Consiglio Nazionale delle Ricerche

Sorption cold energy storage device for solar cooling applications

Dr. Eng. Salvatore Vasta, PhD.
Research Engineer
Thermally Driven Heat Pumps

Consiglio **N**azionale delle **R**icerche (CNR)
Istituto di **T**ecnologie **A**vanzate per l'**E**nergia "Nicola Giordano" (ITAE)
Via Salita S. Lucia sopra Contesse n. 5
98126, Messina, ITALY

P: +39.090.624.404/296 - F: +39.090.624.247
Skype: salvo-vasta
W: www.itae.cnr.it - E: salvatore.vasta@itae.cnr.it

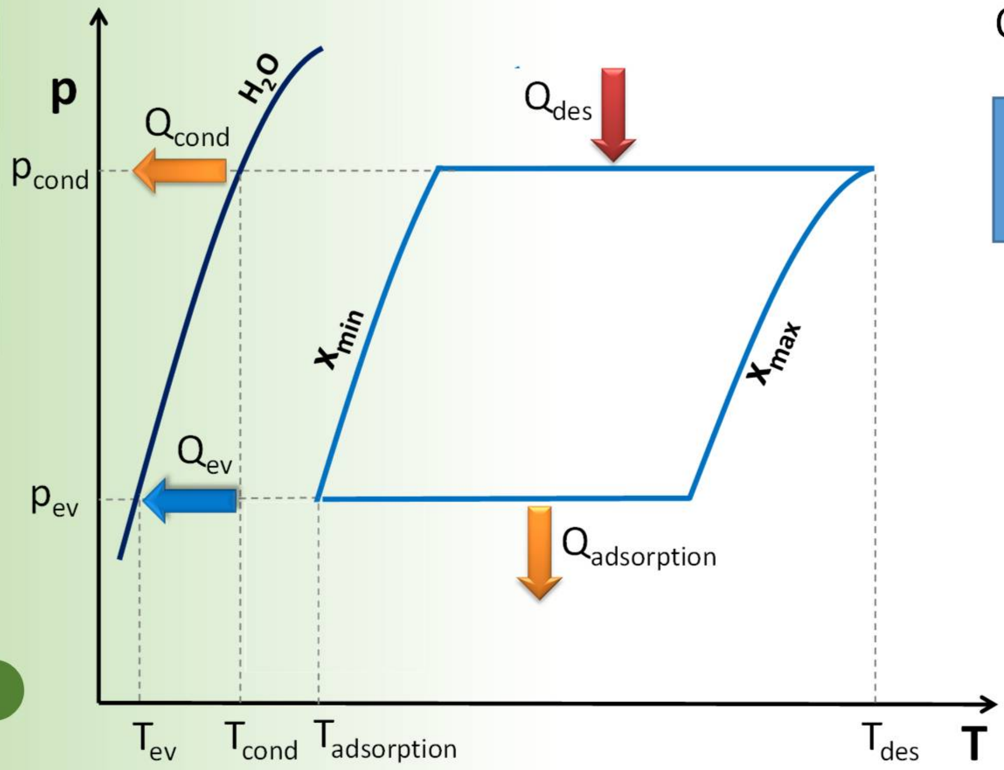
IDEA & CONCEPT

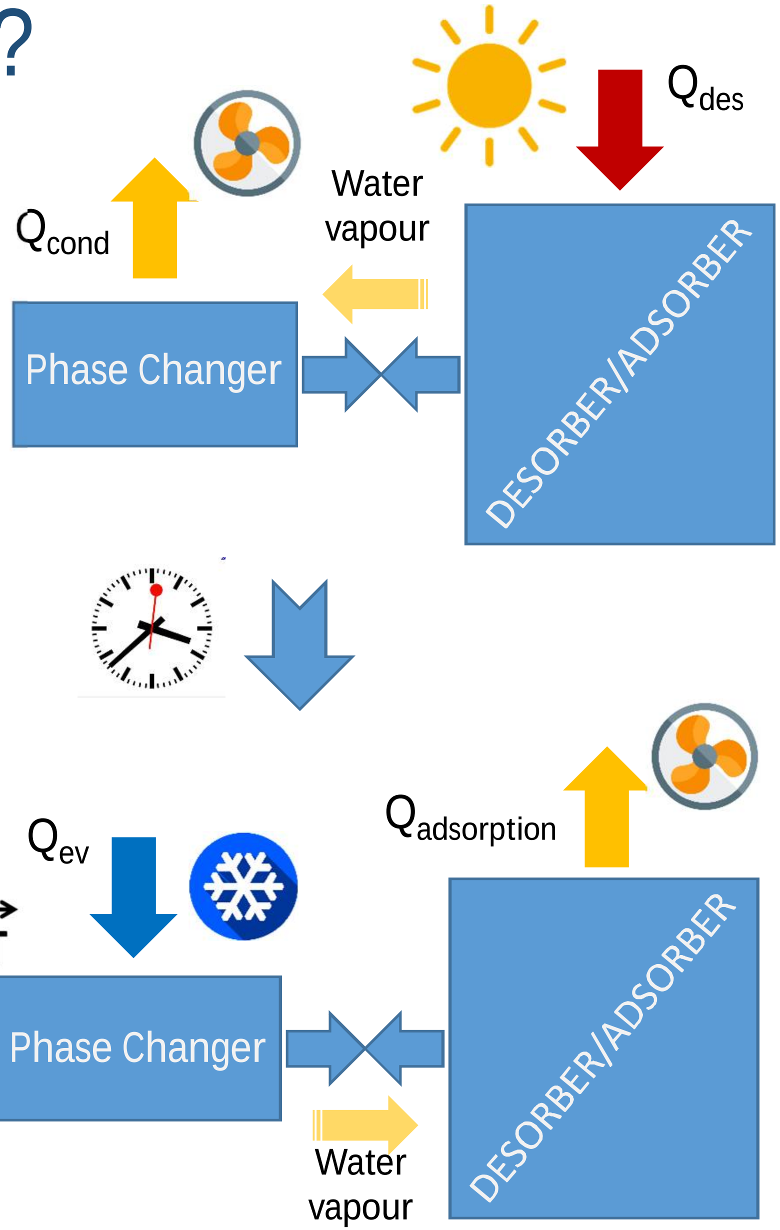
- **Design and realize a Solar Sorption Cold Storage based on a Zeolite/Water pair**
- **Define an assessment procedure to characterize the SCS**
- **Test the system and the procedure**
- **Analyze the data**
- **Improve the prototype and the assessment procedure**

SUMMARY

- **Sorption Cold (Heat) Storage requirements and constrains (FULL SCALE)**
- **Lab Scale system sizing and design**
- **Lab Scale system realization**
- **Tests**
- **Discussion on results**

HOW SHOULD IT WORK?





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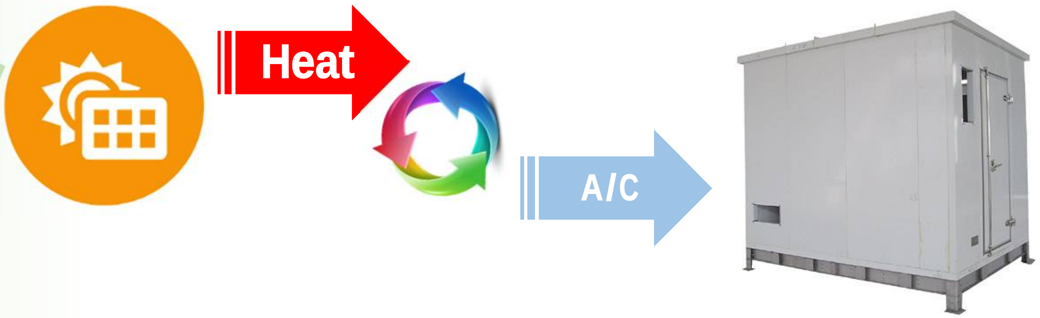
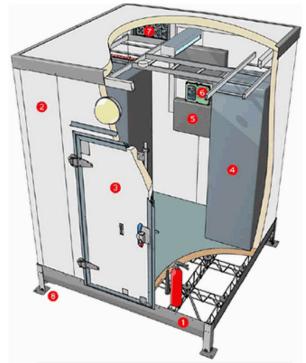
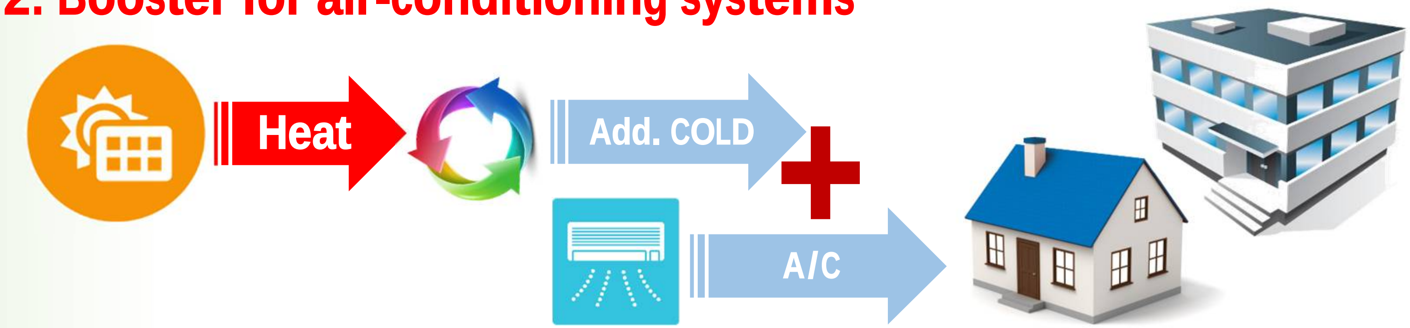
APPLICATIONS

1: Cooling of Telecommunication shelters trought solar heat

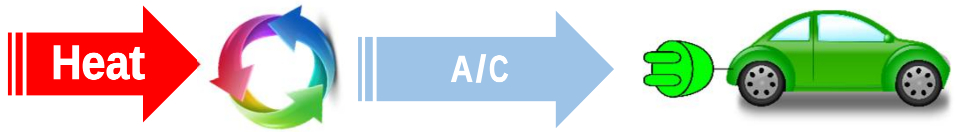




2: Booster for air-conditioning systems



3. Other mobile/stationary application



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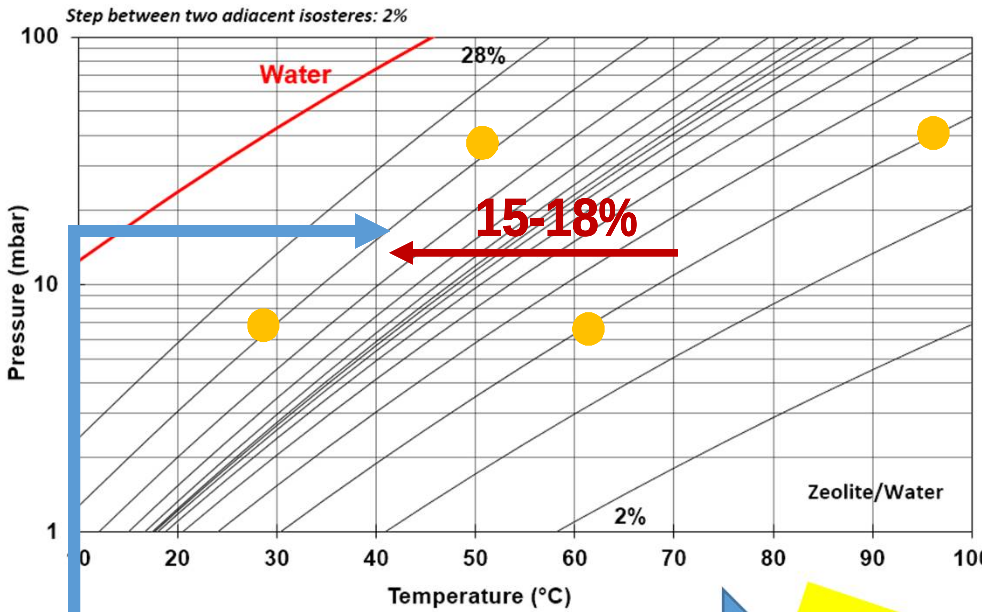
REQUIREMENTS & CONSTRAINTS

FULL SCALE

Product	Parameter	Value	Unit		
	Storage Capacity	2	kWh		
	Discharge Time	2	h		
	Avg. Power	1	kW		
	Water needed	2.9	l		
	Design temperatures	Adsorber		Phase Changer	
	Charge	95	°C	35	°C
	Discharge	35	°C	10	°C
	Useful ΔX	15%			
	Ext. Amount of zeolite	19.4	kg		



LAB SCALE

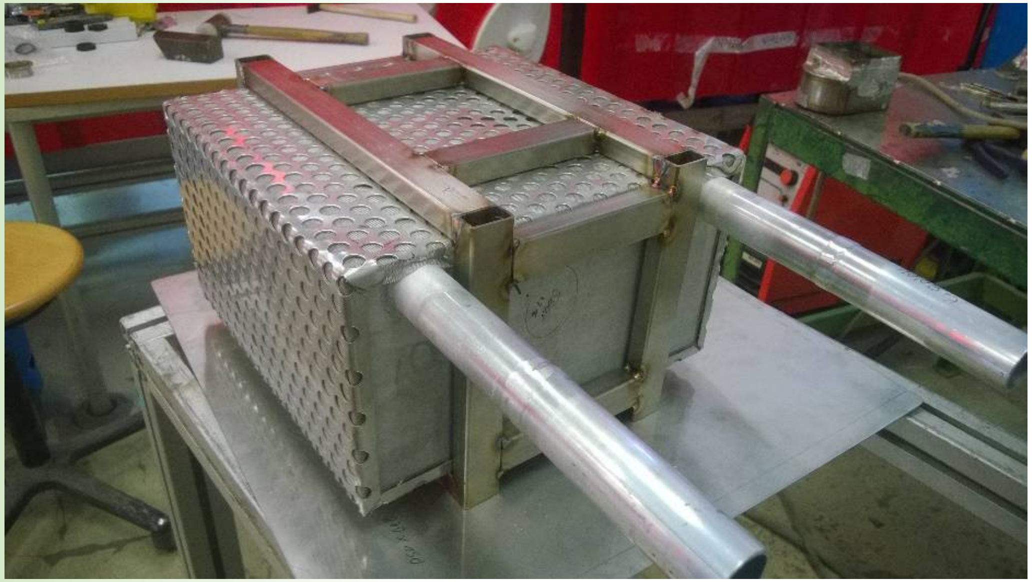
Prototype	Parameter	Value	Unit
	Portion of Product	25%	
	Storage Capacity	500	Wh
	Avg. Power	250	W

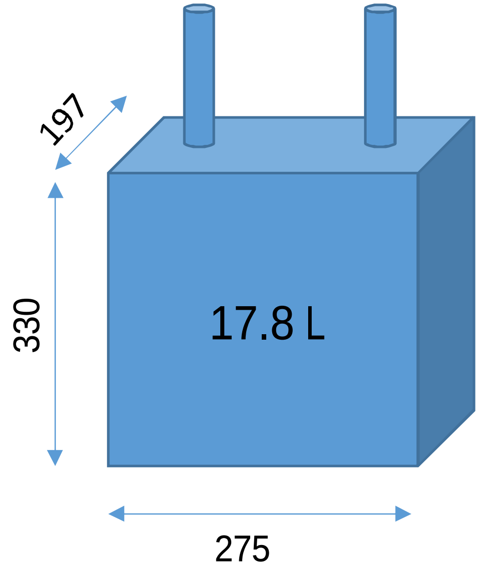
Adsorber design			
		Theoretical	Real
Total Capacity	Wh	500	636.40
Total Capacity	kJ	1800	2291.04
Water to be evaporated	kg	0.727	0.925
Expected adsorption capacity	kg/kg	0.15	0.15
Minimun zeolite mass	kg	**4.85**	**6.17**

87 W Thermal Losses @ nominal conditions

SYSTEM REALIZATION

DESORBER/ADSORBER





Zeolite FAM Z02
Grains
1 – 2 mm dia.

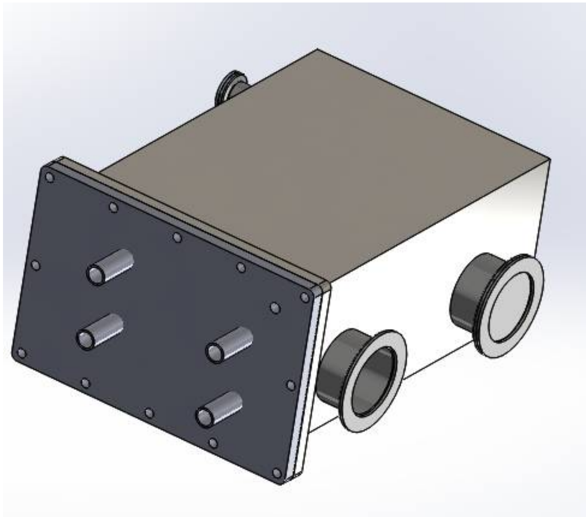
EXCHANGER mass	5595	g
ZEOLITE mass	4476	g

- 28 % respect to the design (6.17 kg)

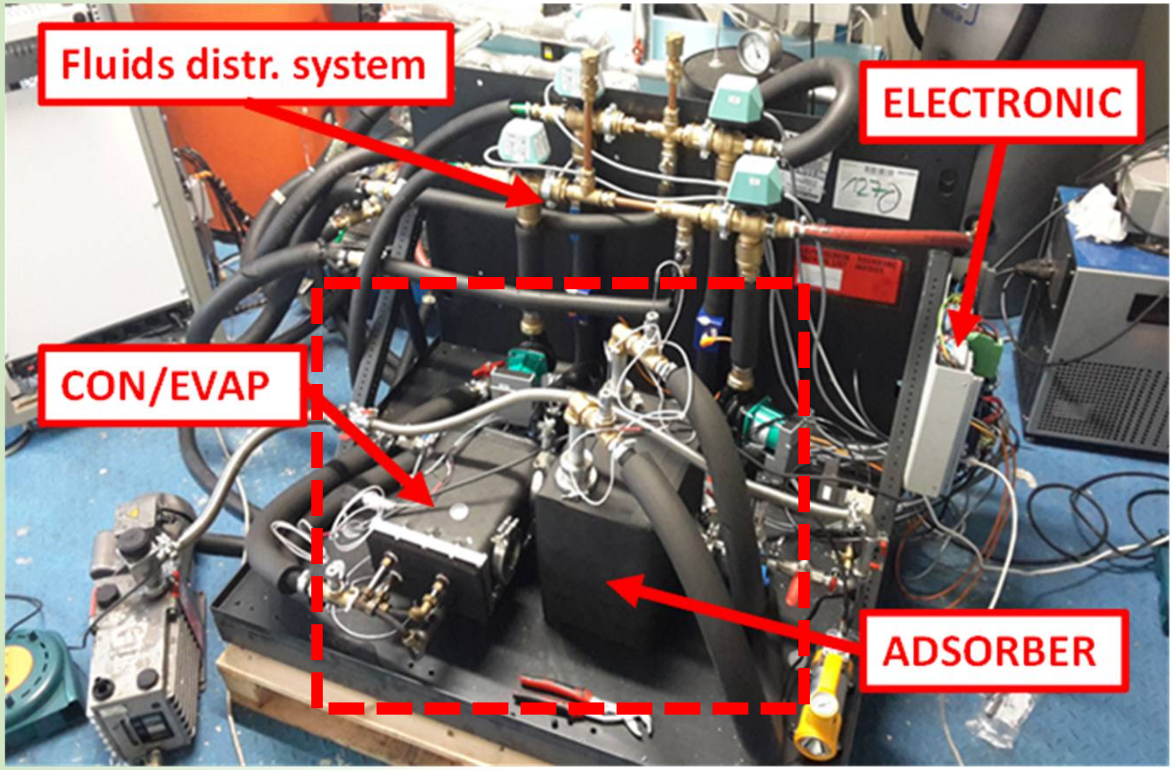
SYSTEM REALIZATION/2

Phase Changer

- Cu/SS finned tube HEXs
- SS chambers
- Design nominal power: 3.5 kW
- Measured evap/condensing Power: up to 3 kW



SYSTEM REALIZATION/3



MONITORED PARAMETERS

- T in/out Adsorber
- T in/out Phase Changer (CON/EVAP)
- T liquid phase into Phase Changer
- Adsorber loop flow rate
- Phase Changer loop flow rate
- Adsorber pressure
- Phase Changer Pressure
- T shell
- T ambient

SYSTEM REALIZATION/4 - Dimensions

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Adsorber

Overall dimensions [mm]	250 x 553 x 774
Internal dimensions of the chamber [mm]	240 x 543 x 769
Cover dimensions	308 x 613 x 10
Connections on the cover	-2 x 3/8 '' pipes for the connection of the hydraulic circuits -1 x ¼'' connection for the thermocouple -1 x DN 16 vacuum flange for the connection of a pressure sensor -1 x DN 16 vacuum flange for the vacuum circuit
Connections on the chamber	-2 x DN50 connections for the connection with the phase changer (or 2 phase changers in case of future expansions)
Material	AISI316

Phase Changer

Overall dimensions [mm]	304 x 177 x 298
Internal dimensions of the chamber [mm]	302 x 175 x 296
Heat exchangers	4 x copper/SS tube-and-fin heat exchangers
Connections on the chamber: front	-2 x 3/8 '' pipes for the connection of the hydraulic circuits -1 x ¼'' connection for the thermocouple -1 x DN 16 vacuum flange for the connection of a pressure sensor -1 x DN 16 vacuum flange for the vacuum circuit
Connections on the chamber: lateral	-2 x DN50 connections for the connection with the adsorber (or 2 adsorbers in case of future expansions)
Material	AISI316

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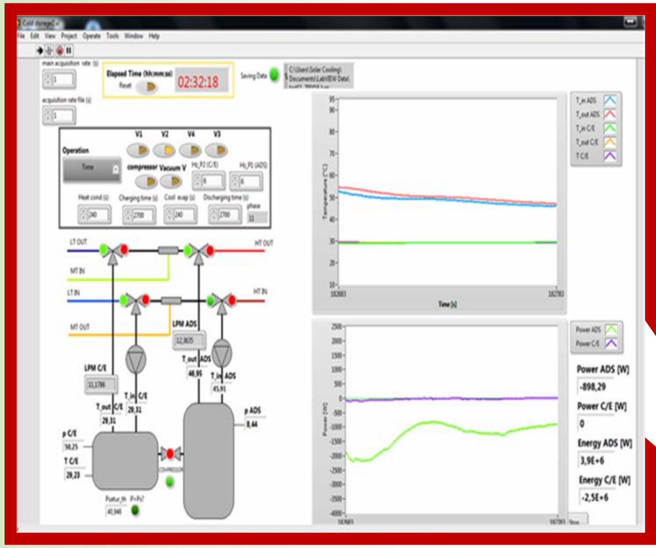
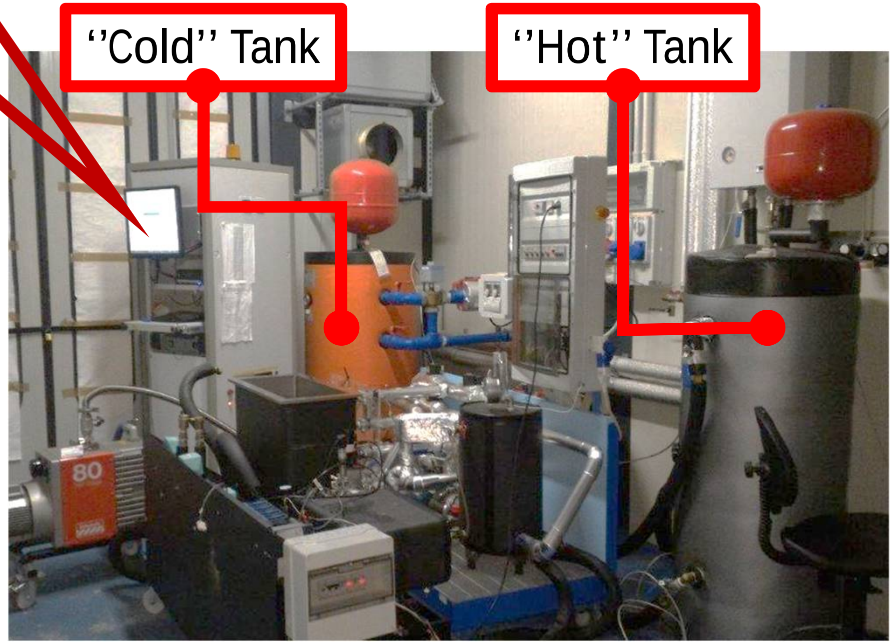
TESTS – Testing bench description



CENTRO P ROVE
National Research Council of Italy



Features

- Variable flow hydraulic pumps
- High accuracy sensors
- Pressure drop measurements
- Simple/heat recovery cycle operation
- 16 kW electric heater (@95 °C MAX)
- 0 – 20 °C LT simulation ability
- 15 – 50 °C MT simulation ability

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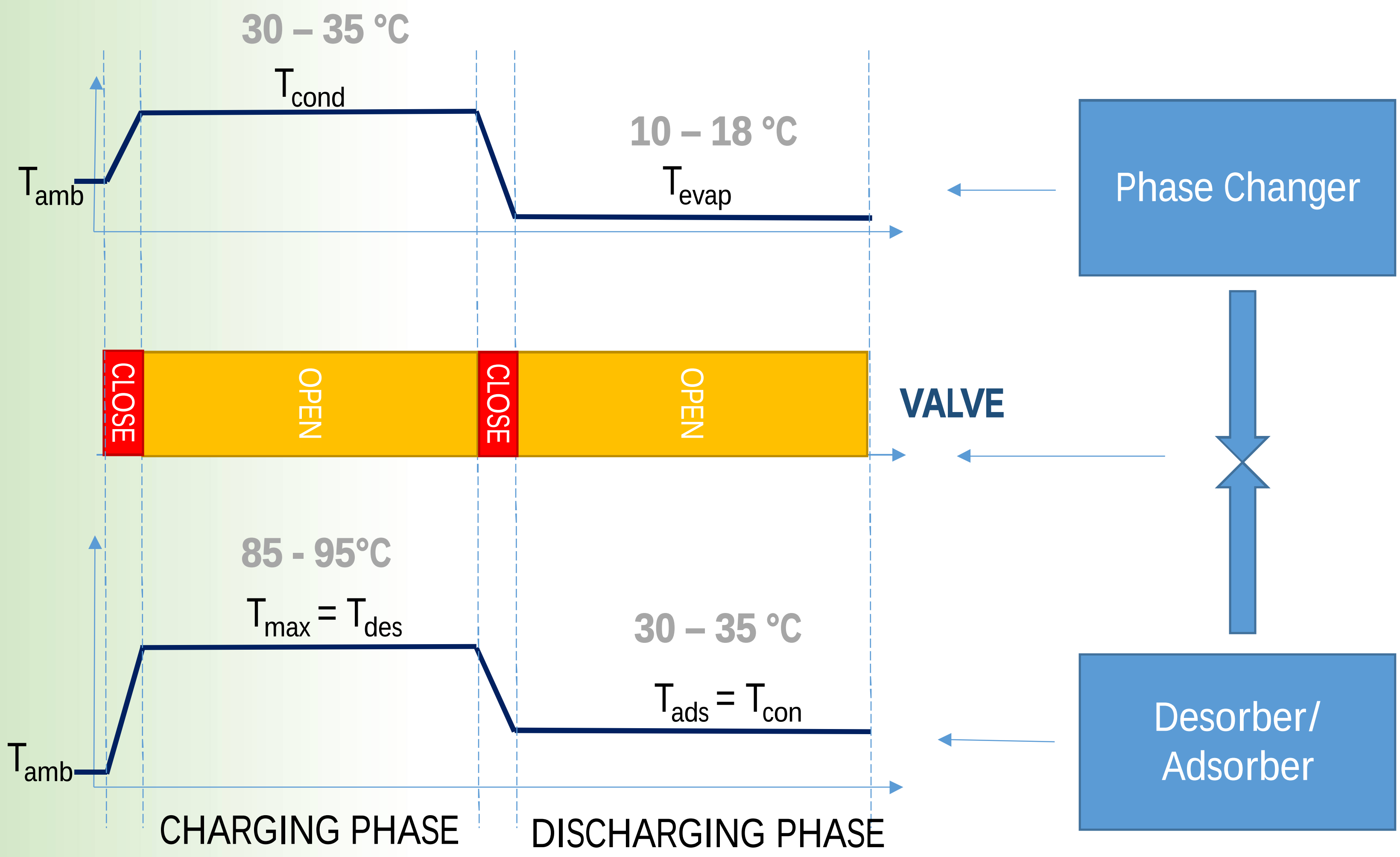
TESTS – Assessment procedure description



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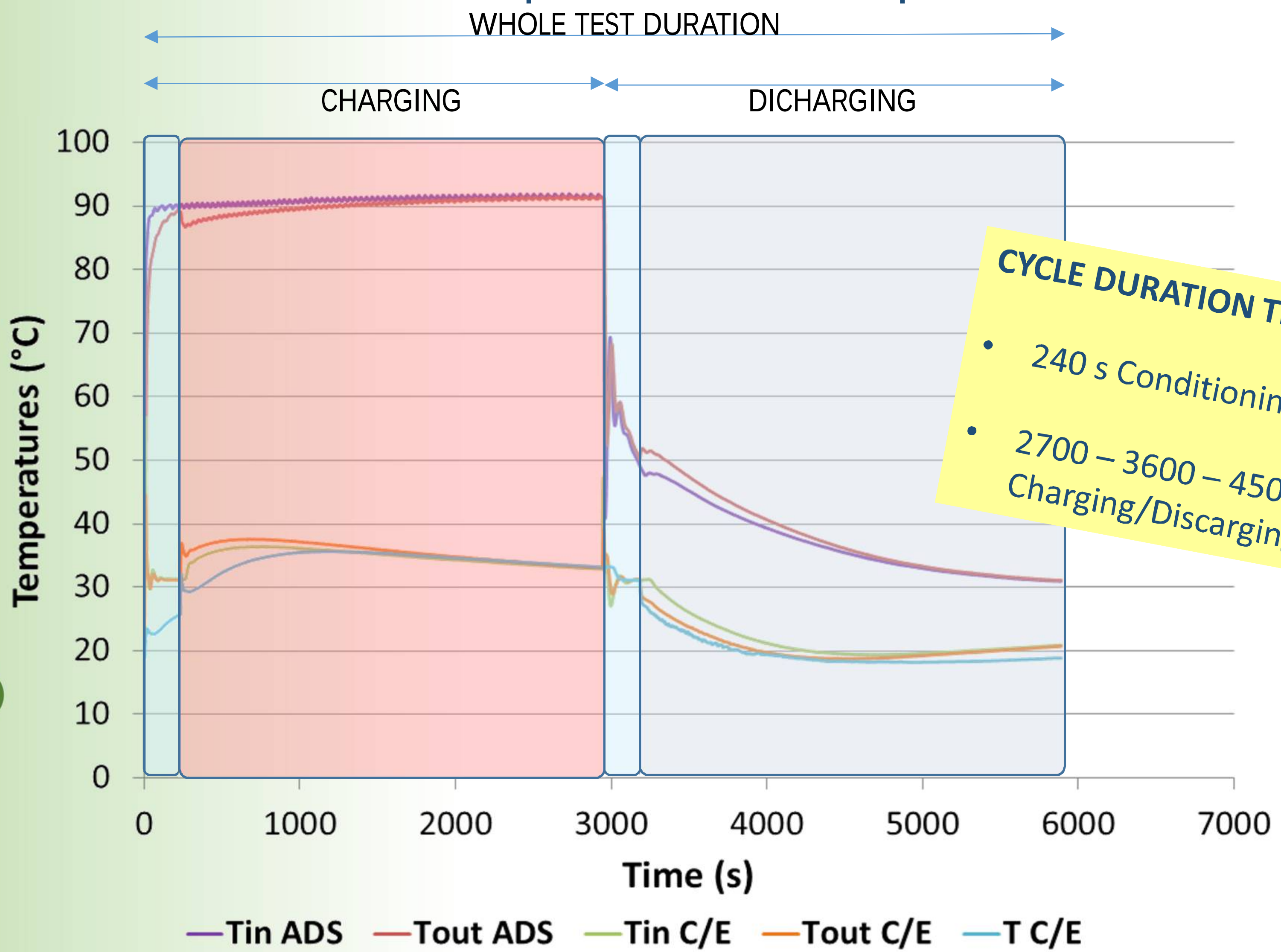
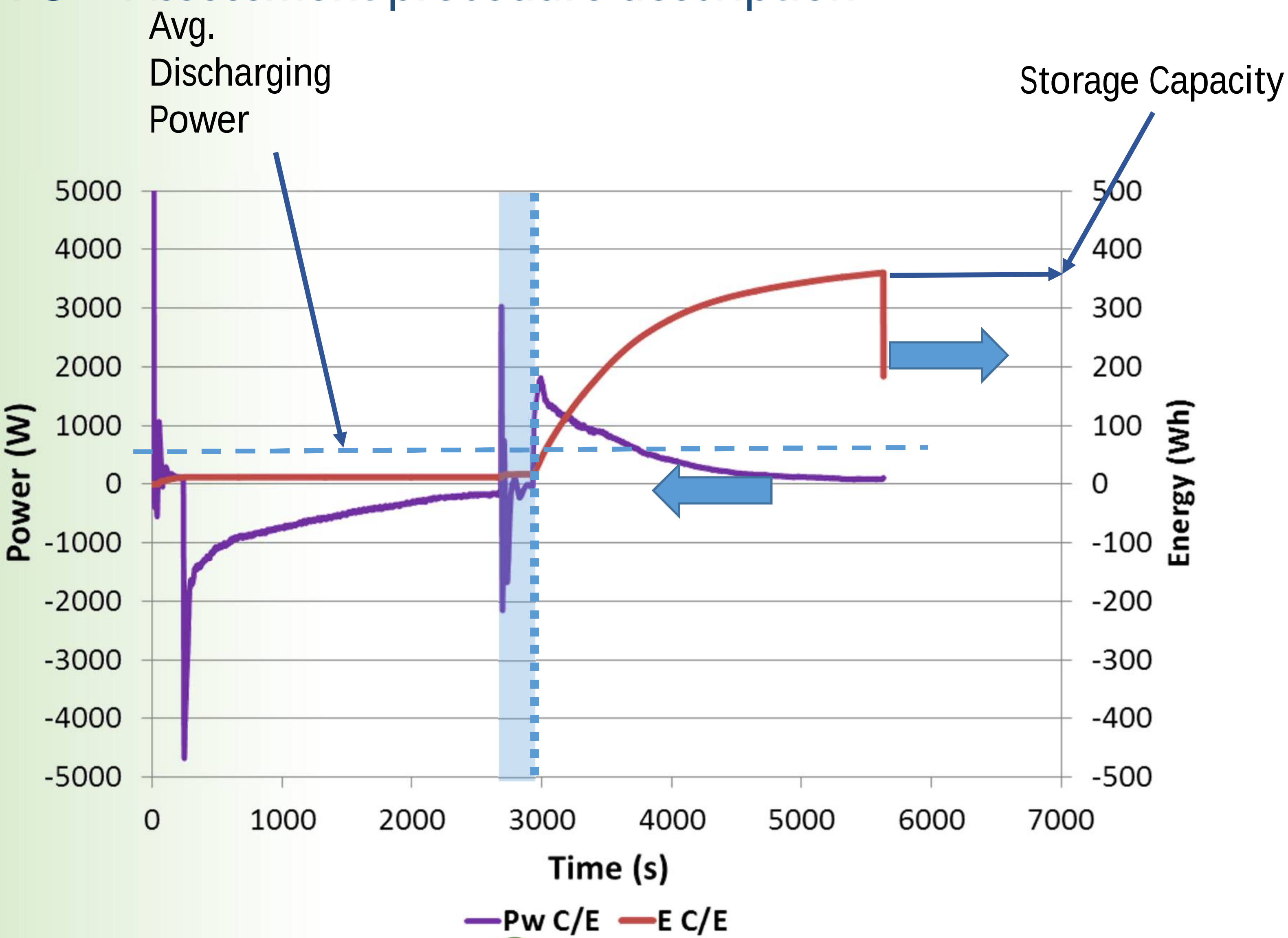
TESTS – Assessment procedure description



CYCLE DURATION TESTED:

- 240 s Conditioning Phases
- 2700 – 3600 – 4500 s Charging/Discarging Phases

TESTS – Assessment procedure description



TESTS

Assessment procedure description

Pre-conditioning period:
all the desired temperatures and flow rates are set in the testing bench and measured.

Start-up period:
Once the temperature levels desired are reached in the tanks, cycling operation of the storage is started. All the parameters are recorded for a duration of at least 5 charge/discharge cycles.

Steady-state period:
The data recorded – for the last 3 cycles - are used for data analysis. Correspondence between the temperature levels set and measured is constantly checked.

Data analysis:
The data collected during the steady-state period are used for the calculation of the key figures selected.

TASK 48

Cold storage	
Discharge power (DP)	$PD = \dfrac{\int_0^{t_{ev}} \dot{m}_{pc} c_p (T_{in,pc} - T_{out,pc}) dt}{t_{ev}}$ [W]
Stored Energy (SE)	$SE = \int_0^{t_{ev}} \dot{m}_{pc} c_p (T_{in,pc} - T_{out,pc}) dt$ [Wh]
Storage Energy Density (SED)	$SED = \dfrac{SE}{m_{adsorbent}} \left[\dfrac{Wh}{kg}\right]$
Storage efficiency (η)	$\eta = \dfrac{\int_0^{t_{ev}} \dot{m}_{pc} c_p (T_{in,pc} - T_{out,pc}) dt}{\int_0^{t_{des}} \dot{m}_{ads} c_p (T_{in,ads} - T_{out,ads}) dt}$

Long- term heat storage	
Discharge power (DP)	$PD = \dfrac{\int_0^{t_{adsorption}} \dot{m}_{ads} c_p (T_{out,ads} - T_{in,ads}) dt}{t_{adsorption}}$ [W]
Stored Energy (SE)	$SE = \int_0^{t_{adsorption}} \dot{m}_{ads} c_p (T_{out,ads} - T_{in,ads}) dt$ [Wh]
Storage Energy Density (SED)	$SED = \dfrac{SE}{m_{adsorbent}} \left[\dfrac{Wh}{kg}\right]$
Storage efficiency (η)	$\eta = \dfrac{\int_0^{t_{adsorption}} \dot{m}_{ads} c_p (T_{out,ads} - T_{in,ads}) dt}{\int_0^{t_{des}} \dot{m}_{ads} c_p (T_{out,ads} - T_{in,ads}) dt}$

Short- term heat storage	
Discharge power (DP)	$PD = \dfrac{\int_0^{t_{cond}} \dot{m}_{pc} c_p (T_{out,pc} - T_{in,pc}) dt + \int_0^{t_{adsorption}} \dot{m}_{ads} c_p (T_{out,ads} - T_{in,ads}) dt}{t_{cond} + t_{adsorption}}$ [W]
Stored Energy (SE)	$SE = \int_0^{t_{cond}} \dot{m}_{pc} c_p (T_{out,pc} - T_{in,pc}) dt + \int_0^{t_{adsorption}} \dot{m}_{ads} c_p (T_{out,ads} - T_{in,ads}) dt$ [Wh]
Storage Energy Density (SED)	$SED = \dfrac{SE}{m_{adsorbent}} \left[\dfrac{Wh}{kg}\right]$
Storage efficiency (η)	$PD = \dfrac{\int_0^{t_{cond}} \dot{m}_{pc} c_p (T_{out,pc} - T_{in,pc}) dt + \int_0^{t_{adsorption}} \dot{m}_{ads} c_p (T_{out,ads} - T_{in,ads}) dt}{\int_0^{t_{des}} \dot{m}_{ads} c_p (T_{out,ads} - T_{in,ads}) dt}$

TESTS – Results

AVERAGE POWER DURING DISCHARGING PHASE:

Up to 520 W

STORED COLD ENERGY:

< 590 Wh

< 132 Wh/kg

30 different measuring points

> 250 total tests

Test	Cycle	HT_in	ADS_av	MT_in	LT_in	t_charge	t_discharge	Delta	W_disch	E
	-	°C	°C	°C	°C	s	s	°C	W	Wh
3	1	88.59	34.91	33.91	14.93	3600.00	3600.00	18.98	415.86	418.86
	2	88.57	34.66	33.55	15.27	3600.00	3600.00	18.27	387.60	396.22
4	1	89.49	33.93	33.66	14.72	4500.00	4500.00	18.94	342.38	452.46
5	1	89.35	34.14	33.56	20.08	4500.00	4500.00	13.48	405.92	521.66
6	1	89.37	34.35	34.03	19.90	4500.00	4500.00	14.13	475.69	590.91
	2	89.38	34.20	34.12	20.42	4500.00	4500.00	13.70	493.24	571.34
7	1	87.11	38.32	38.15	19.84	4500.00	4500.00	18.31	424.15	556.47
	2	87.38	37.39	35.59	19.86	4500.00	4500.00	15.74	373.29	491.33
8	1	85.67	34.91	33.65	19.68	2700.00	2700.00	13.97	518.86	428.61
	2	86.56	36.68	33.00	20.44	2700.00	2700.00	12.56	487.86	401.91
	3	87.41	36.57	31.54	21.28	[illegible]	2700.00	10.26	481.91	399.15
9	1	89.12	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
		[illegible]	[illegible]	32.92	16.20	2700.00	2700.00	16.72	[illegible]	[illegible]
27	1	89.83	33.87	32.89	16.22	3600.00	3600.00	16.67	222.16	204.98
	2	89.92	33.59	32.67	16.45	3600.00	3600.00	16.22	181.55	170.90
28	1	89.23	32.18	28.62	21.08	2700.00	2700.00	7.54	367.07	265.69
	2	89.31	32.66	26.27	21.86	2700.00	2700.00	4.41	406.00	395.31
29	1	89.91	31.24	29.54	17.18	2700.00	2700.00	12.36	426.69	351.09
	2	89.94	31.06	29.11	17.39	2700.00	2700.00	11.73	385.13	312.74
	3	90.18	30.81	29.07	16.90	2700.00	2700.00	12.17	344.90	263.36
30	1	88.99	40.85	40.12	17.95	3600.00	3600.00	22.17	201.96	108.14

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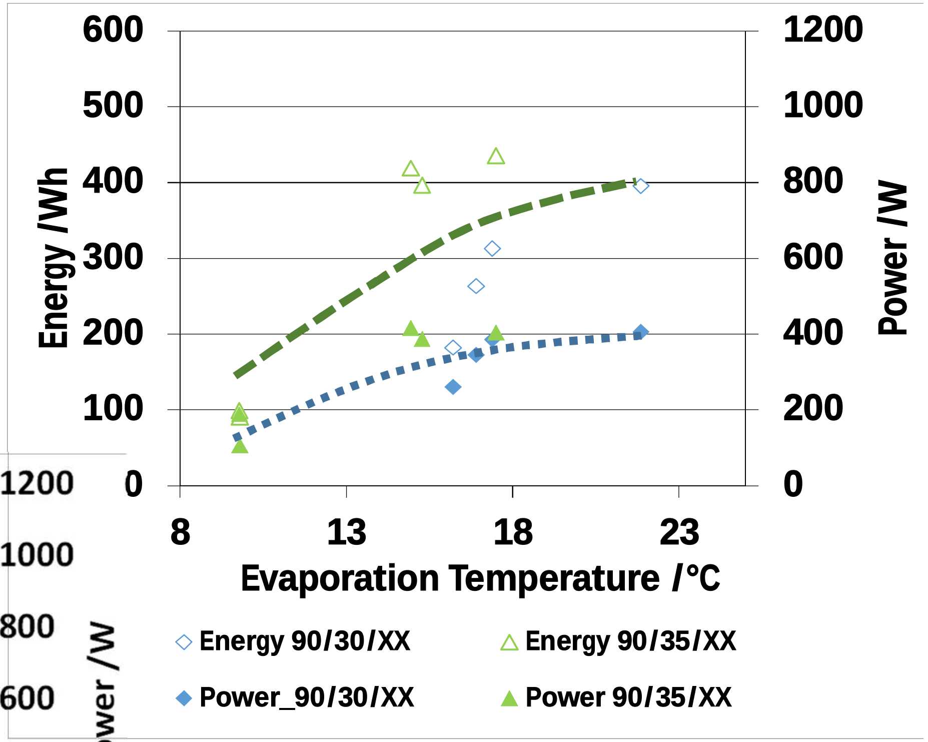
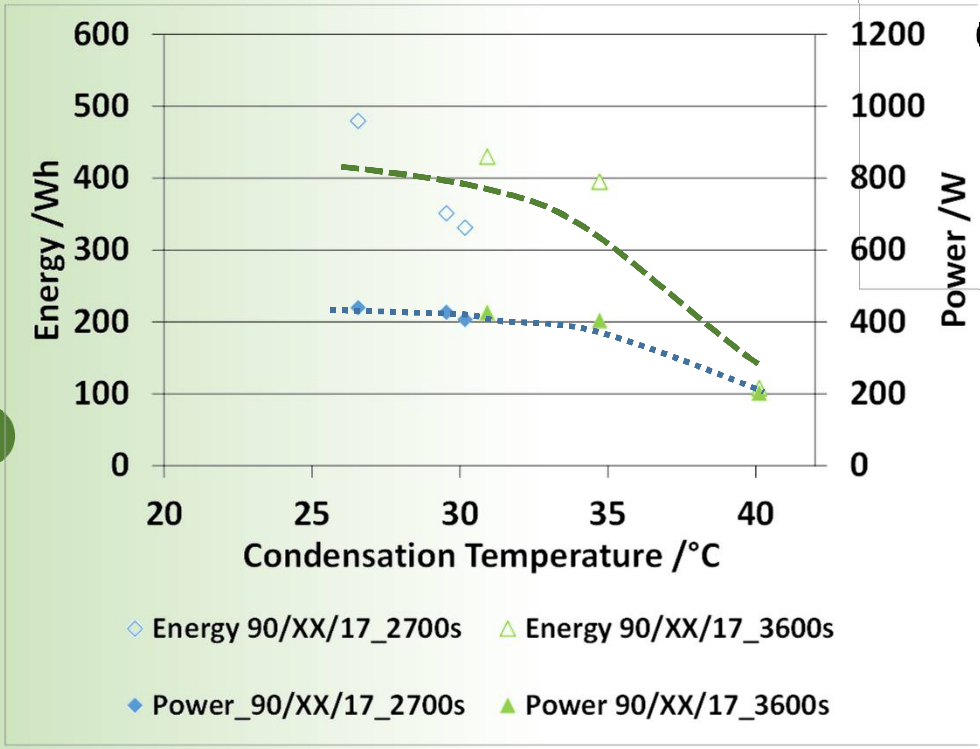
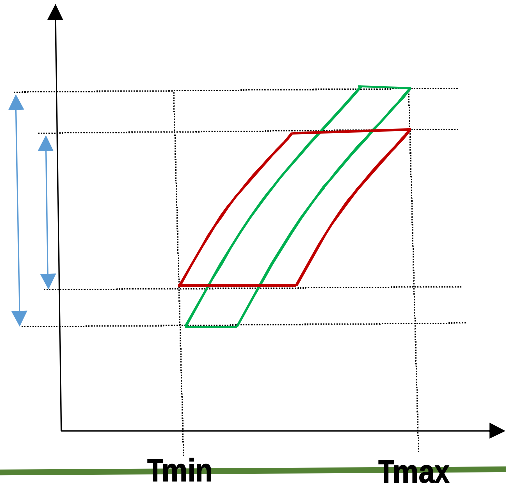
TESTS – Results

Discharging Time: 45 – 60 mins







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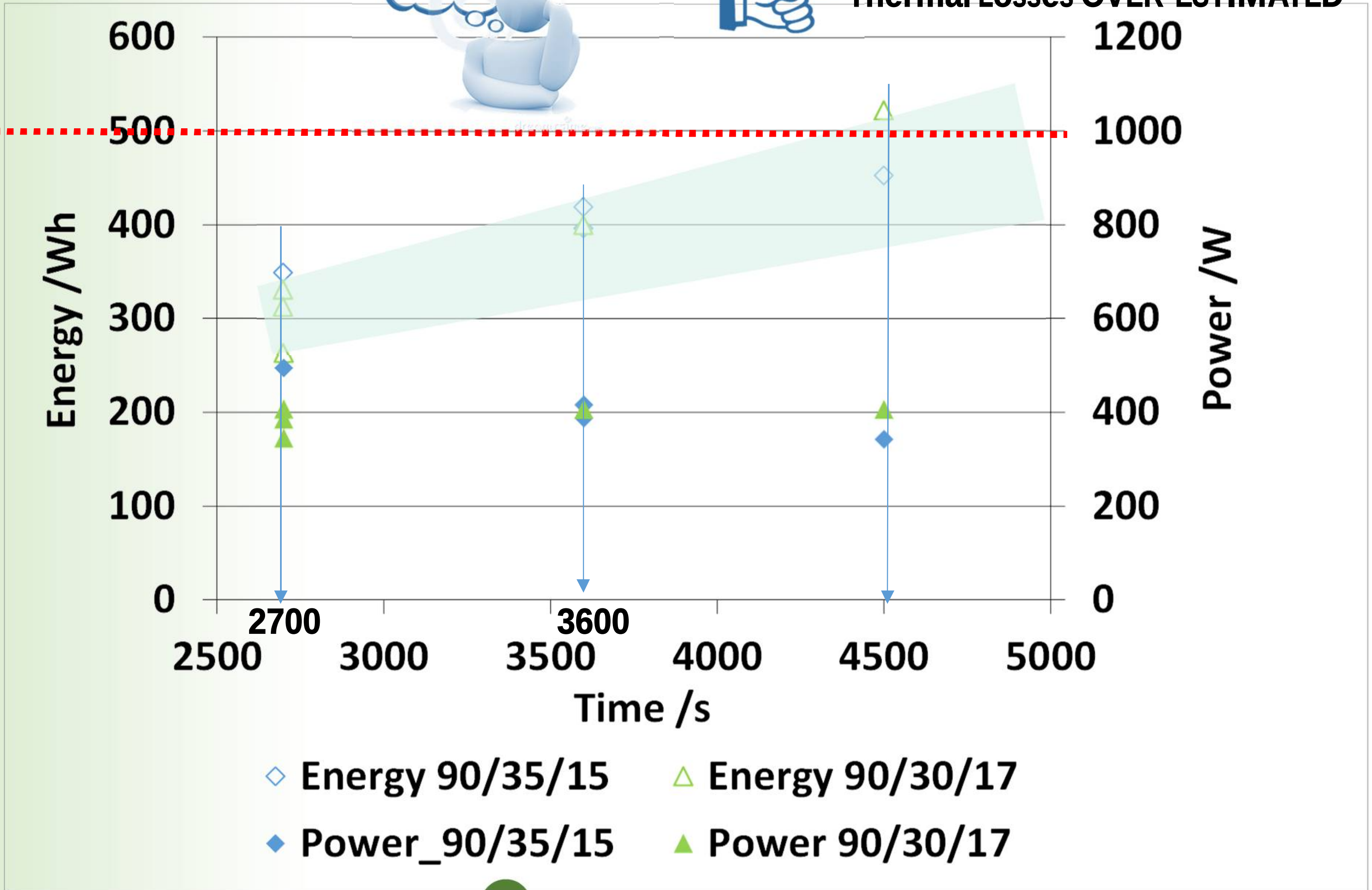
TESTS – Results

MASS ! - 28 % respect to the design

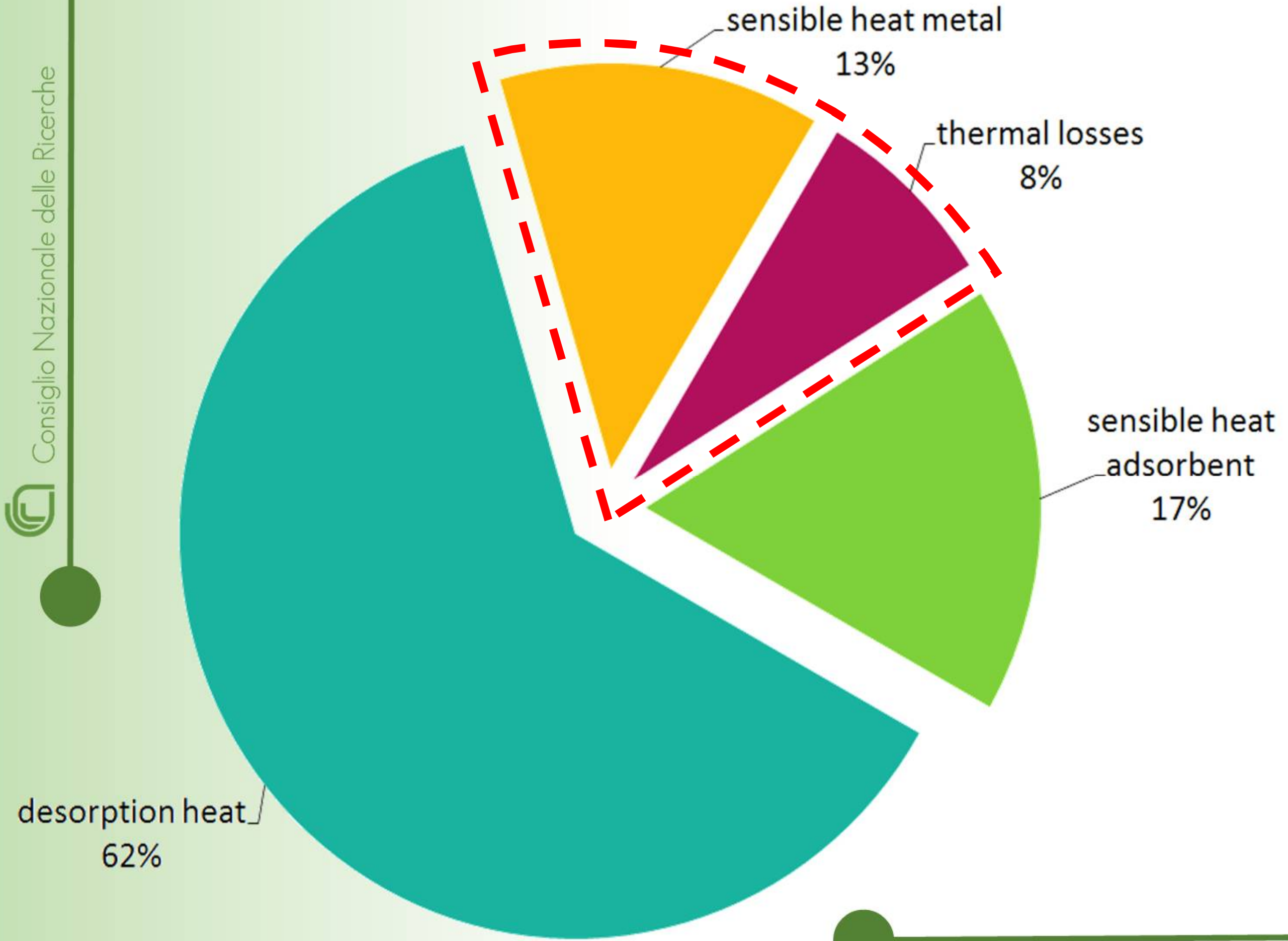
Thermal Losses OVER-ESTIMATED

TARGET

112 Wh/kg
~ 400 kJ/kg



ENERGY BALANCE



A 15% improvement in storage efficiency could be obtained by improving thermal insulation or reducing the amount of metal

(for example, choosing a cylindrical shape with very thin wall or replacing stainless steel with lightweight non-metallic materials)

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CONCLUSIONS

- **A sorption cold storage system, using FAM Z02 Zeolite, for application in telecommunication has been designed, identifing the following desired performance and boundary conditions:**

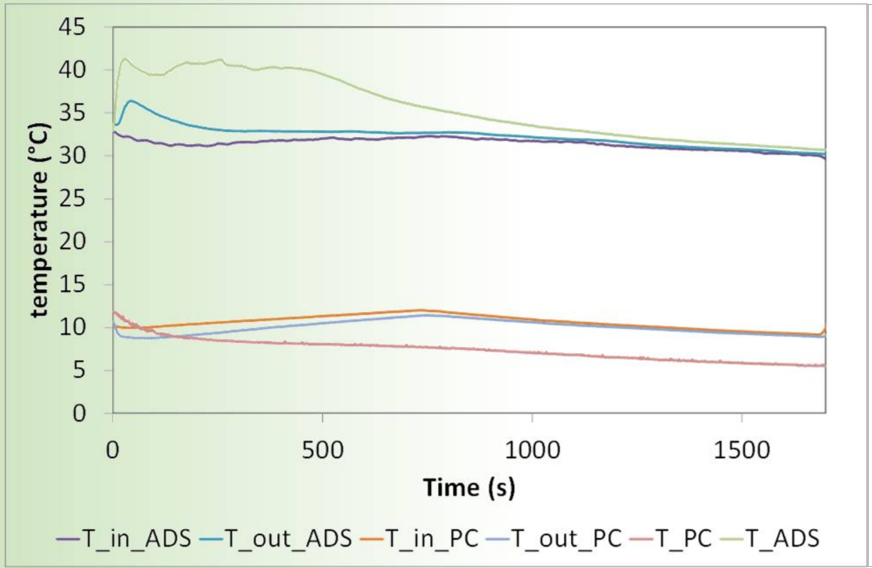
  2 kWh cold storage capacity, 1 kW avg. power, charge @95 °C, discharge (cold useful effect) @ 10-17 °C.

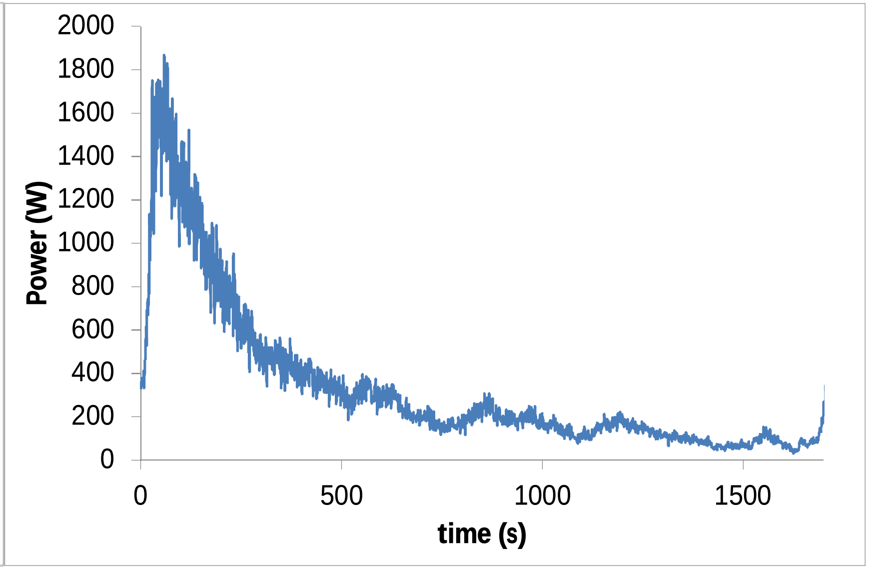
- **A reduced size lab scale system has been designed, realized and tested.**
- **A tentative assessment procedure has been defined and used to partially characterize the lab scale sorption cold storage system (→ T48).**
- **Results showed that the system realized and tested is capable to deliver up to 500 W as avg. cooling power at the selected operating conditions and to store up to 590 Wh of cold. Accordingly the energy density measured is 400 kJ/kg (112 Wh/kg).**
- **More tests and improvements are needed.**

NEXT ACTIVITIES

- **Tests on long term storage (1 week and more)**
- **Improve the testing station → Long Term Tests**
- **Codify the procedure (ANNEX 30?)**
- **Test new composite materials (SWS family)**
- **Investigate corrosion issues**

Heat storage: Vermiculite/LiCl - water





Vermiculite/LiCl lamella HEX adsorber

First experimental results: Average heating power c.a. 350 W for about ½ hour. Peak power 1.8 kW. Energy storage density: 164 kWh/kg_ads (theoretical 417 kWh/kg)

THANK YOU FOR THE KIND ATTENTION!

Systems Thermal Integration

STI Research Group is:
Vincenza Brancato, Andrea Frazzica, Davide La Rosa, Gaetano Maggio, Valeria Palomba, Alessio Sapienza and Salvatore Vasta

Salvatore Vasta

Consiglio Nazionale delle Ricerche (CNR)
Istituto di Tecnologie Avanzate per l'Energia "Nicola Giordano" (ITAE)
C E N T R O P R O V E
Via Comunale S. Lucia n. 40
98126 S. Lucia, Messina, ITALY

P: +39.090.624.404 - F: +39.090.624.247
Skype: salvo-vasta
W: www.itae.cnr.it - E: salvatore.vasta@itae.cnr.it

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