Phase Change Materials (PCMs) for energy storage in Thermal Solar Cooling Systems

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AGENDA

- ✓ Introduction
- ✓ Latent Thermal Energy Storage
- ✓ Example of latent TES for solar cooling
- ✓ PCMs for solar cooling applications
- ✓ Design and testing of latent TES @ ITAE
- ✓ Conclusions and future perspectives

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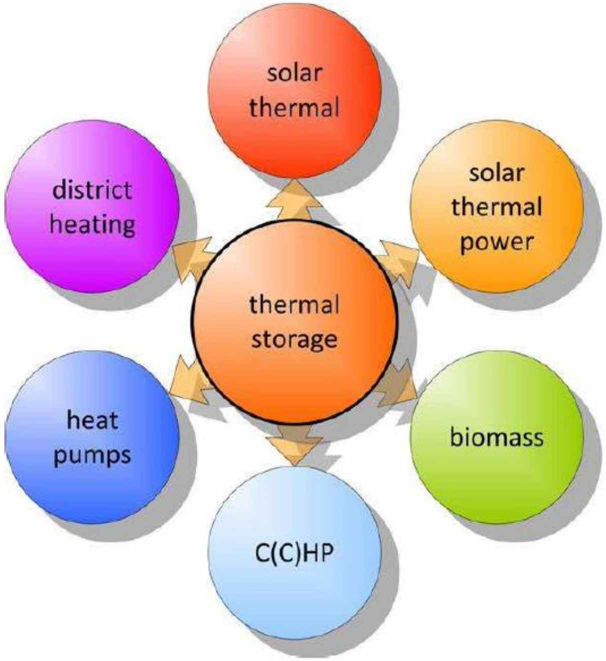
INTRODUCTION

Why do we need a TES?

Main functions

- Supply-demand matching
- Peak shaving
- Flexibility



Field of application of thermal storage

Main parameters

- Quality [°C]
- Capacity [GJ]
- Storage density [GJ/m^3] / [kJ/kg]
- Power [kW]

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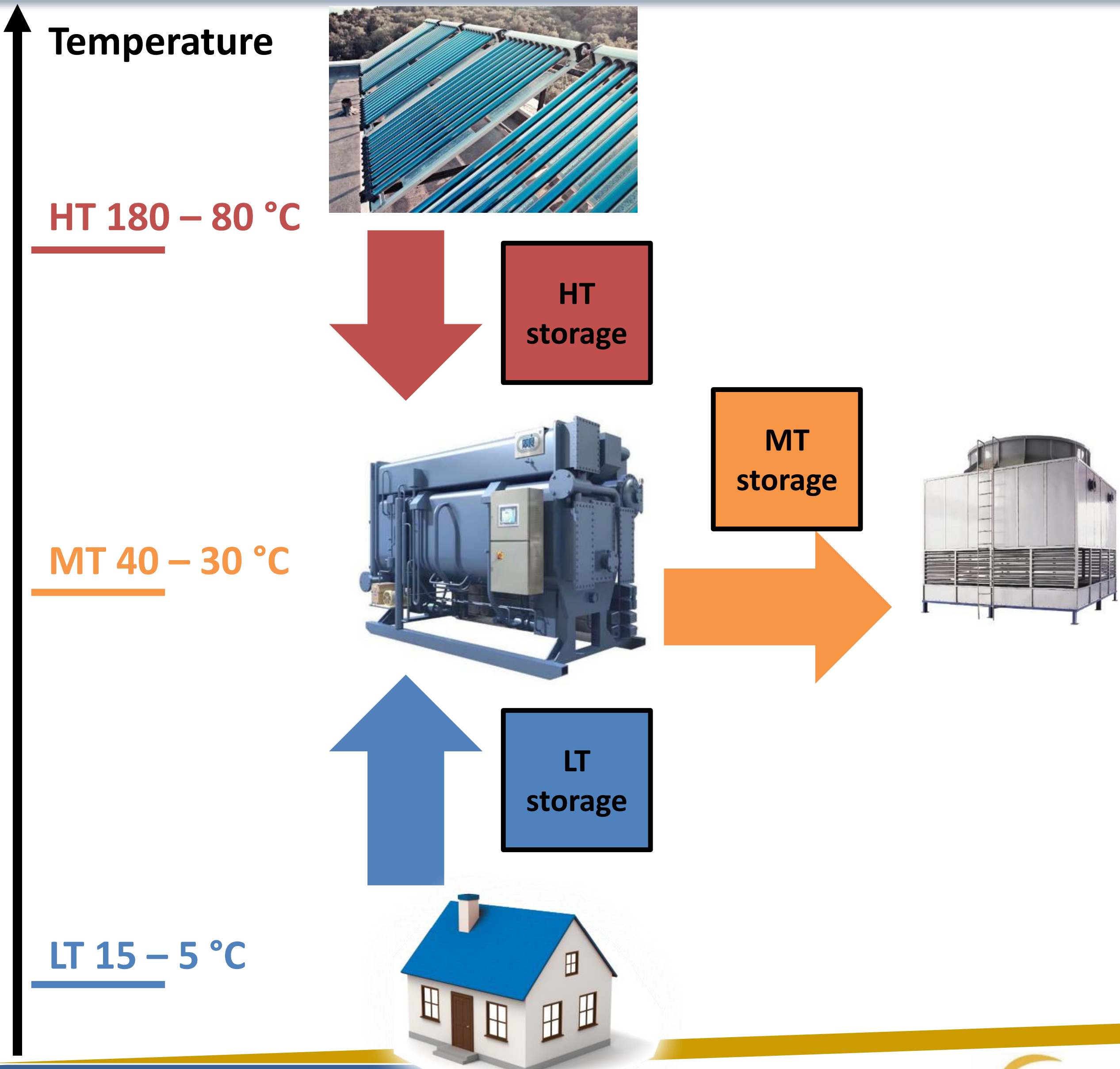
INTRODUCTION

TES in solar cooling systems

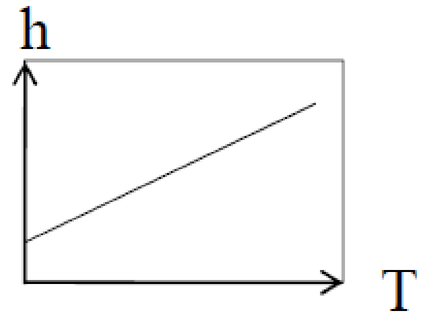


INTRODUCTION

TES technologies

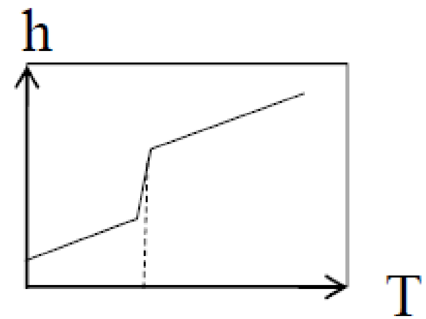
Sensible heat

- Heat capacity of materials
- Water, solids (e.g. concrete, rocks)



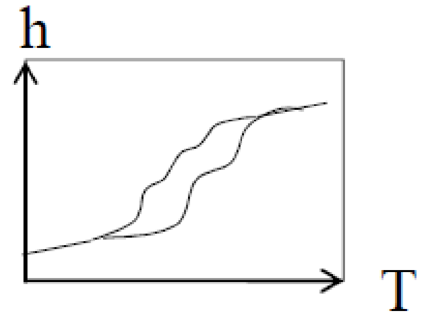
Latent heat

- Phase change
- Water, organic and inorganic PCMs



Thermo-Chemical heat

- Physical or chemical bonds
- Adsorption, absorption, chemical reactions



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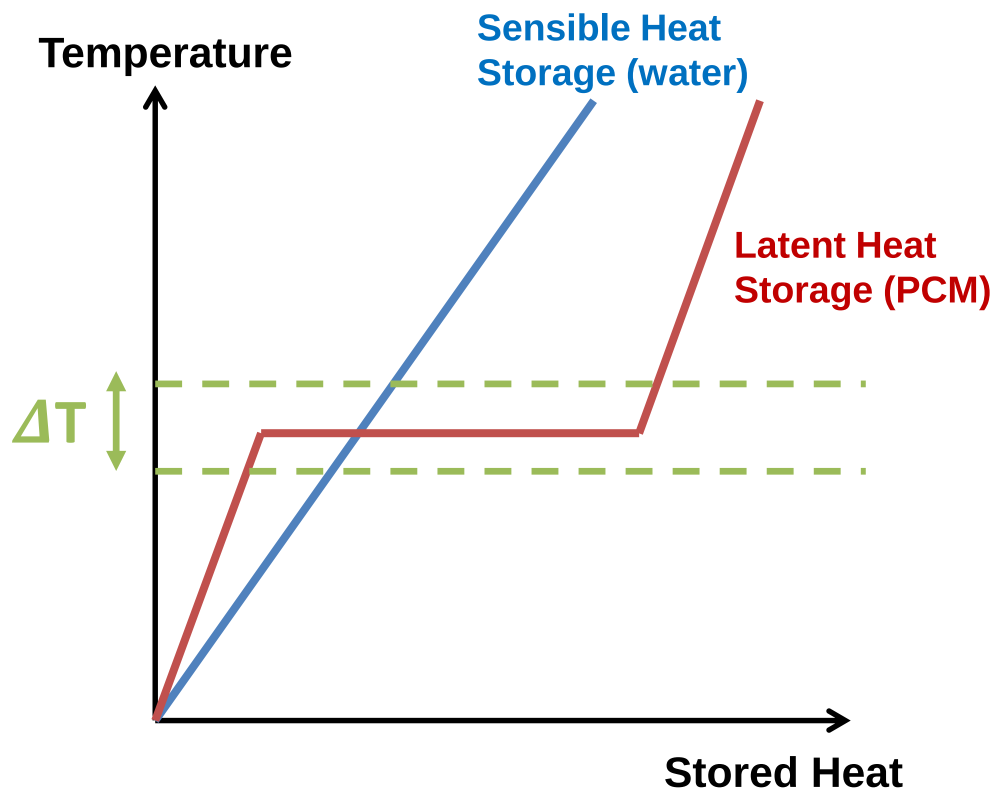
Latent TES concept



Key points:
- Working temperature interval
- Latent and Specific Heat of PCM

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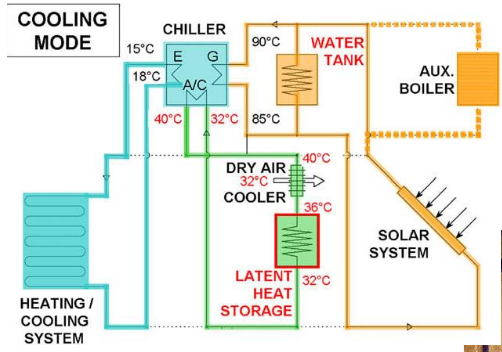
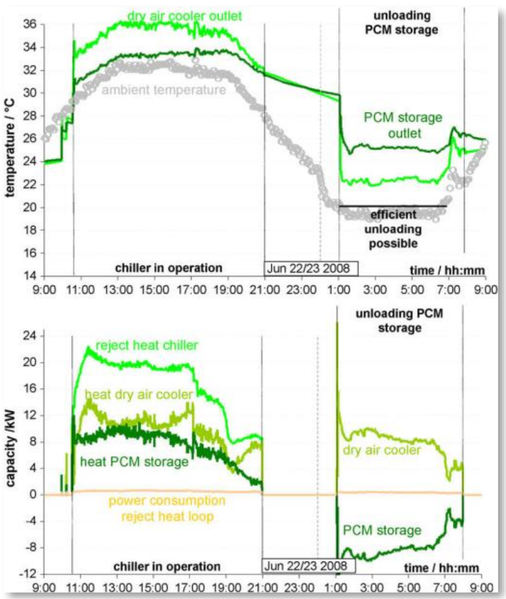
EXAMPLE OF LATENT TES FOR SOLAR COOLING

Few examples in literature about experiments on latent TES for solar cooling

MT storage

Realization and testing of a latent heat storage supporting the heat rejection of an absorption chiller





1. Dry cooler+latent TES can substitute the wet cooling tower
2. Increased absorption chiller performance allows to reduces the over-sizing of the solar collector system.
3. Latent TES power of 10 kW and storage capacity of 120 kWh has proven the feasibility of the storage concept.
4. Positive effect on the SEER (inclunding winter operation) and high system reliability (more than 800 cycles performed)

* "Solar heating and cooling system with absorption chiller and low temperature latent heat storage: Energetic performance and operational experience"– M. Helm, C. Keil, S. Hiebler, H. Mehling, C. Schweigler; International Journal of Refrigeration; 32, 596-606, 2009.

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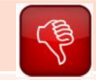
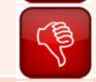
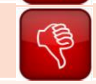
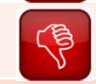
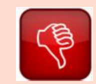
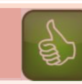
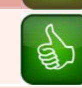
PCMs FOR SOLAR COOLING APPLICATIONS

HT storage

Literature survey

		Material	T_m [°C]	Latent Heat [kJ/kg]	Density [g/cm^3]	Stability
Pure Chemicals	Organics	α-Naphthol (99%) Sigma-Aldrich®	96	163	N.A.	
		Xylitol (99%) Sigma-Aldrich®	94	263.3	N.A.	
		D – Sorbitol (98%) Sigma-Aldrich®	97	185	N.A.	
		Acetamide (~99%) Sigma-Aldrich®	81	241	1.159	
	Inorganics / Hydrated Salts	$KAl(SO_4)_2 \cdot 12H_2O$ (98%) Sigma-Aldrich® (CODE: APSD)	91	184	N.A.	
		$(NH_4)Al(SO_4)_2 \cdot 12H_2O$ (99%) Sigma-Aldrich® (CODE:AASD)	95	269	1.640	
Commercial PCMs	Organics	Plus-ICE A82 PCM prodcucts®	82	155	0.850	
	Inorganics / Hydrated Salts	Plus-ICE S83 PCM prodcucts®	83	141	1.600	
		Plus-ICE S89 PCM prodcucts®	89	151	1.550	

* "Identification and characterization of promising phase change materials for solar cooling applications"– V. Brancato; A. Frazzica; A. Sapienza; A. Freni; Solar Energy Materials & Solar Cells; 160, 225-232, 2017.

Latent TES design: finned tubes

Tube:

- 1D model
- Developed fluid flow
- Radial thermal gradient negligible
- Nu-correlation for heat transfer between tube and fluid

Fin and PCM:

- 3D model
- Half a fin and half a fin gap with PCM
- Convection in liquid state of the PCM is negligible
- Volumetric expansion of the PCM during phase change is neglected

Coupling by heat flow and temperature at inner tube wall

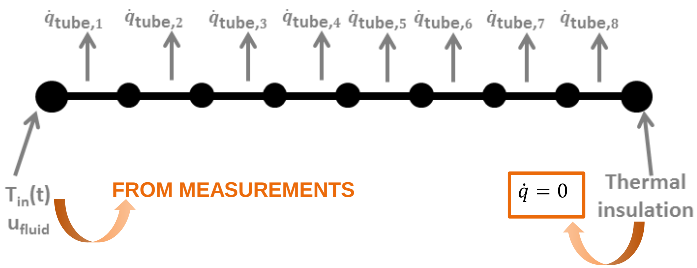
Latent TES design: finned tubes

1D Model

EQUATION

$$A_c \, \rho \, C_p \frac{\partial T}{\partial t} + A_c \, \rho \, C_p \, u \, \nabla T + \nabla \left(-A_c \, k \, \nabla T\right) = Q$$

BOUNDARY CONDITIONS

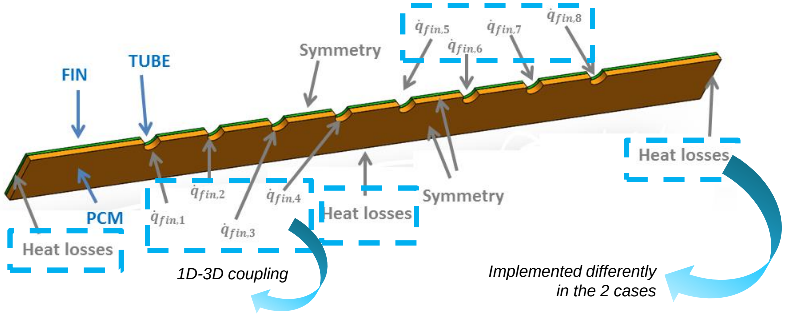


3D Model

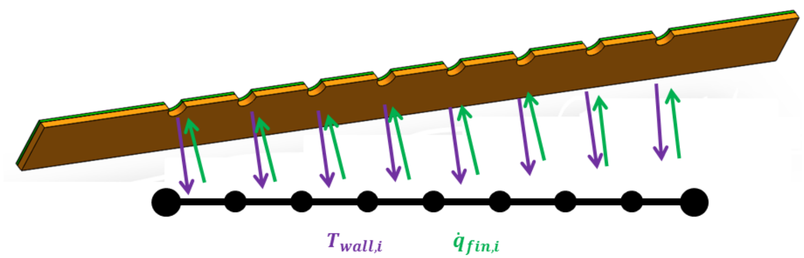
EQUATION

$$\rho \, C_p \frac{\partial T}{\partial t} + \rho \, C_p \, u \, \nabla T + \nabla \left(-k \, \nabla T\right) = Q$$

BOUNDARY CONDITIONS



Coupling of 3D and 1D Model



Taken from 3D model => calculation of heat flux in 1D model

Taken from 1D model => calculation of actual temperature in 3D model

$$\dot{q}_{tube,i} = h \left(T_{fluid} - T_{wall,i}\right)$$

$$\dot{q}_{fin} = \overline{\dot{q}_{tube}} * f$$

$f =$ ratio between corresponding areas in 3D and 1D model

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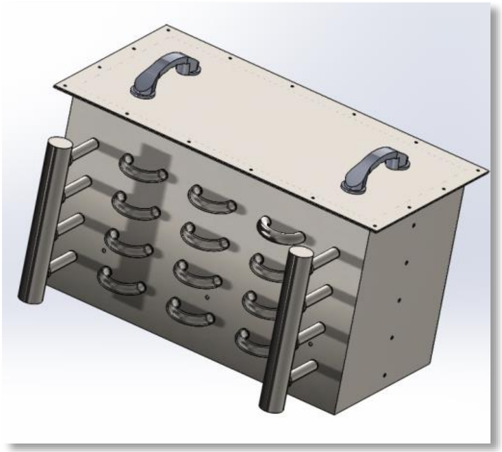
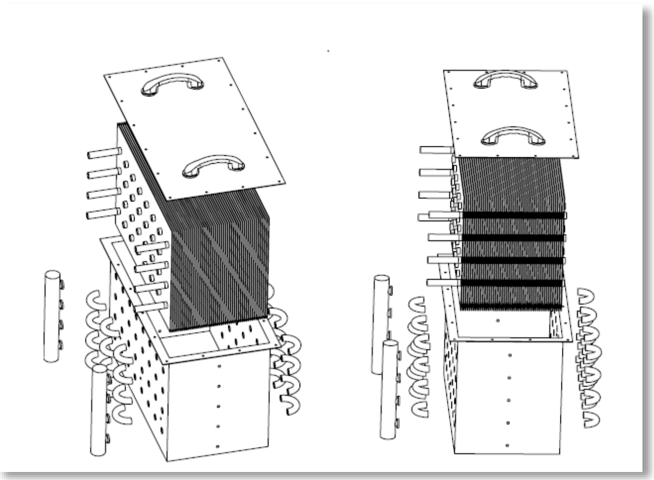
DESIGN AND TESTING OF LATENT TES @ ITAE

Latent TES design: finned tubes



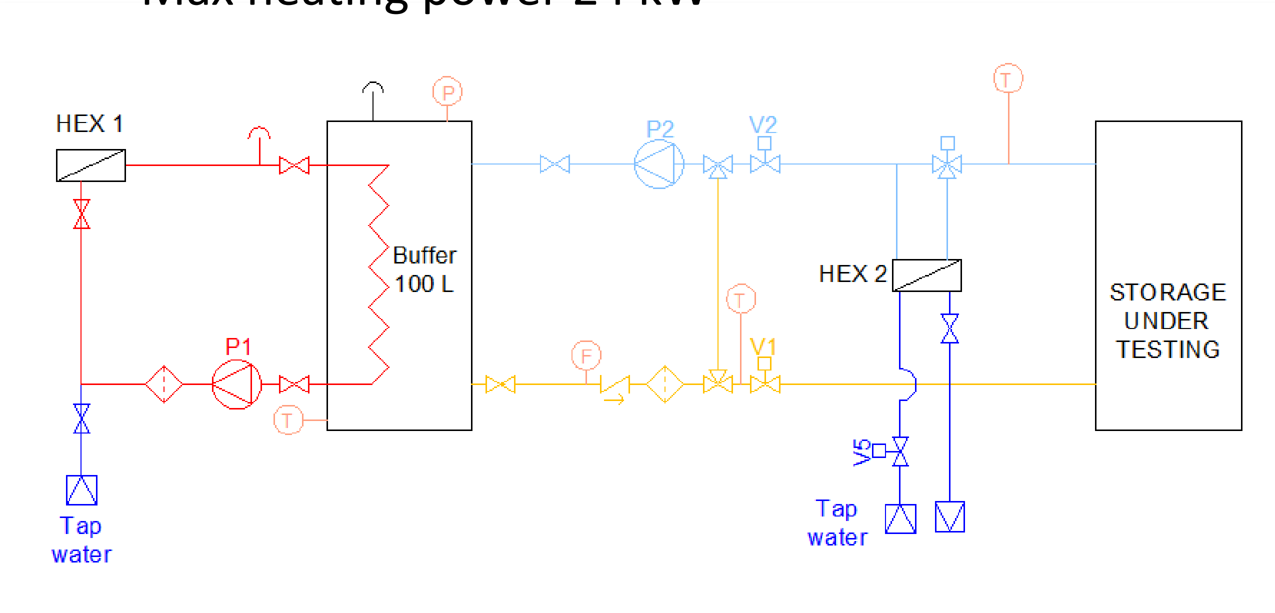


FIN-AND-TUBES HEX

- AISI 416L
- 48 FINS x 5 mm gap
- 4 ranks
- 400x650x350mm
- 38 kg PCM

Testing rig

- Simulation of realistic working boundaries
- Fully automatic operation (charging/discharging)
- Max heating power 24 kW



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Testing conditions

STATIC TESTS			
CHARGE		**DISCHARGE**	
Parameter	Value	**Parameter**	Value
Flow rate [kg/min]	5,10,13.5,17.5, 20	**Flow rate [kg/min]**	3.5,5,10,13.5, 17.5, 20
Initial temperature [°C]	20, 25, 30, 45, 50, 55, 65, 75	**Initial temperature [°C]**	83, 85, 86, 88, 90, 92
Final temperature [°C]	85, 88, 90, 92	**Inlet temperature [°C]**	65, 70, 75
Inlet temperature [°C]	85, 90, 94	**$\Delta T_{0\text{-}fin}$[°C]**	7, 12, 15, 20
DYNAMIC TESTS			
Parameter		Value	
Charge/discharge time [min]		10, 15, 20, 30, 45	
Flow rate [kg/min]		10, 20	

Measured parameters

Charge/discharge energy: $E = \int_0^{\tau_{fin}} \dot{m} c_p (T_{in} - T_{out}) \cdot d\tau$

Average charge/discharge power:

$$P_{ave} = \frac{\int_0^{\tau_{fin}} \dot{m} c_p (T_{in} - T_{out}) \cdot d\tau}{\tau_{fin}}$$

Charge/discharge efficiency:

$$\varepsilon_{ch} = \frac{E_{th,ch}}{E}$$

$$\varepsilon_{disch} = \frac{E}{E_{th,disch}}$$

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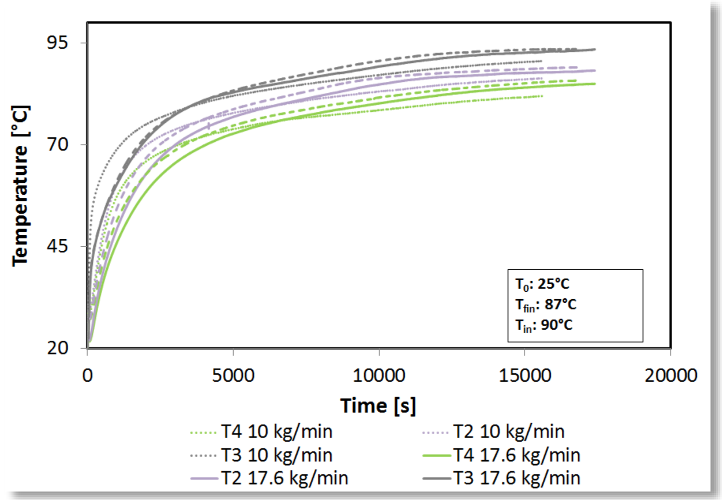
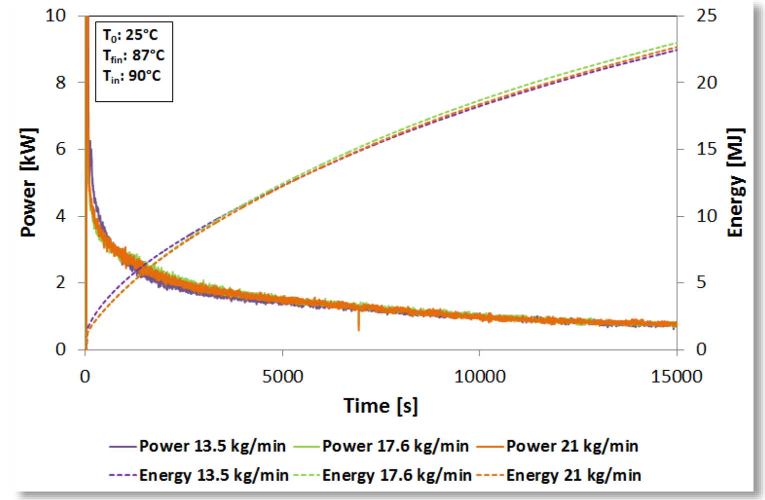
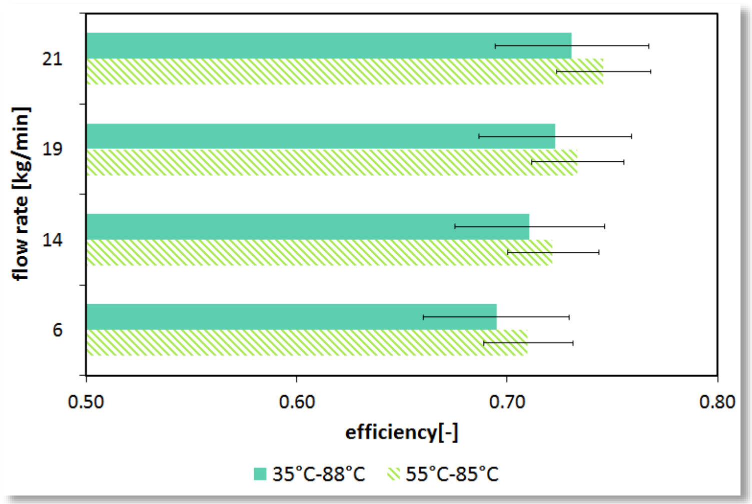
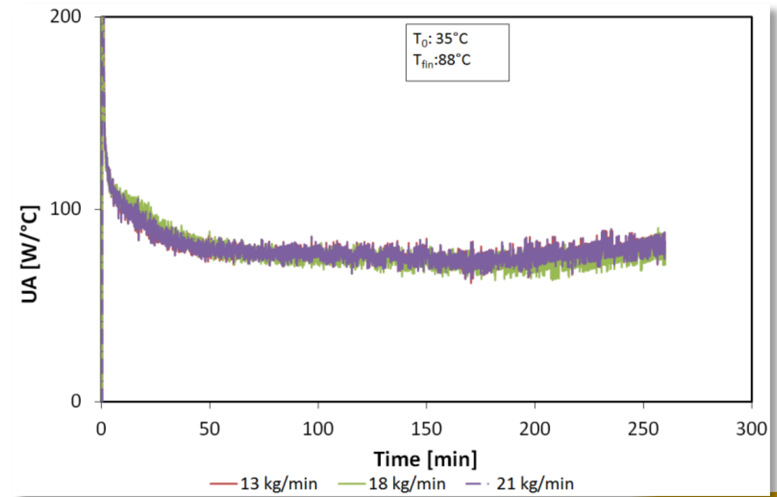
DESIGN AND TESTING OF LATENT TES @ ITAE

Static tests: charging



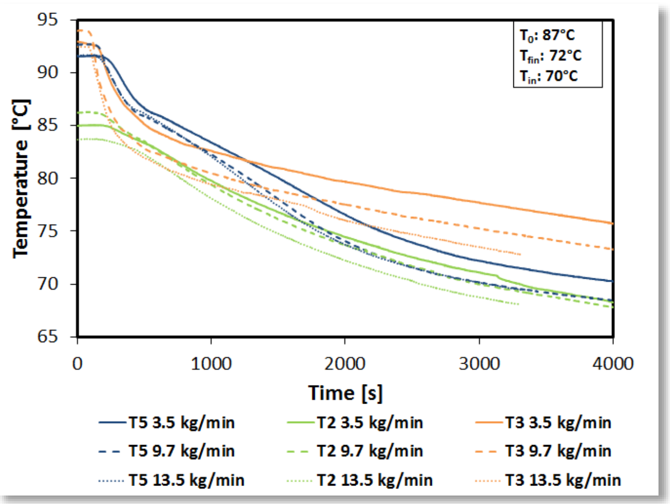


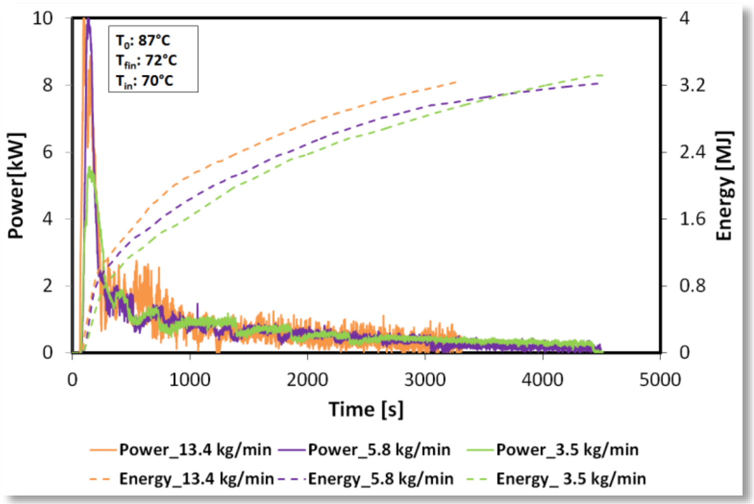


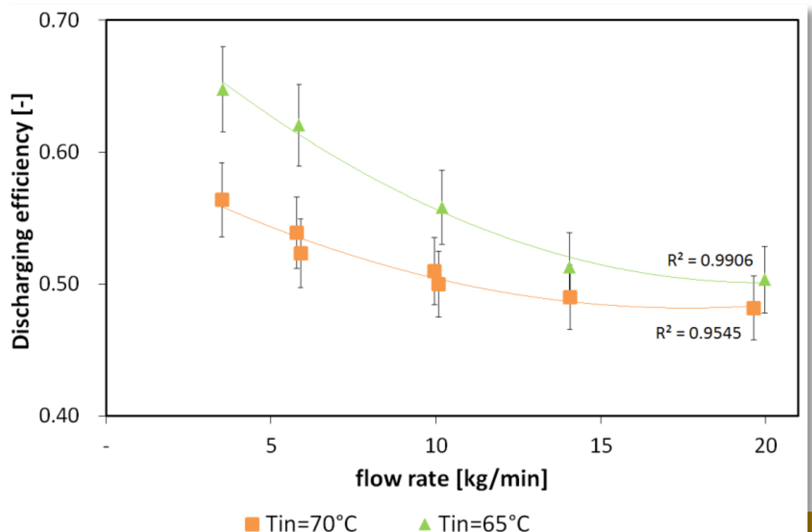


DESIGN AND TESTING OF LATENT TES @ ITAE

Static tests: discharging







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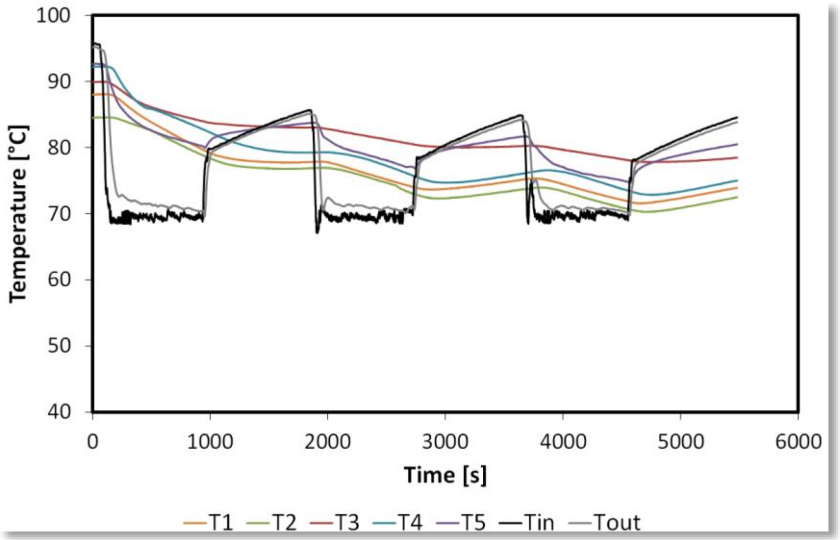
Dynamic tests



Effect of the varied parameters

PARAMETER	VARIATION RANGE	POWER	ENERGY
CHARGE			
Flow rate	3.5 – 20 kg/min	60%	20%
Inlet temperature	90°C – 96 °C	30%	13%
DISCHARGE			
Flow rate	5 – 21 kg/min	40%	-10%
Inlet temperature	65°C – 75 °C	-80%	-20%
ΔT initial-final	7.5 - 20 °C	120%	10%

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CONCLUSIONS …

- ✓ Latent TES can represent a viable solution to increase the compactness of TES for solar cooling applications
- ✓ A TES density 50% higher than sensible water-based systems have been achieved for a finned-tubes latent TES designed, realized and tested @ ITAE labs
- ✓ Discharging efficiencies up to 60% over theoretical ones have been measured
- ✓ Still, low heat transfer efficiencies and low power densities have been achieved

... AND FUTURE ACTIVITIES

- ✓ Second generation of latent TES for solar cooling applications, with higher heat transfer efficiency, realized and tested in lab
- ✓ Test of other classes of PCMs (e.g. hydrated salts) and proper additives to increase thermal conductivity
- ✓ Field test in small scale solar cooling plant, to verify the performance under real working boundaries
- ✓ Extension of the activity towards solar cooling systems driven by concentrating solar collectors (T>120°C)

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Thank you

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