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A hybrid solar air conditioner: Experimental investigation

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ABSTRACT

The removal of moisture from the supply air using conventional air conditioners (A/C) represents a considerable portion of the air conditioning load in hot and humid regions. Desiccant assisted A/Cs are used to address this issue. In this work, the performance of a hybrid A/C, which consists of a desiccant wheel, an enthalpy wheel, and a vapor compression cycle (VCC), is investigated experimentally. The effect of the process air stream's temperature and humidity, and the effect of the ventilation rate on the hybrid A/C performance are investigated. The experimental results show that the hybrid A/C is more effective than the standalone VCC in maintaining the indoor conditions within the comfort zone. The simulation of the complete hybrid solar A/C that uses a concentrating photovoltaic/thermal collector shows that a system coefficient of performance higher than unity is possible.

Conditionneur d'air solaire hybride : étude expérimentale

Mots clés : Photovoltaïque à concentration/ collecteur thermique ; Conditionneur d'air hybride ; Solaire déshydratant ; déshumidification ; cycle à compression de vapeur

1. Introduction

In order to reduce the air conditioning load of buildings, researchers and designers focus mainly on improving the buildings' shell. Therefore, there has been great progress on reducing heat gain via improved insulation materials and fenestrations. This improvement in turn reduces sensible loads of the building, i.e. sensible heat ratio of the building. However, reducing the sensible loads increases the ratio of the latent load to the total air conditioning load. Therefore, addressing the latent load of buildings becomes increasingly important. Regardless of the climate zone, the temperature and humidity have to be controlled in order to maintain space comfort conditions. Conventionally, air conditioning (A/C) systems, based on vapor compression cycles, have to lower the air temperature below its dew point to accomplish

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Nomenclature

Abbreviations

A/C	Air Conditioner
ARI	Air Conditioning and Refrigeration Institute
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
COP	coefficient of performance
DW	desiccant wheel
DWC	desiccant wheel cycle
EW	enthalpy wheel
Exp	experimental
FS	full scale
MMB	moisture mass balance
MRC	moisture removal capacity ($kg_w\ h^{-1}$)
MRR	moisture rejected rate ($kg_w\ h^{-1}$)
RD	reading
RPH	revolution per hour
TC	thermocouple
TRNSYS	Transient System Simulation Program
VCC	Vapor Compression Cycle
W-A-HX	Water–Air Heat Exchanger

Parameters

$\dot{m}$	mass flow rate ($kg_a\ h^{-1}$)
E	energy input rate (kW)
h	moist air enthalpy (kJ kg_a^{-1})
h_{fg}	latent heat of water (kJ kg_w^{-1})
P	compressor work (kW)
Q	heat transfer rate (kW)
RH	relative humidity (%)
R_{speed}	rotational speed (RPH)
T	temperature (°C)
U	uncertainty
w	humidity ratio ($kg_w\ kg_a^{-1}$)
η	efficiency

Subscripts

air	air
amb	ambient
c	cooling
coll-in	incident on the solar collector
DW	desiccant wheel
elec	electric
$elec_{coll}$	collector electrical efficiency
f	dependent variable
ref	refrigerant
regen	regeneration
Req	required
Sys	complete hybrid solar air conditioner system
ther	thermal
VCC	vapor compression cycle
x_i	ith independent variable

dehumidification. This approach makes the compressor operate at higher pressure ratio, hence reducing the cycle coefficient of performance (COP). In addition, an auxiliary heater might be required to sensibly heat the air before it is supplied to the conditioned space.

Desiccant assisted air conditioners offer a solution to meet the humidity and temperature requirements of buildings via decoupling latent and sensible loads. Extensive studies have been carried out on desiccant air conditioners. These studies focus mainly on two key aspects: improving desiccant materials' performance and innovative system configurations. The first aspect involves the modification of conventional desiccant materials (Chung and Chung, 1998; Knez and Novak, 2001; Yano and Fukushima, 2003) and the fabrication of new desiccant materials (Beery and Ladisch, 2001; Mathiowitz et al., 2001a,b; Khedari et al., 2003). The second aspect involves the modification of the basic rotary desiccant air conditioner introduced by Pennington (Pennington, 1955) as illustrated in Fig. 1. For example, the ambient air can be used in the regeneration side of the cycle and the return air can be re-circulated with no fresh air back up to provide the so called recirculation cycle (Waugaman et al., 1993). Another heat exchanger could also be added to the recirculation cycle as in Dunkle cycle (Dunkle, 1965). The performance of rotary desiccant A/C have been investigated experimentally (Kodama et al., 2001; Ge et al., 2008; Enteria et al., 2010; Heidarinejad and Pasdarshahri, 2010; Panaras et al., 2010). The common feature of these cycles is that evaporative cooling is used to handle the sensible heat. This requires the process air stream to be over-dried in order to permit its cooling using the evaporative cooling process. This motivates the introduction of the hybrid air conditioner where the latent load is handled by the desiccant wheel and the sensible load is handled by the vapor compression cycle (VCC). In addition, one can notice that studies on the desiccant air conditioners focus mainly on silica gel and usually do not use standard testing conditions to rate their system performance.

The hybrid desiccant air conditioning system, which is actually an integration of a rotary solid desiccant dehumidification and a vapor compression air conditioning unit, has been reported to not only save electrical consumption, but also to improve indoor comfort. La et al. (2011) experimentally investigated the performance of a two-stage desiccant cooling system coupled with a VCC. Using Transient Systems Simulation (TRNSYS), the system performance was investigated under hot, humid, and extreme humid weather conditions. The system was found to reduce the power consumption by up to 34 percent. Li et al. (2012) reported case study results of the installation of the two-stage rotary desiccant at an electronic plant in china. Evacuated tube air collectors were used to drive a 20 kW desiccant cooling system. The experimental results showed that the system improved the indoor comfort significantly in hot and humid climate conditions. Fong et al. (2010) used TRNSYS to investigate six configurations of solar desiccant cooling systems. All of the six systems had the desiccant cycle coupled with another cycle to accommodate the sensible loads. It was found that coupling the desiccant cycle with a VCC would consume up to 22.6% less yearly primary energy than the basic desiccant wheel cycle. Energy savings of the hybrid system were up to 35.2% when compared to conventional centralized air-conditioners. Beccali et al. (2012) used a VCC with two cooling coils, one was to pre-dehumidify the