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Experimental investigation of a ground-coupled desiccant assisted air conditioning system

Arne Speerforck *, Gerhard Schmitz

Hamburg University of Technology, Institute of Engineering Thermodynamics, Denickestr. 17, 21073 Hamburg, Germany

HIGHLIGHTS

- A ground-coupled desiccant assisted air conditioning system is evaluated experimentally.
- The evaluation is carried out for steady state operation and the cooling period as a whole.
- The suitability of the system to provide comfort conditions is examined demonstrated.
- Energy comparisons with other air-conditioning systems are performed.
- The performance of the borehole heat exchangers for cooling is evaluated.

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ABSTRACT

In a pilot installation at Hamburg University of Technology the coupled operation of an open cycle desiccant assisted air conditioning system with borehole heat exchangers is investigated. The paper presents experimental data recorded during the cooling period 2014. Results show that the electricity demand of the system can be reduced to the parasitic consumption of the fans, wheels and pumps. An electric energy efficiency ratio of 6.63 is achieved, enabling electricity savings of more than 70% compared to a conventional reference system and 54% compared to a desiccant assisted hybrid system relying on an electric chiller. Comfort conditions can be maintained during the whole cooling period. The borehole heat exchangers work highly efficient, exhibiting a seasonal performance factor of 192.

1. Introduction

The building sector is responsible for one third of the global final energy demand [1]. Even though demand for space heating is currently more important than the respective demand for space cooling, a considerable increase in cooling demand is expected due to climate change and income growth in regions with high cooling requirements. According to [2], the final energy demand for air conditioning is expected to be 40 times larger in the year 2100 than it was in the year 2000 and that it will exceed heating demand by 2060. Even for temperate climates a considerable increase is expected. By 2025, the installed cooling capacity in the European market is likely to be 55–60% higher than in 2010 [3]. This increasing demand is seen as one of the prime concerns in energy research [4].

Moisture removal accounts for a significant fraction of the mentioned air conditioning loads during the summer period. In a conventional system the air is cooled below the dew point temperature (e.g. 10 °C) to remove latent loads. Dehumidification causes large cooling capacities which are usually provided by an electric motor-driven vapour compression, causing a high demand for electricity. Therefore, efficient HVAC alternatives are important to lower greenhouse gas emissions related to electricity generation. In an open cycle desiccant assisted air conditioning system dehumidification and cooling can be separated within the process. First, moist air is dehumidified by means of a solid or liquid desiccant. Afterwards, the dried air can be cooled by a heat sink working at a higher temperature level (16 °C). This enables the usage of renewable heat sinks as for example shallow geothermal energy. While thermal energy is required for the regeneration of the desiccant, the required cooling capacity of the cold water cycle is reduced significantly.

These advantages are well established in literature [5]. Accordingly, a considerable amount of research has been conducted studying the design and performance of desiccant wheels either experimentally (e.g. [6–8]) or numerically (e.g. [9–12]). Furthermore, researchers have developed different system configurations

* Corresponding author.
E-mail addresses: arne.speerforck@tuhh.de (A. Speerforck), schmitz@tuhh.de (G. Schmitz).

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Nomenclature

COP	coefficient of performance (–)
EER	energy efficiency ratio (–)
EB	energy balance (–)
f	primary energy factor (–)
h	enthalpy (kJ/kg)
MPF	monthly performance factor (–)
MMB	moisture mass balance (–)
P	electrical power (kW)
p	pressure (Pa)
Q	thermal energy (J)
$\dot{Q}$	thermal power (W)
SPF	seasonal performance factor (–)
T	temperature (°C)
t	time (s)
$\dot{V}$	volume flow (m^3/h)
W	electrical energy (J)
w	air humidity ratio (g/kg)
Δ	difference (–)
δ	relative difference (–)
λ	thermal conductivity (W/mK)
φ	relative humidity (%)

Subscripts

AC	air cooler
AH	air heater
AHU	air handling unit
aux	auxiliary
BHX	borehole heat exchanger
C	cooling
DW	desiccant wheel
el	electrical
eta	extract air
G	gas
HRW	heat recovery wheel
in	inlet
m	month
out	outlet
p	period
PE	primary energy
sup	supply air
th	thermal
v	vaporization
w	water

for different climate zones, overviews are provided in [4,13–17]. These systems can be divided in DEC (Desiccant Evaporative Cooling) systems which over dehumidify the air before it is cooled by water injection and hybrid systems which utilize a closed cooling cycle instead of water injection [13].

Several different hybrid systems have been proposed and were proven to be advantageous (e.g. [18–23]). While most of the systems rely on vapour compression chillers, further heat sinks are enabled through the possible increase of the required cold water temperature. Thermally driven adsorption chillers achieve their best performance for higher temperature levels of the cold water cycle and the thermal energy required to run the chiller can be supplied on similar temperature levels as the energy required for regeneration of the desiccant wheel. Fong et al. [24] proposed and simulated the coupling of a desiccant assisted air handling unit to a closed cycle adsorption chiller. In [25] such a system was investigated experimentally. The study showed that considerable primary energy savings are possible depending on the heat generation processes. Another alternative heat sink enabled through the desiccant wheel is shallow geothermal energy. However, just a few papers have investigated this combination so far. El-Agouz and Kabeel [26] modelled and simulated the integration of a geothermal heat sink in a DEC system in order to precool the air before humidification. They provided system COPs for different ambient conditions and showed that the geothermal heat sink enabled the system to provide better comfort conditions and decrease the supply air temperature. A maximum COP of 1.03 was reported for the presented configuration. They assumed a constant outlet temperature of the geothermal system of 20 °C, seasonal increasing soil temperature through heat rejection during the cooling period was not considered in their study. A similar system configuration is investigated by Enteria et al. [27], who simulate an alternative energy system for a single family detached house in Japan. A U-tube ground heat exchanger of 10 m depth is used in order to support a DEC system. They report that utilization of the low grade geothermal energy benefits the system as it reduces the supply air temperature even during the hottest days of the year. However, details about the ground heat exchanger and its exact contribution to the system are not discussed. The investigation of Khalajzadeh et al. [28] did not incorporate air dehumidification through a desiccant wheel. The combination of an indirect evaporative cooling coil and a ground circuit consisting of four borehole heat exchangers (BHXs) was evaluated. The authors simulated their circle for ambient air and soil conditions representing a chosen day in Theran. The presented system was able to provide comfort conditions in a more efficient way than indirect evaporative cooling alone. The study of Angrisani et al. [29] investigates the coupling of a desiccant assisted air handling unit to a geothermal well of 94 m depth, which is used for heat generation. The heat is used to regenerate the desiccant wheel and drive an absorption chiller for cooling purposes; additionally hot water for domestic use is generated. They found that depending on the actual utilization of domestic hot water primary energy savings of up to 90% can be achieved compared to a conventional reference system. Schmitz and Casas [30] investigated a hybrid system utilizing BHXs for direct cooling. A small cogeneration engine was used for heat generation, the performance of the air handling unit alone was evaluated experimentally and possible primary energy savings of 60% were identified for one stationary point. Radiant cooling and parasitic energy consumption was not taken into account, the air conditioing system as a whole was not evaluated. Details regarding the supply of heat, cold or electricity are not presented by the authors. The presented figures also reveal shortcomings regarding mass and energy balances of the diffferent components of the air handling unit including the desiccant wheel, making results less reliable. The authors reported that the system might not be able to maintain comfort conditions during the whole cooling period, details about the geothermal heat sink and potential seasonal warming of the soil were not presented.

Even though the coupling of BHXs for direct cooling to a desiccant assisted air conditioning system has been identified as an efficient alternative to conventional systems, the literature lacks comprehensive studies of this system configuration. To the author's knowledge no study so far provided a detailed experimental analysis of such a system evaluating its performance for a longer cooling period with varying ambient conditions and taking parasitic energy consumption into account. Performance indicators as latent, thermal or electric COPs have not been presented so far. These quantities however are important to evaluate and compare different system configurations. To increase reliability, energy and water balances for the different components of the air handling unit are presented with the respective quantities.