Applied Thermal Engineering 131 (2018) 412–427

Contents lists available at ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Research Paper

Energy saving potential of a hybrid HVAC system with a desiccant wheel activated at low temperatures and an indirect evaporative cooler in handling air in buildings with high latent loads

F. Comino *, M. Ruiz de Adana, F. Peci

Departamento de Química-Física y Termodinámica Aplicada, Escuela Politécnica Superior, Universidad de Córdoba, Campus de Rabanales, Antigua Carretera Nacional IV, km 396, 14071 Córdoba, Spain

HIGHLIGHTS

- The energy potential and desiccant capacity of two HVAC systems was analysed.
- Both HVAC systems served air to a spa room for 6 different climate zones.
- The energy consumption of the DW-IEC system was lower than that of the DX system.
- High energy savings were obtained with the DW-IEC system for hot climate zones.
- These energy savings resulted in better SCOP values for the DW-IEC system.

ARTICLE INFO

Article history:
Received 10 July 2017
Revised 23 November 2017
Accepted 2 December 2017
Available online 6 December 2017

Keywords:
Hybrid system
Desiccant wheel
Indirect evaporative cooler
High latent loads
Climate zones

ABSTRACT

Air handling in buildings with high latent loads usually requires a high-energy cost to satisfy the user's thermal comfort needs. Hybrid systems composed of desiccant wheels, DW, and indirect evaporative coolers, IEC, could be an alternative to direct expansion conventional systems, DX systems. The main objective of this work was to determine the annual energy consumption of a hybrid system with a DW activated at low temperatures and an IEC, DW-IEC system, compared to a DX system to serve air in a small building with high latent loads, such as spas. Several annual energy simulations for 6 climate zones were performed, analysing electric energy consumption, seasonal mean coefficient of performance, SCOP, and energy consumption per unit of dehumidified water, E_{cons}, of each system. The simulations were based on experimentally validated models.

The annual energy consumption of the DW-IEC system was lower than that of the DX system for the 6 climate zones, achieving significant energy savings, up to 46.8%. These energy savings resulted in better SCOP values for the DW-IEC system. Therefore, the proposed DW-IEC system has high potential to reduce energy costs, achieving the user's thermal comfort.

1. Introduction

Air handling in buildings with high latent loads usually requires a high-energy cost to satisfy the user's thermal comfort needs. Indoor swimming pools or spas are some examples of this type of buildings, which have high internal latent gains, due to the great amount of evaporated water from the wet areas [1]. Excessive air humidity can cause discomfort for the occupants and problems related to the indoor air quality of the building due to fungus and rot [2]. Therefore, an air handling system is required to control the indoor moisture content, while keeping a low energy consumption.

A traditional method of dehumidifying rooms with high latent loads is to introduce a certain air flow rate from outside, this method can only be used when the outdoor humidity ratio is lower than the indoor humidity. In this method [3], the air flow rate required to dehumidify the building was very high. The recommended air change rates per hour values were shown to vary between 4 h^{-1} and and 7 h^{-1} in order to obtain thermal comfort [3]. This dehumidification method could cause discomfort to the occupants in small rooms with high latent loads, such as spas, due to the high air change rates per hour values.

* Corresponding author.
E-mail address: francisco.comino@uco.es (F. Comino).

https://doi.org/10.1016/j.applthermaleng.2017.12.004
1359-4311/

Nomenclature

b	estimated parameter
C	capacity rate of air [kJ h^{-1} K^{-1}]
c_p	specific heat of air [kJ kg^{-1} K^{-1}]
CO	condenser
COP	coefficient of performance
DW	desiccant wheel
DX	direct expansion
EA	exhaust air
E_{cons}	energy consumption per unit of dehumidified water [Wh kg^{-1}]
EIR	electrical input ratio
EV	evaporator
IEC	indirect evaporative cooler
h	air specific enthalpy [kJ kg^{-1}]
HC	heating coil
k	number of parameters
MRC	moisture removal capacity [kg h^{-1}]
$\dot{m}$	mass air flow rate [kg h^{-1}]
$\dot{M}_{pool}$	evaporated water flow of the pool [kg h^{-1}]
Np	number of people
OA	outdoor air
PLF	partial load factor
P	static pressure [mmca]
$\dot{Q}$	heat transfer [kW]
RA	return air
S	area [m^2]
SCOP	seasonal mean coefficient of performance
SHE	sensible heat exchanger
T	dry bulb temperature [°C]
T_{wb}	wet bulb temperature [°C]
UA	overall heat transfer coefficient [kJ h^{-1} K^{-1}]
v	air velocity [m s^{-1}]
$\dot{V}$	volumetric air flow rate [m^3 h^{-1}]
$\dot{V}_w$	water flow rate of indirect evaporative cooler [l h^{-1}]
$\dot{W}$	electric power consumption [kW]
X	input variable
$\hat{Y}$	estimated output value

Greek letters

Δ	increase
ε	effectiveness
ρ	density [kg m^{-3}]
$\sum$	sum
ω	humidity ratio [g kg^{-1}]
Ω	specific mass air flow rate [kg s^{-1} m^{-3}]

Subscripts

a	air
c	condenser
e	evaporator
HC	heating coil
i	inlet
IA	indoor air
lat	latent
N	nominal
o	outlet
OA	outdoor air
p	process air; primary air
s	secondary air
r	regeneration air
sen	sensible
t	total
T	temperature
w	water

Superscripts

'	dimensionless value

Another method widely used in dehumidifying air is that of conventional dehumidification systems based on direct expansion units, DX system, which operates according to the vapour-compression cycle. DX systems reduce the air temperature below its dew point in order to condense water. An increase in the cooling power of the DX system usually produces an increase in its desiccant capacity. However, DX systems have a cooling capacity limit when the required dew-point temperature is very low, close to 0 °C, the freezing point of water. Moreover, the outlet air temperature of DX systems is usually very low, so a post-heating of air flow is necessary, before being supplied to the building. Several DX systems have been studied for indoor swimming pools [4,5], where high energy consumption values were required to dehumidify and heat the air steam. A comparative study between a DX system and an open absorption system to handle air in an indoor swimming pool, was carried out by other authors [6], obtaining significant energy savings with the open absorption system. These studies show the need to search for new HVAC systems in buildings with high latent loads.

Previous studies on energy saving in spas with small volumes and high latent loads have been carried out [7–9]. However, these works focused on the hot water system of swimming pools.

Desiccant dehumidification systems present an alternative solution to DX systems. Desiccant dehumidification systems adsorb water from the air in contact with an area of low vapour pressure at the surface of the desiccant [10]. One type of desiccant dehumidification system widely used is the desiccant wheel, DW, [11,12]. The most influential parameter on the desiccant capacity of a DW is the regeneration temperature [13,14]. Usually, DWs are thermally activated at high temperatures, from 60 °C to 120 °C [15,16], although other studies also showed acceptable DW performance when their regeneration temperatures were below 60 °C [17]. The main disadvantage of DWs is the high outlet process air temperatures [18]. This heat is generated by the adsorption process of the DW, which is delivered from the regeneration section to the process section. Therefore, a cooling system is needed to lower the process air temperature before being supplied.

Cooling systems based on evaporators of a DX system are usually combined with a DW [19,20], but these systems normally require a high energy consumption [21]. Another cooling system that is usually combined with DWs is the evaporative cooler. There are two types: the direct evaporative cooler and the indirect evaporative cooler. The indirect evaporative cooler, IEC, system is one of the most promising technologies in reducing the air temperature because of its higher energy saving capacity compared to DX systems [22]. The IEC system requires two separate air flows to operate. The primary air flow which is cooled and supplied to the building without increasing its humidity ratio and the secondary air flow which is humidified with water supplied to the outside [23].

Many studies about IEC integrated into a desiccant system have been carried out [24–26]. An experimental study on a hybrid system composed of a DW and an IEC was carried out for several summer days in Italy [27]. This system reduced the electrical