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Potential of solar heat pipe vacuum collectors in the desiccant cooling process: Modelling and experimental results

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Abstract

Desiccant cooling is an alternative technique to vapour compression systems. When thermally driven at moderate temperatures, it can be coupled to solar collectors. The use of flat-plate collectors and air collectors has demonstrated low efficiency in the coupling process and so a low potential of solar energy use in desiccant cooling. In this paper the use of heat pipe vacuum tube (HPVT) collectors in a solar desiccant cooling set up is investigated. First, a model for the collectors is proposed and experimentally validated under various operating conditions. A model of the storage tank taking into account thermal stratification is also validated. The experimentally evaluated efficiency of the HPVT collectors for one operating day varies between 0.6 and 0.7. Finally, simulation of the solar desiccant plant cooling a building is performed for different climates over a summer season. The solar fraction and the overall efficiency of the solar plant are calculated for this period and the potential of the vacuum tube collectors is evaluated for application to the desiccant cooling process.
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Keywords: Vacuum solar collectors; Desiccant cooling; Simulation; Experimental set up; Overall efficiency

1. Introduction

Solar energy is used for space heating, hot water production and thermally driven air-conditioning systems including desiccant cooling systems. This air-conditioning technique would be an alternative to vapour compression systems (Jurinak et al., 1984); it has a low environmental impact since water is used as refrigerant and electrical consumption is limited to the auxiliaries. A solar desiccant cooling plant is shown in Fig. 1. It is a thermally driven open cooling cycle based on evaporative cooling and adsorption. With reference to Fig. 1, the cycle operates as follows: first, outside air (1) is dehumidified in a desiccant wheel (2); it is then cooled in the sensible rotary heat exchanger (3) by the return, cooled, air before undergoing another cooling stage by an evaporative process (4). Finally, it is introduced in the room (5). The operating sequence for the return air (6) is as follows: it is first cooled to its saturation temperature by evaporative cooling (7) and then it cools the fresh air in the rotary heat exchanger (8). It is then heated in the heat exchanger fed by the solar energy tank (9) and if needed by a backup (10) and finally regenerates the desiccant wheel by removing the humidity before exiting the installation. Depending on the outside conditions, the air handling unit operates under two main modes: indirect evaporative cooling (IEV) for small cooling loads (return air humidifier and rotary heat exchanger) or desiccant mode (complete operating system, including the regeneration heat exchanger) for higher loads. For moderate summer conditions, in the morning when the outside temperature is low, the indirect evaporative cooling mode is able to keep the room in a comfortable range; there is thus no need for

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Nomenclature

Symbols

AHU	air handling unit
C	heat capacity (J kg^{-1} K^{-1})
E	energy (J)
e	thickness (m)
G	solar global radiation (W m^{-2})
OE	overall efficiency (dimensionless)
H	heat transfer coefficient (W K^{-1} m^{-2})
IEV	indirect evaporative cooling
K	heat loss constant (W K^{-1} m^{-2})
L	latent heat of vaporization (J kg^{-1})
m	mass flow rate (kg s^{-1})
M	mass (kg)
p	power (W)
RH	relative humidity (%)
S	area (m^2)
SF	solar fraction (dimensionless)
T	temperature (K)
u	fluid velocity (m s^{-1})
UA	global heat exchange coefficient (W K^{-1})
V	volume (m^3)
W	humidity ratio (g$_{\text{water vapor}}$ kg^{-1}$_{\text{dry air}}$)
z	coordinate in the fluid direction (m)
ε	emissivity (dimensionless)
λ	conductivity (W K^{-1} m^{-1})
η	efficiency (dimensionless)
$\tau\alpha$	transmission-absorptance coefficient
σ	Stefan Boltzmann constant (W K^{-4} m^{-2})
ρ	density (kg m^{-3})

Subscripts

a	ambiant
b	buffer
c	condenser
f	storage fluid in the manifold
g	glass
H	heat pipe
i	inlet
p	plate absorber
o	outlet
r	return from regeneration
reg	regeneration
sat	saturation

regeneration and the solar heated water can be stored in the tank (Stabat, 2003; Maalouf, 2006). During the day with the rising outside temperature and increasing solar gains the indirect evaporative cooling cannot provide the cooling and so the desiccant mode is then required, while solar energy is needed for the regeneration of the desiccant wheel. The minimum temperature required for regeneration depends on the nature of the desiccant material. It varies from 50 °C for lithium chloride to 60 °C for silica gel. We chose silica gel for its higher dehumidification performances in spite of the higher temperature needed for its regeneration.

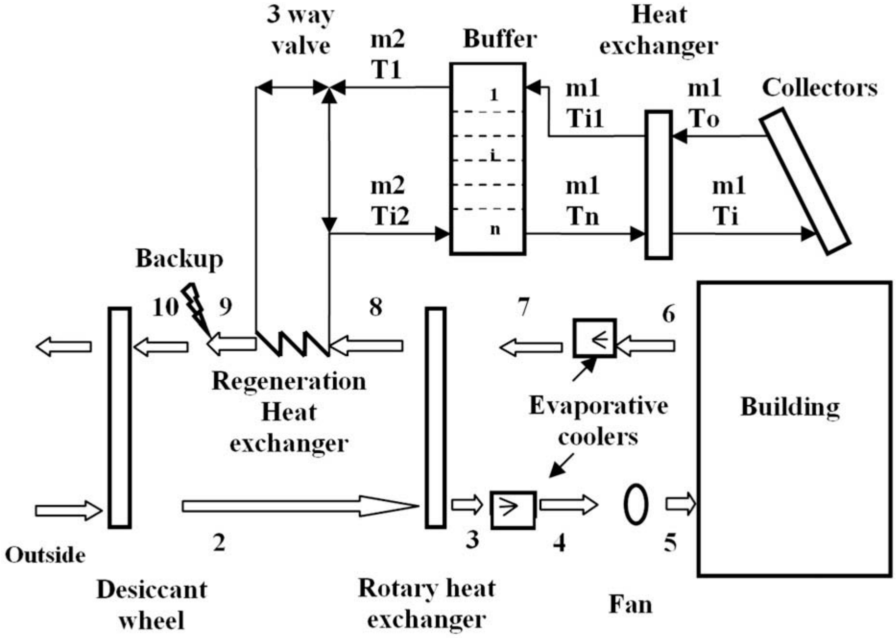

Fig. 1. Solar desiccant cooling installation.

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