Energy Conversion and Management 113 (2016) 331–345

Contents lists available at ScienceDirect

Energy Conversion and Management

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

Dynamic performance assessment of a solar-assisted desiccant-based air handling unit in two Italian cities

G. Angrisani, C. Roselli, M. Sasso, F. Tariello [*]

DING, Università degli Studi del Sannio, P.zza Roma 21, 82100 Benevento, Italy

ARTICLE INFO

Article history:
Received 20 November 2015
Accepted 20 January 2016

Keywords:
Solar desiccant cooling
Desiccant wheel
Dynamic simulation
Thermo-economic analysis
Parametric assessment

ABSTRACT

Desiccant-based air handling units can provide significant operational advantages and can use solar energy as the main heat source. Hereinafter a plant equipped with a silica-gel desiccant wheel is analyzed for two Italian locations (Benevento and Milano).

A parametric study involving collectors types, surfaces, tilt angles and installation site has been performed. The proposed system has been compared with a conventional HVAC unit, through dynamic simulations. In terms of energy and environmental analysis, solar desiccant systems should always be preferred to conventional ones, even when the solar thermal energy surplus is fully dissipated. A maximum primary energy saving of about 10% and 20% with flat plat and evacuated tube collectors, respectively, occurs in both locations. The savings increase up to about 58% and 72% in Benevento and 43% and 58% in Milano, when the solar heat excess is completely used for further energy demands.

One observes that systems with evacuated tube collectors are preferable where the available space for the solar field is small, instead with larger surfaces flat plate collectors are advantaged.

In terms of economic analysis, the shortest payback periods are 6 and 8 years for Benevento and Milano, respectively.

1. Introduction

In the summer operation mode of conventional Heating, Ventilation and Air Conditioning systems (HVAC) the most energy-intensive process consists of the air cooling and dehumidification. Mechanical dehumidification is commonly used to reduce the moisture content of the air flow. This process takes place by reducing the air temperature to low values, lower than the dew point temperature. Alternatively the hygroscopic properties of some materials can be exploited. These substances, such as silica gel, need to be periodically regenerated with low temperature heat. Waste heat [1] from cogeneration devices [2–4], from industrial processes [5,6] or solar thermal energy [7,8] is typically used as thermal energy for regeneration.

Desiccant and Evaporative Cooling systems (DEC) can achieve benefits such as a more accurate humidity control, a better indoor air quality, a significant reduction in CO_2 emissions, primary energy and electricity savings [9] but they are more expensive and more complex from a technological and operational point of view. In addition Solar-assisted Desiccant and Evaporative Cooling systems (SDEC) are equipped with a solar field to collect solar radiation, as well as with back-up systems and heat storage tanks. The last two components are considered to compensate the uncertainty of the source and improve its exploitation.

Numerous parameters affect the operation of DEC and SDEC systems. They have been studied in many papers with different approaches, also with non-conventional layouts. For example, a mathematical model was introduced and experimentally validated by Elzahzby et al. [10]. It is realized to preventively evaluate the performance of a solar-driven hybrid air-conditioning system. It is a one-rotor six-stage unit. A two-stage dehumidification, two-stage precooling and two-stage regeneration process is realized in only one silica-gel desiccant wheel (DW). In terms of thermal COP it was highlighted that it decreases from a maximum value of 2.2 to a minimum of 0.7 increasing the regeneration temperature and the DW rotation speed. Instead thermal COP varies between 1.1 and 0.6 varying regeneration air velocity.

Li et al. [11] arranged a Matlab/Simulink model of a solar heating and cooling desiccant system coupled with solar air collectors. The simulated results showed good agreement with experimental data and so the simulator was used to optimize collector parameters: area, air leakage and insulation. The authors found that thermal COP of the DEC system is about 0.35 and about 76% of the total cooling is provided by the solar-assisted HVAC system. Regarding the seasonal total heating load, about 49% can be handled by solar energy.

---

[*] Corresponding author.
E-mail address: francesco.tariello@unisannio.it (F. Tariello).

http://dx.doi.org/10.1016/j.enconman.2016.01.052
0196-8904/

Nomenclature

A	area (m^2)
a_1	efficiency slope ($W/(m^2\,K)$)
a_2	efficiency curvature ($W/(m^2\,K^2)$)
c	unitary cost (€/N m^3) or (€/kW h) or (€/m^2)
c_p	specific heat (J/(kg K))
C	valorization coefficient (€/m^2)
CO_2	equivalent CO_2 emission (kg/y)
EC	extra cost (€)
E_p	primary energy (kW h/y)
F_1	potential
F_2	potential
F	cash flow per year (€/y)
G	total incident radiation (W/m^2)
g	total solar energy transmittance
$I_{a,tot}$	annual incentive (€/y)
k	tank fluid thermal conductivity (W/(m K))
LHV	Lower Heating Value (kW h/N m^3)
m	mass of node (kg)
MC	annul maintenance cost (€/y)
mc	specific annual maintenance cost (%/y)
$\dot{m}_{down}$	bulk fluid flowrate down the tank (kg/s)
$\dot{m}_{up}$	bulk fluid flowrate up the tank (kg/s)
$\dot{m}_{1in}$	mass flowrate entering at inlet 1 (kg/s)
$\dot{m}_{1out}$	mass flowrate leaving at outlet 1 (kg/s)
$\dot{m}_{2in}$	mass flowrate entering at inlet 2 (kg/s)
$\dot{m}_{2out}$	mass flowrate leaving at outlet 2 (kg/s)
N	number of years
OC	operating cost (€/y)
PES	primary energy saving
S	gross solar collector area (m^2)
t	temperature (°C)
T	temperature (K)
T_{1in}	temperature of the fluid entering at inlet 1 (K)
T_{2in}	temperature of the fluid entering at inlet 2 (K)
U	total loss coefficient ($W/(m^2\,K)$)
V	volume (N m^3/y)

Greek symbols

α	specific emission factor of electricity supplied by the grid ($kgCO_2/kW\,h_{el}$)
β	specific emission factor for primary related to natural gas combustion ($kgCO_2/kW\,h_{Ep}$)
ΔCO_2	equivalent CO_2 avoided emission
Δk	de-stratification conductivity (W/(m K))
ΔT	temperature difference (K)
ΔT_{ln}	logarithmic mean temperature difference (K)
$\Delta x_{i+1\rightarrow i}$	distance between node i and the node below it ($i+1$) (m)
$\Delta x_{i-1\rightarrow i}$	distance between node i and the node above it ($i-1$) (m)
ΔU	additional loss coefficient ($W/(m^2\,K)$)
η	efficiency
η_B	boiler efficiency
η_{col}	collector efficiency
η_{EG}	Italian national electric system efficiency
η_0	intercept efficiency
τ	time (s) or (h)
ω	air humidity ratio (g/kg)

Subscripts

a	ambient
aux	auxiliaries
B	boiler
c	cross section area of the node
$chil$	chiller
col	collector
el	electrical
F_1	potential
F_2	potential
hx	heat exchanger
i	generic node
in	inlet
j	generic air state
k	generic year
NG	natural gas
r	generic bracket
s	surface of the node
$tank$	storage tank
th	thermal
tot	total

Superscripts

AS	Alternative System
CS	Conventional System

Acronyms

AHU	air handling unit
AS	Alternative System
B	boiler
BN	Benevento
CC	cooling coil
CF	cross-flow heat exchanger
CH	chiller
COP	coefficient of performance
CS	Conventional System
DEC	Desiccant and Evaporative Cooling
DHW	domestic hot water
DW	desiccant wheel
EC	evaporative cooler
HC	heating coil
HC2	post-heating coil
HDD	Heating Degree Day
HVAC	Heating, Ventilation and Air Conditioning systems
HW	hot water
HW-HX	hot water heat exchanger
LHV	Lower Heating Value
MI	Milano
PV	photovoltaic cell
PVT	photovoltaic-thermal collector
SC	solar thermal collectors
SDEC	solar-driven desiccant and evaporative cooling system
SPB	Simple Pay Back
TS	tank storage

As concern the solar technologies, in the literature solar air collectors, flat plate and evacuated tube collectors are typically considered. However, in few cases, also hybrid devices (Photovoltaic-Thermal collectors, PVT), or concentrated thermal collectors and concentrated hybrid devices (Concentrated Photovoltaic Thermal collectors) are adopted.

Bourdoukan et al. [12] developed and experimentally validated the simulation model of a solar heat pipe vacuum collectors with a stratified tank under various operation conditions. These components were simulated in combination with a desiccant based air handling unit (AHU) in three different locations characterized by different climates. They demonstrated to be more efficient than