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Cost-optimal sizing of solar thermal and photovoltaic systems for the heating and cooling needs of a nearly Zero-Energy Building: the case study of a farm hostel in Italy

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Abstract

In this paper, the second of two parts, we apply the cost-optimal design method illustrated in Part 1 [1] to a case study. We select a farm hostel located in Enna, Italy, as the local climate and the required energy services are suitable for the development of a solar-assisted nearly zero-energy building. The system is connected to the electric grid and does not use any other thermal energy vector. Energy demand includes heating, cooling, domestic hot water production, lighting and other electric uses, viz. inductance cooking, food refrigeration, local dehumidification, household appliances, and office devices. The building-plant system is described in terms of both technical characteristics of each component and internal loads. According to the proposed simulation-based methodology, we investigate the best design configuration by minimizing the lifecycle cost after 20 years of operation. The results of the procedure identify the optimal solution, in terms of number of solar thermal and photovoltaic panels, volume and control strategy of the thermal storage. Other outputs are the dynamic and seasonal energy balance of each system component and of the whole system, and additional economic parameters. The results show that the proposed method leads to a very favorable design with relevant notable economic and energy benefits with respect to a no-solar design solution (ΔC^{TOT}=11%, ΔE_{IN}^{TOT}=67%). However, several nearly optimal configurations provide very similar outcomes in terms of lifecycle costs, with different initial investment and energy performances. Consequentially, we introduce a multi-objective optimization approach aimed at identifying the best solution in terms of investment availability and energy objectives.

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Keywords: Nearly Zero-Energy Buildings; cost-optimal design; solar thermal; photovoltaics; heat pumps; case study

1. Introduction

In light of the energy uses for the building sector, current European Directives [2] focus on nearly Zero-Energy Buildings (NZEB), which are buildings characterized by very low energy need. Their high energy performance is

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reached through a wise design of the envelope and efficient generation systems, together with the use of renewable sources for the production of both thermal and electrical energy.

Several research projects aim to find the optimal strategy to concurrently obtain high energy efficiency and low installation and operating costs [3,4]. In the first part of this work [1], we illustrated a methodology for the simulation of a solar-assisted NZEB system, consisting in a building envelope, a radiant floor, a heat pump (HP) unit, a thermal storage, solar thermal collectors (ST), and photovoltaic system (PV). A proper design of the whole system can be reached through the proposed "*simulation-based optimization procedure*", which provides as output the cost-optimal sizing of solar technologies and ancillary components (i.e. thermal storage), together with optimal control parameters. In the following sections, we describe the main features of the chosen case study and the results of the applied optimization procedure.

Nomenclature

Acronyms

BOS	balance of system
COP	coefficient of performance
CoSE	cost of saved energy
DHW	domestic hot water
FES	fractional energy savings (see definition in ISO 9488:1999 "Solar Energy – Vocabulary")
HP	heat pump
PER	primary energy ratio
PV	photovoltaic system
RF	radiant floor
ST	solar thermal system
TS	thermal storage

Symbols

C	global cost
C_0	installation cost
E	energy
F_R	ST removal factor
K_{RF}	RF thermal output per surface unit
$NOCT$	nominal operating cell temperature
$P_{th,des}$	peak load
S	surface
T_{off}	switching-off temperature
T_{TS}	thermal storage temperature
U	global heat transmittance of opaque walls
U_L	ST frontal losses coefficient
U_w	global heat transmittance of windows
U_{wf}	water-floor thermal transmittance
V	volume
b_0	incidence angle modifier coefficient for single-cover ST collectors
c_0	unitary installation cost
n	number of PV modules or ST collectors
s	thickness

Greek letters

$\beta_{T,PV}$	PV penalization factor depending on PV technology
η	efficiency
λ	thermal conductivity
$(\tau\alpha)_n$	transmittance-absorptance product for normal-incidence irradiance
ϕ	building time shift

Superscript

II	second-law parameter
*	sol-air temperature
TOT	cumulative value at the end of project lifetime

Subscript

el	electrical
$grid$	electrical grid
inv	electronic converter and other PV system components
ref	reference conditions
th	thermal
w	water

2. Description of the case study

The chosen design case study is a farm hostel in Enna, Sicily, Italy. As mentioned in [1], we developed models for each involved subsystem, viz. envelope thermal needs, radiant floor, air-to-water HP unit, PV generator, ST generator, and thermal energy storage. An hourly time step was chosen. In the following sections, we describe the main thermo-energetic features of each subsystem of the case study.