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Second generation of freescoo Solar DEC prototypes for residential applications

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Abstract

Freescoo is an innovative all-in-one compact solar Desiccant Evaporative Cooling (DEC) air conditioner concept. Results of the first prototype developed were presented at SHC Conference last year. Now a second generation of *freescoo* prototypes for applications in residential and small office buildings have been installed in Italy at ENEA Casaccia and at UNIPA.
The thermodynamic cycle is based on the use of fixed and cooled adsorption beds and advanced evaporative cooling concepts. The adsorption bed, which is a fin and tube heat exchanger packed with silica gel grains, allows simultaneous dehumidification and cooling of the process air. The indirect evaporative cooling process, operated downstream to the dehumidification, is realized using an optimized configuration with two wet plate heat exchangers connected in series. Low wet bulb temperatures reached on the secondary flow, allow supply air temperatures to the room below 20°C.
Systems are designed also for stand-alone operation thanks to a battery accumulator and PV cells installed. No auxiliary device is used for cold production.
The main features of the second generation prototype system are first discussed, as well as some optimizations carried out from the first to the second generation prototype. Results are related both to field monitoring data. Performance indicators such EER and thermal COP, maximum cooling power achieved, stand alone operation data and control issues are presented and discussed.

Keywords: freescoo, compact Solar DEC, Adsorption fixed and cooled bed, stand-alone operation;

1. Introduction

Nowadays DEC systems are present on the market only for medium scale air conditioning applications. This is due to the fact that the concept which large DEC units are based on is not suitable for small scale applications in terms of costs, space and restrictions related to the installation of a centralized air system [4].

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The dehumidification of air based on the adsorption process is commonly carried out using desiccant rotors impregnated or covered by adsorption material (i.e. silica gel or lithium chloride). The component is crossed at the same time by the regeneration and dehumidification stream, to guarantee operation continuity of the air conditioning unit. However adsorption process realized by means of desiccant rotors presents the disadvantage of causing a temperature increase of the desiccant material. This phenomena is caused by the release of adsorption heat due to water condensation in the desiccant material and by the carry-over of heat stored in the desiccant material from the regeneration section to the process section. An increase of the desiccant material temperatures is responsible for lower dehumidification capacity and higher regeneration temperatures required, with a consequent negative impact on the overall system performance [5]. Moreover, with the desiccant rotor technology is not possible to store adsorption capacity into the desiccant material since rotors host only low mass of adsorbent.

In this work, the new *freescoo* all-in-one compact solar air conditioner concept is presented. In this concept, some limits of the adsorption technology based on desiccant rotors can be overcome using the fixed and cooled desiccant bed solution.

Nomenclature

ADS	Adsorption	P	Power
BUI	Building	PV	Photovoltaic
COP_{th}	Thermal Coefficient of Performance [-]	PVT	Photovoltaic/thermal
EER	Energy Efficiency Ratio [-]	Rad	Solar radiation [W/m^2]
h	Specific Enthalpy [kJ/kg°C]	T	Temperature [°C]
HX	Heat Exchanger	RH	Relative Humidity
MR	Mass ratio [-]	x	Humidity ratio [g/kg]

2. Description of the systems

An innovative patented compact solar air conditioning system is here presented. The system was developed by the Italian company Solarinvent srl and is designed for ventilation, dehumidification and cooling purposes in residential and office sectors. In the wintertime, if solar radiation is available, warm air can be delivered to the building. System can be configured to be installed both on flat and sloped roofs, but the design for facade integration is also possible.

Systems are basically composed by a casing which comprises a solar PVT air collector, two adsorption beds, an integrated cooling tower, two plate wet heat exchangers, fans, batteries and all other auxiliaries needed to realize the air handling process also in stand-alone operation.

The fixed and cooled packed desiccant beds, each containing about 13 and 25 kg of silica gel in grains respectively for the smaller and bigger machine, are operated in a batch process. Thanks to the high amount of desiccant used, the bed can be used as open solid sorption storage. This permits that solar energy can be stored in the desiccant media in terms of accumulated adsorption capacity. With this solution, when solar energy is no more available but dehumidification demand occurs, the operation of the system can be guaranteed. A system of air dumpers provides the commutation between the two beds in order to guarantee a continuous dehumidification process. The adsorption heat generated in the desiccant bed during the dehumidification process is rejected to the environment by means of the integrated cooling tower. As well known, this will increase the adsorption performances of the desiccant, permitting a better exploitation of the physical properties of the material. A more detailed explanation of the thermodynamic cycle of the system can be found in previous works [1], [2], [3].

Two different configurations of the concept are discussed below, one having a total flow rate of 500 m^3/h and a collector surface of 2.4 m^2 and the other having a flow rate of 1000 m^3/h and 4.8 m^2 of collector surface. The maximum total cooling power is 2,7 and 5,5 kW at standard summer conditions respectively for the smaller and larger machine ($T_{outside}$ = 35°C, $RH_{outside}$ = 50%, T_{bui} = 27°C, RH_{bui} = 50%). Cooling power can be controlled through variable speed fans.

Fig. 1. Freescoo prototypes installed at ENEA research centre (left) and at University of Palermo (right)

System integrates a solar PVT air collector which provide the heat for the regeneration of the desiccant material. Peak power of the PV cells is about 170 W for one module. Two batteries are used to accumulate electricity produced from PV, which are 65 Ah and 100 Ah respectively in the small and larger machine. If solar PV electricity is not sufficient to drive the system, systems commutates automatically to the grid. All electric components are 24DC driven, this permitting a direct connection with the PV/batteries controller, without the use of DC/AC converters. The rooms which systems are connected with have in both cases an area of about 46 m^2. The volume of the room chosen for the installation at ENEA Research Center is 135 m^3, whereas for the room at University of Palermo is about 190 m^3. It is worth to be noted that for the installation at ENEA an occupation profile of a small teaching room was assumed to design the machine. That's the reason for a double volume air flow rate in respect to the other case. In both rooms auxiliary cooling device are installed. Referring to that, it is important to outline that the monitoring of the systems was aimed to assess the energy performances of the machine itself, with minor interest on the influence on the building.

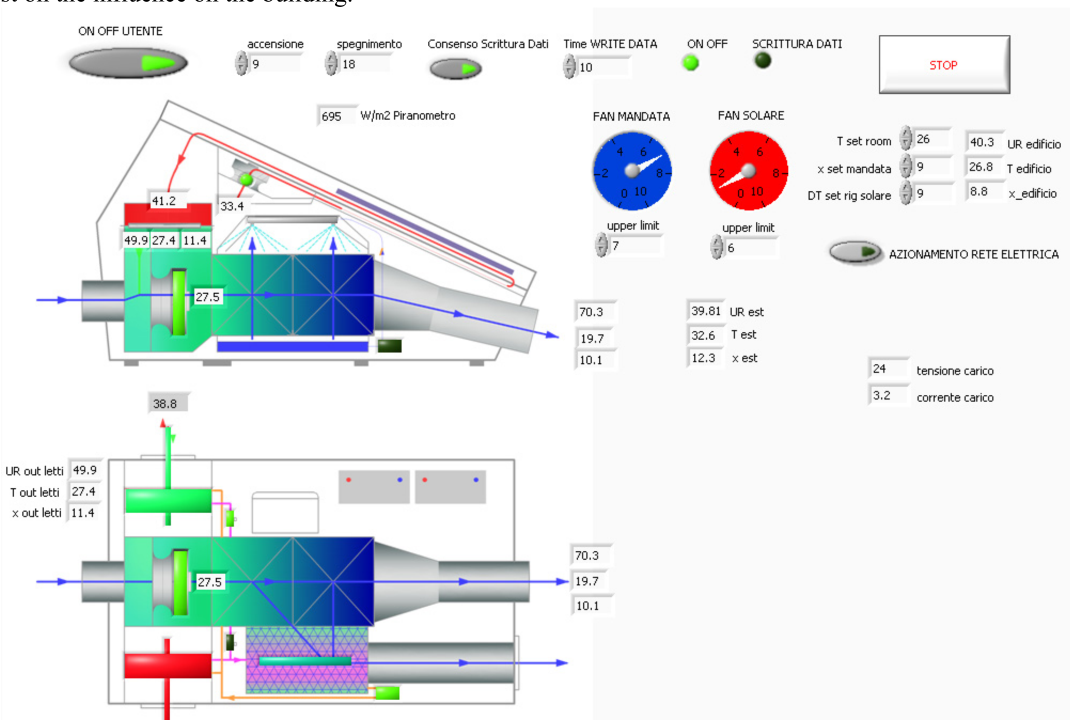

Fig. 2. Control panel developed in Labview for the freescoo prototype at University of Palermo

During test rooms were occupied as normally. At ENEA room temperature was kept to around 25°C by the internal fan coils connected with the auxiliary cooling system, whereas at University of Palermo maximum room temperature in was 26°C. Above this temperature an additional split system was operated.

Measurements of temperatures and humidity at inlet and outlet of main components, air velocity (at supply, return, adsorption beds), electricity consumption, solar radiation were measured. Data acquisition and control strategy were carried out using the Labview environment.

3. Results and discussion

Here below monitoring results are presented. Instantaneous performances for the prototype installed at University of Palermo are first shown. Afterwards results of two weeks operation for the 5,5 kW machine are presented and discussed. Common performance indicators such as EER and thermal COP are used.

In the following diagrams monitoring results and instantaneous performance indicators for one operation day are shown. The selection of the operation day was chosen with the aim to show one of the most important feature of the system, which is the possibility to deliver cooling energy also after the sunset. In this day, system is operated during the morning in regeneration mode for the reactivation of the desiccant beds until 16:00, when the user switches on the system and therefore cooling demand occurs. At this time, system starts to deliver cooling to the building for five hours until 21:00 in the evening.

In Fig. 3 the dehumidification rate achieved by the desiccant beds is reported. During the operation, ambient air could be dehumidified by 5-6 g/kg allowing supply humidity ratio in the range of 10 g/kg and room humidity ratio of about 11 g/kg. This shows the capability of the system to guarantee dehumidification and therefore cooling capacity to the building after the sunset, when no more heat is available for the regeneration of the desiccant material.

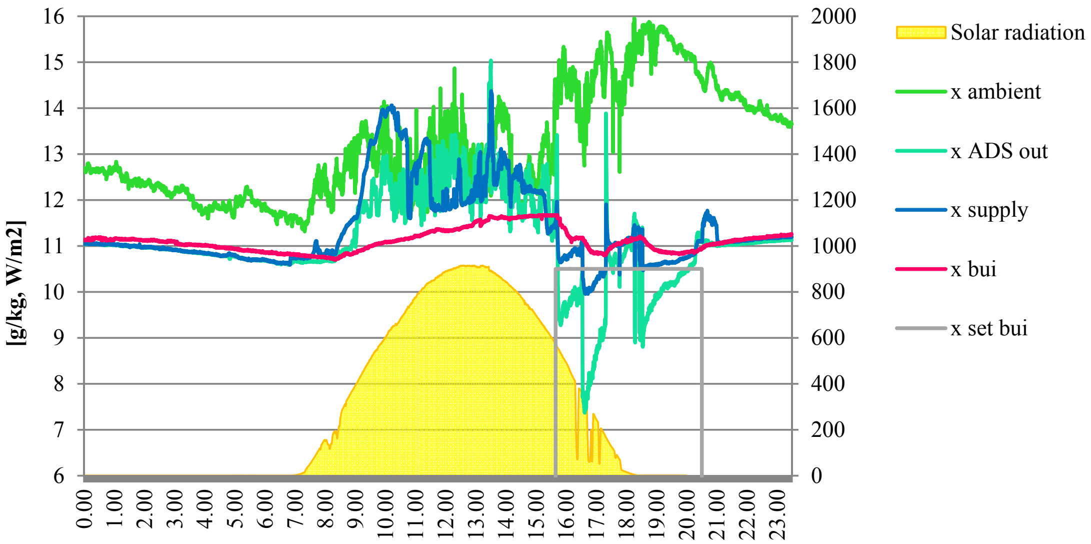

Fig. 3. Dehumidification rate for the selected day of operation – freescoo prototype at University of Palermo

As shown in Fig. 4, supply temperatures to the building ranged between 19° and 22°C. The temperature at the outlet of the desiccant beds is also shown. During the operation of the system in cooling mode is can be observed that the maximum temperature rise of the air across the desiccant beds is about 2-3°C. This is due to the heat rejection operated by means of the integrated cooling tower.

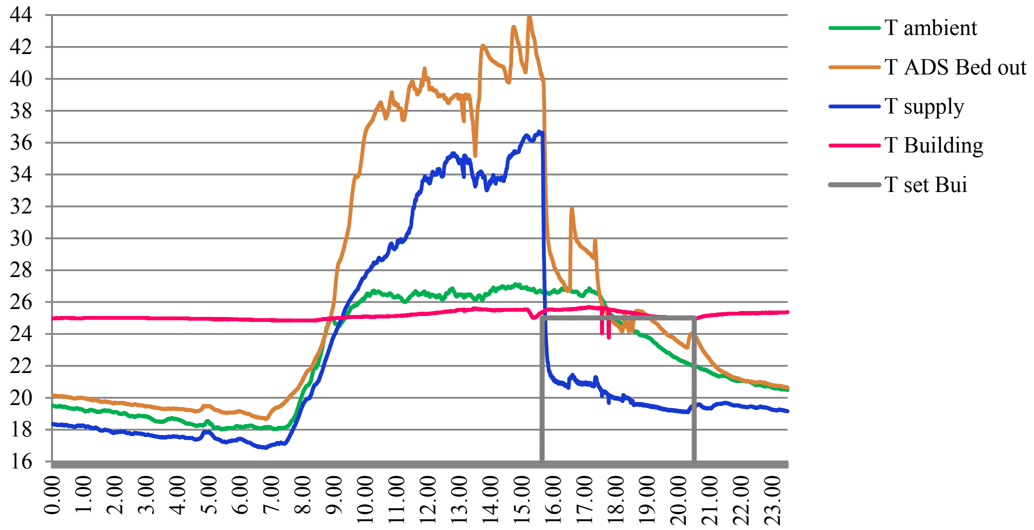

Fig. 4. Temperatures for the selected day of operation – freescoo prototype at University of Palermo

For the same day of operation, Fig. 5 shows the solar heat and the cooling capacity of the system. It is to be mentioned that solar heat takes into account also the pre-heating of outside air used for the regeneration. In fact, the inlet of the solar air PVT collector is located in the internal volume of the machine, this permitting to collect also the heat due to the solar radiation absorbed by the metal casing. Daily calculated efficiency of the collector amounts to 58% if the temperature difference between the inlet and outlet of collector is considered, whereas this rises up to nearly 90% if the mentioned pre-heating is considered. Cooling energy has to be intended as the total cooling energy due to the air handling cooling process. It takes into account the cooling and dehumidification which occurs in the desiccant bed and the sensible cooling due to the wet heat exchangers. It also considers that a portion of the air exiting the wet heat exchangers is drown into the secondary channels and after that, into the cooling tower, not participating to the net cooling production process.

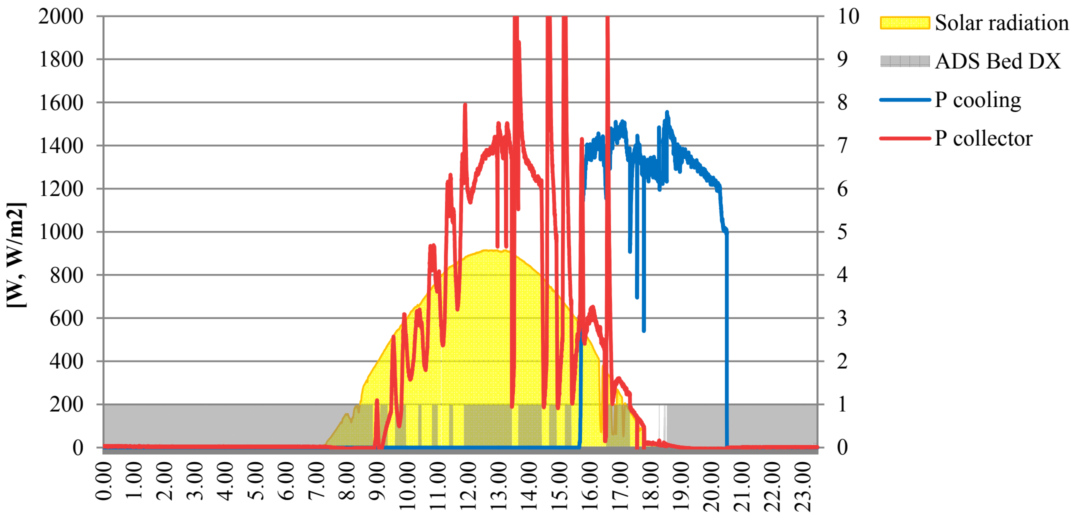

Fig. 5. Cooling power and solar thermal power for the selected day of operation – freescoo prototype at University of Palermo

In the same diagram cooling energy is reported, showing that system is able to provide cooling until 21:00 in the evening. This is due to the accumulated sorption capacity in the desiccant beds which have been regenerated during the morning.

Now some results of the machine installed at ENEA are shown. Results come from monitoring data acquired during 15 summer days of full operation.

First of all, climatic conditions are shown in Fig. 6. Temperatures and humidity ratio occurred during the selected weeks very well represent the typical summer operation conditions of the specific site.
In the following diagrams, data are related to a system operation time from 9:00 in the morning to 18:00 in the afternoon.

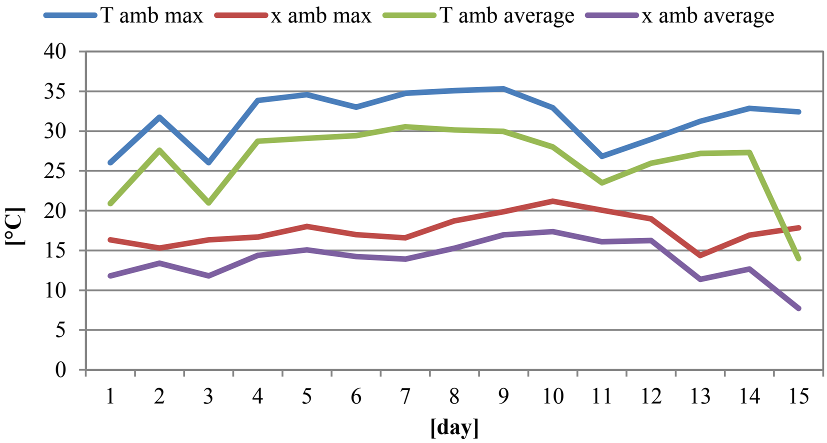

Fig. 6. Average temperatures and humidity for the selected days of operation – freescoo prototype at ENEA

Fig. 7 summarizes the performances of the system in terms of energy production and electricity consumption. It has to be pointed out that the values shown for electricity consumption do not take into account the electricity production from the PV modules. This permits to better investigate the intrinsic electric efficiency of the machine. The average energy efficiency ratio calculated as the whole cooling energy delivered to the total electricity needed is 8,2 (Fig. 8).

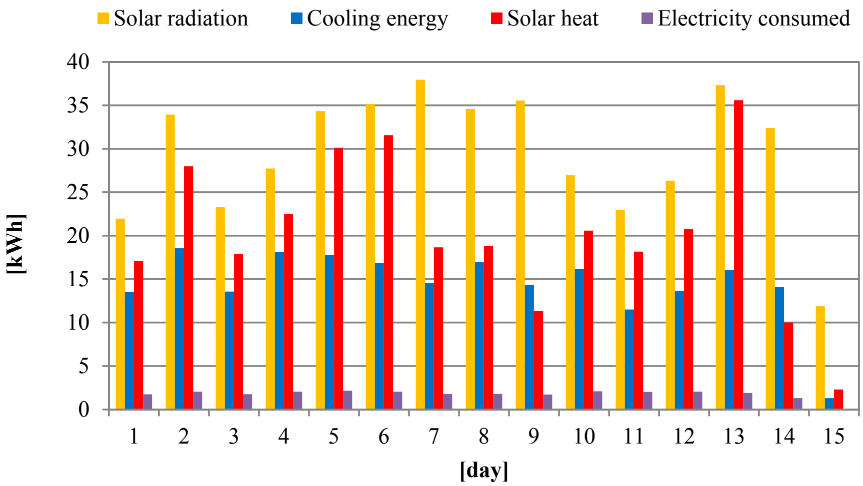

Fig. 7. Energy produced and electricity consumed for the selected days of operation – freescoo prototype at ENEA

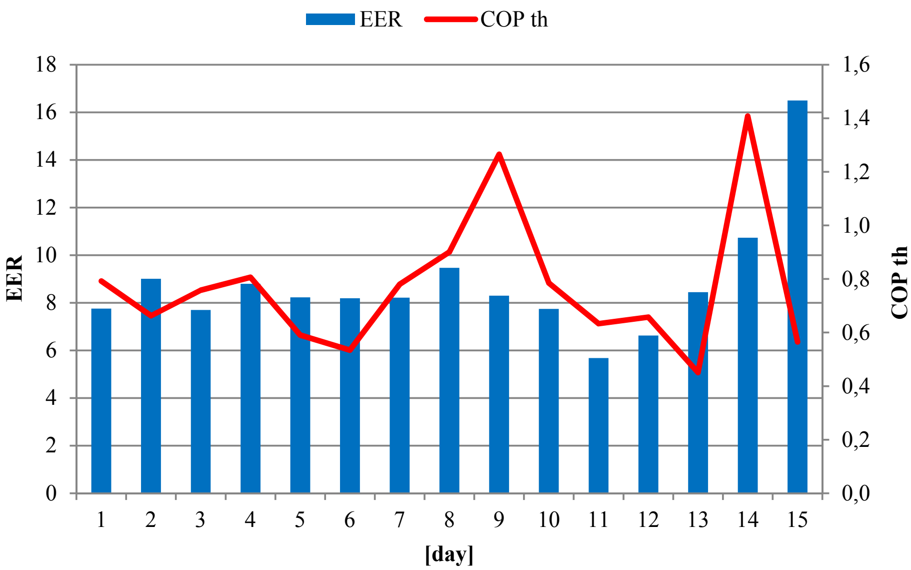

Fig. 8. EER and thermal COP for the selected days of operation – freescoo prototype at ENEA

Finally some data related to the stand alone operation of the system are shown. In particular, Fig. 9 reports the electricity coming from the grid and the PV production during the selected days. As one can notice, system was able to run in stand-alone mode for seven days without any use of energy form the grid. This is a remarkable result which has to be considered as an important added value to the performance figures of the system.

If the calculation of the EER is made considering the real electricity derived from the grid, the average value for the considered operation time is 30,7.

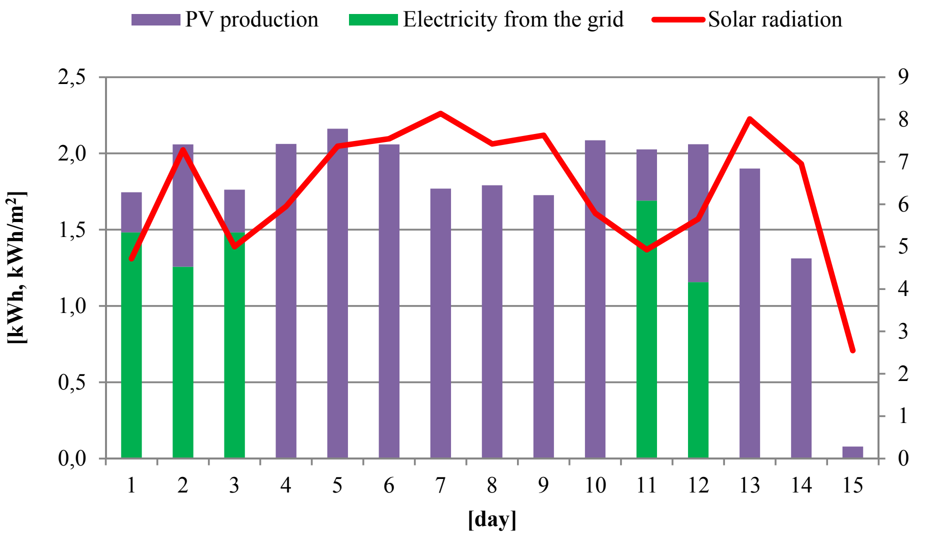

Fig. 9. Electricity consumption from the grid and PV production during two weeks of operation - ENEA prototype

4. Conclusions

A second generation of *freescoo* prototypes for applications in residential and small office buildings have been recently installed in Italy at ENEA Casaccia and at UNIPA.

In general monitoring data have shown good results in terms of energy efficiency of the tested machines

An important feature of the system is the possibility to use the amount of desiccant as sorption storage, thus permitting to supply cooling energy several hours after the sunset.

The use of the integrated PV modules and batteries showed that the stand-alone operation of the system for is also possible. For the prototype installed at ENEA Research Center, average EER calculated taking into account the net electricity taken from the grid during the considered interval of time amounted to 30,7.

Some optimizations are still possible in order to better control the adsorption and desorption processes of each desiccant bed which will increase the cooling capacity of the systems.

Acknowledgements

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