Monitoring and energy performance assessment of the compact DEC HVAC system "freescoo facade" in Lampedusa (Italy)

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Abstract

This work addresses the energy performance of a solar DEC HVAC system working with the freescoo technology coupled with DHW tank for hot water preparation. Freescoo is a patented solar air conditioning concept for ventilation, cooling, dehumidification and heating of buildings for residential and tertiary sectors.
The work presents monitoring results of a system installed at the ENEA Research Center in Lampedusa island. The monitoring of the system started in 2017 and here results for cooling operation are presented. Global seasonal electrical COP of about 10 have been registered.

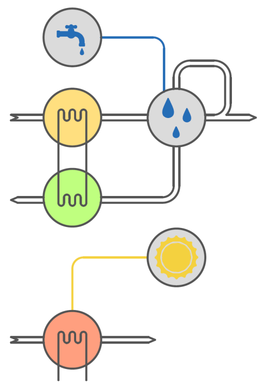
Keywords: compact DEC system, freescoo;

1. Description of the system

In the framework of a project between the Italian Research Institution ENEA and the University of Palermo, novel and efficient HVAC systems have been investigated with the aim to reduce power absorbed and electricity consumption for cooling in small islands such Lampedusa in Sicily.

In this work, the energy performances of a solar DEC HVAC system working with the freescoo technology coupled with DHW production have been investigated.

The operation of the system in summertime can be described as following:



- Outside air (high humidity and high temperature) is drawn through an innovative cooled packed adsorption bed to be strongly dehumidified
- Afterwards the air is cooled down in an indirect evaporative cooling heat exchanger without increasing its humidity
- When the adsorption material gets saturated, solar heat is used for its regeneration (50-60°C)
- The adsorption heat is rejected to the ambient using an internal rejection heat exchanger

The system investigated has a maximum air flowrate of 500 m^3/h, rated cooling power of 2.5 kW and can be operated in ventilation mode (350 m^3/h of fresh air) or in partial recirculation mode (typical 40-60% of fresh air and 60-40% of recirculated air flow rate). Design supply air conditions in summertime are 19-21°C and 8-11 g/kg of humidity ratio with ambient conditions of 35°C and 16 g/kg.

In the wintertime, the system can provide heat recovery and heating to the room when the sun shines. The system is driven by three X-RAY10 evacuated tube collectors by Pleion connected in series and needs about 200 W of power for driving fans and small pumps. Solar heat is also used to prepare DHW in a 300 lt tank connected in series to the freescoo HVAC. This permits to take advantage of higher regeneration temperatures of the desiccant and higher efficiency of the solar collectors. In case of no need for regeneration, solar heat is used only for DHW.

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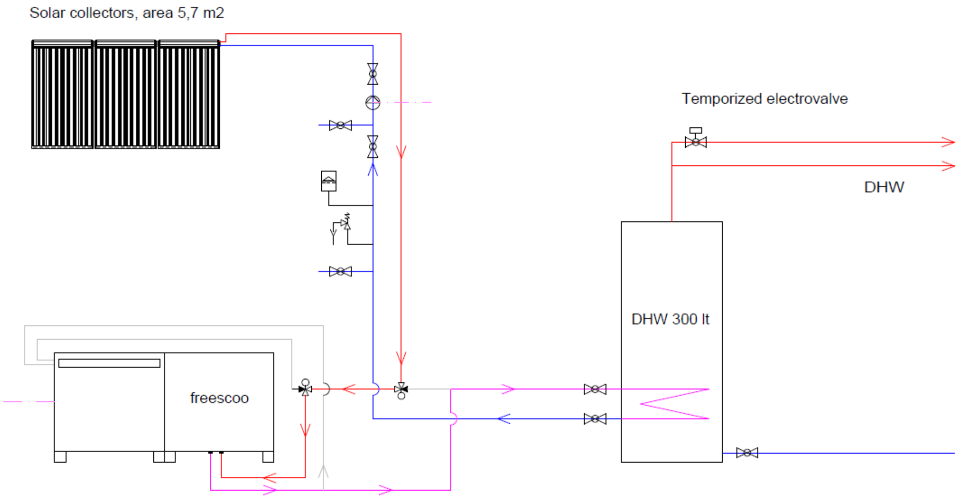

Fig. 1: Scheme of the freescoo system for air conditioning and DHW production

Main system parameters and performance characteristics are summarized in the table 1 while a simple sketch of it is shown in figure 1.

Tab. 1: Main characteristics of the system and rated performance at design summer conditions ($T_{ambient}$ = 35°C $x_{ambient}$ = 16 g/kg, $T_{building}$ = 27°C $x_{building}$ = 10.5 g/kg)

Description	Value	Unit
Volume of the conditioned space	140	[m^3]
Supply air flow rate	0-500	[m^3/h]
Rate of fresh air	30-50	[%]
Total max cooling power	2.5	[kW]
Heating power required for the regeneration	2.5	[kW]
Max Power absorbed	200	[W]
Rated EER for cooling	12.5	[-]
Solar collector area	3 x 1.91	[m^2]
Installed solar collector power (including DHW production)	3.6	[kW]
Volume of DHW storage tank	300	[lt]

For more detailed descriptions of the working principle of the freescoo concept, please refer to previous works of the same authors (Finocchiaro P, et al. 2013, 2014, 2015). Figure 2 shows some picture of the components installed at Lampedusa.

Fig. 2: Picture of the freescoo system for facade integration monitored at ENEA Research Center in Lampedusa

2. Results and discussion

In order to assess the cooling energy performance of the system, an extended monitoring campaign has been performed from June to the end of August 2018. In the following pages, 23 days of operation during August of 2018 will be presented and analysed.

Various measurements of temperature (accuracy ± 0.3°C), humidity (accuracy ± 2.5% of measured value), air velocity (at supply, return, adsorption beds), accuracy of ± (0.5 m/s + 3% of measured value), electricity consumption (accuracy ± 0.5%), solar radiation (2° class according to ISO9060), and water flowrates (accuracy ± 3%) have been conducted at inlet and outlet of the main components. Data acquisition has been performed with a time step of one minute, using the GPRS 2 16-bit acquisition platform from SENECA together with 4 x 8 input analogue modules and 4 x RTD modules. Energy performances have been evaluated according to the monitoring procedure for solar cooling systems developed by the Task 38 and 48 of the International Energy Agency experts.

In the first graph (figure 3), ambient conditions for one selected day of operation are reported. Mean daily temperature and humidity ratio registered are respectively 29.8 °C and 15.5 g/kg with peaks over 32°C and 17 g/kg. Solar irradiation is high reaching 7 kWh/m^2 on the collector plane.

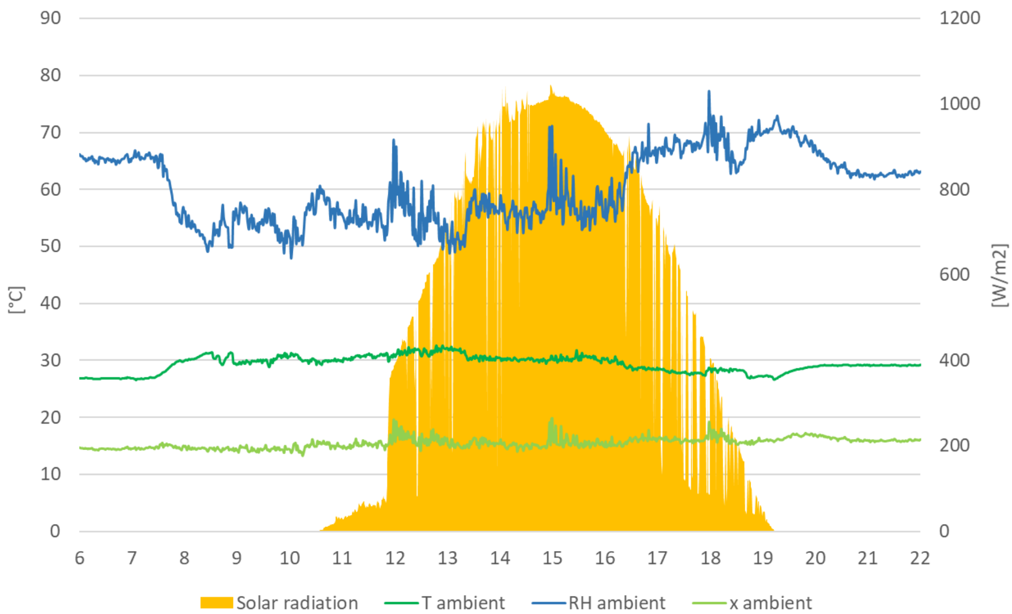

Fig. 3: Ambient conditions for the presented day of operation – Day 17

The behaviour of the system under these conditions is described in the pictures below. In particular, Fig. 4 describes temperature and humidity ratio profiles in the building, at the outlet of the adsorption bed and at the supply point.

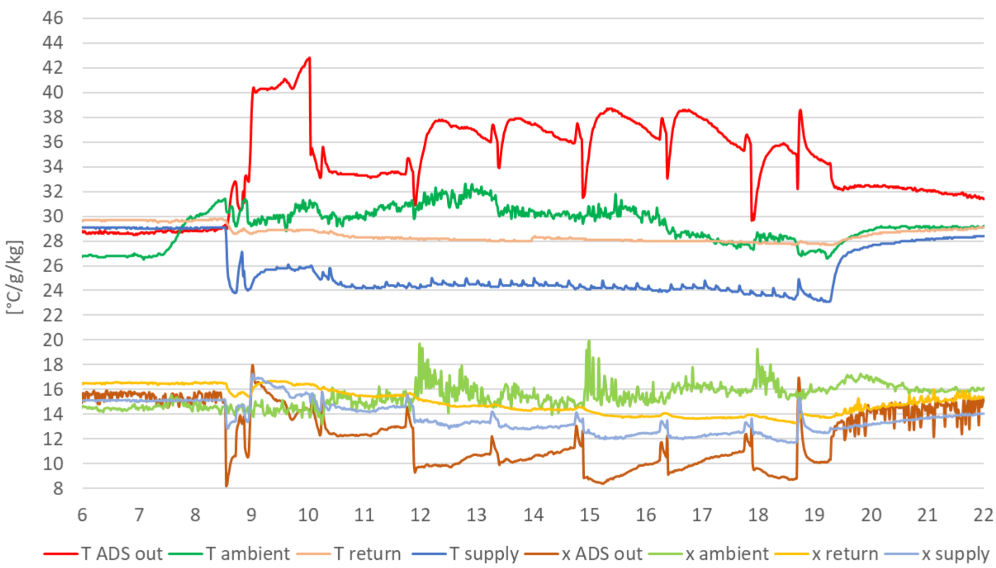

Fig. 4: Temperature and humidity ratio for one day of operation – Day 17

In Fig. 5 instantaneous energy performances such as cooling power, electricity absorbed, and thermal energy used for regeneration and DHW preparation are depicted. It can be noted that, with these conditions, the system has maximum continuous cooling power of about 1.9 kW with only some peaks over 2 kW. Power absorbed is quite constant and about 180 W. Although the cooling power of the system is reasonably high, it can be clearly noted that temperature in the building cannot be maintained at comfort level (Fig.4). This was due mainly to the building cooling loads which are higher than expected and at a lower rate to the lower cooling performance of the system.

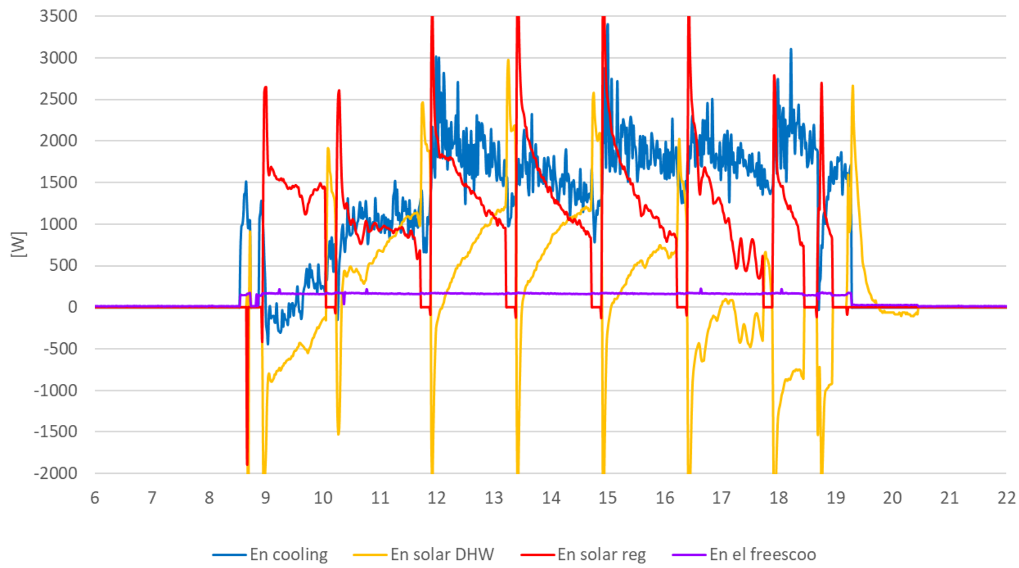

Fig. 5: Energy performance for one day of operation – Day 17

Energy efficiency ratio range mainly from 8 to 12 whereas thermal COP of the desiccant cycle is normally higher than one with some peaks over 2 as reported in Fig. 6. In the calculation of the thermal COP, only the solar heat used for the regeneration has been considered, whereas for the EER the whole cooling energy, including the ambient air handling process, has been considered.

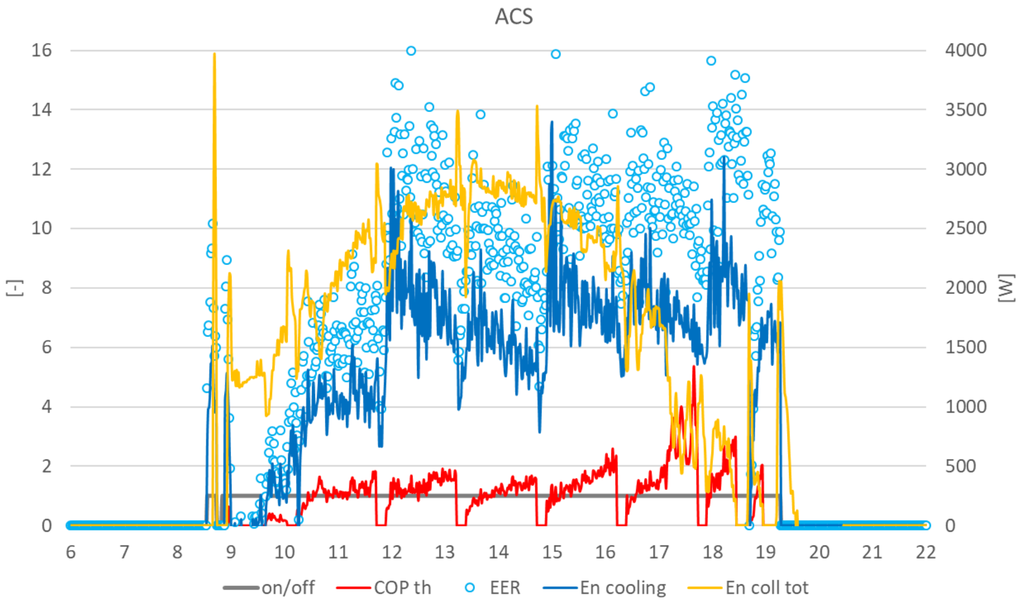

Fig. 6: Temperature and humidity ratio for one day of operation – Day 17

Main energy performance results also including DHW preparation are summarized in the table below for the considered day of operation. Results clearly show the good efficiency of the air handling process, even if it can be stated that there is a lack of performance in terms of cooling power. With these conditions, the adsorption beds are indeed not able to dehumidify enough the air stream before the air enters the indirect evaporative process. This causes a lack of sensible cooling power at the outlet of the HVAC unit.

Tab. 2: Monitored daily performance of the HVAC + DHW for one day – Day 17

Description	**Value**	**Unit**
Cooling energy – due to air handling	15.1	[kWh]
Cooling energy – to the building	10.3	[kWh]
Incident solar radiation	41.1	[kWh]
Solar collector heat	19.9	[kWh]
Electricity consumed	1.9	[kWh]
Total water consumption for cooling	26.8	[l]
Total hours of operation	10.6	[h]
Total DHW consumption	155	[l]
Global electrical COP (HVAC + DHW)	10.7	[-]
EER (freescoo HVAC)	7.9	[-]
COP th (freescoo HVAC)	1.3	[-]
Solar collector efficiency	48	[%]

In the following pages, longer-term energy performances will be presented (23 days of operation). In these days the system has been operated for about 10 hours but under different control conditions. In order to test the behavior of the adsorption beds, different flow rates and ratio between ambient and recirculated air flows have been investigated. In particular, from day 6 to day 15 the system has been operated at half of the nominal flow rate.

It can be noted how the cooling energy delivered is strongly dependent by the humidity ratio of the considered day of operation. For example, considering the days from 16 to 23, the cooling energy line is almost opposite to the one of the humidity ratio. This is due to the fact that, in correspondence to very humid air conditions, system performances fail since the adsorption bed are not able to sufficiently remove the moisture from the ambient air. As result, the indirect evaporative cooling process can only be operated at high wet bulb temperatures and the supply temperature rise then in the range of 24-27°C. The cooling performances are also influenced by the solar heat collected and used for the regeneration of the desiccant. For example, in day 8 the system has a poor performance mainly due to a combination of lack of regeneration heat and high humidity ratio of the ambient air. The dependence from the ambient temperature is indeed less strong. The best performance is reached at day 4 where the system delivers up to 20 kWh of cooling energy.

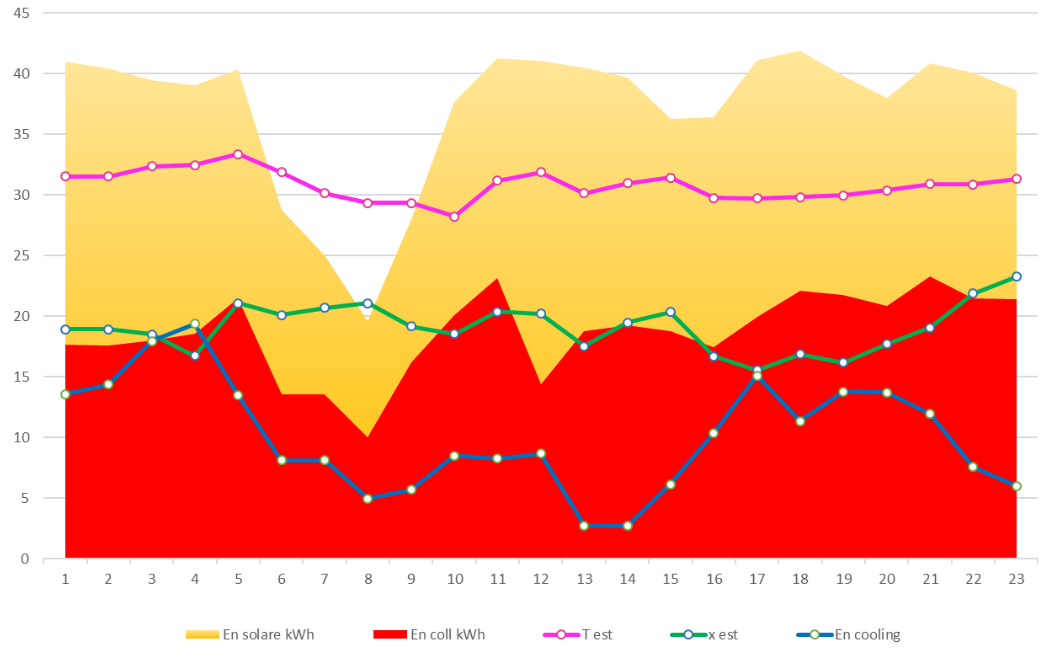

Fig. 7: Ambient conditions for the considered days

More detailed information are also reported in Fig. 8 where EER, efficiency of the solar collectors, and global electric COP are also depicted. Global electric COP is calculated as the sum of cooling energy delivered and heat for DHW divided by the total electricity consumed.

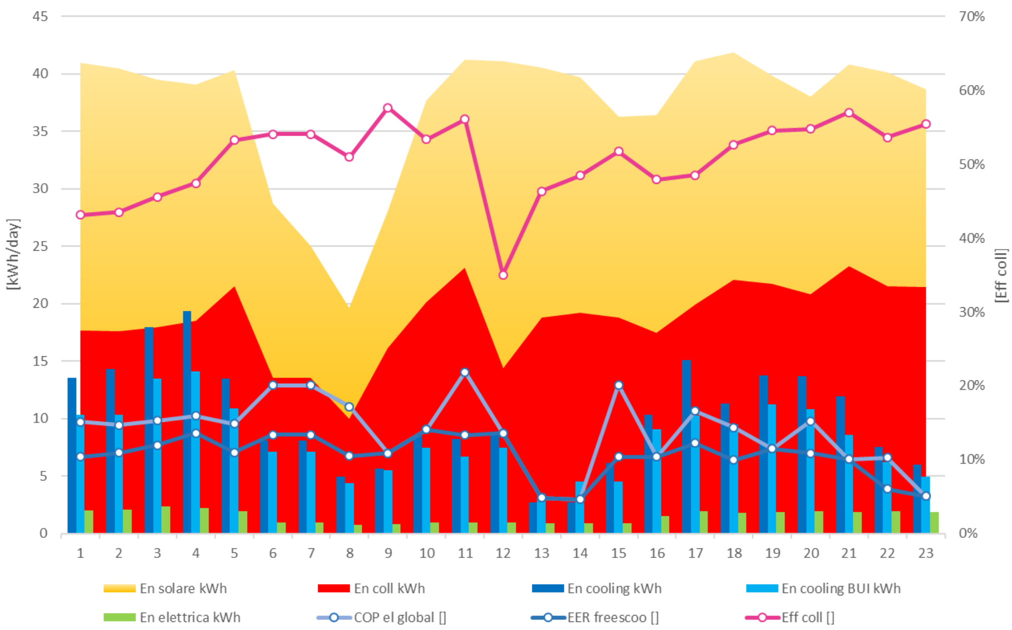

Fig. 8: Energy performance of the freescoo HVAC + DHW preparation for the considered days

Fig 9. describes the heat distribution between DHW preparation and the regeneration of the adsorption beds in the freescoo HVAC together with the heat losses of the circuit and DHW tank. The average share for the regeneration of the desiccant amounts to 46% of the total heat produced by the solar collectors, 24% is used for DHW preparation and about 30% are lost in the ambient. With this regard, it has to be noted that the instantaneous flow rate of DHW could be controlled automatically according to a given profile with an average daily consumption of about 150 liters and in some days it was decided to have no DHW consumption.

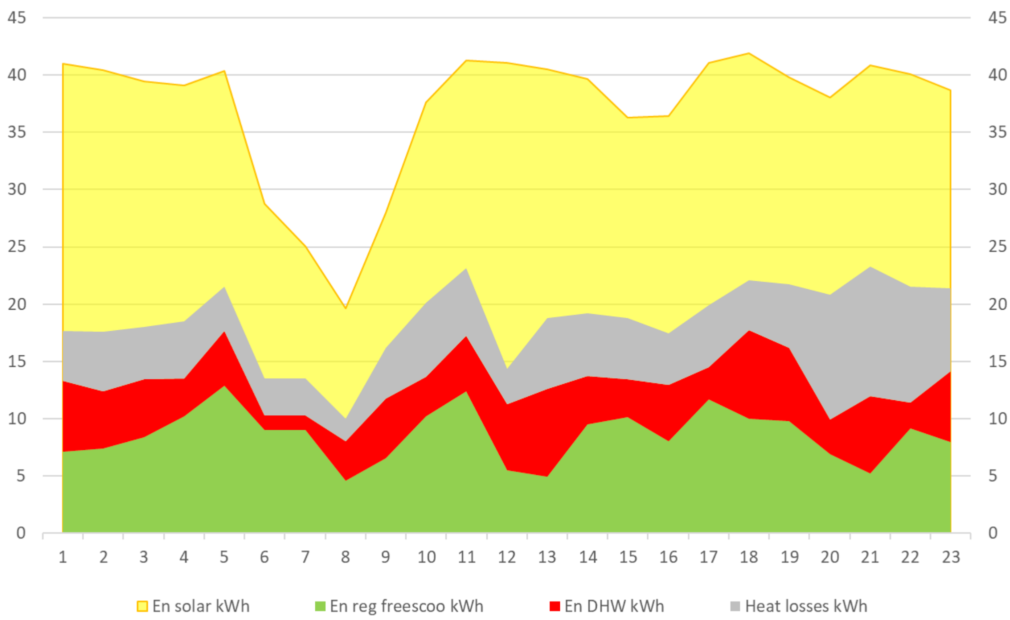

Fig. 9: Temperature and humidity ratio for one day of operation

Delivered hot water temperature at the outlet of the tank ranged from 50 to 60°C whereas the entering water temperature was in the range of 24-26°C.

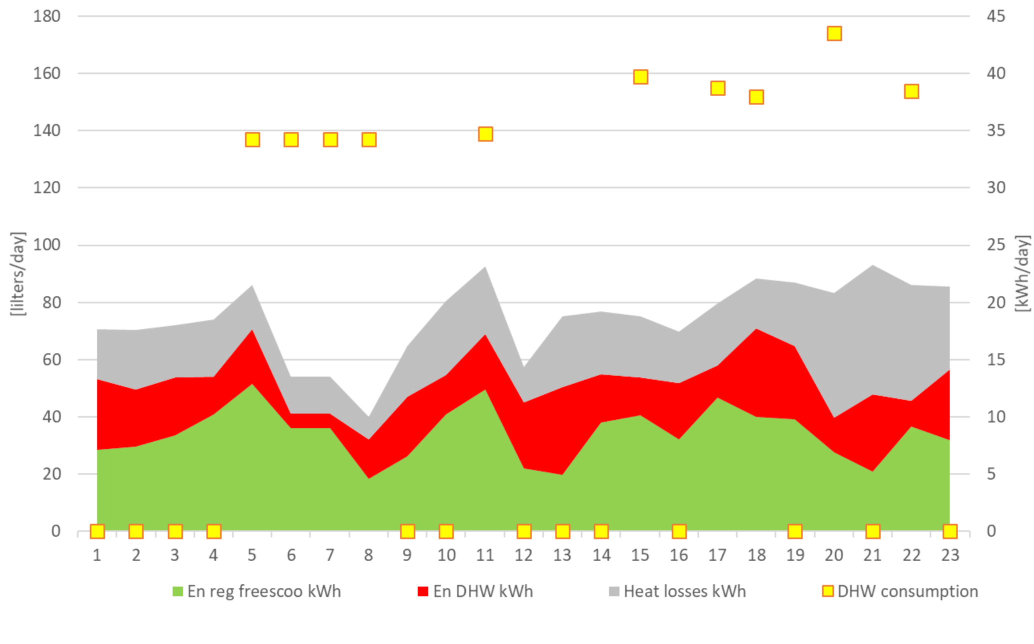

Fig. 10: DHW consumption in liters/day

In Tab.3 global performance results are reported.

Tab. 3: Global performance results for the considered days

Description	Value	Unit
Cooling energy – due to air handling	232	[kWh]
Cooling energy – to the building	188	[kWh]
Incident solar radiation	855	[kWh]
Solar collected heat	429	[kWh]
Solar heat used for regeneration of the desiccant	197	[kWh]
Solar heat used for DHW preparation	105	[kWh]
Electricity consumed	34	[kWh]
Total water consumption for cooling	450	[l]
Mean daily water consumption	19.5	[l/day]
Total hours of operation	230	[h]
Mean daily hours of operation	10	[h]
Total DHW water consumption	1480	[l]
Global electrical COP (HVAC + DHW)	9.8	[-]
EER (freescoo HVAC)	6.8	[-]
COP th (freescoo HVAC)	0.96	[-]
Solar collector efficiency	50.2%	[-]

3. Conclusions

In this work the energy performance of a DEC HVAC working with the freescoo concept and coupled with DHW preparation has been presented. The system has been monitored in summer cycle, showing good results in terms of high energy saving potential with global COP of about 10. However, a lack of cooling performance has been also registered mainly due to the extreme humid ambient conditions of Lampedusa island.

Under these conditions, the adsorption process is not able to efficiently dehumidify the air stream before the air enters the indirect evaporative process, this causing supply temperatures not sufficiently low to meet the sensible loads of the building.

4. Acknowledgements

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5. References

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