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ScienceDirect

Energy Procedia 140 (2017) 423–433

Energy Procedia

www.elsevier.com/locate/procedia

AiCARR 50th International Congress; Beyond NZEB Buildings, 10-11 May 2017, Matera, Italy

On the optimal mix between lead-acid battery and thermal storage tank for PV and heat pump systems in high performance buildings

Alessandro Prada[a,*], Elena Bee[a], Maurizio Grigiante[a], Paolo Baggio[a]

[a]*Dep.of Civil, Environmental and Mechanical Engineering, University of Trento, via Mesiano 77, Trento 38123, Italy*

Abstract

The coming into force of the European Directive 2009/28/CE [1] increases the role of renewable energy sources to satisfy the energy consumptions of new buildings and major renovations. In this respect, the vapor-compression heat pump coupled with PV panels is a promising solution and, consequently, it is increasingly used for residential heating applications. This HVAC solution is especially advantageous in high performance building when low temperature hydronic systems are adopted. However, in these buildings some issues arise in the HVAC control and the building might be easily subject to poor comfort conditions when approaching the nZEB target while maintaining economical convenience. Besides, the seasonal performance of the heating system is strongly dependent on the HVAC design. Hence, the optimal size of the storage components is a key aspect in order to maximize the renewable coverage factor, overcoming the shift in time between PV production and energy demand. For this reason, different strategies may be adopted such as the thermal storage tank or the electricity storage in lead-acid battery.

This paper analyses the mix among the thermal storage tank, the lead-acid battery and the thermal capacitance of the building envelope for the optimal design solutions in three Italian climates. The complex interactions among building, occupants, weather conditions and HVAC systems are considered by means of a dynamic simulation tool. The optimal design solutions were studied, according to the cost optimal approach of the EPBD context, by means of a genetic algorithm developed in Matlab®. The energy performance for heating (EP_h) and the net present value (NPV) are considered as competitive goals.

Peer-review under responsibility of the scientific committee of the AiCARR 50th International Congress; Beyond NZEB Buildings.

Keywords: Heat Pump; Multi-Objective Optimization; Energy Storage; NZEB

* Corresponding author. Tel.: +39-0461-282516.
E-mail address: alessandro.prada@unitn.it

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Peer-review under responsibility of the scientific committee of the AiCARR 50th International Congress; Beyond NZEB Buildings
10.1016/j.egypro.2017.11.154

1. Introduction

Air-to-water heat pumps have an increasing share in the European heating market. According to the European Heat Pump Market and Statistics Report [2], they represent the fastest growing heat pump segment across Europe. This rapid increase in market share is partly linked to the performance improvements in the commercial products, both for nominal and part load conditions, due to the adoption of inverter-driven compressors. Additionally, the aerothermal energy source is considered a renewable source by the European Directive 2009/28/CE and, consequently, air-source heat pumps (ASHP) will have an important role in order to meet the mandatory provisions about the minimum coverage factor of renewable energy sources. In this respect, the ASHP coupled with PV panels is a promising solution and, consequently, it is increasingly used for residential heating applications.

However, it has been observed that some issues arise in the control of the HVAC systems due to the fast changes in energy demand. Consequently, the building might be easily subject to poor comfort conditions when the energy systems are installed in high performance houses which approach the nZEB target while maintaining economical convenience [3]. Additionally, the seasonal performance of the heating system is strongly dependent on the HVAC design, such as the components sizes (heat pump, water storage tank, PV battery), and on the adopted control strategy. Thus, an optimal concurrent design of the HVAC and control systems installed in high performance building is essential to ensure the reduction of energy consumption and the achievement of thermal comfort for the entire heating season [4]. For these reasons, energy storage systems play a key role in the correct integration of the HVAC systems in high performance buildings. In the residential sector, storage systems are used to shave the peak loads, to take advantage of the off-peak tariff and to increase the renewable coverage factor [5]. However, the primary role of these systems is to reduce the discrepancy between the source availability and the energy demand. Hence, energy storages will become essential in high performance buildings since both the energy demand and the renewable energy production are inherently intermittent.

Nomenclature

Alt	Site Altitude [m]
COP_{rated}	Full load rated coefficient of performance at 7/35°C [-]
EP_h	Non-renewable part of the Energy performance for heating [kWh m^{-2} yr^{-1}]
HDD_{10}	Heating degree days on 10°C basis [K day]
HDD_{18}	Heating degree days on 18°C basis [K day]
Lat	Latitude angle [deg]
Long	Longitude angle [deg]
IC	Initial cost [EUR]
NPV	Net Present Value based on 30 years lifespan [kEUR]
n_{batt}	Number of lead-acid battery in series [-]
n_{str}	Number of strings of 3 PV modules in series [-]
Q_{batt}	Capacity of a single lead-acid battery [kWh
SB_{start}	Starting hour of setback adjustment [h]
SB_{stop}	Stopping hour of setback adjustment [h]
SHGC	Solar heat gain coefficient [-]
T_{sb}	Temperature of setback [°C]
U	Thermal transmittance [W m^{-2} K^{-1}]
V_{stor}	Volume of the storage tank [liter]
WFR	Window to Floor ratio [-]
Φ_{rated}	Rated ASHP thermal output at 7/35°C [kW]
κ_m	Areal heat capacity according to [26] [kJ m^{-2} K^{-1}]