ARTICLE IN PRESS

Applied Energy xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

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

Assessing active and passive effects of façade building integrated photovoltaics/thermal systems: Dynamic modelling and simulation

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HIGHLIGHTS

- Dynamic modelling and simulation of building integrated PV/T systems.
- Assessment of the system passive and active effects on the building energy demand.
- Estimation of the impact of the air channel length on passive and active effects.
- Analysis of a case study of an office building located in European climate zones.
- Confirmed system feasibility by achieved energy, economic and environmental results.

ARTICLE INFO

Keywords:
Building integrated photovoltaic thermal system
Dynamic simulation modelling
Multi-floor building
Energy performance analysis

ABSTRACT

This paper analyses the integration of air open-loop photovoltaic thermal systems on the façade of high-rise buildings, with a special focus on their active and passive effects. The system energy performance and its impact on the building heating and cooling demands and electrical production are assessed through a new dynamic simulation model. The developed numerical model of the proposed system, based on a detailed transient finite difference thermal network, is verified by comparing its outcomes to experimental results. With the aim to carry out whole building energy performance analyses, the model is implemented in a dynamic simulation tool for the building energy performance assessment, called DETECt 2.3, and suitably modified to analyse the main building integration energy issues.

To assess the potentiality of the numerical model and the feasibility of the investigated system, a comprehensive case study relative to a multi-floor high rise office building located in several European climate zones is developed. A comparative and parametric analysis is also carried out with the aim to evaluate the system active and passive effects as a function of the building height. Simulation results show that by using building integrated air open-loop photovoltaic thermal systems, an interesting percentage reduction of the heating demand can be obtained. Both passive and active effects contribute to the variation of the thermal and electrical efficiencies. For the investigated weather zones, the innovative system leads to a reduction of the final energy consumptions ranging from 56.8 to 104.4%, approaching the nearly or net positive zero energy building target in the southern climate. Finally, the proposed analysis also aims to show the main implications linked to the design of the system, to be carefully taken into consideration by designers and stakeholders in case of new buildings or renovations.

1. Introduction

According to the IEA statistics for energy balance, the use of energy in buildings accounts for more than one third of total energy end use [1]. In OECD Countries the building sector is responsible for approximately 40% of total final energy consumption, being an important source of pollution. Buildings can play a crucial role to tackle climate change and energy consumptions through the adoption of energy-efficient strategies incorporated into design, construction, and operation of new buildings and undertaking retrofits. In this regard, the achievement of net or nearly zero energy building (NZEB/nZEB) goals has attracted the interest of the research community, building stakeholders, and policy makers supporting the shift toward a low-carbon economy [2].

A ZEB is considered as a building with very high energy

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http://dx.doi.org/10.1016/j.apenergy.2017.09.039
Received 1 June 2017; Received in revised form 31 August 2017; Accepted 10 September 2017
0306-2619/

Please cite this article as: Athienitis, A.K., Applied Energy (2017), http://dx.doi.org/10.1016/j.apenergy.2017.09.039

Nomenclature

A	area [m^2]
a	interest rate [–]
BIPV	Building Integration PhotoVoltaic system
BIPV/T	Building Integration PhotoVoltaic thermal solar collectors system
C	capital cost [€]
c	electricity cost [€/kWh]
CDD	Cooling Degrees Day
C_d	channel coefficient [–]
CFD	computational fluid dynamics
C_{in}	thermal capacitance [J/K]
c_p	specific heat [J/kg·K]
CO_2	carbon dioxide
COP	Coefficient Of Performance
DPB	Discounted Pay Back [y]
D_{eq}	hydraulic diameter [m]
E	energy [kWh]
e	average error [%]
EER	Energy Efficiency Ratio [–]
FEM	Finite Element Method
f_{PLR}	part-load ratio [–]
h	heat transfer coefficient [W/m^2·K]
HDD	Heating Degrees Day
HVAC	Heating, Ventilation and Air Conditioning
I	incident solar radiation [W]
I_{cl}	clothing insulation [clo]
ISR	Incident Solar Radiation [kWh/m^2·y]
j	capital cost per square meter [€/m^2]
k	thermal conductivity [W/m·K]
L	channel length [m]
M	metabolic rate [W/m^2]
$\dot{m}$	flow rate [kg/s]
NPV	Net Present Value [€]
Nu	Nusselt number [–]
NZEB	Net Zero Energy Building
nZEB	nearly Zero Energy Building
OECD	Organisation for Economic Co-operation and Development
p	pressure [Pa]
P	power [W]
PES	Primary Energy Saving [MWh/y]
PI	Profit Index [–]
PMV	Predicted Mean Vote [–]
PPD	Predicted Percentage of Dissatisfied [%]
PV/T	PhotoVoltaic thermal solar collectors
PV	PhotoVoltaic panels
Pr	Prandtl number [–]
$\dot{Q}$	thermal load [W]
R	thermal resistance [K/W]
RC	Resistance Capacitance
Re	Reynolds number [–]
REF	reference system
RES	Renewable Energy Sources
SC	Solar thermal Collectors
SPB	Simple Pay Back [y]
T	temperature [K]
t	time [h]
U	heat transfer coefficient [W/m^2·K]
V	volume [m^3]
v	velocity [m/s]
w	width [m]
X	generic parameter
ZEB	Zero Energy Building

Greek symbols

Δ	variation
δ	thickness [m]
γ	coefficient [–]
λ	thermal conductivity [W/m·K]
μ	dynamic viscosity [Pa s]
η	efficiency [–]
ρ	density [kg/m^3]
θ	temperature [°C]
ν	kinematic viscosity [m^2/s]
ξ	air inlet number [–]

Subscripts/superscripts

air	air-gap air
bck	back plate
ch	channel
c	cooling
cavity	air gap channel
cond	conductive
conv	convective
ev	evaporator
faç	façade
floor	floor
ft	feed-in-tariff
el	electric
exp	measured
g	gains
HVAC	heating and cooling system
h	heating
in	indoor air
mr	mean radiant
N	nominal
out	outside
PV	photovoltaic cell
pur	purchase tariff
rad	radiative
roof	roof
sol	solar
sky	sky
v	ventilation
y	y-coordinate

performance which requires a very low amount of energy, to be covered to a very significant extent, or even completely, by means of renewable energy sources (RES), including energy from RES produced on-site or nearby [2]. Therefore, appropriate ZEB designs or renovations must combine high efficiency active and passive technologies (e.g. natural ventilation, daylighting) with renewable energy production, providing an opportunity for cost-effective measures, aiming at converting the building stock from an energy consumer to an energy producer.

Among the available RES capable of ensuring the conversion toward a sustainable building sector, solar energy has been identified as the most promising, showing the highest potential to meet a significant amount of building energy needs [2]. In addition, as an on-site supply option, it is to be highly preferred, among others, and particularly effective in case of building renovations [3]. Solar energy can be exploited for producing energy needs required for space heating and cooling, domestic hot water production, and electricity. Technologies based on solar RES, such as photovoltaic panels (PV), solar thermal collectors (SC), and photovoltaic thermal solar collectors (PV/T), can be