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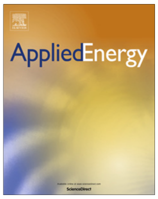

Study of solar regenerated membrane desiccant system to control humidity and decrease energy consumption in office spaces

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HIGHLIGHTS

- A model of solar-regenerated liquid desiccant membrane system was developed.
- The model predicts the humidity removal capacity from the space.
- The model was experimentally validated.
- The system resulted in 10% decrease in indoor relative humidity in Beirut climate.
- The system payback period was about 7 years.

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ABSTRACT

This paper investigates the feasibility of using a solar regenerated liquid desiccant membrane system to remove humidity from an office space. While conventional vapor compression cycles dehumidify the air before supplying it to the indoor space, through using sub cool–reheat process, the proposed cycle absorbs the humidity directly from indoor space through the dehumidifier. The dehumidifier consists of a set of permeable vertical tubes placed in the indoor space with liquid desiccant flowing through them. Solar energy is used as the source of thermal energy required for the regeneration of the desiccant and sea water is used as heat sink to provide the cooling needs of the liquid desiccant.

A mathematical model of the membrane desiccant system was integrated with the internal space model and solar system model to predict the humidity removal capacity from the space at given dehumidification and heat sink temperatures and outdoor environmental conditions. Experiments were performed to validate the model results be comparing exit humidity and temperature of the exit air from the space.

The validated model was applied to a case study consisting of an internal office during the month of August in Beirut hot humid climate. A decrease of 10% in indoor relative humidity is observed when the system was used. The cost of the proposed system was compared to the cost of a conventional vapor compression cycle that provides the same indoor conditions. A payback period of 7 years and 8 month was estimated compared to the investment in the vapor compression cycle.

1. Introduction

The control of indoor humidity is of fundamental importance for thermal comfort of human beings, building material sustainability and energy consumption. Thermal comfort deals with regulating the thermal environment, which includes temperature and relative humidity along with air velocity, around humans. Extreme levels of relative humidity, whether it is high or low, can irritate people's comfort [1]. Not only does it affect people, inappropriate levels of humidity also affect the building structure [2]. Negative impact of elevated moisture levels on building material includes electrochemical corrosion, volume changes, and chemical deterioration [3].

In order to eliminate the preceding negative impacts of elevated moisture levels, indoor humidity should be controlled, either by conventional or non-conventional techniques. In humid climates, the humidity issues are a major contributor to energy inefficiency in HVAC devices. The high humidity of the outside air combined with ventilation requirement increases the latent load. Most conventional air-conditioning systems are not designed to independently control temperature and humidity. The conventional way

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Nomenclature

T	temperature (°C)
T_{room}	indoor room temperature (°C)
c	concentration of water per desiccant (kg_{H_2O}/kg_{CaCl_2})
c_p	specific heat (J/kg K)
h_c	heat convection coefficient (W/m^2 s)
h_m	mass convection coefficient (m/s)
$h_{solution}$	enthalpy of the liquid desiccant solution (J/kg)
r_o	external radius of the pipe (m)
r_i	internal radius of the pipe (m)
E	power input/output (W)
D	diffusion constant of vapor in the pipe wall material (m^2/s)
k	thermal conductivity (W/m K)
m	mass rate (kg/s)
n	number of dehumidification/regeneration pipes
l	length of the pipe (m)
h_{fg}	latent heat of vaporization of the water (J/kg)
U	resistance coefficient per unit length
Q	internal heat generation (W)
Le	Lewis number

Greek letters

ρ	density (kg/m^3)
ω	humidity ratio (kg_{H_2O}/kg_{dryair})
$\omega^*_{solution}$	the equilibrium humidity ratio at surface of solution at temperature and concentration of solution (kg_{H_2O}/kg_{dryair})

Subscripts

solution	$CaCl_2$ and H_2O solution in the permeable tubes
o	outer side of the permeable tube
i	internal side of the permeable tube
inlet	inlet conditions to the space
outlet	outlet conditions to the space
m	mass convection
c	heat convection
a	air
v	water vapor
w	liquid water
d	desiccant $CaCl_2$
g	vapor generation

of moisture removal is cooling the indoor air (using vapor compression cycle) to temperatures below its dew point temperature to condense the excess moisture followed by reheating to the adequate supply air temperature. This is an energy intensive process [4,5]. Recently, research has been oriented towards considering non-conventional, passive and less-intensive methods for controlling indoor humidity. A known sustainable dehumidification technique is the use of desiccant technology as an active\passive method for HVAC applications [6–11].

Conventional desiccant dehumidification techniques utilize solid or liquid desiccant based systems. In the case when a liquid desiccant is used, dehumidification and regeneration tower beds are employed [6,9], whereas in the case of a solid desiccant, a rotary desiccant wheel is used [10]. An attractive feature of desiccant dehumidification systems is their suitability for solar or other low-grade thermal energy applications [6,7]. However, dehumidification of air is traditionally done through direct contact between the strong desiccant solution and the supply air. After the air is dehumidified, it is further cooled to the supply room temperature [9]. This technology can have many negative impacts related to health issues and corrosion problems especially with the entrainment of hazardous salts to the ventilation system due to the direct contact of air with the desiccant material [12].

To overcome the previous problems, researchers have recently implemented hydrophobic membranes to cool and dehumidify the air without direct contact with the desiccant [13–20]. The membranes used are permeable to water vapor but impermeable to liquid desiccant. The membrane–desiccant systems have been used in two different configurations. The first configuration employs a membrane desiccant system that dehumidifies the supply air before entering the indoor space [15–18]. In this configuration (first), there are two compact energy exchangers, one for dehumidifying the air and the second for regenerating the liquid desiccant [15,18]. Since simultaneous heating and cooling are required for the liquid desiccant operation cycle, the liquid desiccant membrane system has been integrated with conventional vapor compression reverse cycle forming a hybrid air conditioning system [19]. The results showed that such integrated system has a higher coefficient of performance (COP) compared to the conventional air conditioning system since the cooling coil is operating at a higher temperature and the regeneration of the liquid desiccant utilizes the dissipated condenser heat [19]. Some of the compact energy exchangers that have been studied in literature are Liquid-to-air membrane energy exchanger (LAMEE) [16] and run-around membrane energy exchanger (RAMEE) [17] systems. The semi-permeable membrane allows simultaneous heat and moisture transfer between the air and desiccant solution streams. A RAMEE is comprised of two or more separated liquid-to-air membrane energy exchangers and an aqueous desiccant solution that is pumped in a closed loop between the LAMEE.

The other configuration (second), which has been less referenced in the literature compared to the first one of hybrid air conditioning system, is the direct indoor dehumidification, where a permeable membrane is placed in the indoor space picking up moisture, as it is generated, directly from the indoor air. Even though this configuration has received less attention than the first one, nevertheless it has a promising performance and can have additional advantages.

Direct indoor dehumidification has many advantages over outdoor dehumidification. It may offer better humidity control for the indoor environment during transient latent load changes if the driving force for the dehumidification process (the difference between the vapor pressure in the air and in the desiccant aqueous solution) is properly regulated to minimize transient delays [11,13]. In the configuration where dehumidification is occurring directly in the internal space, the supply air humidity ratio may not need to be decreased below the indoor humidity ratio as it is the case with the first configuration where the supply air humidity ratio is lowered before delivering the conditioned to the space. It should be noted that in the case of indoor dehumidification, the supply air humidity ratio cannot have higher values than the indoor humidity ratio to prevent any possible condensation.

One of the novel configurations that have been used to perform indoor dehumidification is the Heat and Moisture Transfer Panel (HAMP) [11,13,14]. The analysis of the HAMP was mainly focused on its efficiency and performance in handling internal latent and sensible loads; hence it was placed in an open loop cycle where the liquid desiccant was conditioned before it enters to the indoor space [11,13]. Regenerating the liquid desiccant was not included in both studies [11,13].