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Simulation and parameter analysis of a two-stage desiccant cooing/heating system driven by solar air collectors

H. Li [a], Y.J. Dai [a,*], M. Köhler [b], R.Z. Wang [a]

[a] Institute of Refrigeration & Cryogenics, Shanghai Jiao Tong University, Shanghai 200240, China
[b] University of Applied Sciences Stuttgart, 70174 Stuttgart, Germany

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ABSTRACT

To increase the fraction of solar energy might be used in supplying energy for the operation of a building, a solar desiccant cooling and heating system was modeled in Simulink. First, base case performance models were programmed according to the configuration of the installed solar desiccant system and verified by the experimental data. Then, the year-round performance about the system was simulated. Last, design parameters of solar air collectors were optimized that include collector area, air leakage and thermal insulation. Comparison between numerical and experimental results shows good agreement. During the simulation, the humidity load for 63 days (51.7%) can be totally handled by the two-stage desiccant cooling unit. For seasonal total heating load, about 49.0% can be handled by solar energy. Based on optimized results, the thermal energy subsystem functioned to its expected performance in solar energy collection and thermal storage.

1. Introduction

As one of renewable energy, solar energy can be used as the heat source for building cooling, heating and ventilation to conserve energy, as well as to protect our environment by avoiding pollutions generated during the produce of gas and electricity.

The performance of solar driven desiccant system has extensively been studied theoretically and experimentally over the past several decades. Mavroudaki et al. [1] reviewed the feasibility of solar powered single-stage desiccant cooling in southern Europe. The studies demonstrate that it is feasible in some parts of southern Europe and most of central Europe. Bourdoukan et al. [2] have investigated experimentally the performance of a desiccant air handling unit powered by solar vacuum-tube collectors. The overall efficiency of the solar installation is about 0.55 while the efficiency of vacuum-tube collectors is above 0.6 independently of the operating temperature. Khalid et al. [3] installed a solar assisted heating and desiccant cooling systems for a domestic building and simulated the effects of various designs and operating conditions on the performance of this system and its components. Halliday et al. [4] uses a solar desiccant cooling model to evaluate the feasibility using in United Kingdom for cooling and heating buildings.

Moreover, many investigations have been carried out to use mathematical models to analysis solar driven desiccant system [5,6]. Khalid et al. [7] put forward a solar assisted, pre-cooled hybrid desiccant cooling system for Pakistan and simulated it using TRNSYS, then simulated four modes of the cooling system. Filiz Ozgen et al. [8,9] investigated thermal performance of a double-flow solar air heater having aluminum cans and simulated a new solar air heater through least-squares support vector machines. Ahmed et al. [10] used a desiccant cooling system model to investigate the unglazed transpired solar collector for regeneration of the desiccant and compared its performance with an ordinary flat plate collector. Bourdoukan et al. [11] investigated a solar desiccant plant with high efficiency heat pipe vacuum tubes.

As mentioned above, desiccant system driven by solar energy for building heating and cooling has been investigated. However, two-stage desiccant system using solar air collectors has not been researched in commercial building. In this paper, a procedure for the simulation analyses of a solar driven desiccant cooling/heating system is proposed. It is conceptualized to produce both cooling during summer and heating during winter. This solar desiccant system mainly consists of 92.4 m^2 evacuated tube solar air collectors and a 20 kW two-stage desiccant cooling system for space air conditioning. The guidelines for the design and operation of solar cooling and heating system were formulated as a basis to preliminarily evaluate the efficiency and effectiveness of a solar cooling and heating system for a given building space.

2. Experimental setup description

The solar desiccant cooling and heating system, has been designed, installed, and operated for the Electric Workplace at Himin Solar Energy Group in China [12]. Depending on the demand of

* Corresponding author. Tel.: +86 21 34204358; fax: +86 21 34206814.
E-mail address: yjdai@sjtu.edu.cn (Y.J. Dai).

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Nomenclature

A	surface area (m^2)
cp	heat capacity (J/(kg K))
d	diameter (m)
E	energy consumption (kW)
G	solar radiation (W/m^2)
h	convective heat transfer coefficient (W/m^2 K)
k	heat transfer coefficient (W/m^2 K)
m	mass flow rate (kg/s)
Q	heat transfer capacity (J)
SF	solar fraction
T	temperature (°C)
$TCOP$	thermal COP
t	time (s)
ε	efficiency of heat exchanger
λ	thermal conductivity (W/m K)

Subscripts

1, 2,...,10	refers to the positions described in Fig. 1
Abs	absorber on the inside of vacuum tube
Air	process air in the solar air collector
Amb	ambient condition
a	process air in the heat exchanger
aux	auxiliary energy
c	convection heat transfer
fan	regeneration fan and process fan
HE	heat exchanger
in	inside of surface or inlet of process fluid
out	outside of surface or outlet of process fluid
Pre	process air
pump	pump used in cooling tower
r	radiation heat transfer
*reg*1	first-stage regeneration air
*reg*2	second-stage regeneration air
solar	solar gain from solar collectors
Tube	alumina tube in solar air collector
w	water

air-conditioning, the running modes can be adjusted by switching some valves, which are cooling mode and heating mode, which can be seen in Fig. 1.

- Mode 1: cooling mode. Valve 1, 2, 3, 4 are opened while valve 5, 6 are closed, the solar air conditioning system runs in cooling mode.
- Mode 2: heating mode. Valve 5, 6 are opened while valve 1, 2, 3, 4 are closed, after the solar collector, the process air is supplied to room directly.

Psychometric chart shown in Fig. 2 illustrates the evolution of air treatment through the cooling mode. The process air follows the following processes:

- 1 → 2 1st stage dehumidification of process air in the first wheel; the procedure is almost adiabatic and the air is heated by adsorption heat and the hot matrix of the wheel coming from the regeneration side;
- 2 → 3 sensible cooling of the process air in heat exchanger to cooling water to improve the potential of dehumidification in 2nd stage;
- 3 → 4 2nd stage dehumidification of the process air in the second wheel;
- 4 → 5 sensible cooling of the process air in heat exchanger to cooling water to optimize system performance;
- 5 → 6 evaporative cooling; the process air experiences an enthalpy increase procedure and the air is dehumidified, while the temperature is decreased;

The regeneration air follows the following processes:

- 7 → 8/9 the regeneration air heated by solar air collectors is humidified and the desiccant wheel is regenerated.

3. Evaluation of the system performance models

Due to the proposed system is mainly composed by rotary desiccant wheel, heat exchanger, direct evaporative cooler, solar air collector, its mathematical model can be established by combining models of these components.

3.1. Solar air collectors

This solar collectors system with a total area of 92.4 m^2 was integrated into three subsystems. Each subsystem was consisted of 4 three-stage modules and 1 two-stage modules. The evacuated-tube solar air collectors were installed in series and oriented in 15° east from true north. Each evacuated-tube solar air collector

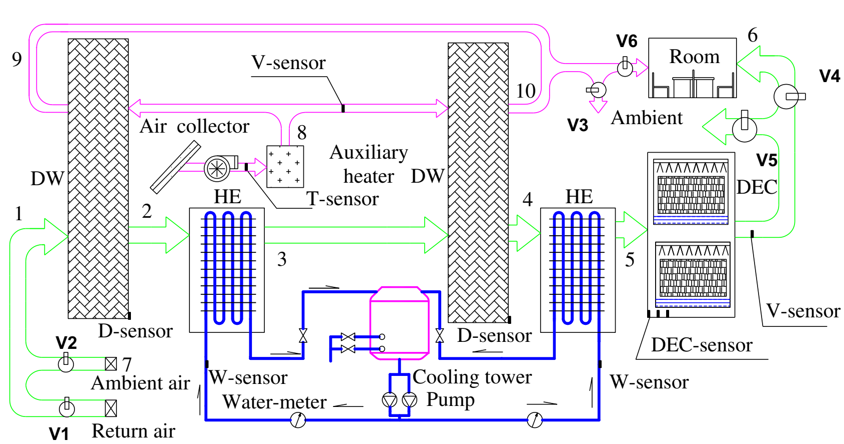

Fig. 1. The configuration diagram of two-stage desiccant cooling system.