# SOLAR DESICCANT COOLING SYSTEM OPERATING IN PALERMO (ITALY): RESULTS AND VALIDATION OF SIMULATION MODELS

Marco Beccali, Pietro Finocchiaro, Bettina Nocke

Dipartimento di Ricerche Energetiche ed AMbientali (DREAM) – Università degli Studi di Palermo
Via delle Scienze bld. 9 – 90128 Palermo – tel +39091238911 – Fax +39091484425
e.mail: marco.beccali@dream.unipa.it

## Abstract

This paper concerns the validation of a set of simulation models used to describe the performances of the components and the overall operation of a solar desiccant and evaporative cooling system. The experimental data come from the monitoring of a real system located at the University of Palermo, Dept. DREAM, fully monitored since July 2008 according to IEA-Task 38 standards. Performance figures, either instantaneous either integrated on daily and monthly periods, have been calculated both with monitoring data and simulation results, and then compared each other. This comparison permitted to evaluate the accuracy of the models at different time horizons and consequently to calibrate them. Results are presented by sample hourly profiles for the most significant variables and by monthly values of thermal COPs and Solar-DEC fractions.

## Description of the system

The observed DEC system is and an air handling unit (AHU) designed for primary air operation, with an average air mass flow rate of 1250 kg/h and is coupled with a radiant ceiling providing the required sensible heating power and only part of the cooling demand. Two auxiliary cooling coils present on the supply air path make possible a pre-dehumidification and a re-cooling of the air, in case that cooling/dehumidification effects provided by the desiccant process is not sufficient to meet the load. The heat rejection of the auxiliary water chiller is partially recovered in a air-heating coil displaced in the AHU return air path. In this way part of the condensation heat is delivered to the air stream and used for the regeneration of the desiccant wheel. Further temperature increase (above 60°C) is then provided by the heat generated by the liquid solar collectors loop. In winter operation, the heat coming from the solar collectors (supported by an auxiliary heater) is used to feed the radiant ceiling and the heating coil in the supply side of the AHU [1].

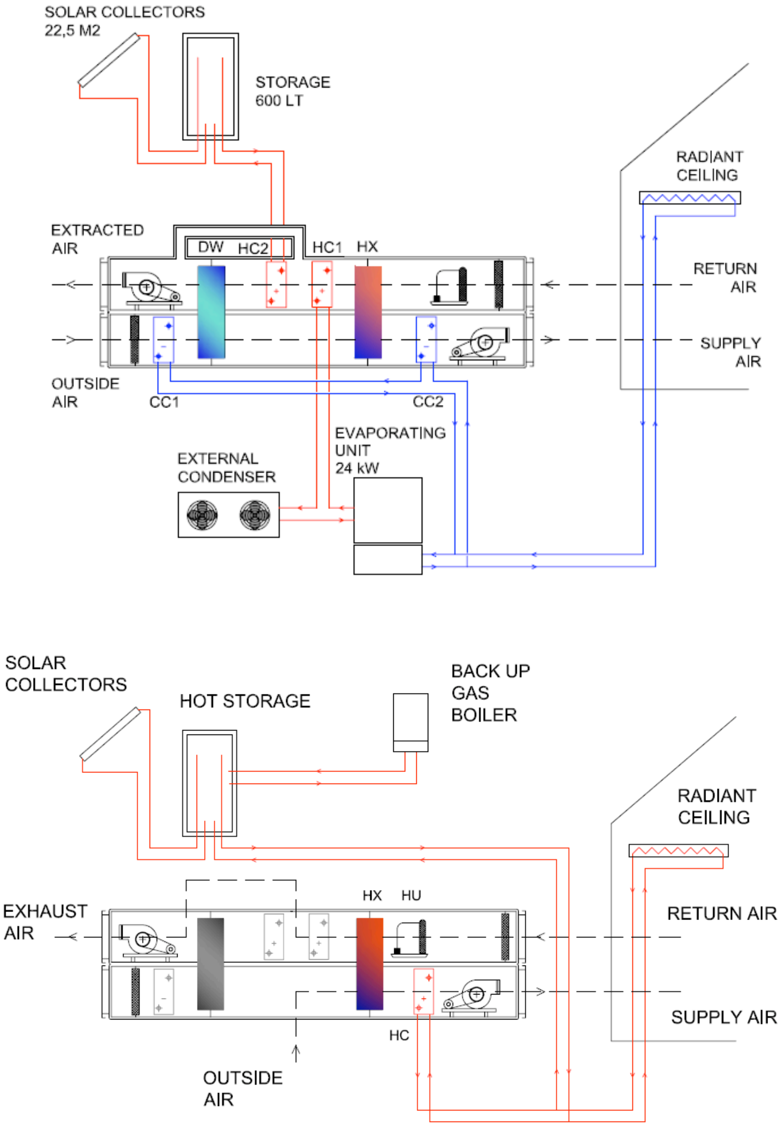


**Figure 1 – Functional schemes for summer and winter operation modes**

## Description of the TRNSYS model

A complete mathematical model, including weather data processing, reference building latent and sensible loads, AHU-components, solar collectors, auxiliaries and control strategy, was developed in the TRNSYS platform [2]. Models used are both standard TRNSYS and TESS-libraries routines [3] as well as customized ones. The model used for the simulation of the desiccant wheel is a non-standard TRNSYS

type, called 278, and developed at Fraunhofer ISE Freiburg in 2004. The core components of the system model are the control units implemented by means of specific algorithms as well as types such as PID, thermostats and other components directly influencing the dynamic behaviour of the system [4,5].
Measured weather data were used as inputs for the AHU model with the same time-step (10 minutes) used in the monitoring output file. In this way, simulation outputs were directly comparable to measured data.
By analysing the errors between the outputs under identical input conditions, the simulation model could be adapted to the actual process.
For a more reliable comparison of the simulation results with monitoring data, a time period of six months was chosen. In particular, the months investigated were July, August, September and December, January, February.
Simulations were carried out taking the following variables of the actual system as inputs of the model:

- Meteorological data (incident solar radiation, temperature and humidity of outside air)
- Hourly operation time periods
- Supply and return flow rates
- Set points (outlet air temperature/humidity of coils, chilled water temperature of auxiliary chiller, etc...)

The control strategy implemented in the model corresponds to the one used in the actual system, except for what concerns the radiant ceiling. In particular, the PID controller in the real system operates with the outside air temperature as controlled variable, whereas room temperature is used in the simulation model.
Air leakages in the heat exchanger were also considered by means of a “virtual” mixing valve downstream to it (adding to the process air a certain amount of return air). This trick was necessary in order to describe the actual data measured in the two sides of the component. After the improvement of the sealing the by-pass factor has been reduced accordingly.

## Simulations results and comparison with monitoring data

Simulations were carried out under the above-mentioned conditions. In this paragraph, a comparison between simulation and monitoring results is done by means of some examples on daily basis for summer and winter operation.

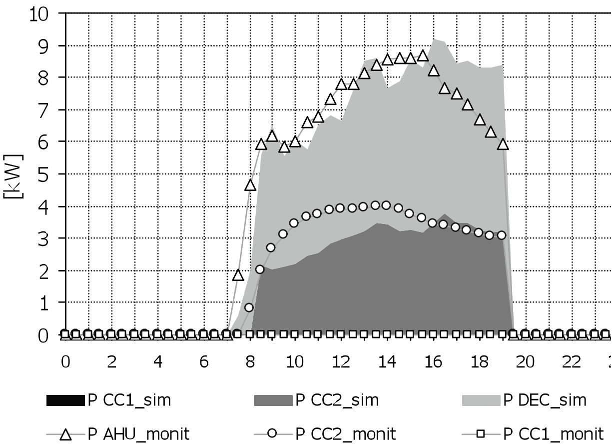


**Figure 2: Distribution of cooling power delivered from AHU - simulation versus monitoring, 26 July 2008**

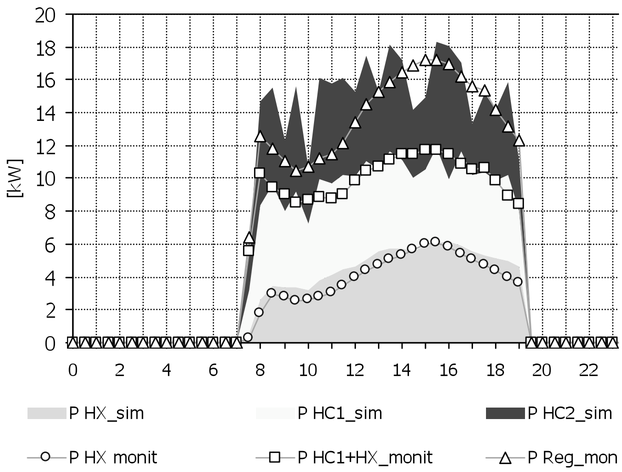


**Figure 3: Heating power for re generation - simulation versus monitoring, 26 July 2008**

Figure 2 shows the cooling power provided by the AHU, spitted into the contributions of desiccant and evaporative cooling (DEC) and of both the auxiliary cooling coils CC1 (pre-cooling) and CC2 (re-cooling).

The cooling power related to the DEC process (desiccant wheel and indirect evaporative cooling, $P_{DEC}$) has been calculated subtracting from the total AHU cooling power (mass flow times the enthalpy gap) the power delivered by the two auxiliary cooling coils:

$$P_{DEC} = P_{AHU} - P_{CC1} - P_{CC2}$$

It is worth noting the good correlation between the total cooling power of the AHU calculated by TRNSYS simulation and the one assessed from the monitoring data, (in this day the first cooling coil did not work). Taking into account the single steps of the process it is clear that the performance of the DEC cooling power is overestimated by 14%, whereas the second cooling coil CC2 power is underestimated by 14% (this coil is set to the required inlet conditions, and its performance depends on the one of the component before). Figure 3, showing the power provided for the regeneration of the wheel in the return air path, shows the good assessment made by the simulation model for the performance of the sensible heat exchanger (HX) and the first heating coil HC1. The total regeneration heating power calculated for the selected day by the simulation model is by 8% greater than the monitored one.

Similar results for the heating power delivered by the AHU in winter operation are shown in Figure 4 and 5 (for the day 6 December 08).

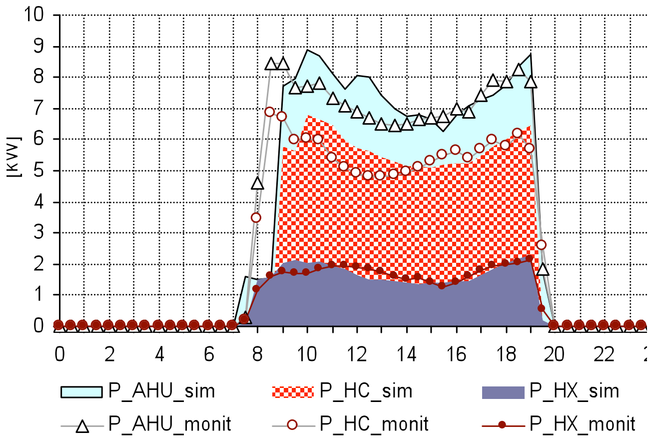


**Figure 4: Simulated heating power delivered from AHU and radiant ceiling in comparison with measured data, 6 December 2008**

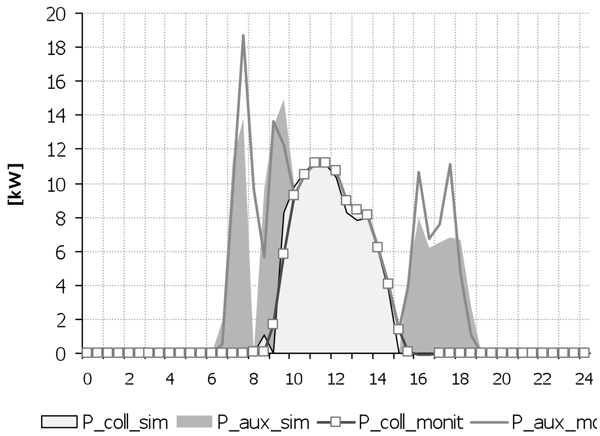


**Figure 5: Simulated heating power from solar collectors and auxiliary heater in comparison with measured data. 6 December 2008**

Figure 4 shows that the calculated heat exchanger (HX) performance nearly corresponds to the measured one. The simulated heating coil performance as well as the whole AHU's one, is slightly time-shifted.

Results from simulation and measured data are almost identical regarding the heat produced in the solar collectors (Fig. 5). It can also be noted that the auxiliary gas boiler allows to meet the heating load when solar radiation is not sufficient (at the beginning and at the end of the day). The calculated heating power of the gas boiler is slightly lower than in the actual process.

In order to appreciate the reliability of the models in a longer time periods, some important monthly and seasonal performance-indicators for cooling operation have been assessed.

The "thermal COP" is defined as the DEC cooling power divided by the available regeneration heat. For the specific case, two COPs can be defined considering in the

firs case only the contribution of the solar regeneration coil HC2 or, in the second case, both the coils: HC1 (condensation heat recovery coil) and HC2.
The following equations indicates the two ratios

$$COP_{thHC2} = \frac{Q_{DEC}}{Q_{HC2}} \qquad COP_{thHC1+HC2} = \frac{Q_{DEC}}{Q_{HC1+HC2}}$$

where $Q_{DEC}$ is the "desiccant cooling effect" not considering the contribution of both the auxiliary cooling coils CC1 and CC2 ($Q_{ColdBack\text{-}up}$) calculated as follows:

$$Q_{DEC} = \sum_t \dot{m} \cdot (h_{Supply} - h_{AMBIENT}) - Q_{ColdBack-up}$$

Another indicator used to evaluate the performance of desiccant systems is the Solar DEC-Fraction that indicates the fraction of cooling power provided by the DEC process to the total cooling power of the AHU.

$$Solar - DEC - Fraction = \frac{Q_{DEC}}{Q_{AHU}}$$

The Primary Energy Ratio is defined as the ratio between the cooling energy delivered by the system and the consumption of primary energy (in this case without auxiliary heating):

$$PER = \frac{Q_{cool}}{Q_{EL} / \varepsilon_{EL}}$$

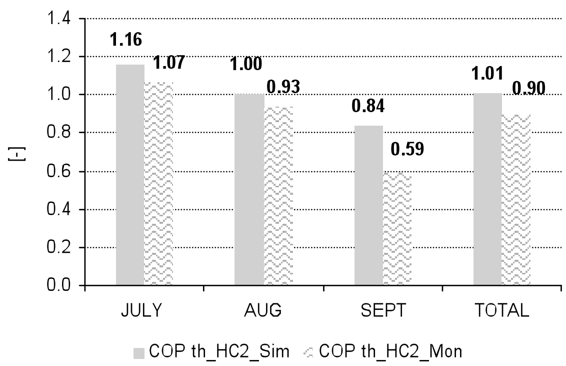


Figure 6: COP th HC2 – simulation vs. monitoring

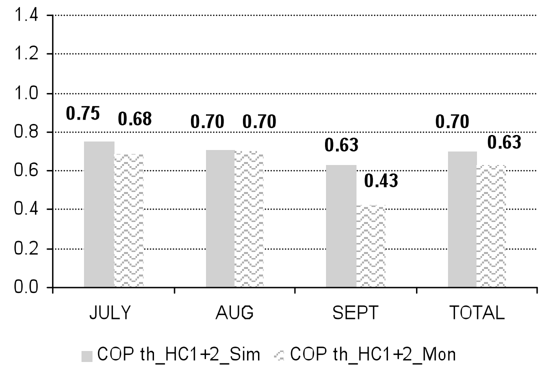


Figure 7: COP th HC1+2 – simulation vs. monitoring

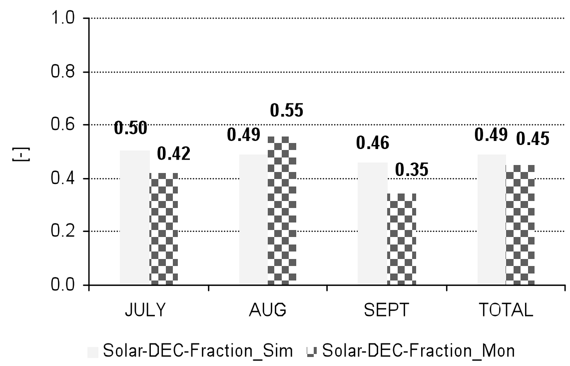


Figure 8: Solar-DEC-Fraction – simulation vs. monitoring

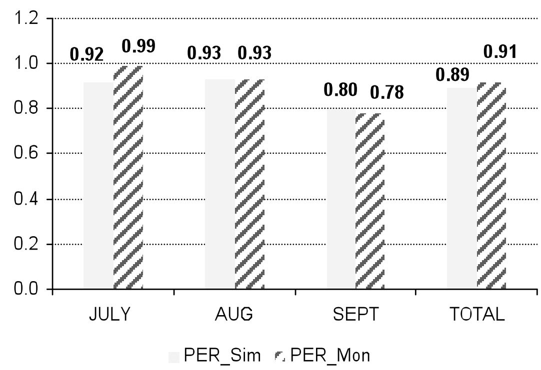


Figure 9: Primary Energy Ratio – sim. vs. monitoring

The calculated and the measured figures of the above mentioned indexes are shown in figures 6, 7, 8 and 9 on monthly and seasonal time basis. Table 2 synthetizes the errors between calculations and measurements.

| | error simulation vs. monitoring data | | | |
|---|---|---|---|---|
| | Solar-DEC-Fraction | COP th_HC2 | COP th_HC1+2 | PER |
| JULY | 20% | 9% | 9% | -7% |
| AUG | -11% | 7% | 1% | 0% |
| SEPT | 34% | 42% | 48% | 2% |
| **TOTAL** | **9%** | **13%** | **12%** | **-3%** |

Tab. 2 Error of simulation results vs. monitoring results, July – September 2008

Looking at the values coming from the monitoring campaign, the technical efficiency of the actual system is good. Nevertheless, the system performance could improved by solving some practical problem. The most important was the air leakage in the sensible heat exchanger. Seasonal Primary Energy Ratio in September is the worst because of the low efficiency of the auxiliary chiller, working with low cooling demand and continuous on-off operation. The decrease of thermal COP in August and September is also related to the lower exploitation of solar heat for regeneration. Regarding the comparison between simulation and monitoring results, the simulation model in the whole season leads to assess better performances of the system than the actual ones. Best correlations occur when the system runs with the higher loads.

## Conclusions

Simulation results generally gave better performance than the measured figures. The results related to the whole AHU simulation and carried out for longer time period have the best agreement with measured data. Good results have been obtained also for the single component behaviour. Further developments of the control strategy will allow to catch also the hourly performances in best way. Different results carried out of performance indicators, namely the Solar-DEC-Fraction.

A reliable set of models of the system components and of the whole system is a powerful tool to design and test possible improvements of the system allowing to assess the effects of changes in the regulation (including tuning in set points), in the process scheme as well as the introduction of new components/treatments.

## Reference


[1] Beccali M., Finocchiaro P., Luna M., Nocke B**.,** Monitoring of a solar desiccant cooling system in Palermo (italy). First results and test planning, Proc. Of the Intern. Conference EUROSUN 2008, Lisbona (P), 7-10 October 2008

[2] Beckman W.A. et al. “TRNSYS, Reference manual” Solar Energy Laboratory, Madison, USA, 2001

[3] Thermal Energy System Specialists. 2873 Cimarron Terrace. Madison, Wisconsin.

[4] Finocchiaro P., “Analisi numerica di sistemi Desiccant Cooling alimentati ad energia solare per applicazioni in climi mediterranei” – PhD Thesis - Università degli Studi di Palermo, 2007

[5] Nocke B., “Monitoraggio e valutazione energetica di un impianto sperimentale Desiccant Cooling ” – PhD Thesis - Università degli Studi di Palermo, 2009


## Acknowledgments


This work has been carried out in the framework of the Research Plan “R&D activities of general interest for the National Electric System” funded by the Italian Ministry of Economic Development (MSE). The subtask was co-ordinated by Marco CIttterio (ENEA) and Marco Beccali (Unipa-DREAM)