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A novel renewable polygeneration system for hospital buildings: Design, simulation and thermo-economic optimization

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HIGHLIGHTS

- A new solar trigeneration model is designed and dynamically simulated.
- The system supplies electrical, cooling and heating energy to Hospital buildings.
- The energy demand data are measured for one year.
- The economic profitability of the system is satisfactory even without public funding.

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ABSTRACT

This paper presents an analysis of a possible energy retrofit of an existing University Hospital District, located in Naples (Italy), by using an innovative renewable polygeneration system. This system integrates both Concentrating PhotoVoltaic/Thermal collectors (CPVT) and Solar Heating and Cooling (SHC) technologies. The CPVT parabolic trough collectors are equipped with triple-junction PhotoVoltaic (PV) cells: this technology usually shows ultra-high energy conversion efficiencies. The main components of the system are: CPVT collectors, a single-stage LiBr–H_2O absorption chiller, storage tanks and balance of plant devices. The system is assumed to be installed at a University Hospital District located in Naples (Italy), equipped with a gas-turbine cogeneration system. The data regarding cooling, heating and electrical demands and productions are measured for a one-year operation. The CPVT produces electrical energy, which is consumed in part by the system parasitic loads, whereas the eventual surplus is fed in the electrical grid. Simultaneously, the CPVT provides heat, used for space heating, for domestic hot water and/or to drive the absorption chiller, which produces cooling energy. The system is designed and dynamically simulated in TRNSYS environment, including detailed and validated mathematical models for the simulation of all the components. The results are analysed from both energy and economic points of views, using parametric analyses and thermo-economic optimizations. The energy performance of the system is excellent since all electrical and thermal energies produced by the renewable system are consumed by the user. The economic results show that the system can be profitable (pay-back period around 12 years) even without any public funding. In case of feed-in tariffs, the system becomes extremely profitable from the economic point of view. The thermo-economic optimization, based on a mixed heuristic/deterministic algorithm, shows that the system profitability can be further improved, increasing solar field area and decreasing storage specific volumes for m^2 of collectors installed.

1. Introduction

Over the last decades, due to the not sustainable trends in energy supply and demand, the energy sector has increasingly focused on energy savings through measures aiming at the reduction of energy demands and the increase of energy efficiency. Both measures play a critical role in addressing environmental and economic goals. Nowadays, in Europe nearly half of the energy consumption is needed in the heating sector and, at the same time, the energy demand for cooling and air-conditioning is rising rapidly [1]. Therefore, the promotion and use of renewable energy heating and cooling systems and equipment have become

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Nomenclature

A	area
ACH	Absorption CHiller
AHE	Auxiliary Heat Exchanger
AHU	Air Handling Units
BOP	Balance of Plant
C	concentration ratio
CHCP	Combined Cooling Heating and Power
CHP	Combined Heat and Power
CHW	CHilled Water
COP	Coefficient of Performance
c_e	electricity unitary cost [€/kW h]
c_g	thermal energy unitary cost [€/kW h]
c	specific heat [J/kg K]
CPVT	Concentrating PhotoVoltaic Thermal solar collectors
CSHCP	Concentrating Solar Heating Cooling and Power
CT	Cooling Tower
CW	Cooling Water loop
DE	District Energy
DH	District Heating
DHC	District Heating and Cooling
DHW	Domestic Hot Water
E	electric power [kW]
ETC	Evacuated Tube solar Collectors
J	cost function [€]
G	incident radiation on the PV surface
GT	Gas Turbine
h_c	convective heat transfer coefficient [W/m^2 K]
h	hours [h]
H	enthalpy [kJ/kg]
HE	Heat Exchanger
HF	Hot Fluid
HS	Hydraulic Separator
HVAC	Heating Ventilation and Air Conditioning
HW	Hot Water
IAM	Incident Angle Modifier
I	global solar irradiance [kW/m^2]
LHV	natural gas Lower Heating Value [kJ/Sm^3]
M	mass of fluid [kg]
$\dot{m}$	mass flow rate [kg/s]
OC	Operating Cost [€]
ORC	Organic Rankine Cycle
P	power production [kWh]
PE	Primary Energy [kWh]
PEC	Primary Energy Consumption [KWh]
PEM	Polymer Electrolyte Membrane
PTSC	Parabolic Trough Solar Collectors
PV	PhotoVoltaic panels
PVT	PhotoVoltaic Thermal solar collectors
Q	heat [kWh]
RS	Reference System
S	tank layer surface area [m^2]
SCF	Solar Collector Fluid
SHC	Solar Heating and Cooling
SPB	Simple Pay Back
ST	Solar Trigeneration
T	temperature[°C]
TK	tank
UA	Overall loss coefficient [kJ/(h K)]
V	volume [m^3]
WHE	Waste Heat recovery boiler

Greek letters

α	absorptance [−]
β	control function [−]
γ	control function [−]
δ	thickness [m]
λ	conductivity [W/m K]
ε	emissivity [−]
ε_{HE}	effectiveness of the load heat exchanger [−]
η	efficiency [−]
$\eta_{el,t}$	thermoelectric conversion efficiency [−]
σ	Stefan–Boltzmann constant [W/m^2 K]

Subscripts

a	outside air dry bulb
ap	aperture area
ACH	absorption chiller
b	beam radiation
back	back
CT	cooling tower
CPVT	concentrating photovoltaic solar collectors
conc	concentrator
cool	cooling
el	electricity
f	fluid
front	front
gross	gross electrical power
inv	inverter
HE	Heat Exchanger
in	inlet
mod	module connections
net	net
out	outlet
opt	optical
pump	pump
PV	PV layer
PVT	PhotoVoltaic Thermal solar collectors
req	required
sky	sky equivalent temperature
sub	metallic substrate
TK	tank
th	thermal energy
top	top surface area
tot	total radiation

necessary to fulfil the European targets in the renewable energy sector [2], as well as to significantly contribute to the reduction of the EU's energy consumption and energy import dependence [3]. As a result, due to a cooperative effort among researchers and government agencies [4], several innovative efficient systems have been investigated, such as: ventilation systems [5], advanced solar cooling systems [6], ground-source heat pumps [7], cogeneration [8], renewable microgeneration [9], etc. In this framework, the optimal combination of emerging high-efficiency technologies, of renewable energy sources and of district heating and cooling, also coupled with measures to reduce the energy demand of buildings, has to be properly considered when planning, designing, building and renovating industrial or residential areas [4]. The present work focuses on the investigation of a novel solar polygeneration system