



Comparison of the performance of two different DOAS configurations involving conventional and renewable energies

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ABSTRACT

Spanish building regulations have increased the ventilation rates creating humidity control problems. Dedicated outdoor air systems (DOASs) including a desiccant wheel can dry the ventilation air so that the cooling units are relieved of the latent loads carried by the ventilation air and those generated inside the building. The purpose of this study was to compare the performance of two different DOAS configurations in terms of primary energy consumption under different Spanish climates. The DOAS comprising a desiccant wheel and a conventional refrigeration system was called DOAS-A. The DOAS comprising a desiccant wheel regenerated by solar air collectors and an indirect evaporative cooler was called DOAS-B. The performance of both DOASs was simulated with TRNSYS, and the models were validated with data from experimental setups built at the Miguel Hernández University of Elche (Spain) and at the Technical University of Cartagena (Spain). It was found that the DOAS-B configuration consumed less primary energy than the DOAS-A configuration for commercial use, that is, when the latent load coincides with the supply of solar radiation. These savings reached 68.3% in Seville owing to its high level of solar radiation. It was also found that the net sensible load supplied by the ventilation air to the conditioned space was negative for all climates. This sensible cooling capacity was shown to be greater at lower outdoor dry-bulb temperature and lower latent load.

1. Introduction

The high ventilation rates imposed by Spanish building regulations have created problems with humidity control. This has resulted in an increased use of dedicated outdoor air systems (DOASs) that include desiccants to remove moisture from air by sorption. Although liquid desiccant systems are also used, solid desiccants are more common in commercial buildings.

A desiccant wheel is commonly used to dehumidify the ventilation air before it enters the building, so that the cooling units are relieved of the dehumidification load carried by the ventilation air (ASHRAE, 2016). Outdoor air can be dried to a condition below the indoor design dew point, removing the moisture loads generated inside the building as well.

A temperature rise in the supply air occurs at the desiccant wheel because of the conversion of latent heat to sensible heat as moisture is removed from air. Conventional vapor compression air-conditioning equipment or an indirect evaporative cooler (IEC) is usually incorporated into the DOAS to remove this sensible heat. Several configurations have been proposed and analyzed in the literature (La et al., 2010).

The separation of cooling and dehumidification can increase the overall efficiency of the HVAC system (Ling et al., 2014). The 2010 Energy Performance of Buildings Directive (EU, 2010) establishes that the nearly zero or very low amount of energy required by *nearly zero-energy buildings* should be covered to a very significant extent by energy from renewable sources, including that produced onsite or nearby. Thermally driven DOASs in HVAC systems with separate cooling and dehumidification allow the possibility of using solar thermal energy.

Studies on DOAS comprising a desiccant wheel driven by liquid solar collectors are common in recent years, using either evacuated tube (Misha et al., 2016) or flat plate collectors (Finocchiaro et al., 2012). Using PV/thermal solar collectors is also relatively common (Saghafifar and Gadalla, 2016); however, little has been presented in the literature on experiences with solar air collectors. This technology was used as the heat source for the DOAS installed at the seminar room and cafeteria of the Chamber of Trade and Commerce in Freiburg, Germany. The viability of this solar-assisted desiccant cooling system based on its annual performance was analyzed with TRNSYS (Henning, 2007).

Literature also shows that it is worth studying how different climates affect the performance of specific DOAS configurations (Wrobel

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Nomenclature

c	air specific heat (J/kg·K)
G	solar radiation (W/m ²)
$\bar{h}_g$	average enthalpy of water vapor (J/kg)
$\dot{m}$	mass flow rate (kg/s)
$\dot{Q}$	heat transfer rate (W)
RH	relative humidity (%)
S	collector surface (m ²)
T	temperature (°C)
$\dot{V}$	volumetric flow rate (m ³ /h)
W	humidity ratio (g/kg)
WB	wet-bulb temperature (°C)

Greek symbols

η	efficiency
ρ	density (kg/m ³)
ϵ	effectiveness

Subscripts

a	air
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aux	auxiliary
c	condenser
col	collector
db	dry bulb
dw	desiccant wheel
des	design
e	evaporator
exp	experimental
ext	exterior
iec	indirect evaporative cooler
int	internal
in	inlet
lat	latent
out	outlet
pr	primary
req	required
sec	secondary
sen	sensible
sim	simulated

et al., 2013). Climate influences the performance of equipment that is part of the DOAS such as IECs, which are effective alternatives to conventional cooling systems and can reduce primary energy consumption (De Antonellis et al., 2016).

The objective of this work was to compare the performance of two different DOAS configurations under different Spanish climates, and to report the results using the primary energy consumption and the net sensible energy supplied to the conditioned space. The first DOAS configuration consumes conventional energy and the second one implements solar energy and indirect evaporative cooling technologies.

2. Materials and methods

2.1. DOAS-A experimental setup

Two configurations of DOASs were compared in this work. The first one (DOAS-A), comprises a desiccant wheel and a conventional refrigeration system. In this configuration, the ventilation air is precooled in the evaporator before going through the desiccant wheel, where it is dried and its temperature increased. The energy for the regeneration air is provided by the condenser of the refrigeration equipment.

Fig. 1a shows a view of the DOAS-A built at the Miguel Hernández University. It is equipped with a non-commercially available refrigeration system, whose cooling coil (evaporator) is upstream of the desiccant wheel. Fig. 1b displays the scheme of the DOAS-A including the position of the sensors used to measure its performance.

The desiccant wheel of the experimental setup of DOAS-A (Fig. 1a) is a structured packing impregnated with silica gel that rotates at 12 rph. It has a diameter of 0.55 m and a depth of 0.2 m. When ventilation air passes through the wheel, the vapor pressure differential drives the water vapor from the air onto the desiccant. The regeneration air flows through half of the wheel section to reactivate the desiccant. Even though a low-temperature level thermal energy (heat rejected at the condenser of the refrigeration system) is used to heat the regeneration air, the vapor pressure of the desiccant is raised above that of the surrounding air. Water then moves from the desiccant to the regeneration air.

Table 1 presents the specifications of the sensors used for measuring the properties of the ventilation and regeneration airflows. They were connected to a data acquisition unit (Keysight 34972A). The R-134a

temperature and pressure were measured at the locations shown in Fig. 1b. The compressor power consumption was also registered.

2.2. DOAS-B configuration with solar air collector experimental setup

The second configuration (DOAS-B) also includes a desiccant wheel. However, the cooling of the ventilation air takes place in an IEC after passing through the desiccant wheel. The heating of the regeneration air is achieved by means of a solar air collector field.

The solar air collector selected for this study was Twinsolar 2.0 (Grammer Solar GmbH). The experimental installation to characterize its thermal behavior was arranged on the top of a building of the Technical University of Cartagena (Spain) as shown in Fig. 2a. It consists of a thermal module with a solar collecting surface of nearly 2 m², oriented toward the south with a slope of 30°, nearly 10° lower than Cartagena's latitude, a fan located at the solar collector outlet to set the airflow rate through the collector, sensors for measuring the properties to calculate the solar air collector performance and a data acquisition system.

The TRNSYS model used for the simulation of the DOAS-B operation is integrated by the model developed with the data from the solar air collector experimental facility, the desiccant wheel model validated with data from the experimental setup for DOAS-A and the IEC model that was taken from the bibliography where it was also validated with experimental data. Fig. 2b shows the scheme of DOAS-B and the position of the sensors used to measure the performance of the solar air collector.

The duct air temperature (at the inlet and at the outlet of the collector), airflow rate through the collector, and outdoor conditions were measured to understand the panel behavior under different operating conditions. The solar collector includes a PV module coupled to a fan to produce the outdoor airflow rate within the solar collector. In this way, irradiation is coupled with the airflow rate generated in the system. The manufacturer provides the following equation to correlate the volumetric airflow rate with irradiation (in the range of 100–1000 W/m²):

$$\dot{V} = 44.1 \ln(G) - 196.4 \quad (1)$$

However, in the experimental facility the fan is uncoupled from the PV module supplied by the manufacturer in order to be able to keep the airflow rate fixed. A Pt100 temperature sensor was used to measure the

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