buildings
  - Cost reductions and technical improvements in next-generation high and low-temperature PCMs and composite PCMs could help increase deployment of latent thermal storage in buildings

Innovation potential for long term (>10 years) according to IRENA

- Power
  - Development for thermochemical for CSP
  - Molten salt-based storage could enable fossil fuelled power plants to be reused for renewable energy storage
- Industry
  - Chemical looping and other thermochemical storage systems integrated into manufacturing processes alongside renewables could aid decarbonisation of processes that require higher temperature process heat
- Cold chain
  - The use of liquid air in LAES could bring down costs and open up new applications, particularly in combined cold and power systems; Retrofit of existing fossil-fuelled network to deliver TES-stored, renewably generated cold

Innovation potential for long term (>10 years) according to IRENA

- District heating and cooling
  - PCMs and thermochemical systems are anticipated to enhance opportunities for combined cooling and power applications; Sector integration and smart control technologies will facilitate the harvesting (and storage) of waste heat/cold from other sectors and applications
- Buildings
  - Research and development activities focussing on realising material and system improvements in thermochemical TES technologies could see these move into demonstration.

Contents

- Introduction to thermal energy storage (TES)
- TES technologies
- TES applications
- Innovation potential according to roadmaps
- Research trends and gaps in academic literature

Bibliometric analysis

- Bibliometric analysis is as an interesting technique that allows studying the scientific progress of a certain topic
- Results of bibliometric analysis can be applied for a specific research area to:
  - Understand the main networks and institutions working on it
  - Identify the main journals publishing study related to that topic
  - Have a complete view of the last research trends, hotspots and gaps

Bibliometric analysis

Query formulation

- TITLE-ABS-KEY ("Thermal energy storage" OR (storage AND ("latent" OR "sensible" OR "thermochemical" OR "sorption"))) AND TITLE-ABS-KEY (latent OR "phase change materials")

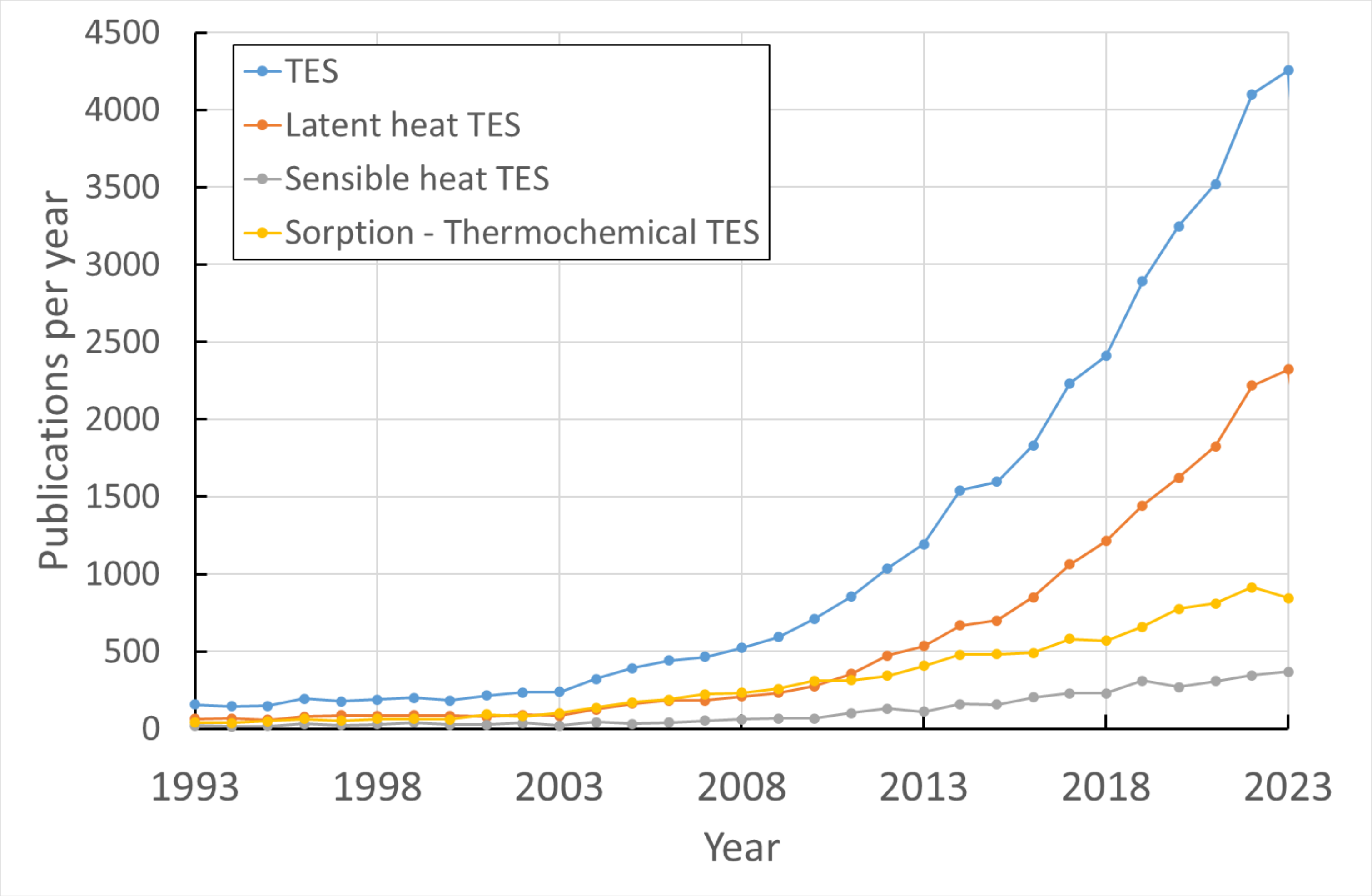
Bibliometric data from Scopus database

- Authors
- Country
- Institutions
- Journal and subject
- Keywords

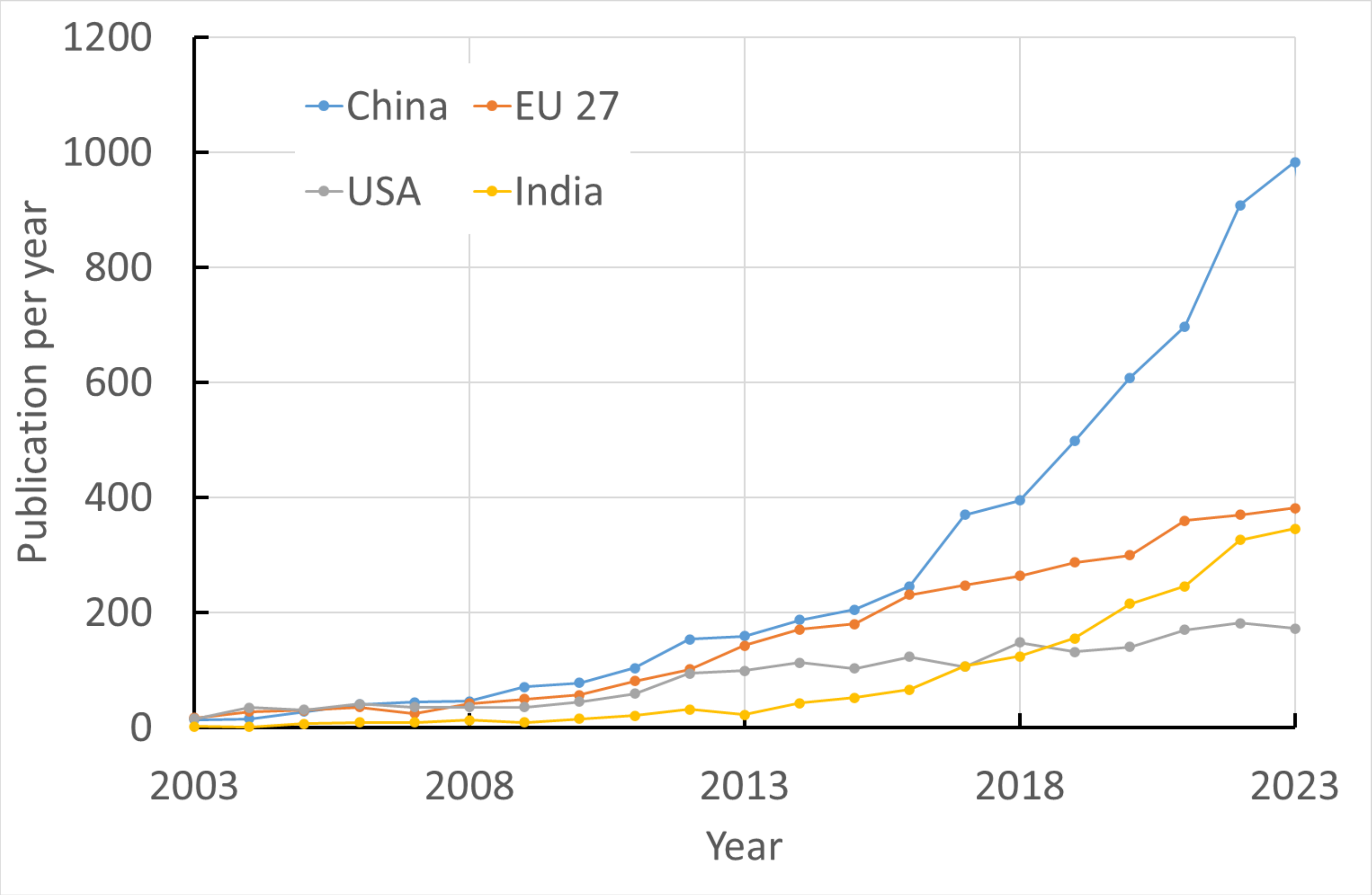
Elaboration of the bibliometric data

- Quantitative analysis (publications per year)
- Co-occurence between keywords (VOSviewer)

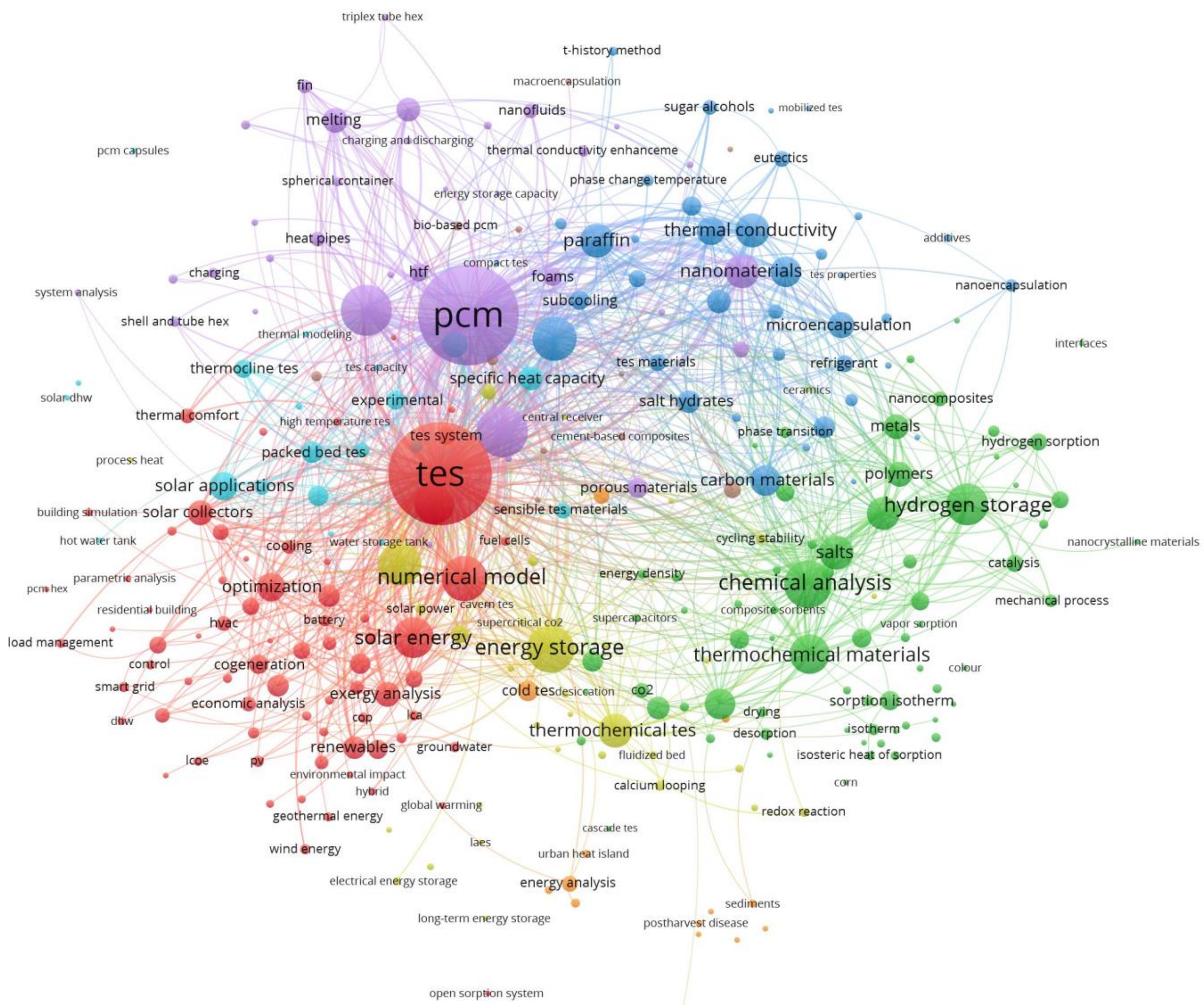
Bibliometric analysis



Bibliometric analysis



State-of-the-art

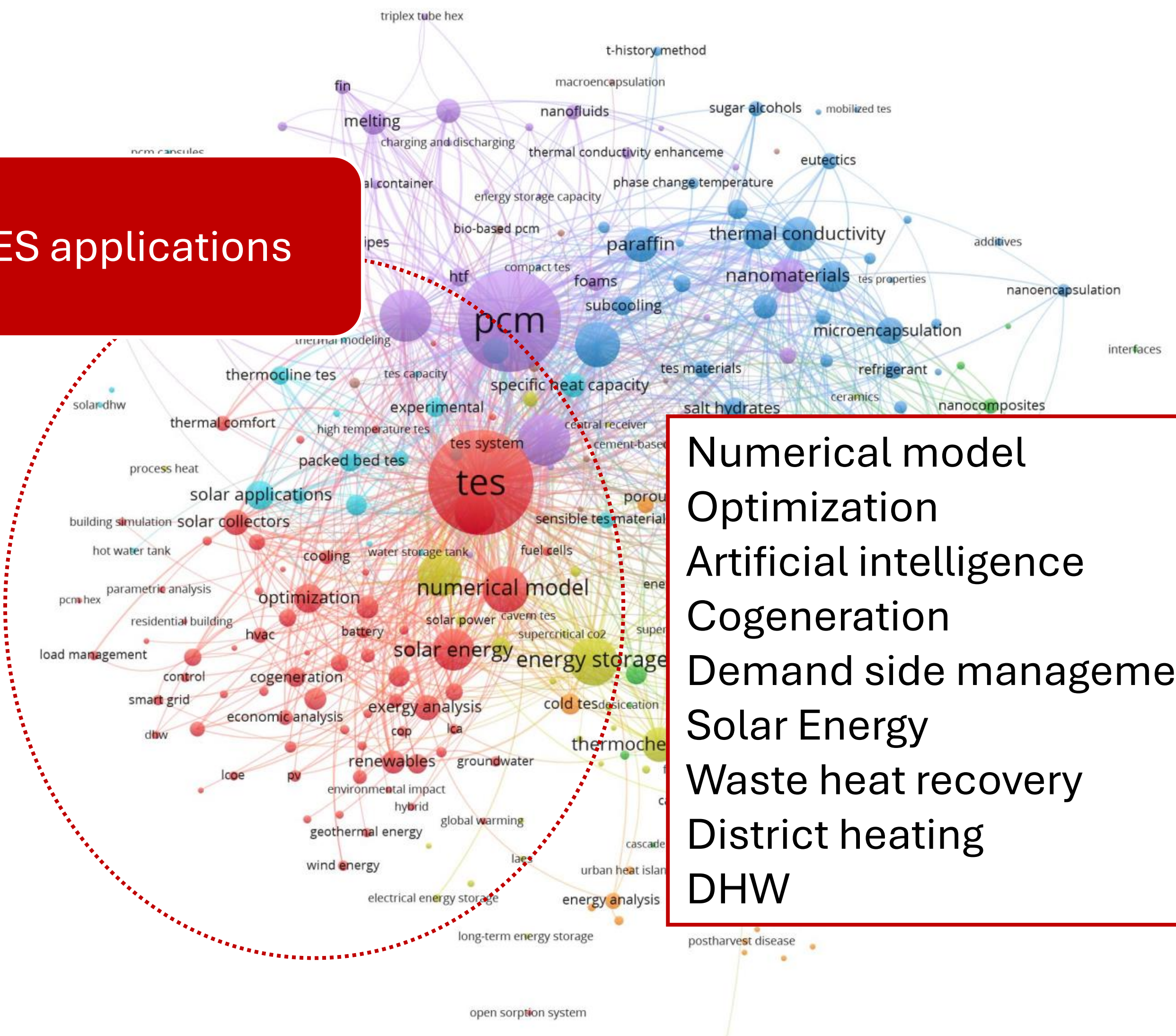


VOSviewer

Cabeza, L. F., de Gracia, A., Zsembinszki, G., Borri, E. Perspectives on thermal energy storage research. Energy 231 (2021) 120943.

State-of-the-art

TES applications

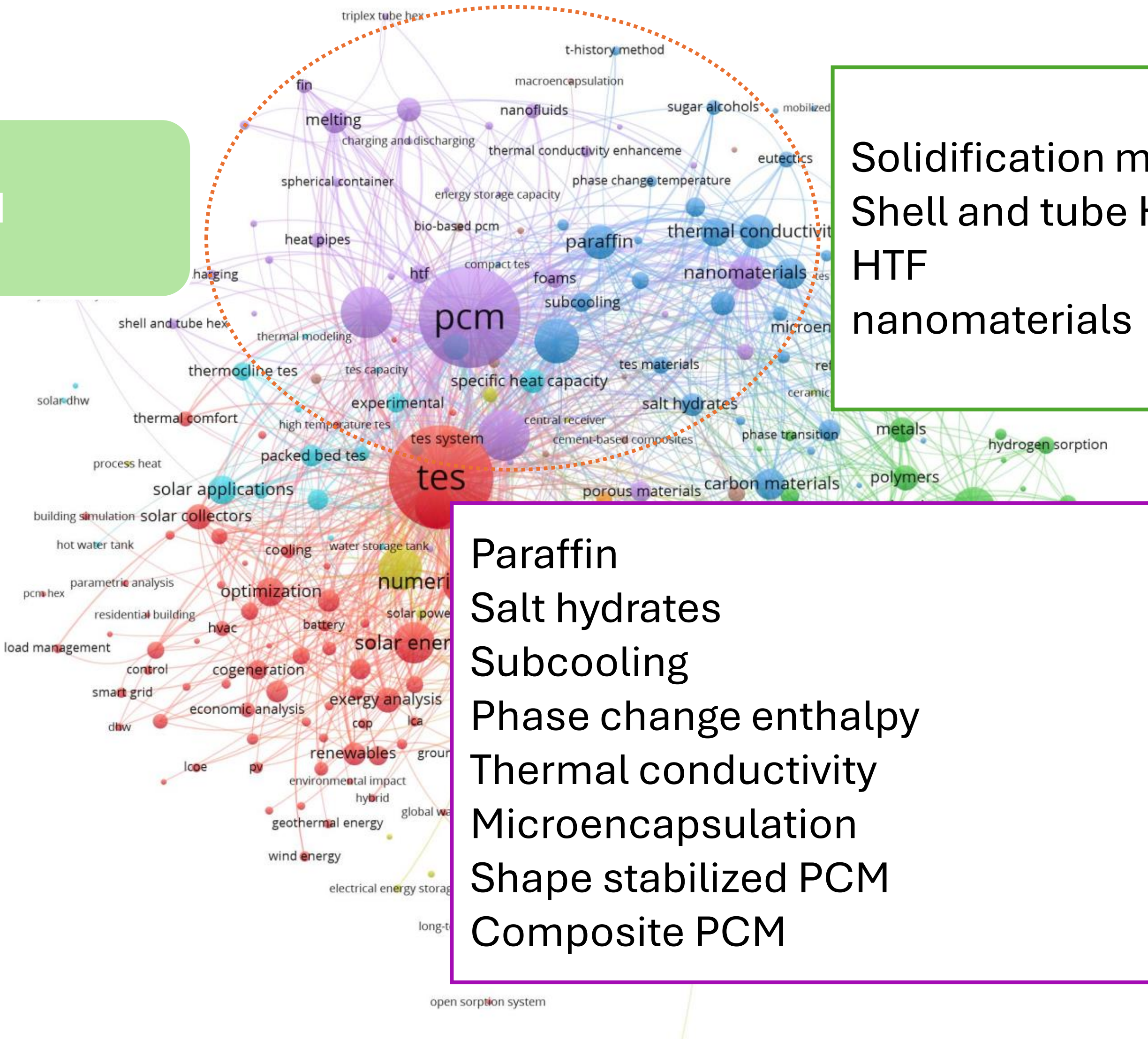


Numerical model
Optimization
Artificial intelligence
Cogeneration
Demand side management
Solar Energy
Waste heat recovery
District heating
DHW

Cabeza, L. F., de Gracia, A., Zsembinszki, G., Borri, E. Perspectives on thermal energy storage research. Energy 231 (2021) 120943.

State-of-the-art

PCM



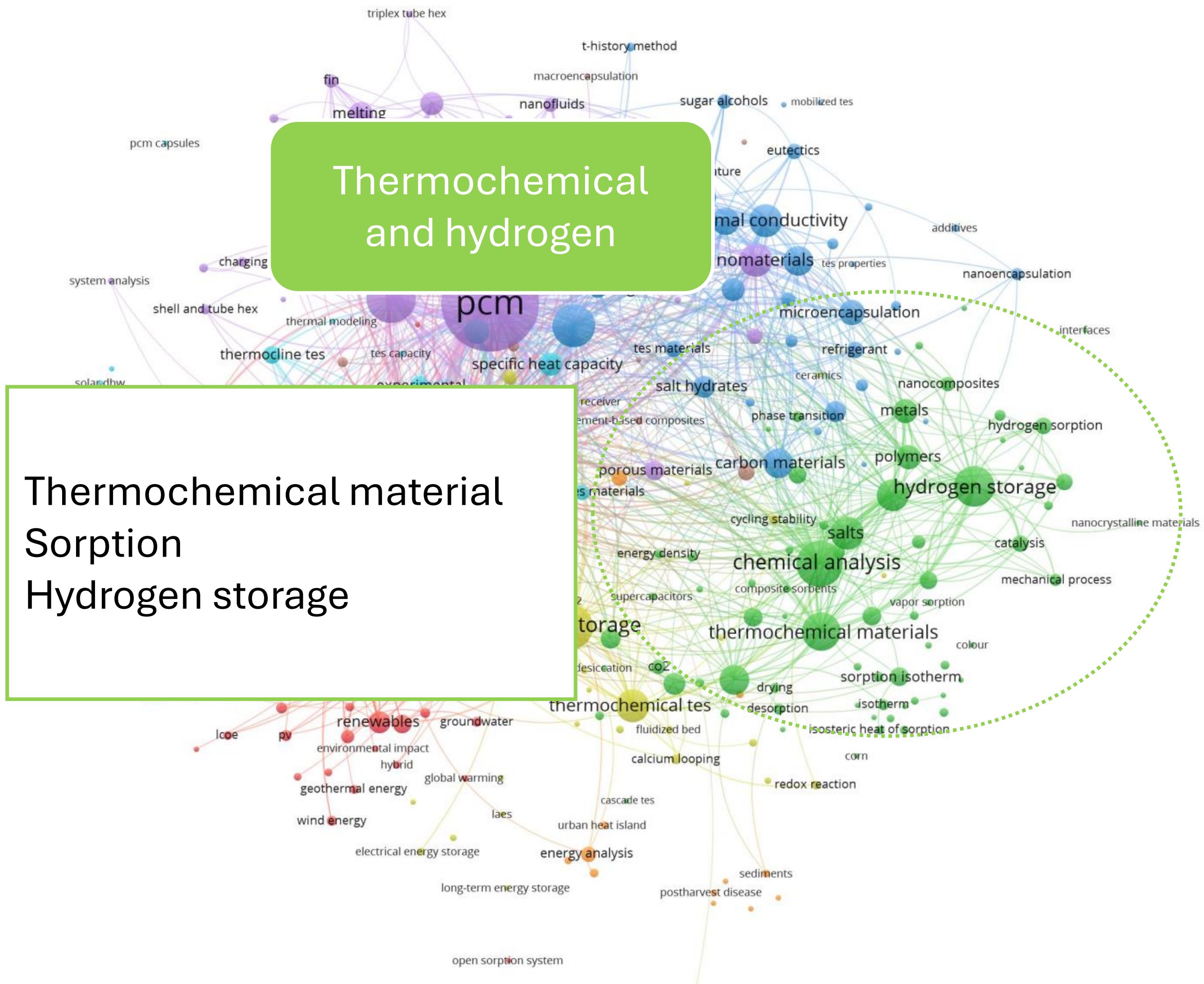
VOSviewer

Solidification melting
Shell and tube HEX
HTF
nanomaterials

Paraffin
Salt hydrates
Subcooling
Phase change enthalpy
Thermal conductivity
Microencapsulation
Shape stabilized PCM
Composite PCM

Cabeza, L. F., de Gracia, A., Zsembinszki, G., Borri, E. Perspectives on thermal energy storage research. Energy 231 (2021) 120943.

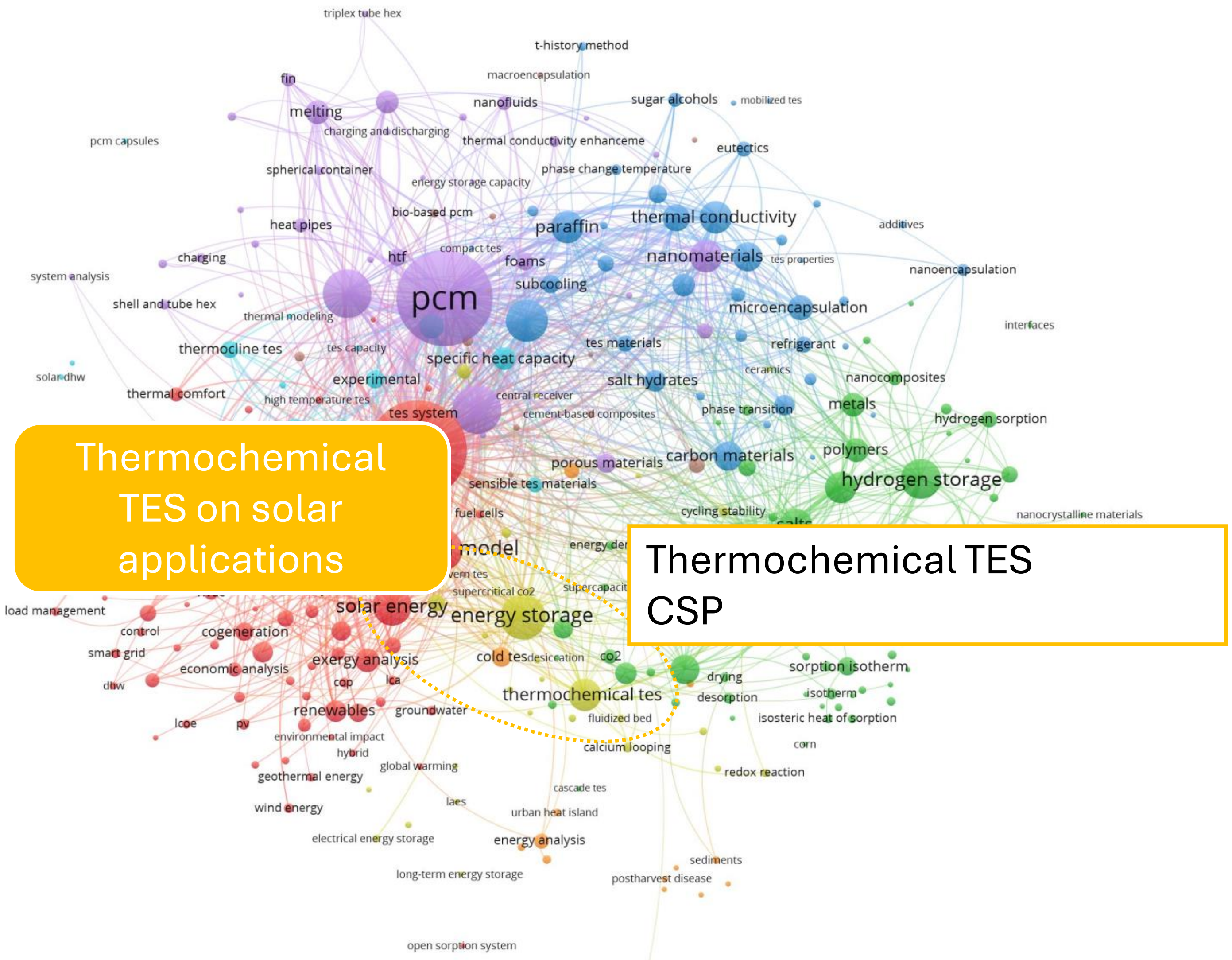
State-of-the-art



Thermochemical material
Sorption
Hydrogen storage

Cabeza, L. F., de Gracia, A., Zsembinszki, G., Borri, E. Perspectives on thermal energy storage research. Energy 231 (2021) 120943.

State-of-the-art



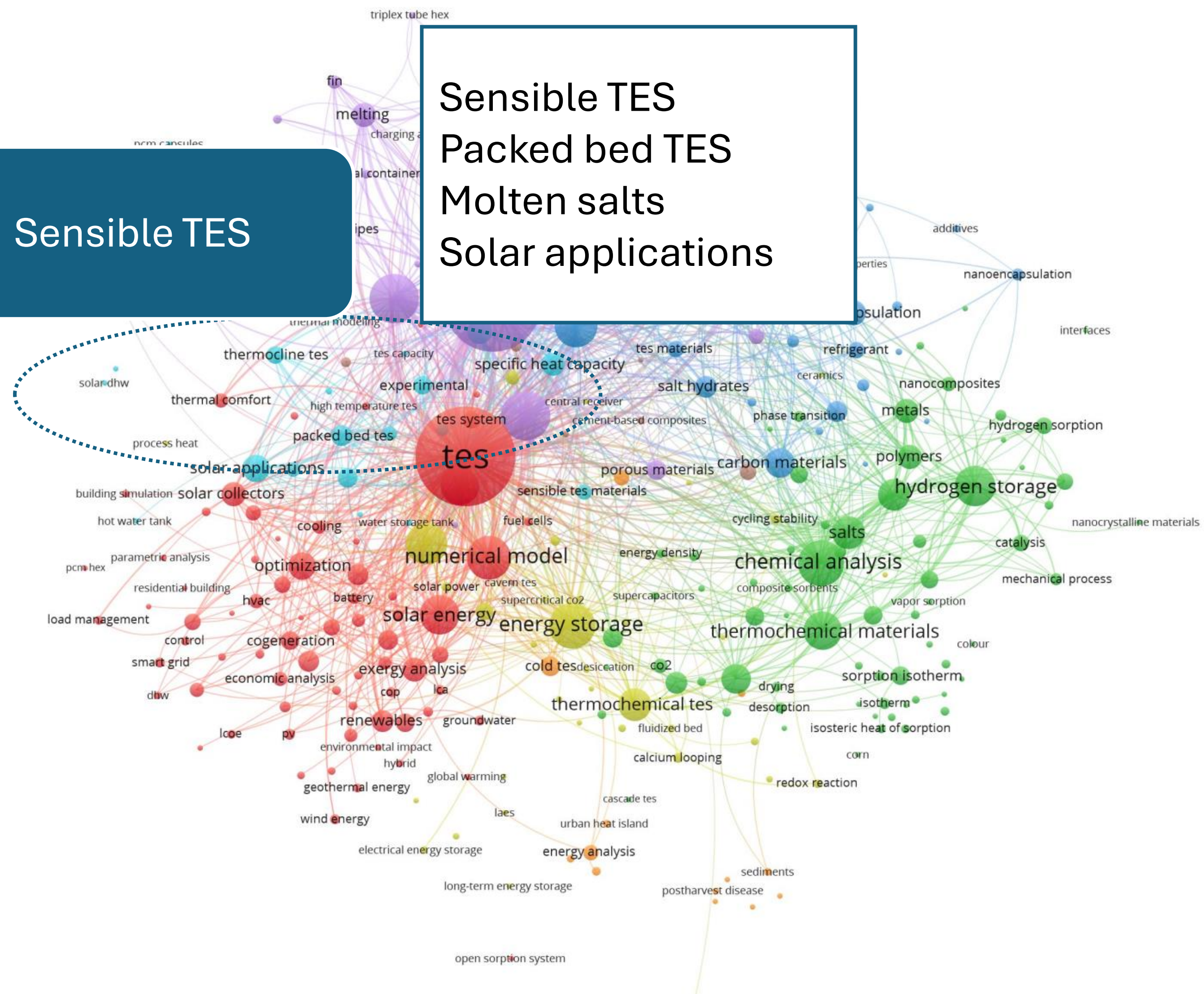
Cabeza, L. F., de Gracia, A., Zsembinszki, G., Borri, E. Perspectives on thermal energy storage research. Energy 231 (2021) 120943.

VOSviewer

State-of-the-art

Sensible TES

Sensible TES
Packed bed TES
Molten salts
Solar applications



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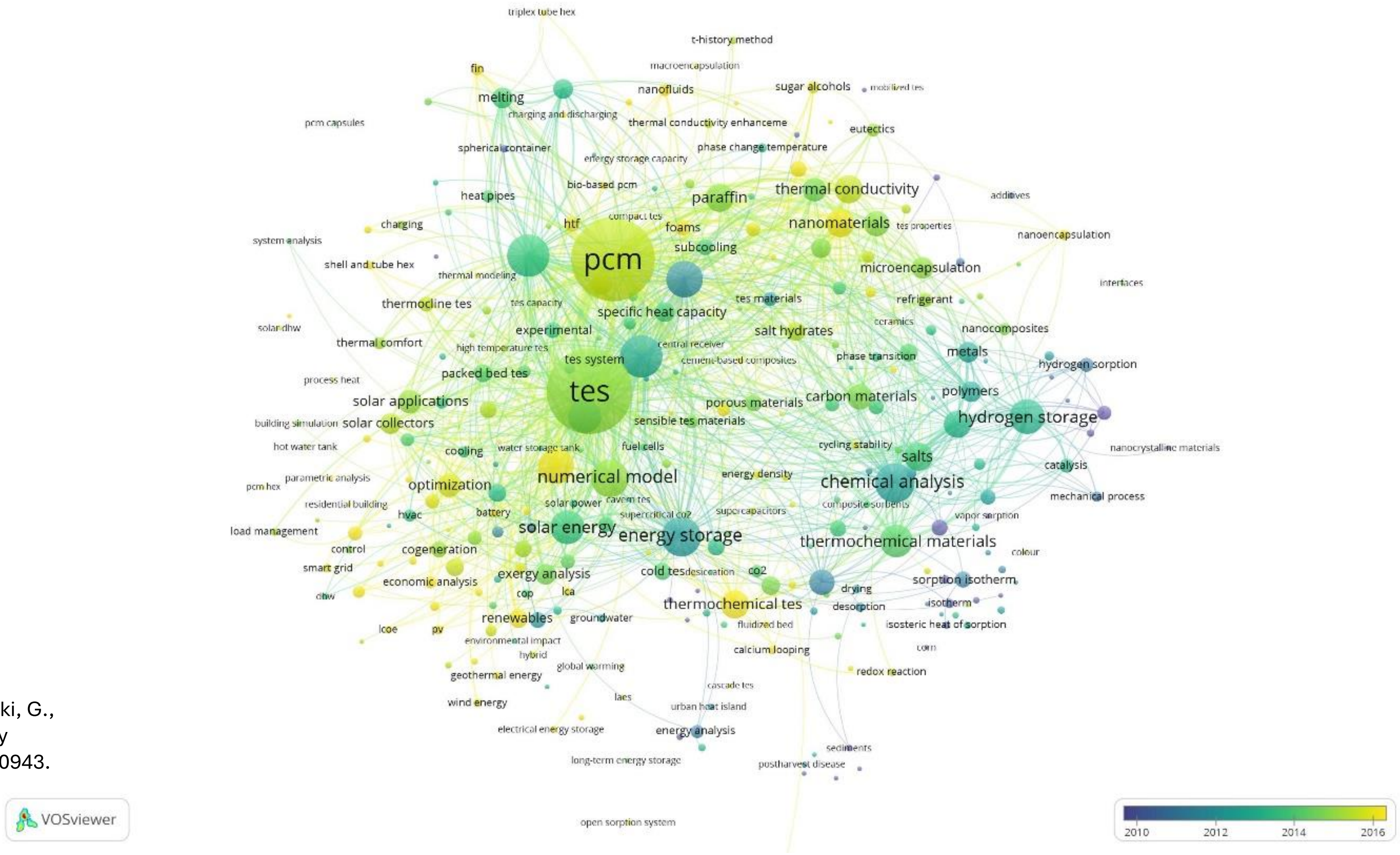
State-of-the-art

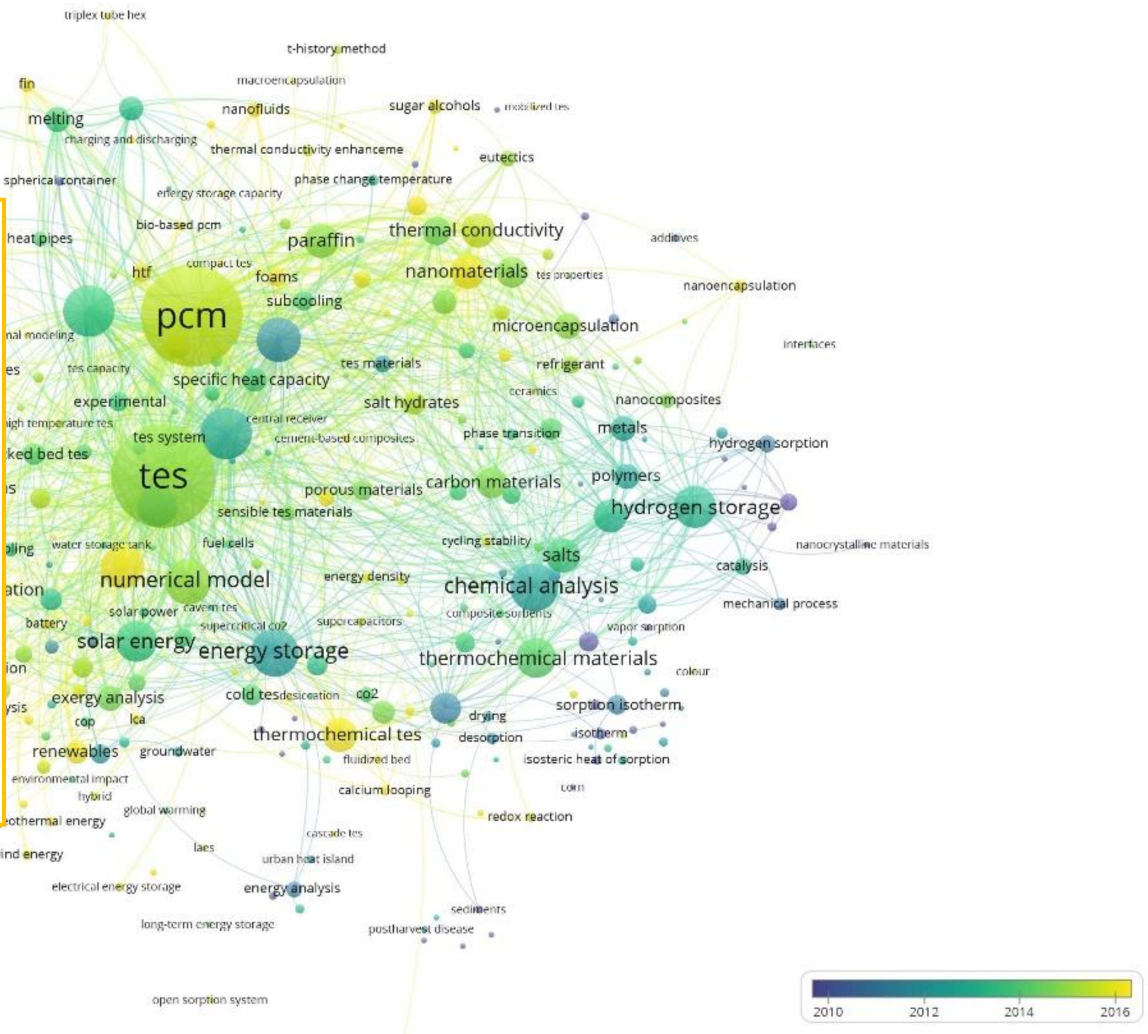


Cabeza, L. F., de Gracia, A., Zsembinszki, G., Borri, E. Perspectives on thermal energy storage research. Energy 231 (2021) 120943.

State-of-the-art

Recent trends

- Thermochemical TES
- Economic analysis
- Smart grid
- Renewables
- Optimization
- Nanomaterials
- Shell and tube HEX
- Fins
- Bio-based PCM
- Foams



VOSviewer

Cabeza, L. F., de Gracia, A., Zsembinszki, G., Borri, E. Perspectives on thermal energy storage research. Energy 231 (2021) 120943.

Bibliometric analysis

- Main research gaps to overcome barriers related to TES
  - Studies based on economics and techno-economic analysis
  - Studies based life-cycle assessment of TES and systems integrated to TES
  - Studies based on social aspects
  - Development of TES materials with enhanced properties and low cost
  - Use of innovative techniques to optimize the use of TES (i.e. artificial intelligence and advance control)
  - Some application of TES needs to be further investigated (waste heat recovery, refrigeration and cooling, cryogenics, high temperature applications)

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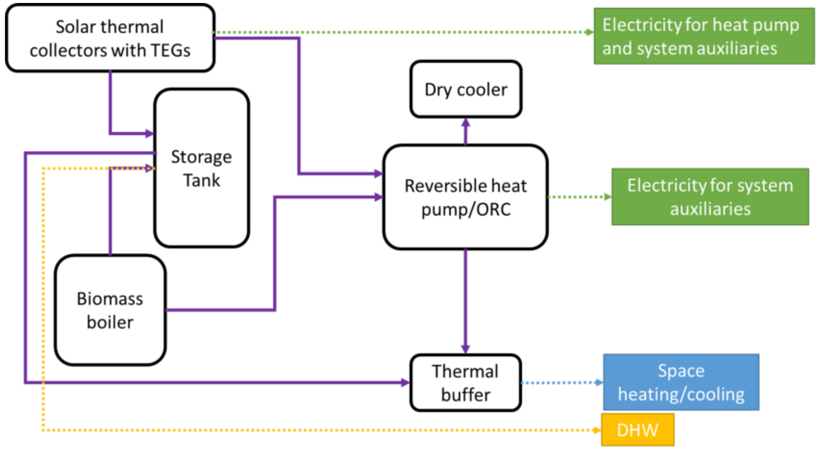
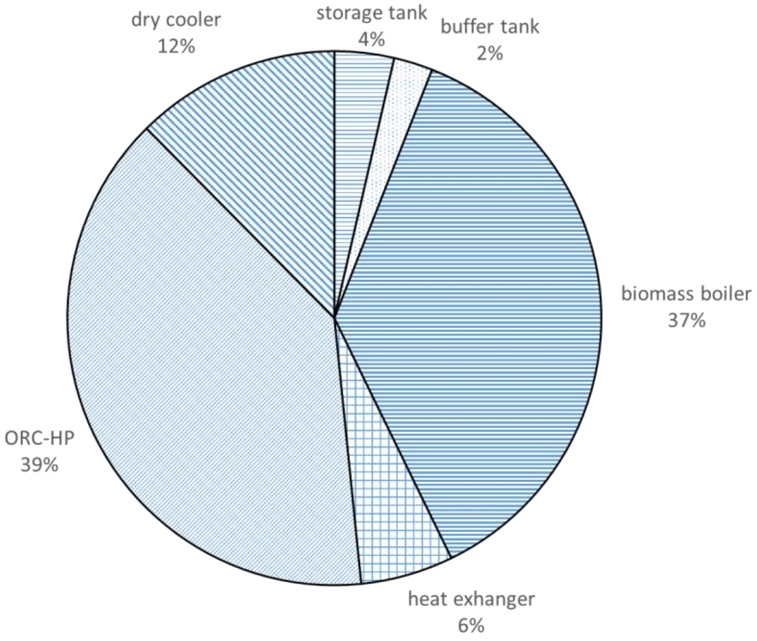
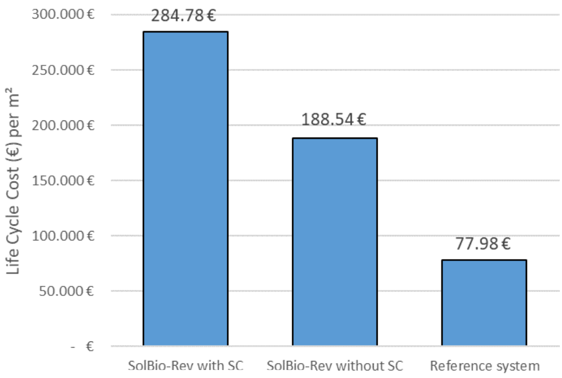
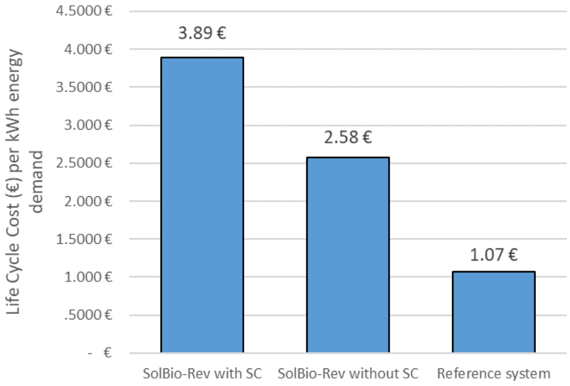
Economic analysis of TES and system integrating TES









Baumgarten, S., Borri, E., Zsembinszki, G., Charalampidis, A., Karellas, S., Opel, O., Cabeza, L.F. Economic assessment of a novel system based on solar and biomass energy for residential applications in continental climates. Presented at ECOS 2024

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 814945 (SolBio-Rev)

Bibliometric analysis

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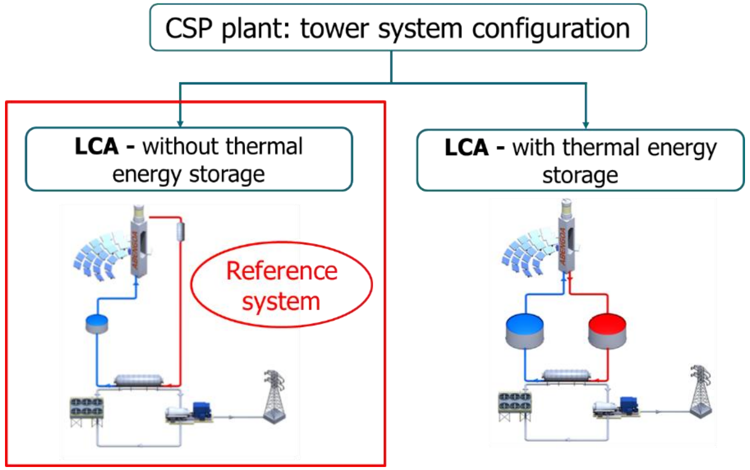
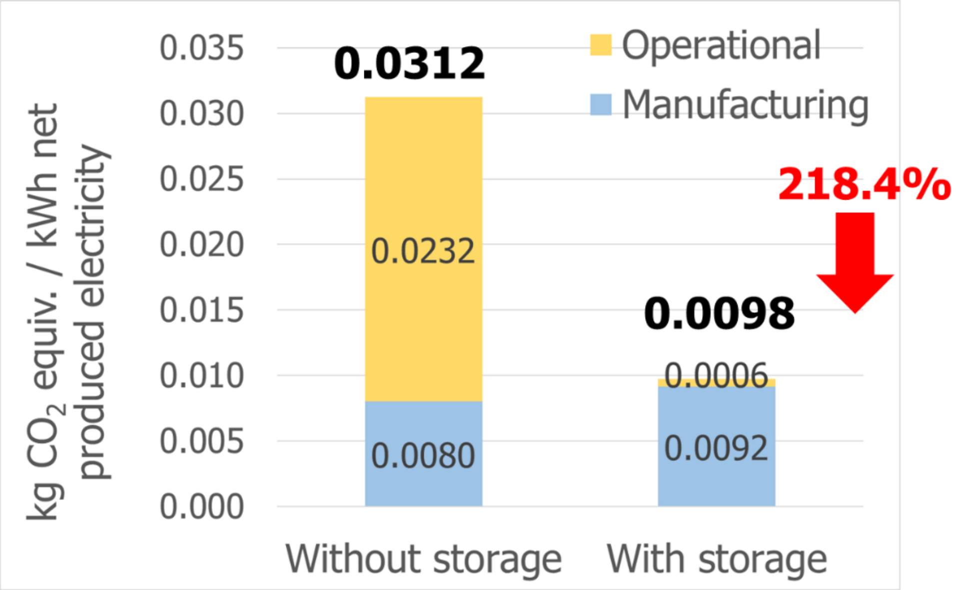
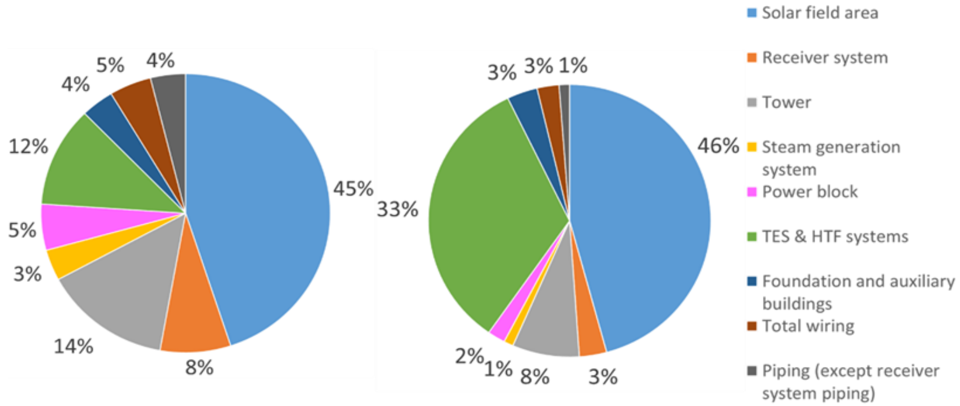
Life-cycle assesment of energy systems with TES







Gasa, G., Prieto, C., Lopez-Roman, A., Cabeza, L.F. Life cycle assessment (LCA) of a concentrating solar power (CSP) plant in tower configuration with different storage capacity in molten salts. Journal of Energy Storage 53 (2022) 105219

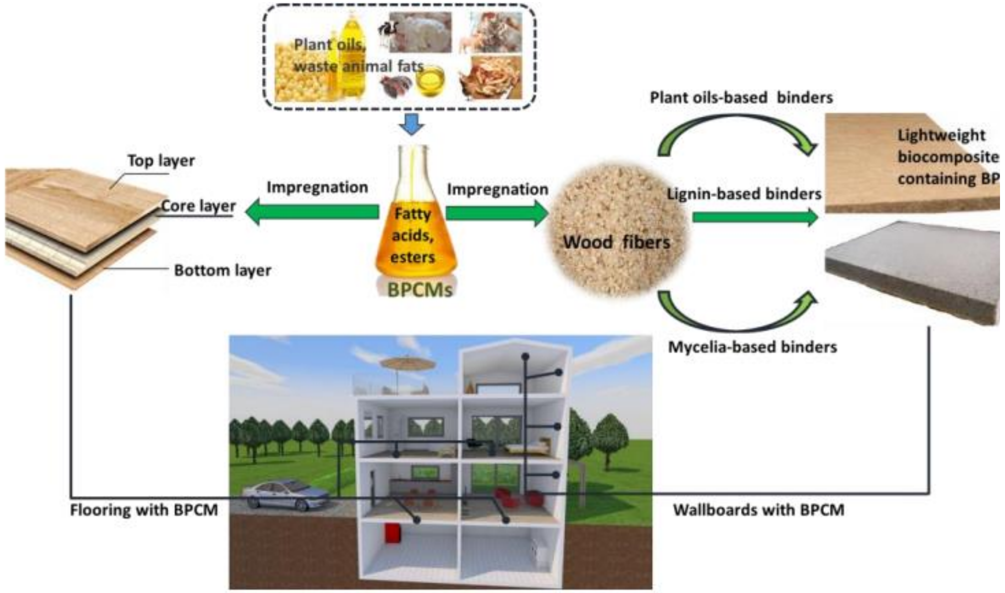
CSP-ERA.NET is supported by the European Commission within the EU Framework Programme for Research and Innovation Horizon 2020 (Cofund ERA-NET Action, N° 838311). This study receives funding from the Ministerio de Ciencia e Innovación - Agencia Estatal de Investigación (MCIN/AEI/10.13039/501100011033) through the PCI2020-120695-2 project and the European Union "NextGenerationEU"/PRTR

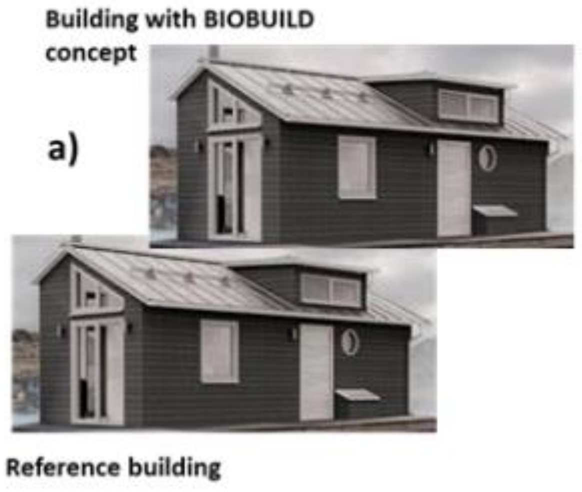
Circularity in TES

- Considering circularity during the design of new products and technologies is a key aspect that will be a priority of policymakers, researchers, and society in general
- Rules of circular design
  - 5R: reuse, repair, redistribute, refurbish, and finally remanufacture
  - All materials used must be available as close as possible to the location of use following the concept km0 of the food industry
  - When selecting any material, the extraction process should be considered and the material with lower impact of the extraction process should be selected
  - When designing the new storage tank and all its components an easy green decommissioning should be a key objective
  - When designing the new storage tank, local production and short transportation will be sought after and preferred
  - The operational energy, water, and materials consumption should be evaluated and reduced as much possible

Sustainability - use of bio-based PCM in TES

- Integration of fully bio-based PCM into solid wood and fibres to produce novel bio-composite building materials with significantly improved thermal properties

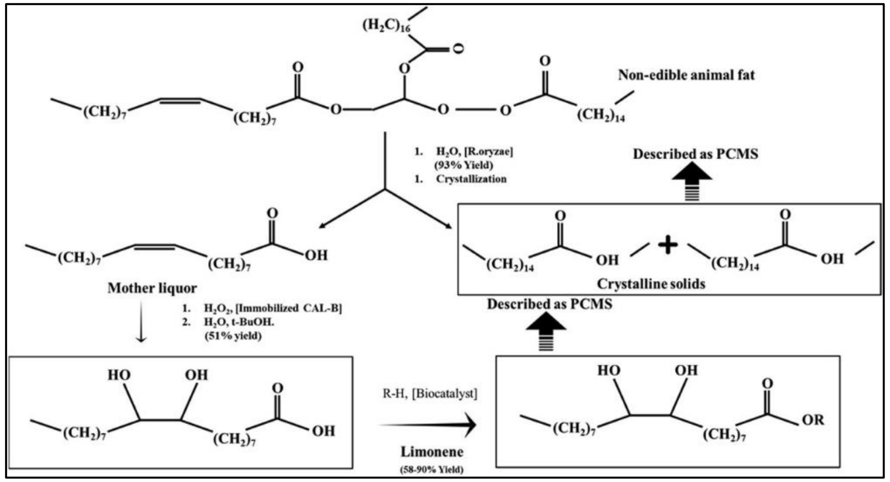


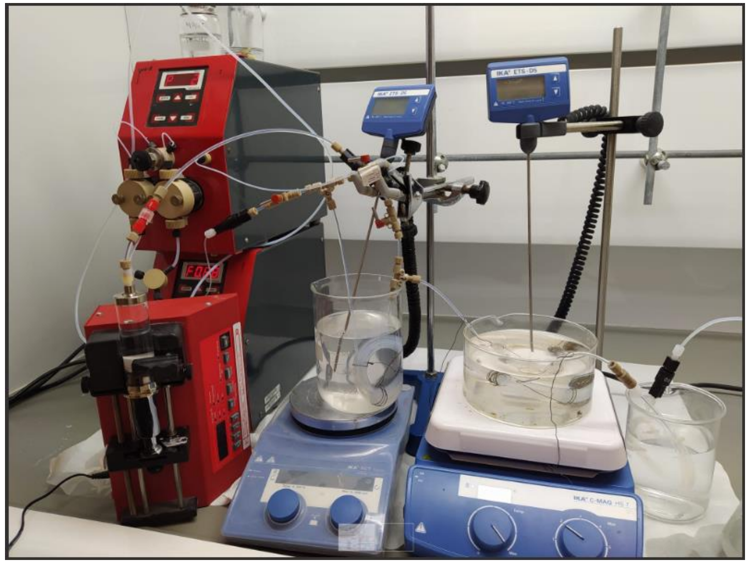


This project was co-funded by the European Union's Horizon Europe Research and Innovation Programme under grant agreement 101135629 (BIOBUILD). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them

Sustainability - use of bio-based PCM in TES

- Development of bio-based PCM for building applications





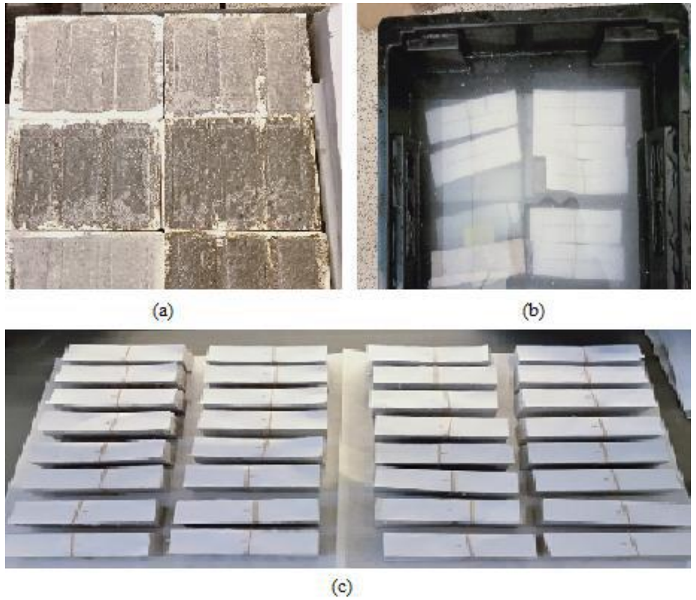
ThumbsUp

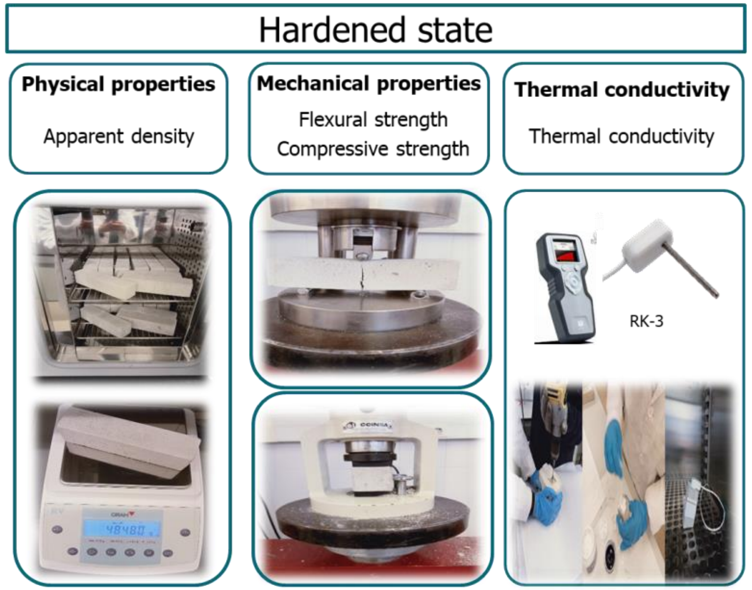
This project was funded by the European Union's Horizon Europe Research and Innovation Programme under grant agreement 101096921 (THUMBS UP). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or CINEA. Neither the European Union nor the granting authority can be held responsible for them.

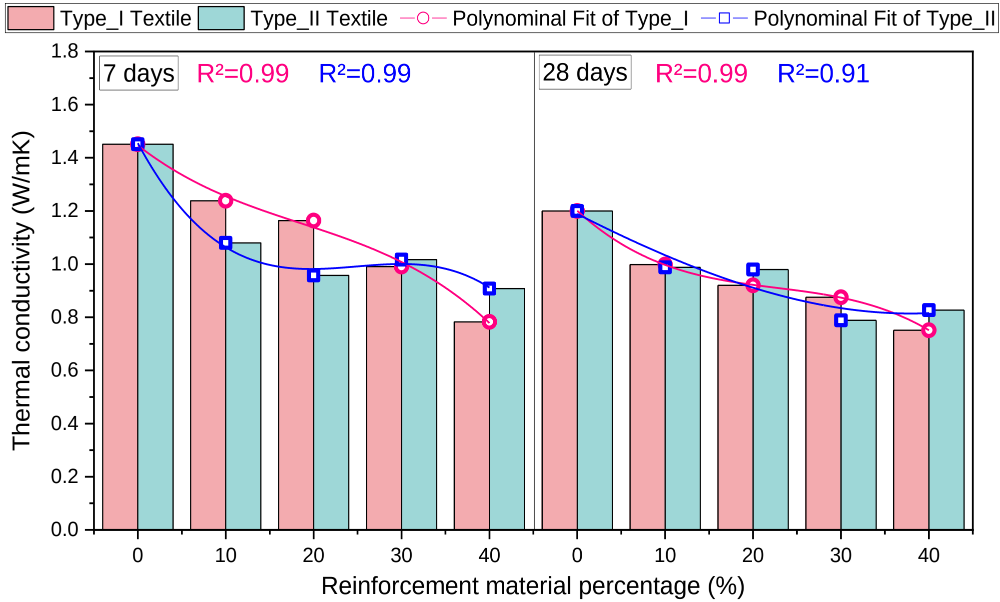
Sustainability - Use of by-products in TES

- By-products from the textile industry in mortar with PCM

Ayed, R., Borri, E., Zsembinszki, G., Bouadila, S., Cabeza, L. F., Lazaar, M. Use of Textile Fiber Waste to Improve the Thermal and Mechanical Performance of Cement-Based Mortar. Presented to International Conference" Coordinating Engineering for Sustainability and Resilience" (2024)







CSTO2NE

This project was funded by the European Union's Horizon Europe Research and Innovation Programme under grant agreement 101086302 (CSTO2NE). Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union or REA. Neither the European Union nor the granting authority can be held responsible for them

Bibliometric analysis

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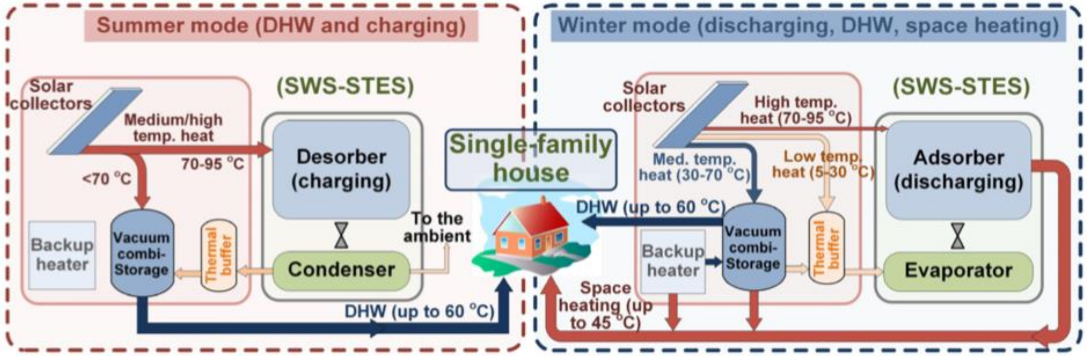
Social aspects on TES



Component	A1-A3 stages	A4-A5 stages	B2-B4 stage	C1 stage	C2 stage	C3 stage	C4 stage
STES	3						
PCM tank	4						
Water Tank	4						
Solar Collectors	5	2.75	3.5	4	4.5	5	5
Controller	2.7						
Gas Boiler	4						
Heat exchangers	3						
Total	**4**						

Stakeholder	Sub-categories
Local Community	Delocalization and migration
	Community engagement
	Cultural Heritage
	Respect of indigeneous rights
	Local employment
	Access to immaterial resources
	Access to material resources
	Safe and healthy living conditions
	Secure living conditions
Value Chain Actors	Fair competition
	Respect of intellectual property rights
	Supplier relationships
	Promoting social responsibility
Consumers	Health and safety
	Feedback mechanism
	Consumer privacy
	Transparency
	End of life responsibility
Workers	Freedom of association & collective bargaining
	Child labour
	Fair salary
	Working hours
	Forced labour
	Equal opportunties/discrimination
	Health and safety
	Social benefits/social security
Society	Public commitments to sustainable issues
	Prevention and mitigation of armed conflicts
	Contribution to economic development
	Corruption
	Technology development

Borri, E., Zsembinszki, G., Cabeza, L.F. Evaluation of the social impact of an energy system for residential heating applications based on a novel seasonal thermal energy storage. Journal of Energy Storage 86 (2024) 111210

This project received funding from the European Union's Horizon 2020 research and innovation programs under the project SWS-Heating (764025)

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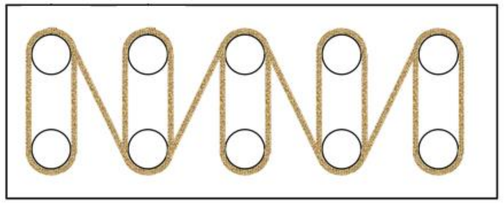
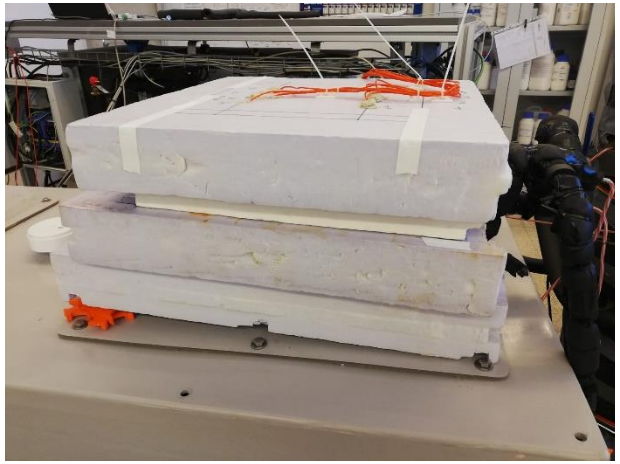
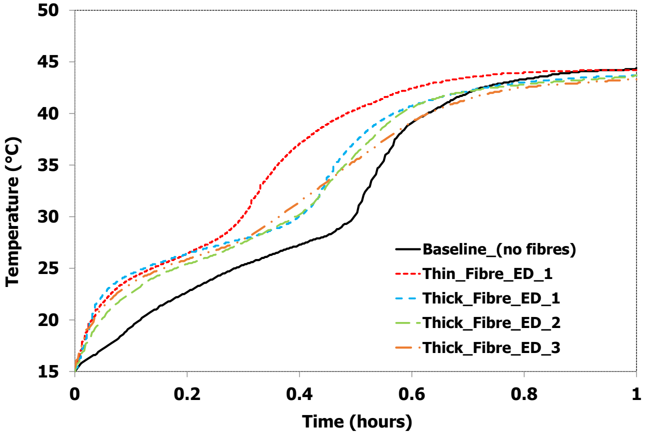
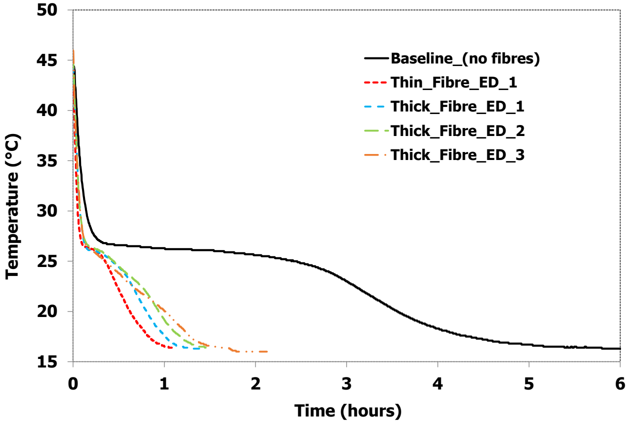
Heat transfer enhancment of shell and tube HEX









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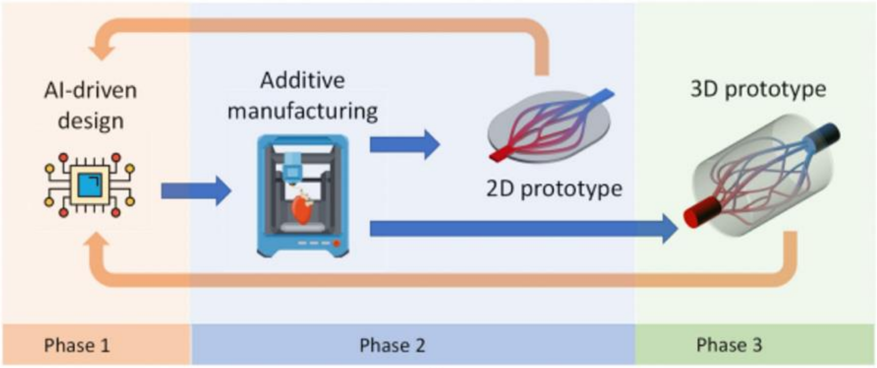
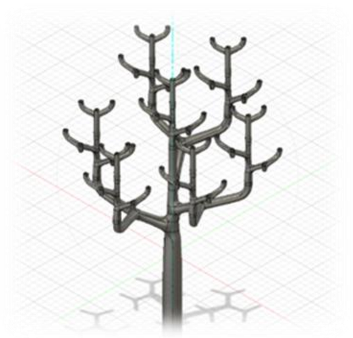
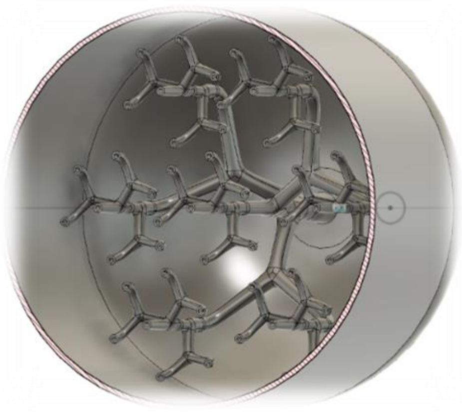
Bibliometric analysis

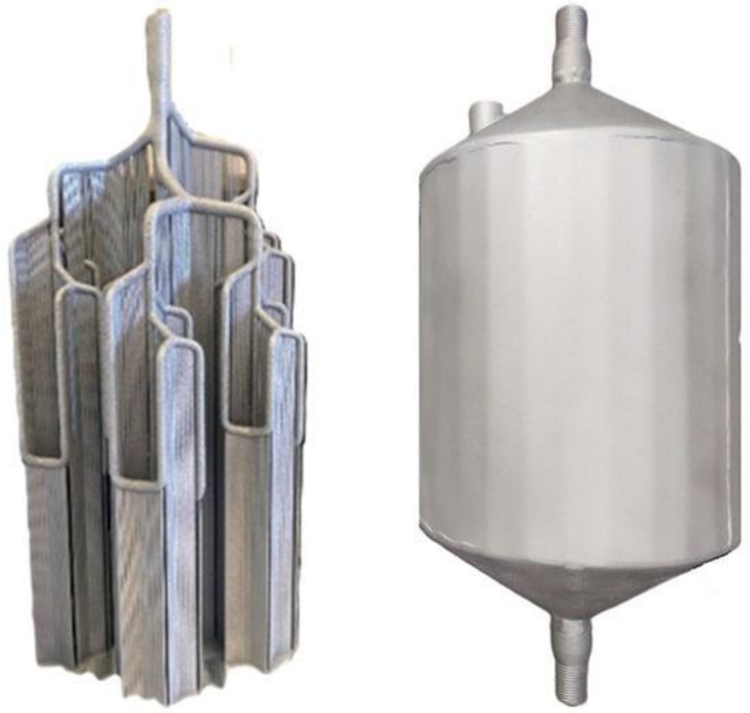
- Main research gaps to overcome barriers related to TES
  - Studies based on economics and techno-economic analysis
  - Studies based life-cycle assessment of TES and systems integrated to TES
  - Studies based on social aspects
  - Development of TES materials with enhanced properties and low cost
  - Use of innovative techniques to optimize the use of TES (i.e. artificial intelligence and advance control)
  - Some application of TES needs to be further investigated (waste heat recovery, refrigeration and cooling, cryogenics, high temperature applications)

AI-aided design of high-performance thermal energy storage tanks inspired by nature









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Bibliometric analysis

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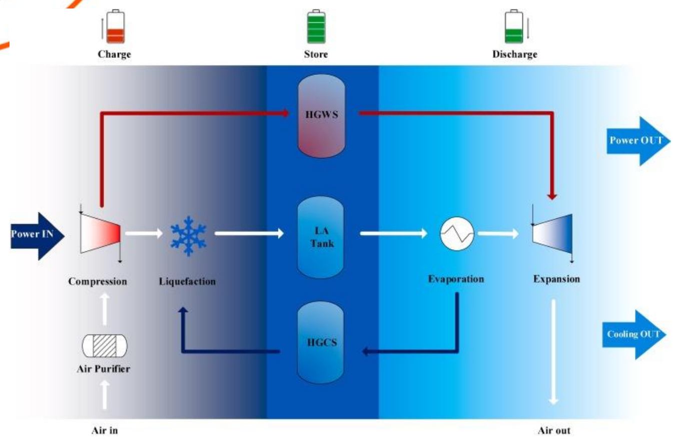
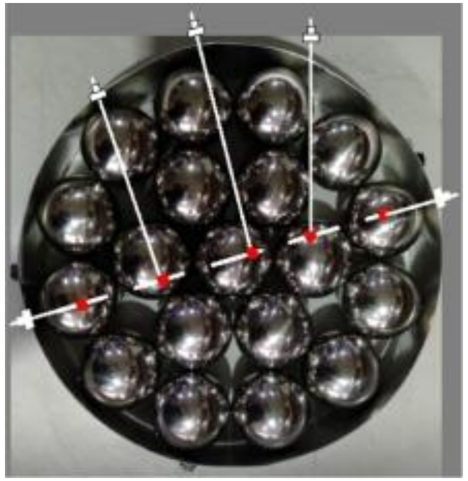
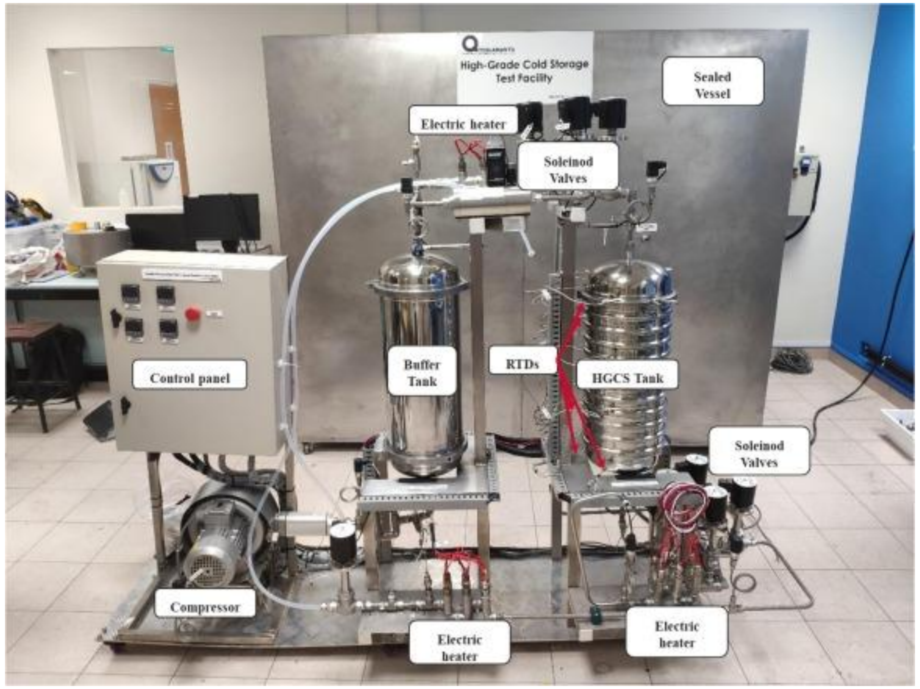
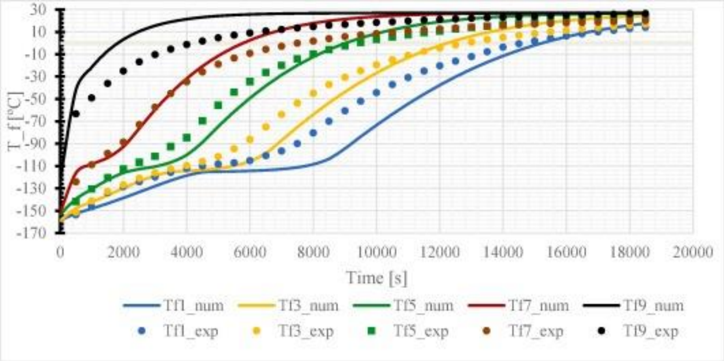
Development of cold TES for LAES applications









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Thanks for the attention

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