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Dynamic performance assessment of a micro-trigeneration system with a desiccant-based air handling unit in Southern Italy climatic conditions

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ABSTRACT

In this work, a system consisting of a small scale trigeneration system, in which a heat-led microcogenerator interacts with a desiccant-based cooling system, equipped with a silica-gel desiccant wheel, is analyzed. The system provides the air-conditioning service to a lecture room during summer and winter periods and, over the whole year, thermal energy for domestic hot water production to a nearby multi-family house.

Electricity from the cogenerator is used to drive the electric chiller, the auxiliaries as well as further electric appliances of the lecture room.

This trigeneration system is compared with a reference system, equipped with a conventional air handling unit, based on cooling dehumidification for summer air conditioning. Electricity to power the electric chiller, the auxiliaries, as well as electric appliances is drawn from the grid. Thermal energy for winter space heating, air post-heating during summer and domestic hot water purposes is provided by a natural gas boiler.

Experimental tests, as well as data derived from manufacturers, are used to implement a model of both systems. Simulations were then performed by means of TRNSYS software to compare their thermo-economic performance.

A sensitivity analysis has been performed, to analyse the effect of the share of cogenerated electricity consumed on-site. The analysis shows encouraging results, given the Italian energy context for the small scale trigeneration system, in terms of primary energy consumption and equivalent carbon dioxide emissions reductions, with maximum values of 7.70% and 15.3%, respectively; on the other hand, it is difficult to achieve a reasonably short pay-back period for the system, even if it accesses all the support mechanisms introduced by Italian legislation for small scale gas fuelled trigeneration systems and a very high amount of cogenerated electricity is used on-site.

1. Introduction

During last years, air conditioning demand has spread, both in the commercial and the residential sector. This caused a sensible increase in primary energy consumption, especially in industrialized countries, where people spend the major part of the day in confined environments, requiring high indoor air quality and suitable thermal comfort [1].

The operation of a heating, ventilation and air-conditioning (HVAC) system is usually performed to achieve comfortable indoor conditions. But HVAC systems consume large amounts of energy. Therefore, it is very important to investigate the possibility of efficiently achieving, for the specific application and building type, the desired indoor environmental conditions, reducing energy consumption and greenhouse gas (GHG) emissions.

The demand for summer cooling in domestic and commercial sectors is usually satisfied by electrically driven units; this involves high electric peak loads and black-outs. This trend is determining increasing interest in small scale trigeneration systems fuelled by natural gas (gas cooling systems), able to shift energy demand in summer from electricity to gas, and allowing the exploitation of the natural gas surplus during the warm season.

A suitable technology for gas cooling is represented by desiccant-based dehumidification systems, eventually integrated with conventional vapour compression cooling systems. In the most common configuration, they use a desiccant wheel (DW), in which moist air is dehumidified by the adsorbent material, to balance latent loads of the indoor ambient. To guarantee continuous operation, the wheel has to be regenerated by a hot air stream.

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Nomenclature

c	specific heat capacity, kJ/(kg K)
CHP_Bonus	bonus related to energy savings of CHP, €/kW h_{El}
COP	coefficient of performance, –
EC	extra cost, €
EER	energy efficiency ratio, –
$FESR$	fuel energy saving ratio, –
F_k	yearly cash flow, €/y
f_T	conversion factor from MW h to tep, tep/MW h
FIT	feed-in tariff, €/kW h_{El}
g	solar gain, –
h	number of operating hours, –
K	correction factor for white certificates calculation, –
LHV	lower heating value, kW h/N m^3
m	mass, kg
$\dot{m}$	mass flow rate, kg/s
MC	maintenance cost, €/h or €/y
n	number of years, –
NE	net energy, MW h
NS	net saving, toe
OC	operating costs, €/y
OE	output energy, MW h
P	power, kW
PE	primary energy, MW h
PER	primary energy ratio, –
PES	primary energy saving, –
PLR	partial load ratio, –
SPB	simple payback period, y
T	temperature, °C
U	overall heat transfer coefficient, W/m^2 K
UP	unitary price, €/kW h or €/N m^3
XE	exported energy, MW h

Acronyms

AHU	air handling unit
CHP	combined heat and power
DCS	desiccant cooling system
DHW	domestic hot water
DW	desiccant wheel
GHG	greenhouse gas
HVAC	heating ventilation and air conditioning
IHE	internal heat exchanger
MCHP	micro combined heat and power
MCCHP	micro combined cooling heating and power
MFH	multifamily house
PS	proposed system
RIC	reciprocating internal combustion
RMSE	root mean standard error
RS	reference system
TES	thermal energy storage
WC	white certificates

Greek symbols

$\Delta CO_{2,eq}$	avoided equivalent CO_2 emissions, –
ξ	allocation factor, –
η	efficiency or effectiveness, –
μ	specific emission factor, kg_{CO_2}/kW h
ψ	surplus factor, –

Subscripts

$Cool$	cooling
$CO_{2,eq}$	equivalent carbon dioxide
DHW	domestic hot water
El	electric
F_1, F_2	F_1 and F_2 potentials
$Fuel$	fuel primary energy
m	mains
NG	natural gas
PE	primary energy
PS	proposed system
ref	reference value
RS	reference system
s	supply
Th	thermal

Superscripts

*	related to effective primary energy consumption of MCHP
aux	auxiliaries
$chil$	chiller
DCS	desiccant cooling system
DHW	domestic hot water
GB	gas boiler
$Grid$	electric grid
HC	heating coil
$MCHP$	micro combined heat and power
s	with subsidy
TES	thermal energy storage

During last years, thanks to its benefits [1], this technology is also spreading in residential and tertiary sectors and office buildings; however, in Europe this technology is still rarely implemented, neither in countries with significant cooling requirements of building, such as Italy, due to several obstacles, such as high investment costs and lack of knowledge about performances and cost/benefit ratio.

As regards thermal energy requirements to regenerate the desiccant material, it is possible to use a "free" thermal energy source, such as solar energy or waste heat recovered from a microcogenerator, eventually integrated with a conventional fossil-fuelled heating system (e.g. a boiler).

The performance of solar assisted heating and desiccant cooling systems for a domestic residence located in Baghdad was evaluated in [2]. Simulation of the open cycle solar assisted desiccant cooling system (DCS) showed that ambient and regeneration temperature, heat exchanger and evaporative cooler effectiveness have major influences on the system performance, whereas the dehumidifier has a minor effect.

A solar hybrid cooling design is proposed for high cooling load demand in hot and humid climate in [3]. The hybrid system utilizes solar energy for driving an absorption chiller and regenerating a desiccant wheel. The potential application of the solar hybrid cooling system was evaluated for the high-tech offices in the subtropical climate through dynamic simulation. The annual primary energy consumption of the solar hybrid cooling system was lower than that of the conventional vapour compression refrigeration system up to 36.5%.

A solar desiccant cooling and heating system was modelled in Simulink in [4]. Year-round performance about the system was simulated. Design parameters of solar air collectors were optimized that include collector area, air leakage and thermal insulation. During the simulation, 51.7% of the humidity load was totally handled by the two-stage desiccant cooling unit. For seasonal total heating load, about 49.0% was handled by solar energy.

When thermal energy from a microcogenerator is used to activate thermally-driven cooling equipment (as a DCS), the system is a microtrigeneration unit (MCCHP – micro combined cooling, heat-