Renewable and Sustainable Energy Reviews 81 (2018) 1112–1146

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Solar heating and cooling systems by absorption and adsorption chillers driven by stationary and concentrating photovoltaic/thermal solar collectors: Modelling and simulation

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ARTICLE INFO

Keywords:
Solar heating and cooling systems
Dynamic energy performance analysis
Concentrating photovoltaic/thermal panels
Flat plate photovoltaic/thermal panels
Adsorption and absorption chillers

ABSTRACT

Solar heating and cooling systems are a promising technology which may significantly contribute to the reduction of greenhouse gas emissions, the enhancement of energy efficiency, and the increase of renewables share in the building sector. The available literature show a high number of papers aiming at investigating solar heating and cooling systems based on heat driven and solar technologies, configurations, operating strategies, and financing issues. Nevertheless, none of the papers available in literature investigates the possibility to replace conventional solar thermal collectors by flat plat and concentrating photovoltaic/thermal systems, also producing renewable electricity. To cover this lack of knowledge, in this paper a dynamic simulation model of novel solar polygeneration heating and cooling systems is presented. Such dynamic simulation model is developed and implemented in a computer code, written in MatLab, and allows investigating the energy, economic and environmental performance of such novel solar polygeneration systems, based on both adsorption and absorption chiller technologies fed by dish-shaped concentrating and flat photovoltaic/thermal collectors. In order to show the potentiality of the presented tool, a comprehensive parametric case study is carried out to find out the optimal system configurations, as a function of crucial design and operating parameters and of weather conditions. The presented case study analysis refers to a small cluster of four buildings, including office and residential spaces, located in different European weather zones. The modelled solar polygeneration systems simultaneously produce electricity, space heating and cooling, and domestic hot water; electricity is self-consumed or delivered to the electrical grid. For comparative purposes, two different back-up system configurations, based on an electric chiller and a condensing gas-fired heater are also taken into account as conventional reference building-plant systems.

By means of this systematic parametric analysis, comprehensive guidelines for system designers, practitioners and/or researchers focused on the development and use of solar heating and cooling systems are provided.

1. Introduction

1.1. Literature review

In the last decades, a significant effort has been paid towards the sustainable development, with a particular attention to environmental issues, especially to those associated with energy use and production. In the field of sustainable development, the building sector plays a crucial role, showing a high potential of energy savings [1–6]. To reduce the primary energy consumption due to space heating and cooling in residential and commercial buildings, more effective policies towards the challenging goals of greenhouse gas emissions reduction, energy efficiency improvement, and increase of renewables share, have been defined, such as those arising from the recent global agreements among countries on new national emissions targets (e.g. COP21) [7–9].

In order to reach these goals, researchers and institutions, especially in Europe, are devoting a particular effort in the investigation of effective measures for the energy efficiency and the development of renewable energy based technologies for building applications, necessary to provide the highest environmental benefits [10–13]. Among the available technologies, supported by global actions to improve renewable energy access, Solar Heating and Cooling (SHC) systems have attained a significant attention. Such technology is capable to greatly exploit the solar energy to provide space heating and cooling all over

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http://dx.doi.org/10.1016/j.rser.2017.07.056

Nomenclature

A	Solar collector gross area (m^2)
a_1	global heat loss coefficient [$W/(m^2\ K)$]
a_2	temperature dependence of the global heat loss coefficient [$W/(m^2\ K^2)$]
AbCH	Absorption CHiller
AdCH	Adsorption Chiller
AH	Auxiliary gas-fired Heater
C	geometric concentration ratio (-)
C^{TK}	Tank thermal capacitance (kJ/K)
c_p	specific heat capacity (kJ/kg K)
cu	unitary cost (€/kWh)
CDD	Cooling Degree Days (Kd)
CI	Investment capital cost (€)
COP	Coefficient of Performance (-)
CPVT	Concentrating PhotoVoltaic/Thermal collectors
CT	Cooling Tower
DNI	Direct Normal Irradiation (kWh/m^2)
DHW	Domestic Hot Water
E	Electricity (W)
h	specific heat transfer coefficient ($W/m^2\ K$)
f	ratio of absorption chiller capacity to peak cooling load (-)
F'	collector efficiency factor (-)
FGE	Electricity fed to the grid (kWh)
G	incident solar radiation (W/m^2)
GTI	Global Tilted Irradiation (kWh/m^2)
HDD	Heating Degree Days (Kd)
ISR	incident global horizontal Solar radiation ($kWh/m^2\ y$)
LHV	Low Heating Value (kWh/Nm^3)
$\dot{m}$	fluid mass flow rate (kg/s)
$MEFG_{PV}$	economic profit related to the electricity fed to the grid (€/y)
$MESC_{PV}$	economic saving related to the buildings self-consumed electricity (€/y)
NOC net	operating cost of the proposed system layout (€/y)
NPEC	Net Primary Energy Consumption (kWh)
OC	Operating Costs (€/y)
P	Power (W)
PEC	Primary Energy Consumption (kWh)
PES	Primary Energy Consumption (kWh)
PS1	Proposed System including an electric chiller as auxiliary device
PS2	Proposed System including a gas fired heater as auxiliary device
PVT	PhotoVoltaic/Thermal collectors
q	thermal flux (W/m^2)
Q	thermal power (W)
RS	Reference System
s	ratio of solar field surface area to the peak cooling load (m^2/kWf)
SC	Solar collector field area (m^2)
SCE	Self-consumed electricity (kWh)
SF	Solar Fraction (-)
SHC	Solar Heating and Cooling
SPB	Simple PayBack (y)
T	temperature (K)
TK	Storage tank
U	heat transfer coefficient ($W/m^2\ K$)
v	ratio of TK1 volume to solar field surface area (l/m^2)
V	Volume (m^3)
WCH	Water-cooled electric Chiller

Subscripts

a	outdoor environment
abs	absorber plate
act	activation
AbCH	Absorption CHiller
AdCH	Adsorption Chiller
aux	auxiliary
b	beam
chill	chilled
cool	cooling
CP	Compressor
el	electrical
Ev	Evaporator
fit	feed in tariff
g	gas
gl	glazed PVT collector
gle	glazed PVT collector with low-e coating
gro	gross
i	inlet
inv	inverter
HT	High Temperature
heat	heat
load	load
loss	thermal losses
L	Power
LT	Low Temperature
m	average
max	maximum
n	optical
nel	conventional average national electricity
o	outlet
opt	optic
par	parasitic
PV	photovoltaic
ref	reference
s	summer
SC	Solar collector
SP	Set Point
STC	standard test conditions
th	thermal
TOT	total
ugl	unglazed PVT collector
useful	useful energy
w	winter

Greek symbols

α	ratio of solar field surface area to chiller capacity (m^2/kW)
β	the temperature coefficient on power (K^{-1})
η	efficiency (-)
$\tau\alpha$	effective transmittance-absorbance product (-)

the year, significantly contributing to achieve the above mentioned challenging targets [14]. Particularly during summer, solar cooling systems are able to time shift the space cooling energy demand from electricity to solar energy, which is efficiently and simultaneously exploitable with low or negligible environmental impact [15]. In SHC systems, solar thermal energy is generally obtained by means of solar thermal collectors (flat plate, evacuated tubes, parabolic trough, etc.) [16–18]. Produced thermal energy may be directly used for heating purposes and domestic hot water preparation or supplied to thermally-driven chillers for cooling energy production [14,19]. As a result, SHC