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ScienceDirect

Energy Procedia 140 (2017) 434–446

Energy Procedia

www.elsevier.com/locate/procedia

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

Performance evaluation of a building integrated photovoltaic (BIPV) system combined with a wastewater source heat pump (WWSHP) system

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Abstract

This paper deals with both energetic and exergetic performance assessments of two combined systems as a whole. The first one is a Building Integrated Photovoltaic (BIPV) system while the second one is a wastewater (WW) Source Heat Pump (WWSHP) system. Both systems were installed at Yasar University, Izmir, Turkey within the framework of EU/FP7 and the Scientific and Technological Research Council of Turkey (TUBITAK) funded projects, respectively. The BIPV system was commissioned on 8 February 2016 and has been successfully operated since then while the WWSHP system was put into operation in October 2014. The BIPV system has a total peak power of 7.44 kW and consists of a total of 48 Crystalline Silicon (c-Si) modules with a gap of 150 mm between the modules and the wall, and a peak power per PV unit of 155 W_p. The WWSHP system consists of three main sub-systems, namely (i) a WW system, (ii) a WWSHP, and (iii) an end user system.
Two systems considered have been separately operated while the measured values obtained from both systems have been recorded for performance assessment purposes. In this study, a combined system was conceptually formed and the performance of the whole system was evaluated using actual operational data and some assumptions made. Exergy efficiency values for the WWSHP system and the whole system were determined to be 72.23% and 64.98% on product/fuel basis, while their functional exergy efficiencies are obtained to be 20.93% and 11.82%, respectively.

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10.1016/j.egypro.2017.11.155

It may be concluded that the methodology presented here will be very beneficial to those dealing with the design and performance analysis and evaluation of BIPV and WWHP systems.

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

Keywords: buildings; BIPV; building integrated photovoltaic; wastewater source heat pump; WWSHP; exergy; exergy efficiency.

1. Introduction

The energy consumption of the buildings accounts for 40% of the total energy consumption in the EU while buildings are also responsible for 36% of the CO_2 emissions [1]. These numbers clearly indicate how important energy efficiency issue in buildings is and therefore the building sector can be regarded as one of the most important factors for the achievement of the EU's 20/20/20 targets. Currently, there are two main legislations in the EU regarding the energy consumption in buildings, namely Energy Performance of Buildings Directive (2010) and Energy Efficiency Directive (2012). Within the context of these two directives; EU countries should make energy efficient renovations to at least 3% of buildings owned and occupied by central government, only purchase buildings with high energy efficiency and all new buildings must be nearly zero energy buildings by 31 December 2020 (public buildings by 31 December 2018) [1].

Wastewater (WW) discharged from buildings to sewerage systems reserves huge amounts of thermal energy, which can be used as heat source in HPs. It can also be considered as a sustainable and renewable source in big cities [2,3].

According to a study performed, the heat loss via WW for a traditional building in Switzerland accounts to 15% of its demand and 6000 GWh of thermal energy is lost via WW every year in Switzerland [4]. This study indicates that the sew-age systems are one of the largest sources of heat loses in buildings. Therefore, any attempt to recover this heat loss has the potential to increase the energy efficiency of the buildings. One of the ways to benefit from this heat is using WW as a heat source of heat pumps (HPs), which are known as clean and energy efficient heating and cooling solutions in buildings. At present, there are more than 500 WWSHPs installed around the world, with a capacity range of 10 kW – 20 MW [4]. This makes sense because WW represents a very suitable and efficient heat source for HPs with its main characteristics: (i) huge amounts especially in big cities, (ii) having higher temperatures than the outdoor air temperature in winter, (iii) having lower temperatures than the outdoor air temperature in summer, (iv) having low temperatures fluctuations during the seasons. According to the measurement data of Beijing Gaobedian WW treatment plant (WWTP), the WW temperature ranges from 13.5 to 16.5 ℃ in winter, which is about 20℃ higher than outdoor temperature while in summer the WW temperature varies be-tween 22 and 25℃, which is 10℃ lower than outdoor temperature [5]. Due to the huge potential of WW, numerous studies have been conducted and found in the open literature, as comprehensively reviewed by Hepbasli et al [2]. For further information about WWSHPs, this study can be addressed.

According to the International Energy Agency, the share of renewables in electricity generation is expected to rise up to 25% of the total power generation in 2018 [6]. PV generated electricity is also estimated to double its share by 2018 compared to 2011 [7]. In this regard, Building Integrated PV (BIPV) systems play an important role in generating electricity. BIPVs are defined as PV modules, which can be integrated in the building envelope (into the roof or façade) by replacing convention-al building materials (e.g., tiles) [8]. Therefore, BIPVs have an impact of building's functionality and can be considered as an integral part of the energy sys-tem of the building.

As stated earlier, according to the energy performance of buildings directive, all new buildings have to be nearly zero-energy by the end of 2020. To achieve this target, renewable energy sources (RESs) should be used as much as possible to cover the energy consumption of the buildings. In this context, solar energy (especially, PV technology) seems to be the most suitable RES technology to be used in buildings. PV systems in buildings can be divided in two sections as building attached PVs (BAPVs) and BIPVs. BAPVs are mostly roof-top mounted PV systems, which are added after the construction and have no direct effect on the functionality of the structure [9]. On the other hand, BIPVs are integrated on the façade or the roof of the building by replacing building materials, such as tiles and