High temperature SHC systems with LFR collectors and molten salts thermal storage

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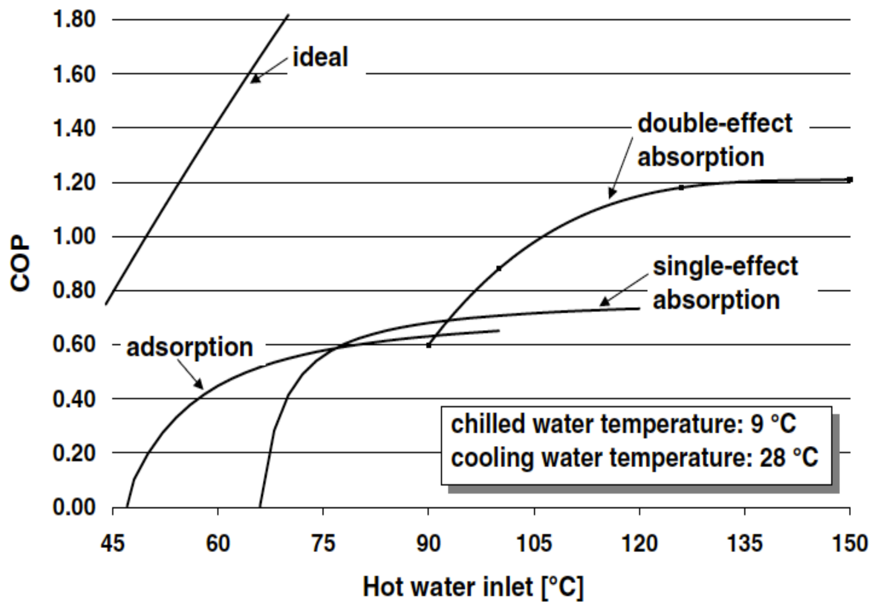
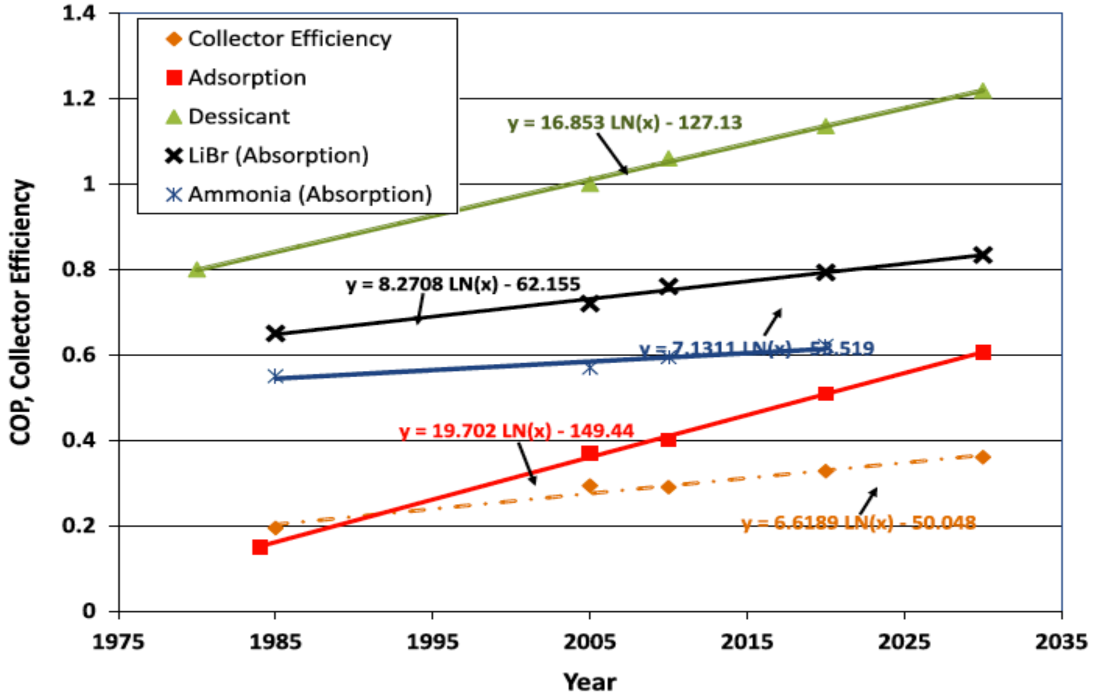
Looking for a better performance



COP vs inlet temperature in various sorption chillers compared with the ideal limit (Henning, 2007)

The combination of concentrating solar collectors with double-effect absorption can even double the thermal COP of the cycle, reaching values above 1.

Efficiency is growing both in collectors and chillers



Current and projected efficiencies for thermal AC and medium temperature ST collectors (Otanicar et al., 2012).

Large fields of concentrating solar panels can even supply triple-effect chillers, claiming a COP of 1.8. High inlet temperature is required.

TRIPLE EFFECT CHILLER

Product Information

Cooling capacity: 100 – 1000 TR (350 – 3500 kW)

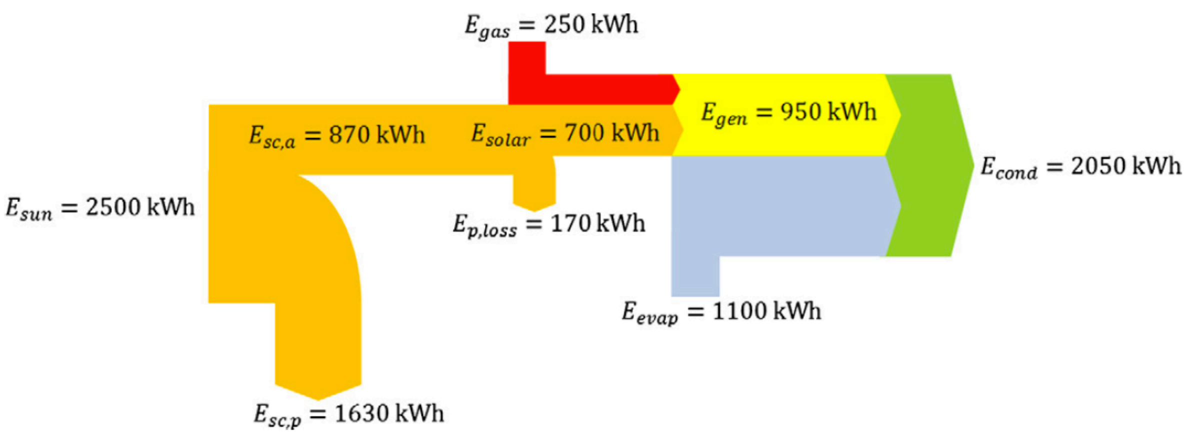
Chilled water
Lowest outlet temperature: 5°C
Chilled water delta T – 30°C max

Cooling water
Design inlet temperature: 25°C – 32°C
Minimum inlet temperature: 10°C

Driving heat source
Steam (Pressure: 10 – 25 bar.g, Dry saturated) or Hot Water (Inlet temperature: 190°C – 225°C)

Hybrid solar-gas cooling

- An experimental plant (Bermejo et al.2010) has been installed by the Engineering School of Seville in Spain, where a double-effect LiBr/H_2O of 174 kW nominal power is fed by a pressurized hot water flow coming from a 352 m^2 solar linear Fresnel collector, working in parallel with a direct-fired natural gas burner. Nominal COP of the chiller is 1.34.
- Pressurized water is heated up to a maximum operating temperature of 180 °C. The collector can generate a thermal power up to 100 kW.



The daily average COP was ranging from 1.1 to 1.25, with a solar fraction of 75%, with the remaining 25% was supplied by the gas burner. The adoption of a storage system is recommended by this study.

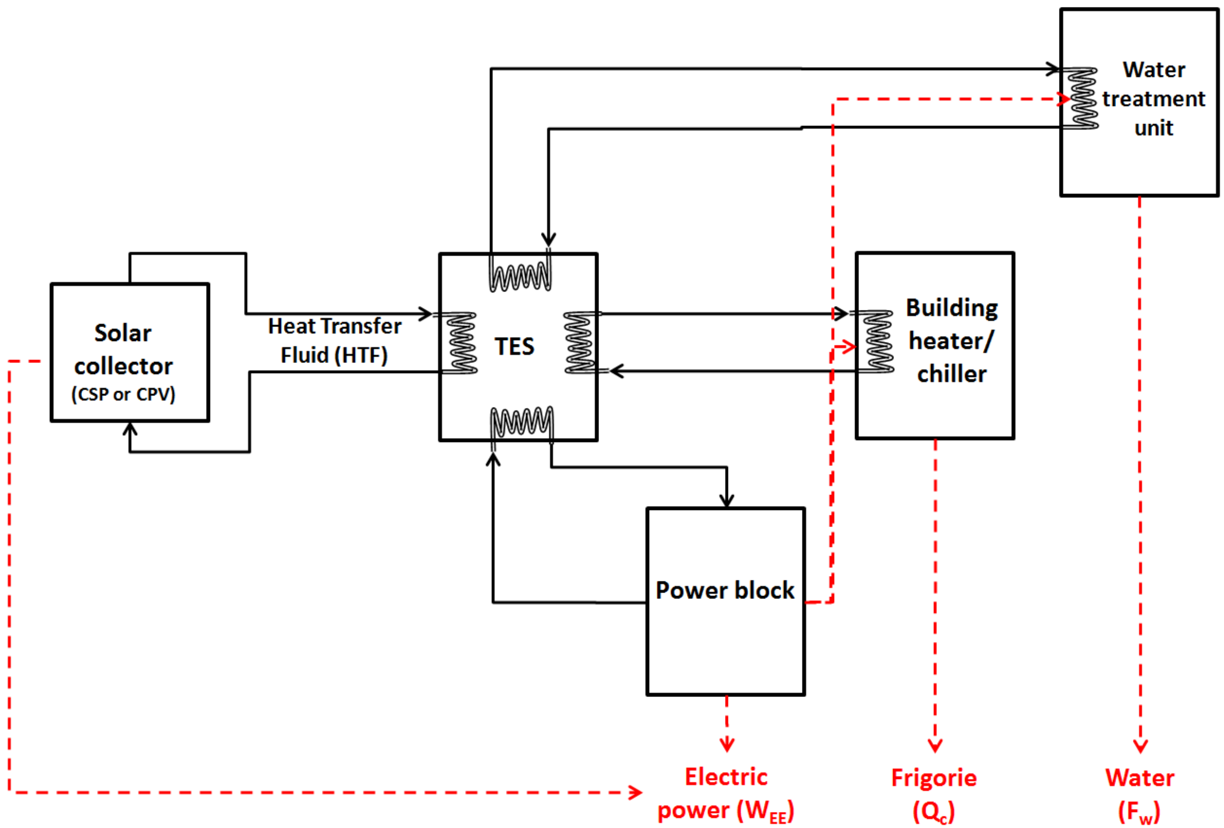
Trade-off of solar concentrators

- Dependence of the collector performance by the position of the sun.
- Short collectors are not effective due to the end effect.
- High impact of uncleanness or cloudy sky (even 50% of the efficiency).
- Heat losses during the night and the startup phase.

The STS-Med project explored four different layouts

- **France :** CEA, CEEI Provence
- **Italy:** Consorzio ARCA (coordinator), ENEA, Sicilian Region
- **Greece :** Institute of Accelerating Systems and Applications
- **Cyprus :** The Cyprus Institute, CCCI
- **Egypt :** Academy for Scientific Research and Technology, Elsewedy Electric, New and Renewable Energy Authority
- **Jordan :** Al Balqa, Ministry of Energy and Mineral Resources, Millenium Energy Industries

Solar polygeneration through a TES – centered approach



	Cyprus	Egypt	Italy	Jordan
				
Location	Aglantzia, on the roof of a school, next to the NTL	Markaz Belbes, nearby the Sekem medical center	University of Palermo, on the ground at ARCA premises	Irbid, roof a building of the Al Balqa University College
Latitude Longitude Elevation	35°08'28.1"N 33°22'50.7"E 176m	30°25'05.5"N 31°38'07.8"E 35m	38°06'01.0"N 13°20'37.3"E 50m	32°29'13.2"N 35°53'24.0"E 648m
DNI per year (SolarGis)	2142 $kWh.m^{-2}$	1958 $kWh.m^{-2}$	1703 $kWh.m^{-2}$	2377 $kWh.m^{-2}$
Type of collector	LFR	LFR	LFR	PTC
Aperture area	184.32 m^2	299.50 m^2	483.84 m^2	163.2 m^2
Thermal oil	Duratherm 450	Therminol 66	Paratherm NF	Seriola eta 32 - Total Lubmarine
Peak power	70 kW	115 kW	190 kW	85 kW
Receiver length	32 m	52 m	84 m (3 x 28 m receivers rows)	38.56 m
Working temperature	170°C	140°C	280°C	240°C

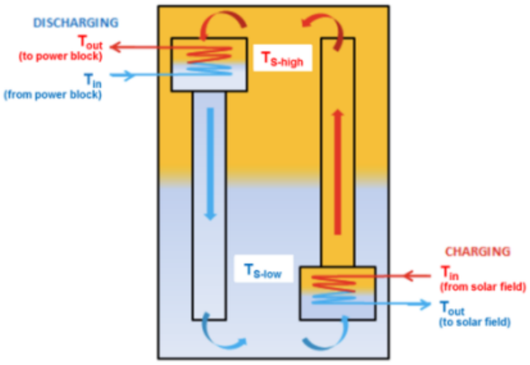
Thermal storage

	Cyprus	Egypt	Italy	Jordan
Medium	Pressurized water	Thermal oil (Therminol 66)	Ternary molten salts mixture (CaNO3 NaNO3 KNO3)	Thermal oil (Seriola eta 32 - Total Lubmarine)
Storage Volume	2.0 m^3	2.8 m^3	8 m^3	1.3 m^3
Storage capacity	100 kWh	21 kWh	400 kWh	30 kWh
Average temperature	146°C	140°C	260°C	240°C

Thermal oil tank in Jordan

Tanks at Cyl

Tank of molten salts (ARCA) and buffer of oil



Molten salts storage designed by ENEA

Absorption chillers and Power units

	Cyprus	Egypt	Italy	Jordan
Model	YAZAKI WFC-SC10	YAZAKI SH10	Broad BCT 23	Robur ACF 60-00 HT
Type	LiBr – Single effect	LiBr – Single effect	LiBr – Double effect	Ammonia – Single effect
Firing medium	Water	Thermal oil	Thermal oil	Thermal oil
Cooling capacity	35 kW	35 kW	23 kW	17.1 kW
Inlet temperature	88°C	88°C	200°C	240°C
COP cooling	0.7	0.7	1	0.6
Heating capacity		48.3 kW	23 kW	

Steam turbine at Al Balqa

Chiller at Cyl

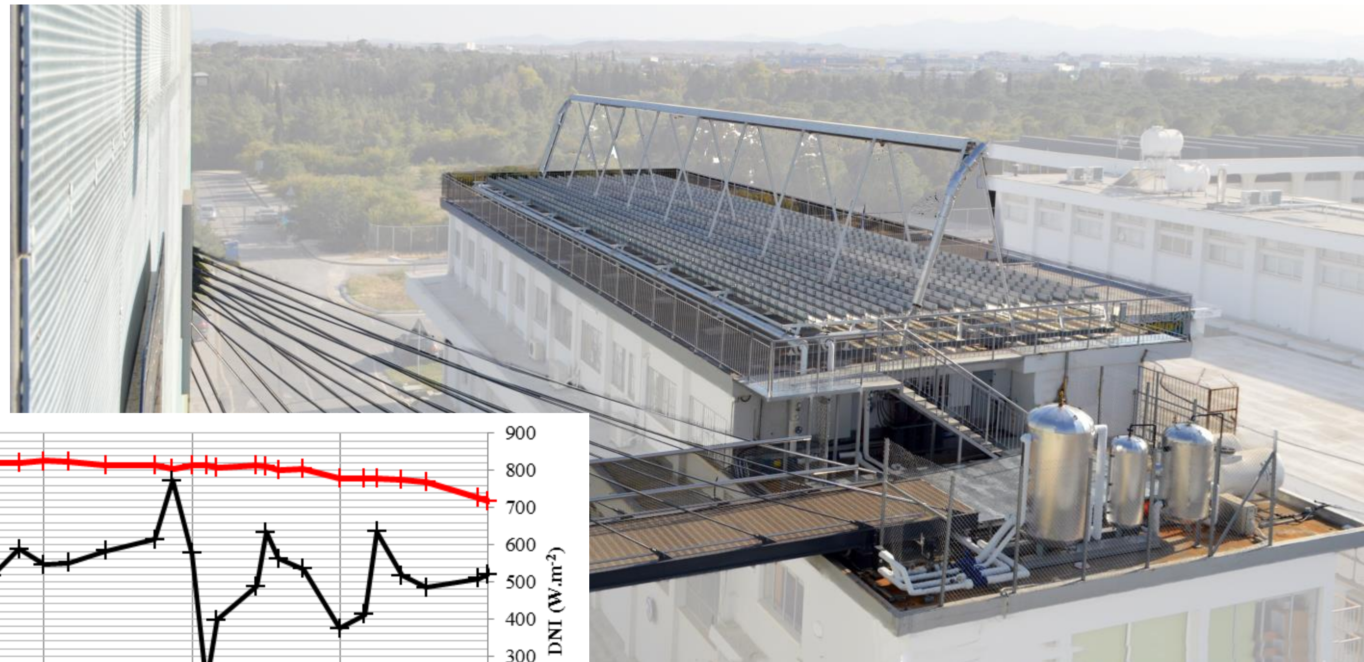
Chiller at ARCA

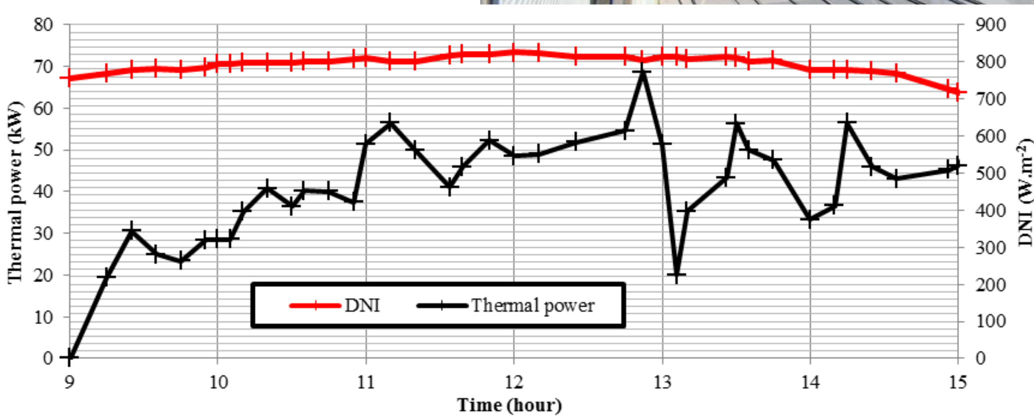
Chiller at Al Balqa

ORC at ARCA

	Egypt	Italy	Jordan
Element	ORC	ORC	Steam turbine
Electric power	4.3 kW	10 kW	1.2 kW
Medium	Thermal oil	Thermal oil	Steam

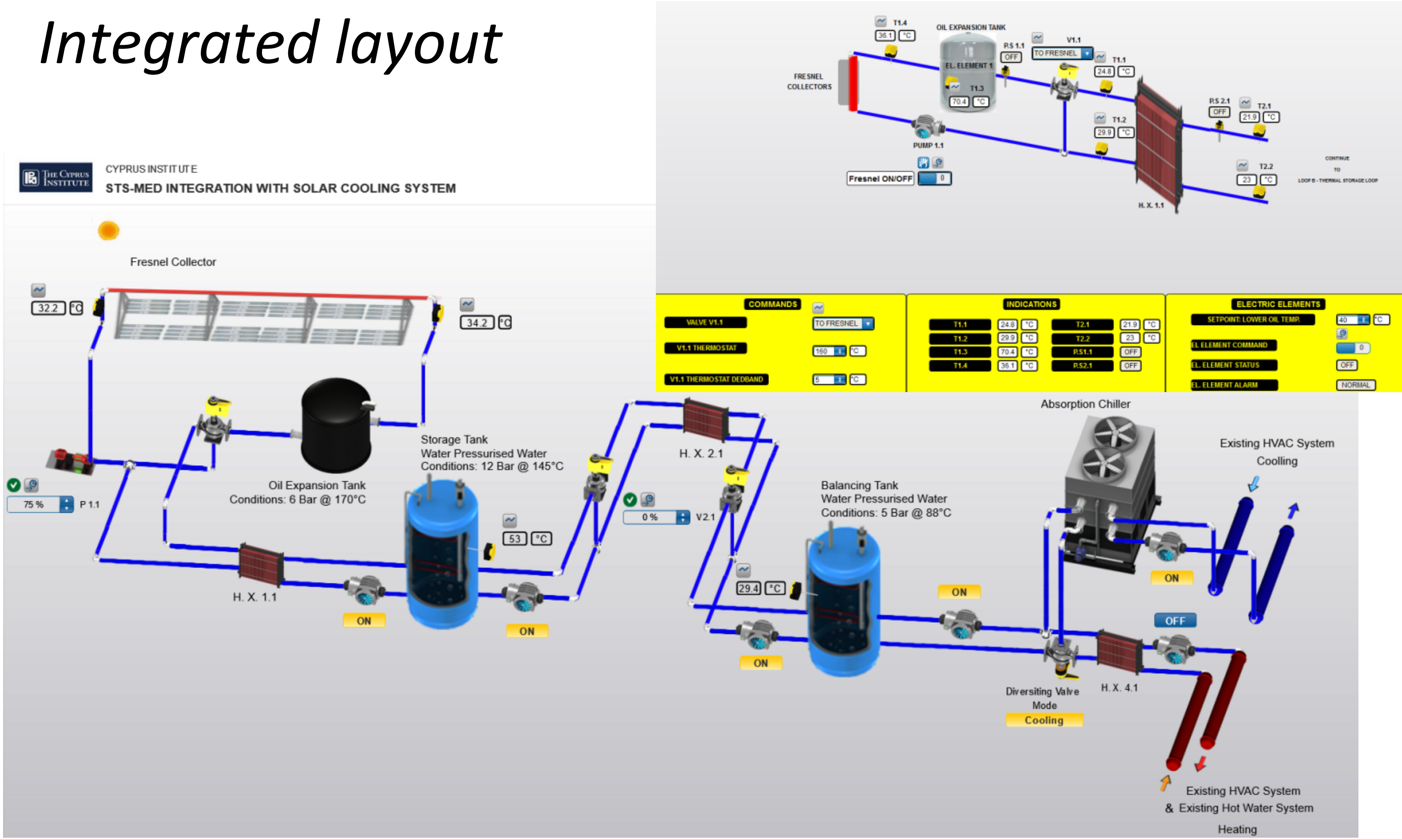
Operation of the plant in Cyprus





Thermal power and DNI on the 26th of July 2016 (CyI)

Integrated layout

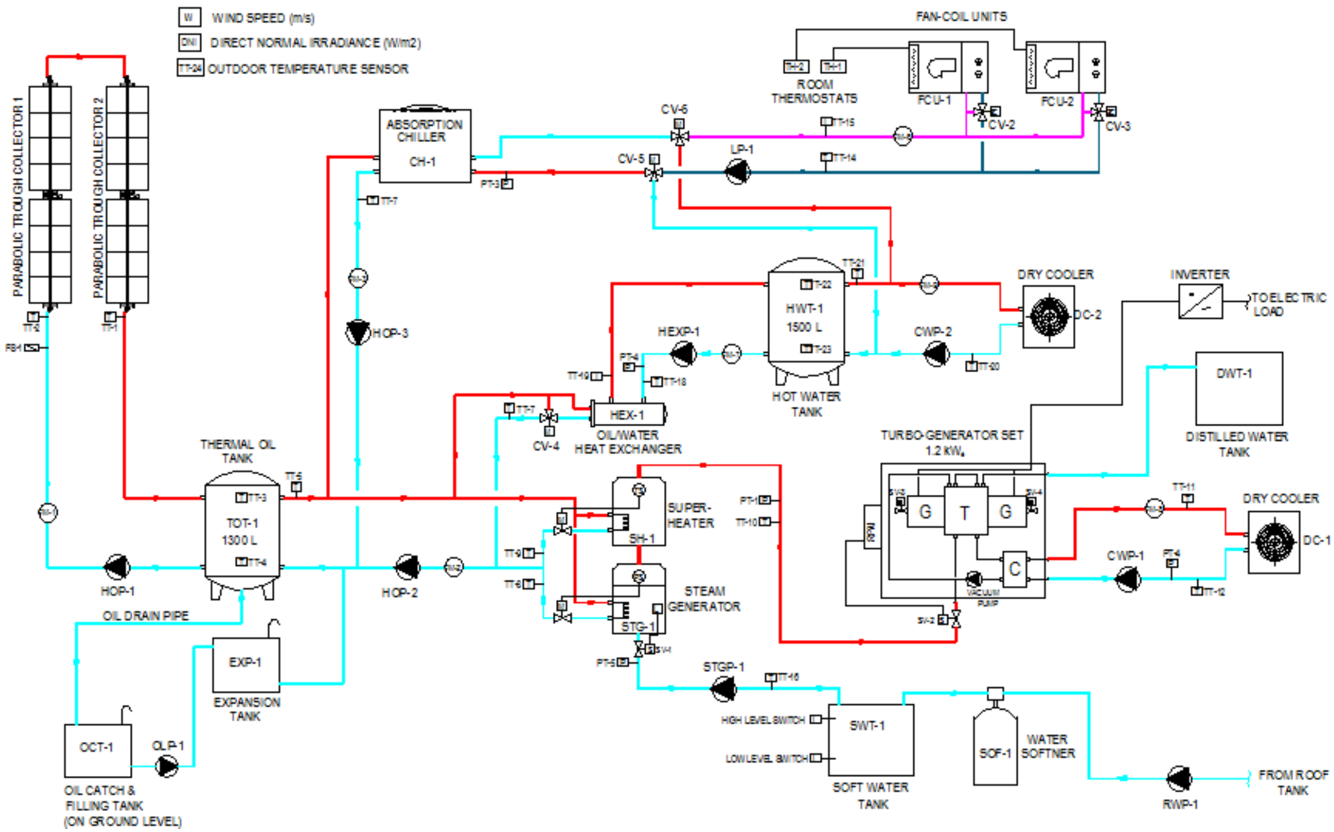


Expected performance

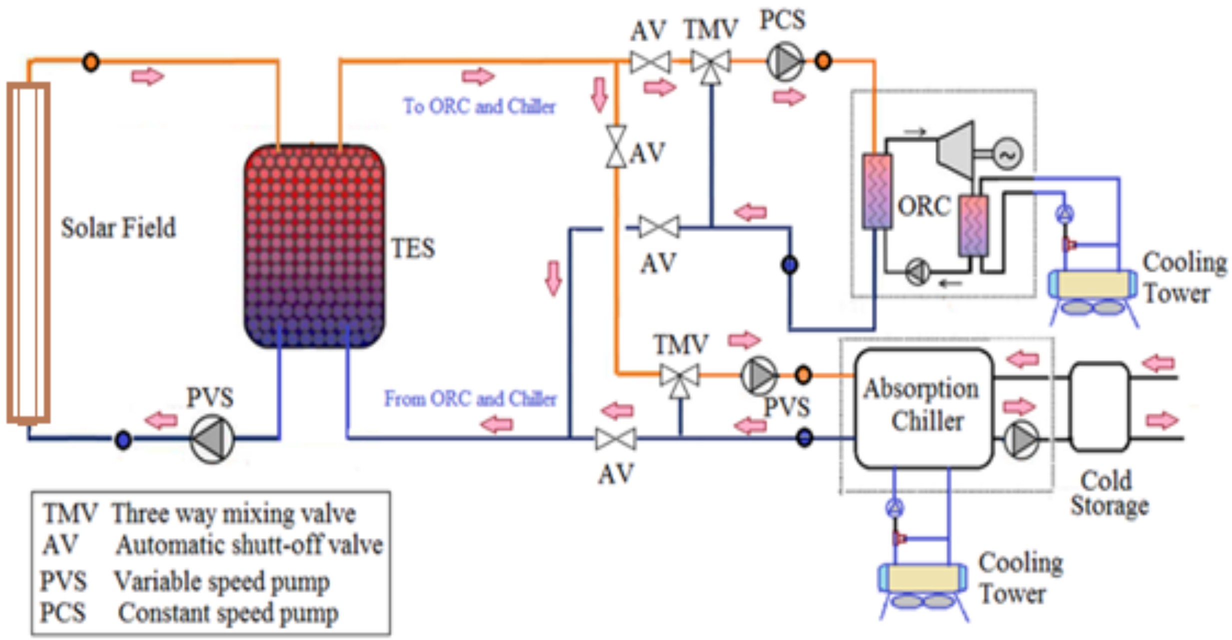
Element	Characteristics
Mirrors	288 mirrors (2,000 mm x 320 mm dimension per unit) Global aperture area of 184.32 m^2 Three focusing distances according to the position of each row 144 collecting units distributed into18 rows x 8 modules
Motorization	72 DC motors (1 for a couple of collecting units) controlled by 18 PLC/36 drivers
Receiver	32 m long Secondary reflector on top Vacuum tube receiver
Weight	8 tons distributed on 9 beams
Orientation	Receiver is aligned with the local meridian
Heat transfer fluid	White oil (Duratherm 450)
Maximum thermal power	70 kW 170°C outlet nominal temperature

	Month	Monthly SHC capacity [kWh]	Monthly HVAC thermal supply [kWh]	Building thermal needs covered by SHC [%]	Monthly HVAC electric energy consumptions [kWh]	Monthly HVAC electric energy consumptions with SHC [kWh]	Monthly SHC electric energy saving [kWh]	HVAC electric energy saving due to SHC [%]
Scenario 1 (Optical efficiency at 46%)	*January*	1,471.3	19,819.8	7.4%	6,384.8	5,949.6	435.1	6.8%
	February	2,384.2	18,785.4	12.7%	5,942.2	4,997.5	944.6	15.9%
	March	5,259.9	11,012.1	47.8%	3,374.9	2,134.1	1,240.7	36.7%
	April	6,172.6	7,743.9	79.7%	2,237.2	821.7	1,415.5	63.2%
	May	6,896.0	11,060.2	62.4%	3,151.5	1,163.0	1,988.4	63.1%
	June	7,851.7	19,320.8	40.6%	5,292.4	2,476.6	2,815.7	53.2%
	July	7,620.5	34,985.8	21.8%	8,315.0	5,966.7	2,348.2	28.2%
	August	8,580.9	34,022.3	25.2%	9,259.4	5,571.1	3,688.3	39.8%
	September	4,661.7	34,200.6	13.6%	7,968.7	6,715.0	1,253.7	15.7%
	October	3,233.4	12,927.	25.0%	3,345.3	2,782.3	563.0	16.8%
	November	1,874.7	5,446.6	34.4%	1,784.1	1,550.4	233.7	13.1%
	December	1,135.2	13,264.9	8.6%	3,943.4	3,803.1	140.2	3.5%
	Annual	***57,142.4***	***222,589.8***	***25.7%***	***60,999.3***	***43,931.7***	***17,067.5***	***27.9%***
Scenario 2 (Optical efficiency at 60%)	*January*	1,919.8	19,819.8	9.7%	6,384.8	5,743.2	641.61	10.0%
	February	3,110.6	18,785.4	16.6%	5,942.2	4,631.7	1,310.5	22.0%
	March	6,861.8	11,012.1	62.3%	3,374.9	1,634.6	1,740.2	51.5%
	April	8,052.0	7,743.9	104.0%	2,237.2	210.6	2,026.5	90.5%
	May	8,995.7	11,060.2	81.3%	3,151.5	305.2	2,846.2	90.3%
	June	10,242.1	19,320.8	53.0%	5,292.4	1,353.1	3,939.3	74.4%
	July	9,940.4	34,985.8	28.4%	8,315.0	4,991.8	3,323.1	39.9%
	August	11,193.3	34,022.3	32.9%	9,259.4	4,144.5	5,114.9	55.2%
	September	6,081.2	34,200.6	17.8%	7,968.7	6,115.8	1,852.9	23.2%
	October	4,218.1	12,927.0	32.6%	3,345.5	2,415.9	929.4	27.7%
	November	2,446.1	5,446.6	44.9%	1,784.1	1,354.8	429.3	24.0%
	December	1,481.7	13,264.9	11.2%	3,943.4	3,687.5	255.8	6.4%
	Annual	***74,543.2***	***222,589.8***	***33.5%***	***60,999.3***	***36,589.2***	***24,410.1***	***40.0%***

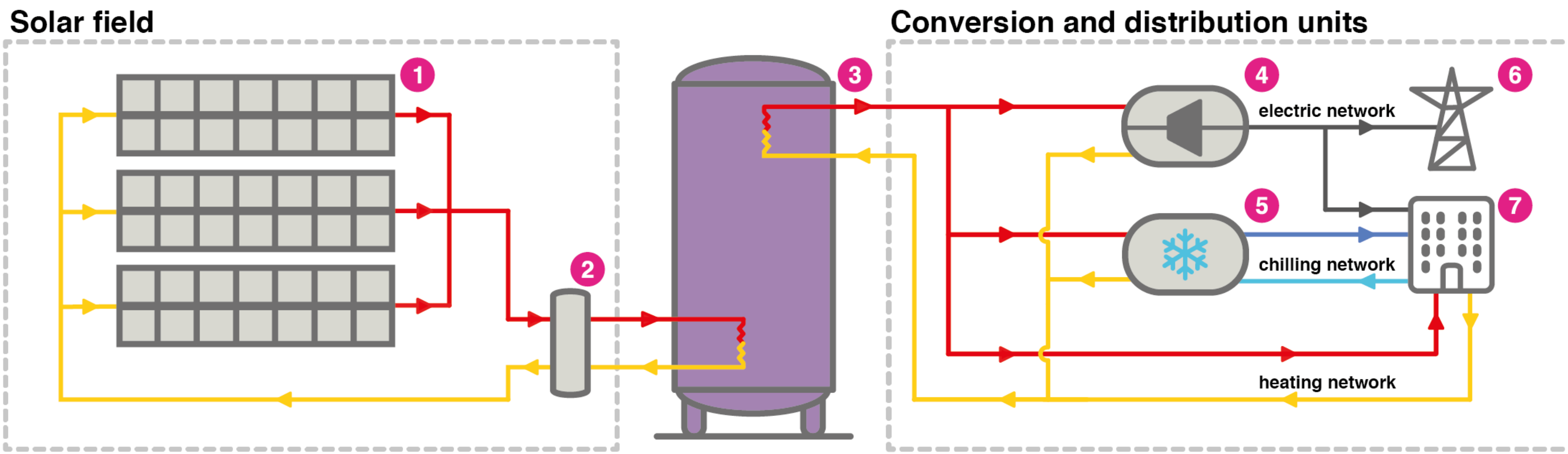
Layout in Jordan



Layout in Egypt

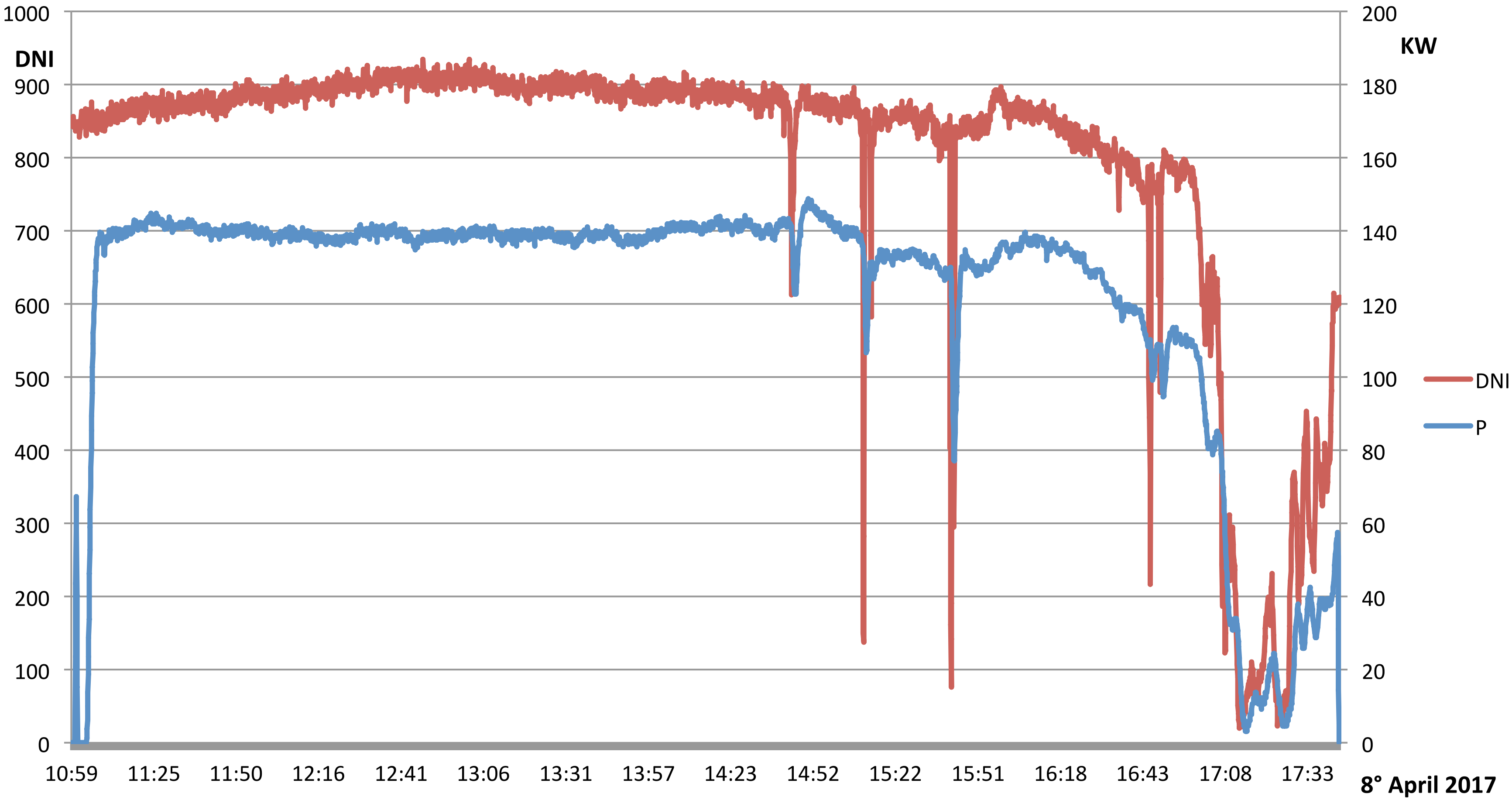


Layout in Palermo



1. Linear fresnel reflectors
2. Nitrogen pressurized expansion vessel
3. Thermocline molten salts storage
4. ORC turbine
5. Absorption chiller
6. Public electricity grid
7. Final users

The LFR solar field in Palermo



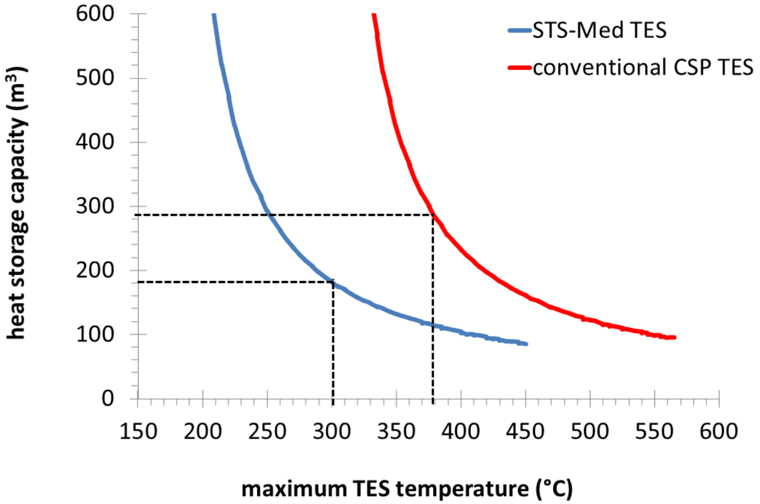
The oil thermal loop

- The plant should reach a peak thermal power in July of 230 kW.
- The annual estimated thermal energy production is about 310 MWh.
- The three collectors are connected in parallel in three corresponding oil loops, each with an inverter pumps (10 m^3/h each) managed by an appropriate algorithm of speed control relying upon dedicated flow meter sensors.
- The oil is heated by the solar field up to a nominal temperature of 270°C. For the regulation of the thermal energy balance a 800 litres oil puffer tank is employed both as expansion vessel and as a dumper of the temperature fluctuations in the outlet oil.
- Electronic two-way valves modulate the thermal energy into the heat exchangers according to the available energy from the solar field.

The molten salts TES in Palermo

- The approach is stems from the CSP industry, where TES systems commonly make use of “solar salts” (molten nitrates mixture $NaNO_3/KNO_3$ 60/40 w/w), in two-tanks heat storage system operating from 290°C (cold tank) to 380°C (hot tank) when oils are used as HTF in the solar field.
- In smaller plants (as the SHCs) it is rather difficult to replicate such a complex scheme. This is partially due to the lower temperatures and to the need of expert personnel to manage molten salts loops. Therefore, an innovative TES system has been specifically developed in STS-Med project. This system is still based on the use of molten salts, but the management of the TES is eased.

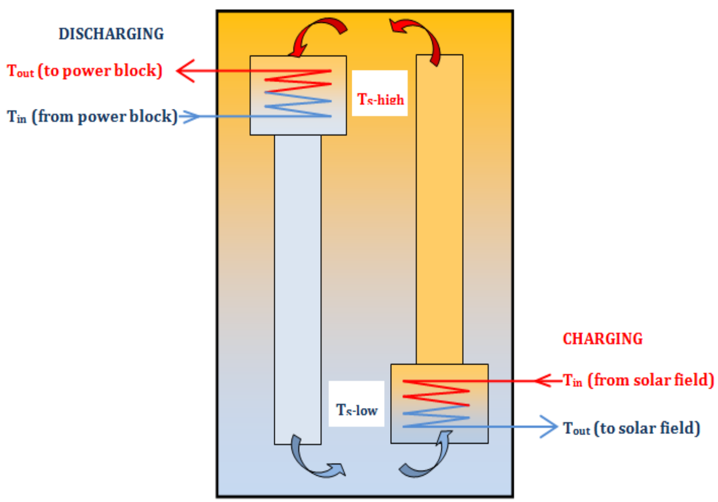
- A different salt with much lower melting temperature is applied, consisting of the eutectic ternary mixture $CaNO_3/NaNO_3/KNO_3$ (42/15/42 %w).

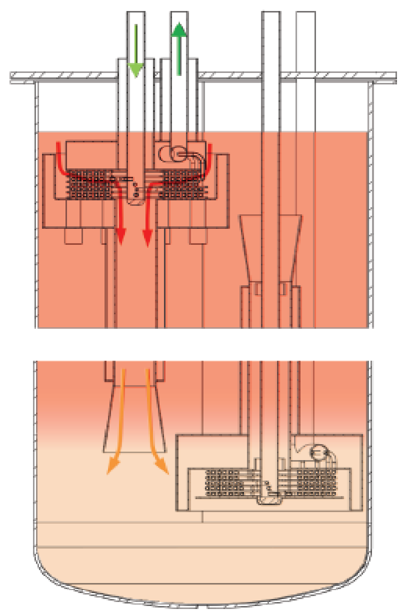


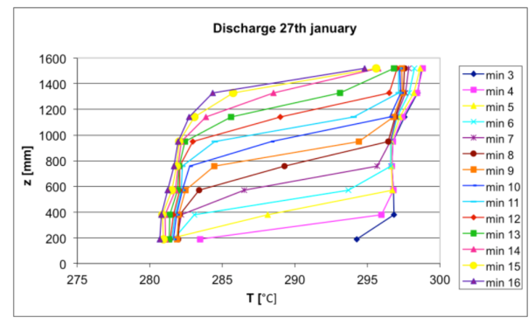
- While the typical binary mixture has a melting temperature around 220°C, this mixture is characterized by a melting temperature around 120°C. Hence, the temperature range is much more compatible with SHC applications.

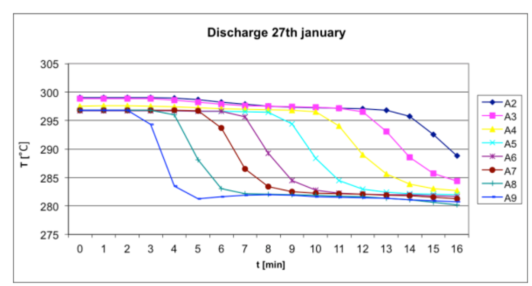
- The two-tank TES is replaced by a single-tank system avoiding the external pumping of the molten salts and the management of molten salts pipelines. Charging and discharging are achieved inside the single tank where given temperature gradients and molten salts circulation are easily determined, therefore, besides lower equipment volume and cost reduction potentials, the plant operator should not take much care of pumping and managing molten salts flows.

- The operation concept is based on the properties of unmixed molten salts in the tank to stratify in temperature along the vertical axis, as an effect of their low thermal conductivity and the density variability with temperature.
- Two helicoidally shaped heat exchangers are placed on the top and bottom of the tank, immersed in the molten salt. The heat exchangers are integrated within two corresponding oil loops, designed to remove and supply the heat in the temperature range of 150-400°C. The working principle is based on the thermal stratification of the molten salt resulting from the heat exchange in the two coils during the charge and/or discharge phases.









- After the concept validation on a prototype built in ENEA (Rome) with an inner volume of 0.9 m^3 , the design has been up-scaled for the demonstration plant in Palermo.
- Specifically, further optimizations and improvements have been made in this version to work in a thermal range of 160-260°C.
- It is characterized by an inner volume around 8.0 m^3 (1.8 m diameter, 4 m height) corresponding to effective heat capacity of about 400 kWh (thermal).
- The charging/discharging thermal power is in the order of 250/125 kW (thermal).
- The tank has been insulated with a 20 cm coating of rock wool.

Planned developments

- Certification of the LFR performance
- Optimization of LFR cost
- Greenhouse/solar canopy integrated design
- Optimization of TES cost and performance
- Integrated control system
- Scale-up projects
- Testing triple-effect
- Hybridization with solar/gas

Thank you!