Desiccant cooling simulation and design in Matlab/Simulink environment: implementation and validation of the model

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Abstract

A mathematical model of several configurations of Solar Desiccant and Evaporative Cooling systems has been developed, in order to be integrated in a novel software platform for dynamic simulation of the whole building-HVAC system (ODESSE). The model has been realized in Simulink [1], by adapting some blocks of the SIMBAD [2] toolbox libraries and by creating new ones for some components, as well as for the control strategy. A series of tests has been carried out for a performance comparison either with a set of reliable models already implemented in TRNSYS [3], either with monitored data acquired from an experimental plant installed at DREAM. The results are analysed and, finally, conclusions are given.

1. Introduction

This paper describes the product of a research conducted by DREAM and ENEA on the development of mathematical models of Solar Desiccant and Evaporative Cooling systems (DEC) for the integration in a new software platform for dynamic simulation of the whole building-HVAC system (ODESSE). This research has been carried out in the framework of “R&D activities of general interest for the National Electric System” funded by Ministry of Economic Development (MSE) [4]. ODESSE allows to assess the technical-economic feasibility of interventions for the energy improvement of existing buildings or districts, and it is supposed to be decisive in the ecobuilding's design. Since ODESSE has been realized using MATLAB/Simulink software, the models of DEC systems have been implemented on the same platform by adapting some blocks of the SIMBAD toolbox libraries: air fans, rotating heat exchanger, simple static models of heating and cooling coils, divergent and convergent valves. New blocks have been implemented in Simulink for humidifiers and desiccant wheels, as well as for the control strategy.

In order to evaluate the performance of the Simulink model, a series of tests has been carried out, for a comparison with both the results of reliable models already implemented by DREAM in the TRNSYS platform, and the data coming from the monitoring of an experimental Solar DEC plant installed at DREAM's department since 2008 [5].

2. System configurations and control

Four DEC configurations models have been implemented:

A) standard DEC with solar collectors;
B) standard DEC with solar collectors and auxiliary cooling;
C) standard DEC with two auxiliary cooling coils and condensation heat recovery;
D) conventional AHU system.

Figure 1 shows the various components that can be installed in a DEC system and their ubication. Table 1 shows whether each component is present or not in a given configuration.

Various settings are initialized in a *.m file*, which is launched automatically when the simulation is started. These are: the DEC configuration to be simulated (A÷D), the type of collectors (air/water), the type of desiccant wheel, the design parameters of the components, the temperature and humidity set-points.

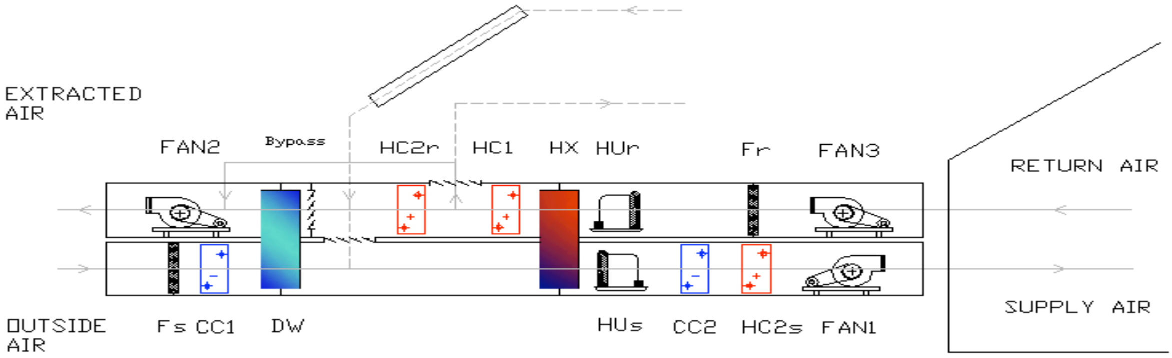

Figure 1. Components of a DEC system

Every DEC configuration is controlled according to a control strategy which is similar to the one described in Table 2, suitable for DEC configurations with two auxiliary cooling coils, heat recovery on the condensation side of the cooling machine and liquid collectors.

		Configuration			
Component	***Symbol***	A	B	C	D
Filter (supply air)	Fs	■	■	■	■
Cold battery / pre-dehumidification	CC1		■	■	
Desiccant wheel	DW	■	■	■	
Heat exchanger	HX	■	■	■	■
Humidifier (supply air)	Hus	■	■	■	■
Sensible aux cooling coil	CC2		■	■	■
Heating coil	HC2s	■ [1]	■ [1]	■ [1]	■
Fan (supply air)	Fan 1	■	■	■	■
Filter (return air)	Fr	■	■	■	■
Fan (return air)	Fan 3	■ [2]	■ [2]	■ [2]	■ [2]
Humidifier (return air)	Hur	■	■	■	
Condensation heat recovery coil	HC1			■	
Solar regeneration coil	HC2r	■ [3]	■ [3]	■ [3]	
Fan (return air)	Fan 2	■	■	■	■
Notes:	[1] optional [2] only present when air collectors are used [3] if air collectors are used, the solar regeneration coil HC2r is absent; instead, the air flows through the collector				

Table 1. Components of each DEC configuration

		ACTIVE COMPONENTS								
OPERATION MODE		Desiccant wheel	Heat exchanger	Supply humidifier	Fans	Regeneration coil HC2	Cooling coils CC1 and CC2	Return humidifier	CONDITION	
-2	Solar heating + Aux		●		●				T supply < T set point_winter	↑ Heating load
-1	Solar heating		●		●				T supply < T set point_winter	
0	Ventilation				●				T supply & RH acceptable	
1	Indirect evaporative cooling		●		●			●	T supply > T set point_summer	
2	Desiccant cooling	●	●	●	●	●		●	T supply > T set point_summer or RH supply > RH set point_summer	Cooling load
3	Active cooling	●	●	●	●	●	●	●	T supply > T set point_summer or RH supply > RH set point_summer	↓

Table 2. Control strategy of DEC systems for increasing heating/cooling load

The time step of the simulation is set to 5 minutes and the “mode selector” block, which is activated every three time steps, checks the supply air conditions. If temperature and relative humidity are within the desired ranges, the operation mode will not change; on the contrary, if any variable is out of the range, the operation mode will be increased or reduced, to increase respectively the AHU heating or cooling power. The dead bands around the set points are ± 0.5°C for temperature and ± 5% for relative humidity.

In the cooling season, three operation modes are possible. The system starts in the *ventilation mode*, where no active air handling is performed, but only the fans are switched on (mode 0). In mode 1, only *indirect evaporative cooling* is performed by means of a heat recovery wheel and the humidifier on the return side. In mode 2, the *solar desiccant cooling* cycle is operated by means of the regeneration coil (HC2r), solar collectors, desiccant wheel and supply and return humidifiers. In mode 3, the *auxiliary back-up system,* as well as the cooling coils CC1 and CC2, are switched on to meet the cooling loads in case of high loads.

In the heating season, the first operation mode (-1) allows *heat recovery and solar heating*, while in mode -2, the *auxiliary back-up system* is activated.

In order to choose which components are turned on/off in each of the six operation modes, several vectors are defined in the initialization file for the various configurations and the correct one is chosen and applied by a suitable block of the Simulink model (figure 2). Finally, an ON/OFF input drives the whole system; it comes from the ODESSE platform and it allows to switch on the plant only during the working hours.

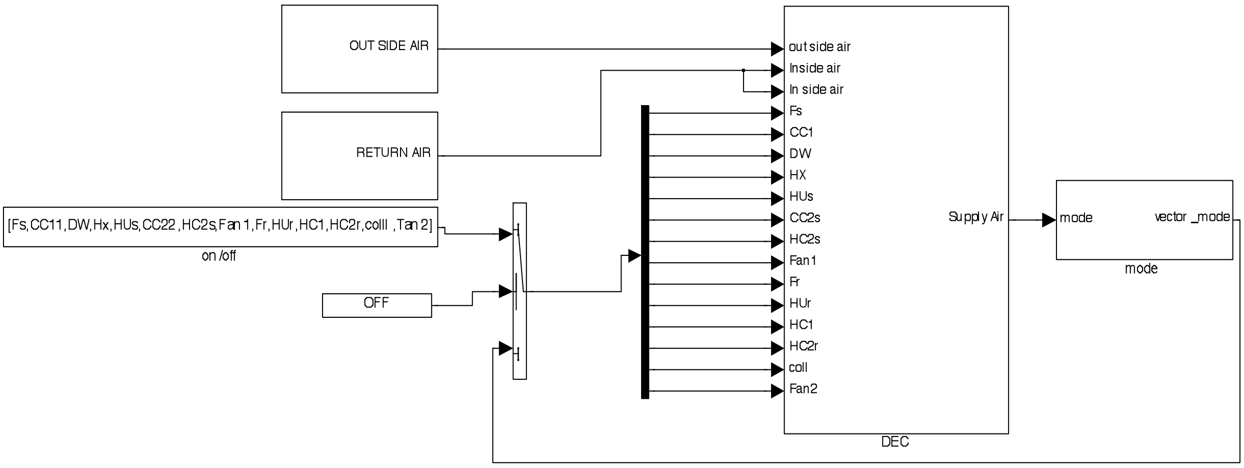

Figure 2. Simulink general scheme of the DEC system

3. Description of the model

The model is composed of several interconnected blocks, which implement the components of figure 1. The main input and output of each block are vectors which contain the parameters of the air before and after that component: temperature [°C], absolute humidity [Kg_V/Kg_A], pressure [Pa] and flow rate [Kg/h]. Each block has an additional input that allows the control system to turn on/off the component and a flag that specifies whether the component is present or not when the user chooses various DEC configurations. Hence, absent components don't cause any pressure decrease. According to figure 1 a bypass parameter allows the user to modify the flow rate of the regeneration air which invests the desiccant wheel. This latter component has been implemented on the basis of the model developed by Beccali et al. [6]-[7], which has been derived by interpolating experimental data obtained from the manufacturers and by developing correlations for predicting outlet temperature and absolute humidity. Specifically, the model is used to predict the performance of three type of desiccant rotors manufactured by using different kind of solid desiccants: Silica Gel and LiCl.

The Simulink model at present does not implement the whole building-HVAC system, but just the DEC system; hence, the interaction with chiller and collectors models is realized at fixed supply temperatures.

4. Results and discussion

Simulation results carried out for a typical summer day with TRSNYS and SIMULINK models are presented in the following diagrams, with the aim to compare the considered models with real data, which come from the monitoring of DREAM's experimental plant (configuration C). Input data used for the simulations are related to 26th July, 2008; output data in the graphs are meaningful during working hours (from 7.00 to 19.00). Figure 3 shows temperature and humidity ratio of process air at the outlet of the desiccant wheel for the two models in comparison to the monitored data. Good correlation between the two models can be noted, both in terms of temperature and humidity ratio. The difference with monitored data is probably due to the high bypass fraction of the regeneration air used in the real system.

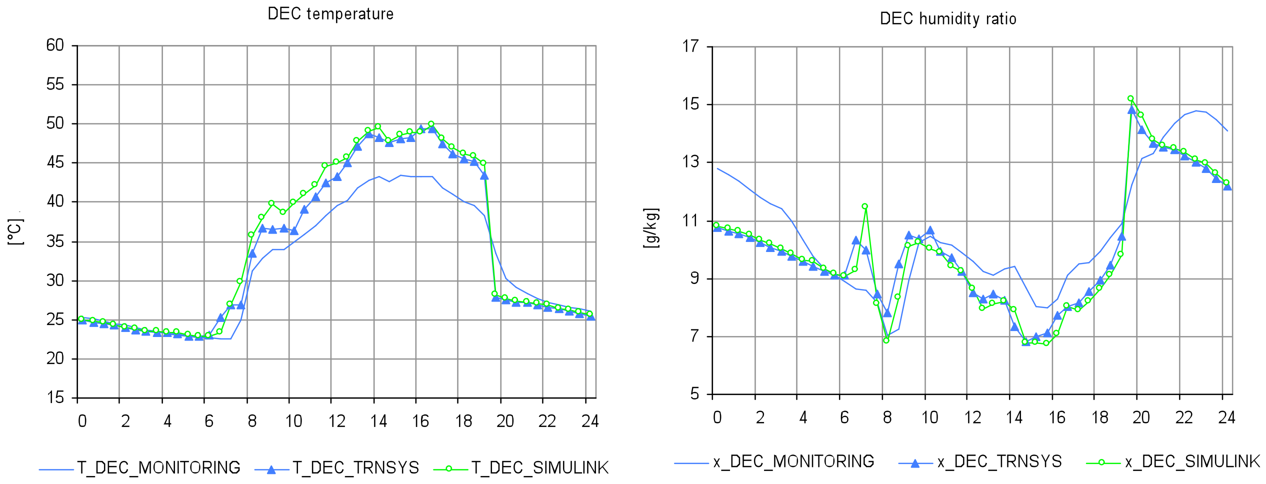

Figure 3. Daily results: temperature and humidity ratio at outlet of the desiccant wheel

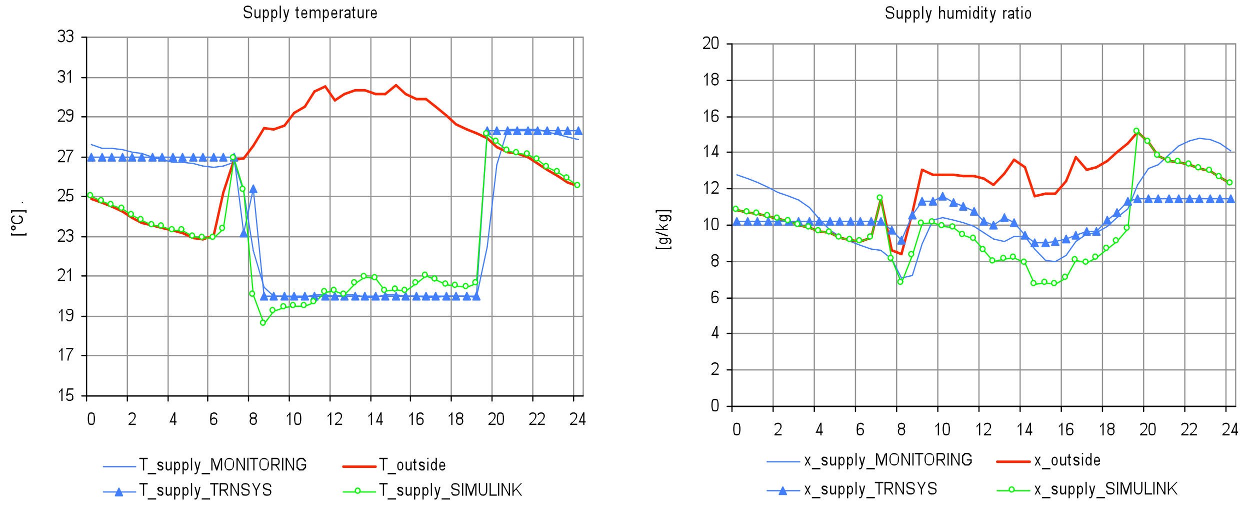

Figure 4. Daily results: temperature and humidity ratio of supply air

In figure 4 supply air conditions provided by the desiccant unit to the building are shown. It can be noted that simulation results obtained with the TRNSYS model fit well with monitored data in terms of temperature difference around the set point. The SIMULINK model returns a lower precision due to the parameters of the several PID controllers, which need a better tuning.

Furthermore, monthly simulations have been carried out in order to extend the comparison also to the average energy performance of the system. Input data used for these simulations are related to a time period of one month, namely July 2008. As a performance indicator, the “thermal COP” has been chosen, which is defined as the

DEC cooling power divided by the available regeneration heat. For the specific case, two COPs can be defined, i.e. considering only the contribution of the solar regeneration coil HC2r or both HC1 (condensation heat recovery coil) and HC2, according to the following equations:

$$COP_{thHC2} = \frac{Q_{DEC}}{Q_{HC2r}}, \qquad COP_{thHC1+HC2} = \frac{Q_{DEC}}{Q_{HC1+HC2r}}$$

where Q_{DEC} is just the "desiccant cooling effect", not considering the contribution of the auxiliary cooling coils CC1 and CC2. Another simple performance indicator used to evaluate desiccant systems is the "Solar DEC-Fraction", which indicates the fraction of cooling power provided by the DEC process to the total cooling power of the AHU, according to the following equation:

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

Figure 5 shows monitoring and simulation results in terms of thermal COP and solar DEC fraction of the desiccant cycle. In the same figure, errors between simulation results and monitoring data are also shown.

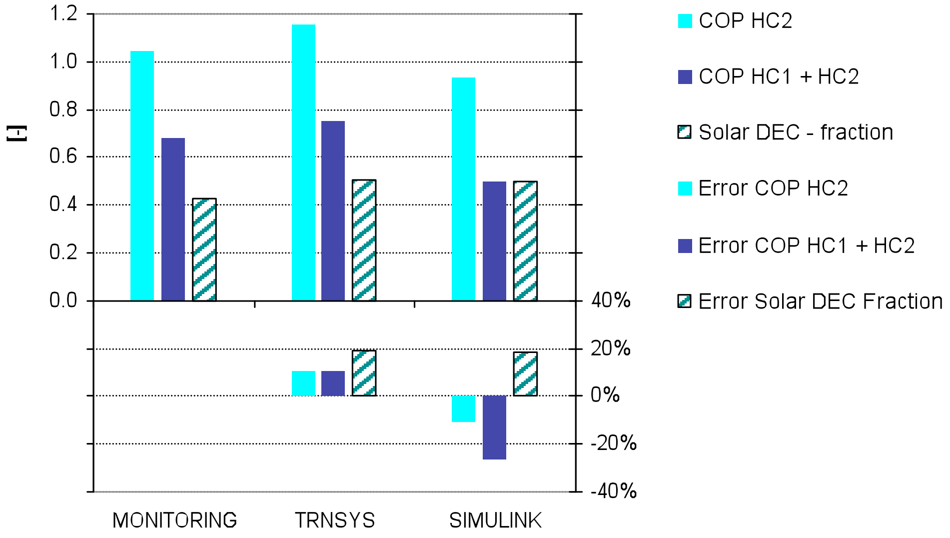

Figure 5. Monthly results: thermal COPs and Solar DEC fraction of the desiccant cycle

In general, it can be noted that, if only the heat provided by solar coil HC2 is considered, COP values are quite high in comparison to standard desiccant cycles values, which are lower than 1%. The figure shows that TRNSYS model overestimates the COP of the cycle of about 10% whereas SIMULINK model underestimates it of about 25%, if both contributions of the regeneration heating coils HC1 and HC2 are taken into account. The lower values obtained with the SIMULINK model are probably due to the fact that, for the time being, no interaction with the chiller model is performed and the heat recovery is operated at fixed temperature of 40°C. In terms of Solar DEC-fraction both models overestimate the performance of the DEC cycle of about 20%, so results are comparable.

Conclusion

The simulations proved that the Simulink model has been correctly implemented and that it shows an overall good correlation with the TRNSYS model, both in terms of temperature and humidity ratio. This allows future developments of this study, where the DEC model will be integrated in the ODESSE platform, by linking it with the solar collector and chiller models already developed, and with the model of the building. Then, using ODESSE user interface, the user will be able to size DEC and auxiliary systems and to perform dynamic simulations of the whole building-HVAC system.

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