The Use of Desiccant Cooling System with IEC and DEC in Hot-Humid Climates

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***Abstract*-Indoor moist surroundings affect air cleanliness and thermal comfort when relative humidity is above 70%, which may lead to condensation within the building structure and on interior and exterior surfaces and subsequent development mould and fungi. Moreover, the humidity issue is a major contributor to energy inefficiency in HVAC devices. The objective of this study was to investigate the feasibility to apply the desiccant cooling system in hot-humid climate for interior thermal comfort purpose. Using measured data sets, validation of TRNSYS basic model was undertaken. Two models of cooling system using Indirect Evaporative Cooling (IEC) and Direct Evaporative Cooling (DEC) were simulated for different climatic conditions. The result shows that the desiccant cooling system with IEC and DEC can be a suitable solution for thermal comfort in buildings in hot-humid climate.**

Keywords- Desiccant Cooling; Desiccant Wheel; Heat Wheel, Dry-bulb Temperature; Relative Humidity; Evaporative Cooler

I. INTRODUCTION

The desiccant air conditioning system utilizes the capability of desiccant materials in removing the air moisture content by sorption process. All materials that attract moisture at different capacities are called desiccant [1]. The removal of the moisture from the desiccant wheel can be done by heating. The solid-based system uses solid desiccant materials in the removal of air moisture content. There are several kinds of solid desiccant materials: silica-gel, titanium silicates, calcium chloride, activated alumina, zeolite (natural and synthetic), molecular sieve, lithium chloride, organic-based desiccant [1].

The desiccant cooling system is based on the application of the desiccant material in removing air moisture content. The sorption process in the solid material is done by absorption or adsorption. The desiccant wheel is regenerated by heat. The air after passing the desiccant wheel is dry and hot due to the conversion of air latent energy to sensible energy. To reduce the air temperature a heat wheel is used.

Recently several researchers have used solar energy to regenerate the desiccant wheel [2, 3-5]. Over a number of years several authors have investigated the design and operation of such systems. Khoukhi et al studied the experimental set-up of conventional twin rotor desiccant cooling system [6] and Enteria et al. modelled the twin rotor desiccant cooling for parametric investigation [7]. The author investigated the feasibility of using the desiccant cooling system in hot-humid areas [8]. An extensive paper summarizing the thermally activated desiccant cooling technology in the issue of energy and environment has been published by Enteria et al. [1]. Napoleon et al. investigated the thermal activated desiccant cooling experimentally and showed the dependence of the desiccant system upon the performance of its components and the climatic conditions [9]. Nagaya et al. investigated the application of the solid desiccant wheel in the automobile air-conditioning system [10]. The result shows that the system is efficient compared to the conventional system. Carnago et al. [11] investigated the application of cooling system in Latin America and in tropical and equatorial cities. Fong et al. conducted investigation regarding the application of solar desiccant cooling system in sub-tropical climate of Hong Kong [12]. An experimental study of a solar–regenerated liquid desiccant ventilation preconditioning system has been performed by Katejaneken [13]. Other extensive researches on liquid desiccant cooling are done by numerous researchers [14-16]. Liquid desiccant cooling system relies on the liquid desiccant in controlling air moisture by means of absorption process.

The main purpose of this study is to investigate the feasibility of using cycle that combines sorptive dehumidification with heat recovery to create thermal comfort in hot-humid climate.

II. EXPERIMENTAL FACILITY

The experimental facility has a physical set-up shown in Fig. 1. Two controlled chambers A and B are used to simulate the outdoor and indoor conditions, respectively. Chamber A has temperature range from -10°C to 40°C with accuracy of 2%. Chamber B has temperature range from 10°C to 40°C with accuracy of 1%. The humidity can be controlled and varied depending on the needed condition for both chambers. The source of raw air for both controlled chambers is fan. The cooling process operates when the temperature set-value is lower than the ambient air temperature. Otherwise, the heating process operates. Similar process is used for the humidity control. If the ambient air humidity is high, dehumidification process operates. Otherwise, the humidification process operates. The air is moved from the chambers to the testing one by fan.

The desiccant based system consists of desiccant dehumidifier, heat recovery and heater for the desiccant wheel regeneration. The performance of the whole system depends on the performance of its components. This task has been already conducted in Laboratory in Tohoku University [1]. The parameters considered for the evaluation were the rate of volumetric flow, the regeneration temperature, and the wheel rotational speed [1].

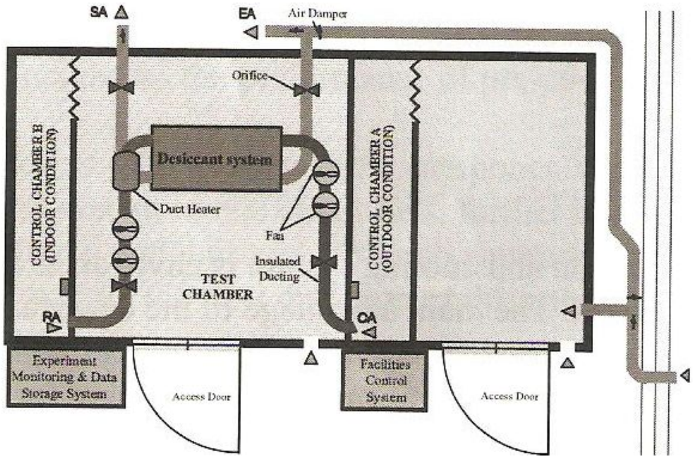


Fig. 1 Experimental facilities

III. MODELLING AND SIMULATION

The typical desiccant cooling air system as shown in Fig. 2 is an open heat-driven cycle which comprises a desiccant wheel in tandem with a thermal wheel. A regeneration coil located in the return air stream drives the whole cycle.

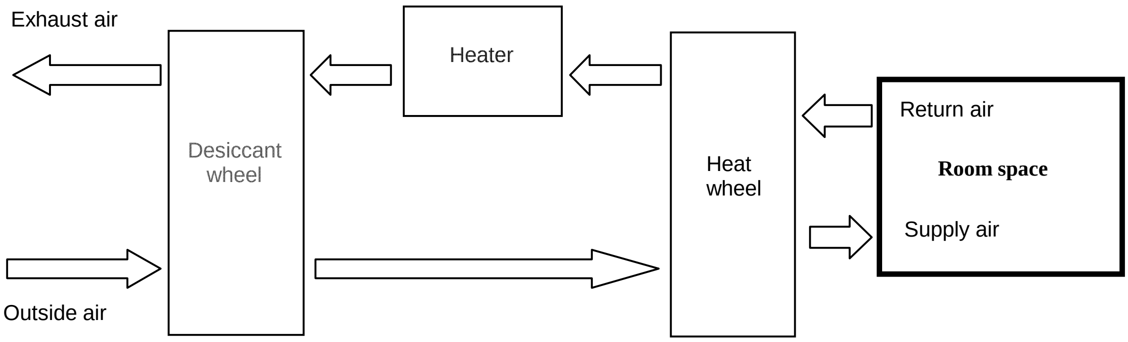


Fig. 2 Schematic diagram of the basic desiccant cooling system

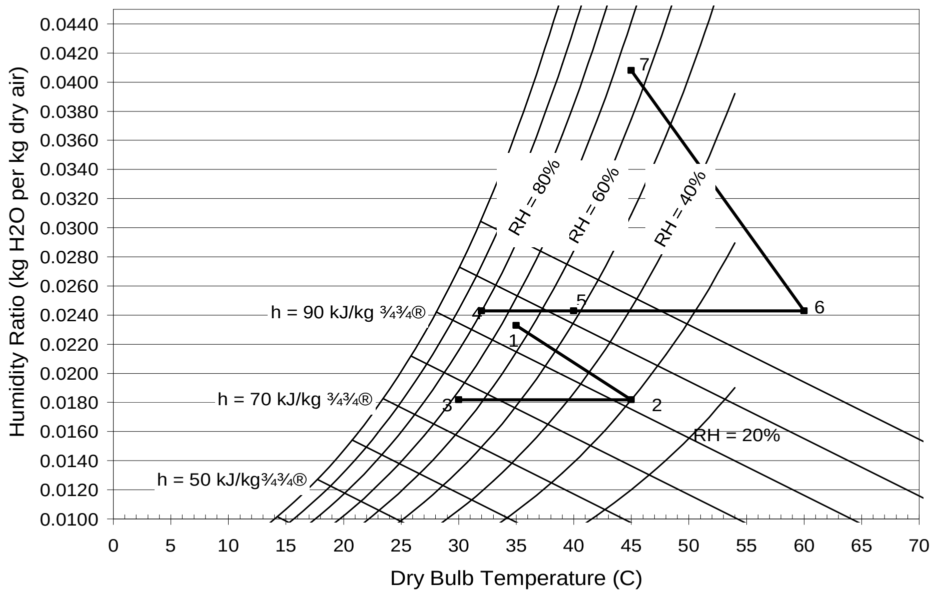


Fig. 3 Psychrometric chart showing a typical desiccant cooling process

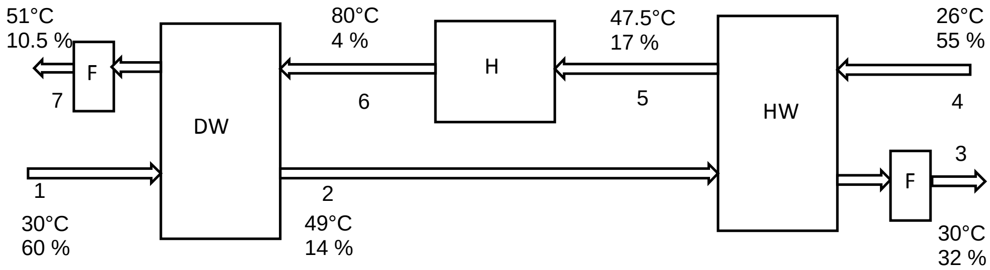
The psychrometric chart shown in Fig. 3 illustrates the cooling/dehumidification process. During the summertime hot moist air at for example 35 ºC and 21 g/kg moisture content is drawn through the desiccant wheel so that it comes of at say 45 ºC and

18 g/kg moisture content. The supply air stream then passes through the thermal wheel where it is sensibly cooled to say 30 ºC.

On the return air side, air from the room space at for example, 31 ºC and 24 g/kg moisture content enters the thermal wheel. As the return air stream passes through the thermal wheel, it is sensibly heated. The air is then heated up to approximately 60 ºC in order to regenerate the desiccant coil. It should be noted that in order to reduce system operation costs approximately 20% of the return air flow by-passes the regenerating oil and the desiccant wheel [17].

Fig. 4 shows the schematic diagram of the basic desiccant model which was under experimental investigation. This basic model is used for comparison with the experimental data obtained previously. Standard component such as DW, HW and heater were used to simulate the thermal behaviour of the whole system under hot-humid climate using TRNSYS, which is an abbreviation of Transient Simulation.

TRNSYS is a simulation environment and an open modular structure for the transient simulation of system used to validate new energy concepts. A TRNSYS project is typically set up by connecting components graphically in the simulation studio [18]. The two effectiveness values of the DW proposed by Banks which is discussed in TRNSYS manual have been used in the simulation.



F: Fan H: Heater DW: Desiccant Wheel HW: Heat Wheel

Fig. 4 Simulation result of the basic desiccant cooling system

The considered desiccant wheel is a silica-gel coated wheel with 300 mm external diameter and 100 mm depth.

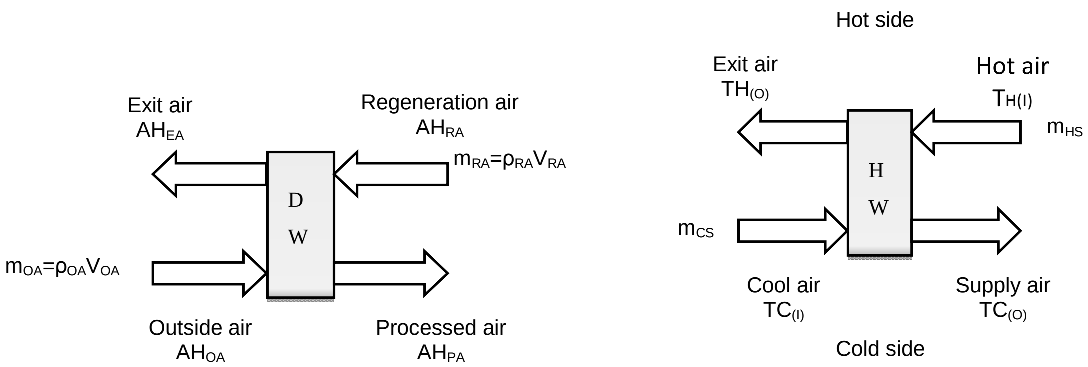


Fig. 5 The schematic diagram of the desiccant wheel (left) and heat wheel (right)

Fig. 5 shows the schematic diagram of the wheel and the governing performances were based on National Renewable Energy Laboratory (NREL) testing manual [19]. The dehumidification performance of the desiccant wheel is based on moisture removal capacity or MRC given by

$$MRC = m_{OA}\left(AH_{OA} - AH_{PA}\right) \tag{1}$$

The amount of moisture removal capacity or sorption rate is the same at the regeneration side which is the moisture removal regeneration (MRR) expressed as

$$MRR = m_{RA}\left(AH_{EA} - AH_{RA}\right) \tag{2}$$

To evaluate the characteristics and performance of the experiment, the moisture mass balance (MBB) determined the quality of gathered data and thus the MBB is a checking factor and expressed as

$$MMB = \frac{MRC}{MRR} \tag{3}$$

For acceptable accuracy of gathered data, the ratio of MBB should be within 0.5 to 1.5 [9].

The heat wheel is coated with silicone-acrylic compound. The physical appearance and dimension of the heat wheel is the same as the desiccant wheel. The main purpose of the heat wheel is for sensible heat recovery only

$$Eff_{Average} = \frac{m_{CS}\left(T_{C(O)} - T_{C(I)}\right) + m_{HS}\left(T_{H(I)} - T_{H(O)}\right)}{2m_{Minimum}\left(T_{H(I)} - T_{C(I)}\right)} \tag{4}$$

$Eff_{Average}$ is the average effectiveness of the heat wheel. The m_{CS} and m_{HS} are the mass flow rates (hot and cold sides), kg/s. $T_{C(I)}$ and $T_{C(O)}$ are the temperature of air in the cold side (inlet and outlet), °C. $T_{H(I)}$ and $T_{H(O)}$ are temperature of air in the hot side inlet and outlet, °C. $m_{Minimum}$ is the minimum flow rate of either hot or cold side, kg/s.

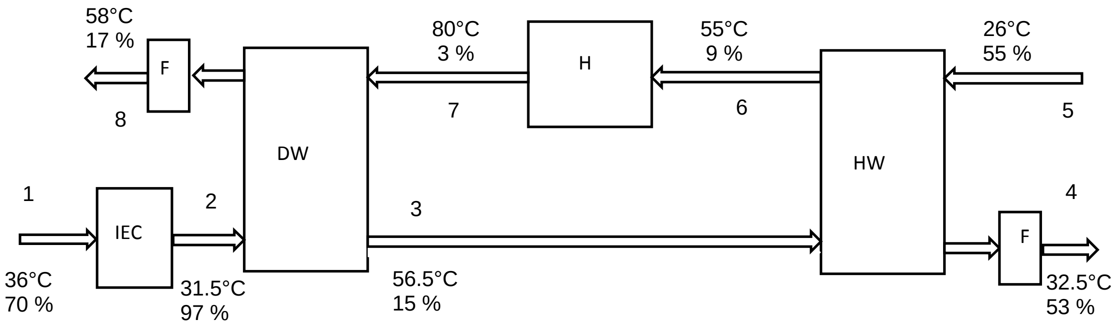
IV. RESULTS AND DISCUSSION

The basic model of the DW combined with HW and heater for the DW regeneration shown in Fig. 4 has been validated against the experimental published data [2]. Table I shows the comparison between the experimental data and the simulated ones. The air conditions for the outdoor air (point 0) are set at value of 30°C and 60% Rh. The volumetric flow rate is 120 m^3/h. The return air (point 3) is set at value of 26°C and 55%Rh and flow rate of 120 m^3/h. The result of the simulation shows that the DBT and Rh are within the accepted range compared with the experimental ones. The differences are mainly due to the initial value of some intrinsic parameters of the model such as the DW and HW effectivenesses, which must be thoroughly investigated and adjusted in the future.

TABLE I EXPERIMENTAL AND SMLATON RESULTS

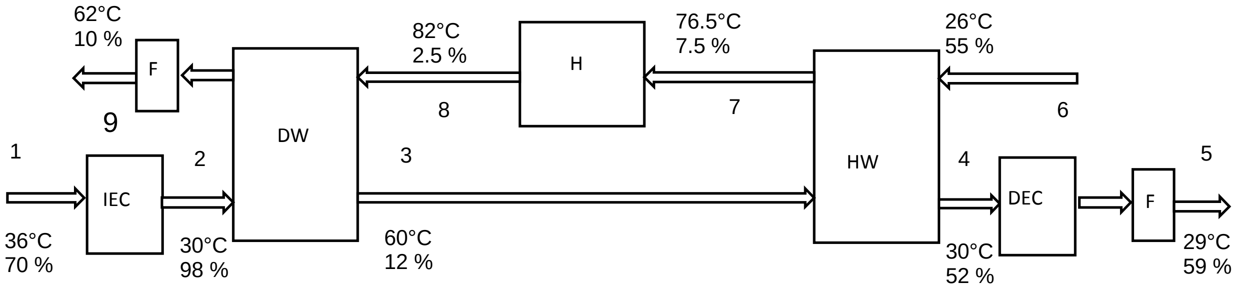
		1	2	3	4	5	6	7
DBT [°C]	Experimentation	30.8	59.2	33.5	26.1	52.6	80	51.9
DBT [°C]	Simulation	30	49	30	26	47.5	80	51
RH [%]	Experimentation	58.5	9.1	35.3	55.5	13.3	3.9	20.1
RH [%]	Simulation	60	12	32	55	17	4	10.5
% Difference	DBT	2.5	17.2	10.4	0	9.7	0	1.7
	RH	2.5	24.1	9.3	1	21.7	2.5	47.7

The basic model of the desiccant cooling system is limited in term of input data of the DBT. Indeed, for high DBT, TRNSYS does not have the capability to converge towards the solution. Therefore, a pre-cooling system using indirect evaporative cooler IEC will solve the problem. The desiccant cooling system with IEC is shown in Fig. 6. It can be seen that the Rh of the supply air (state 4) decreases by 24 %, while the DBT decreases by 9 %. By adding direct evaporative cooler DEC as shown by Fig. 7, the DBT drops to 29°C and Rh rises to 59 %, which are considered as appropriate indoor condition for thermal comfort.



F: Fan H: Heater DW: Desiccant Wheel HW: Heat Wheel IEC: Indirect Evaporative Cooler

Fig. 6 Schematic diagram of the standard desiccant cooling system with pre-cooling



F: Fan H: Heater DW: Desiccant Wheel HW: Heat Wheel IEC: Indirect Evaporative Cooler DEC: Direct Evaporative Cooler

Fig. 7 Schematic diagram of the standard desiccant cooling system with pre-cooling and DEC

V. CONCLUSIONS

The desiccant cooling system presented in this paper which combines the desiccant wheel with heat wheel can be a suitable solution for hot-humid climate. The basic model by means of TRNSYS has been validated against the experimental data obtained from Tohoku University in Japan.

Combining the basic desiccant model with IEC and DEC allows reducing significantly the DBT to 29°C and keeping Rh within the accepted value 59 % considering hot-humid outside climate at 36°C and 70%.

The performance of the desiccant cooling system will be studied more for further improvements. One of these improvements is to combine with the desiccant cooling a solar air heating system for the DW regeneration.

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