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ScienceDirect

Energy Procedia 78 (2015) 1974 – 1979

Energy Procedia

6th International Building Physics Conference, IBPC 2015

Investigating the effect of roof configurations on the performance of BIPV system

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Abstract

Adopting renewable energy production systems is a promising technology in sustainable building design to reduce the increasing global energy demand and CO_2 emissions. On the other hand, heat losses through building envelope account for more than half of the total heat losses in a building. An integrative technology, coupling airtight building envelopes with renewable energy technologies is a shift towards near net-zero energy buildings (NZEB). In this feasibility study, the performance of building-integrated photovoltaic (BIPV) system installed on cold and warm roof configurations of a low-rise residential building, with high efficiency insulation has been investigated using TRNSYS. The associated energy performance and efficiency of BIPV system has been examined. Simulated data indicated that the cold roof improved efficiency of BIPV system, throughout the year.

Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL

Keywords: Building-Integrated Photovoltaic(BIPV); Net Zero Energy Building(NZEB); TRNSYS

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1. Introduction

In recent times, there is increasing interest and research in renewable energy technologies, driven by the insecurity of supply, increasing costs, and environment degradation issues associated with fossil energy sources. Of all renewable energy sources currently available, solar energy is the most abundant, inexhaustible and clean one. In one day, the irradiation from the sun on the earth gives about 10,000 times more energy than daily use from mankind [1]. Considering that fossil fuel sources supplied 82% of the world's energy consumption in 2013, there is

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1876-6102
Peer-review under responsibility of the CENTRO CONGRESSI INTERNAZIONALE SRL
doi:10.1016/j.egypro.2015.11.387

significant potential to use solar energy [2]. Furthermore, energy consumed in the building sector represent the greatest portion (about 40% or more) of the total energy usage in many countries, making the building sector the biggest single contributor to total energy consumption [3, 4]. The building sector, be it residential or commercial, is characterized by a diverse array of energy uses, as well as varying sizes and types of buildings in a wide range of climates; therefore, no single method can be used to improve energy efficiency. Rather, a broad array of available technologies can be employed to reduce emissions whiles ensuring energy efficiency. One of the most promising renewable energy technologies is Building-integrated photovoltaic (BIPV). BIPV are photovoltaic modules that replace conventional building envelope materials, and produces electrical energy on site directly from the sun [1]. BIPVT system can be integrated as outer layer component of building envelope, namely: roof, façade, parapet, balcony, or sun shading element integrations. Thus BIPV serves a multifunctional purpose as a building envelope component and electrical power generator. Architecturally, BIPV improves the aesthetics of the building design. Particularly in countries such as South Korea where there is pressure on land-use, BIPV offers an effective solution by using a building's own surface area. It was reported that the first BIPV system in South Korea was installed on the south façade and on the roof of the Samsung Institute of Engineering and Construction Technology, in the Gihung region in 1998 [5]. The BIPV could cover 10% of the SIECT building's (combined gross building floor area of 25,161 m^2) required lighting energy on a typical day in summer. The integration of photovoltaic (PV) within both residential and commercial roofs offers the largest potential market for PV [6]. Recently, a novel solar multifunctional Photovoltaic/Thermal/Day lighting roof system with green building design was reported [7]. The roof system achieved excellent light control at noon, and generated electricity and hot air by surplus light. In general, the peak efficiency (< 20%) of PV modules drops with increasing operating temperatures. For monocrystalline (c-Si) and polycrystalline (pc-Si) silicon solar cells, the efficiency decreases by about 0.45% for every rise in temperature; for amorphous (a-Si) silicon solar cells, the efficiency decreases by about 0.25% per degree rise in temperature, depending on the module design [8]. The temperature of the PV panel is increased primarily by the absorbed solar radiation that is not converted into electricity. In the case of a building with warm roof configuration and integrated with BIPV as roof, the enclosed warm air beneath the back surface of the PV panel could be secondary temperature source against the efficiency of the PV. In this study, a BIPV system integrated on warm and cold roof configurations for a residential building is modelled with TRNSYS using metrological data for Daejeon, South Korea. The objective of this study is to evaluate the performance of the BIPV system with respect to electrical energy generated, BIPV operating temperature, roof and room space temperature for summer and winter seasons; comparing simulated results of the roof configurations.

2. Methodology

2.1. Description of system

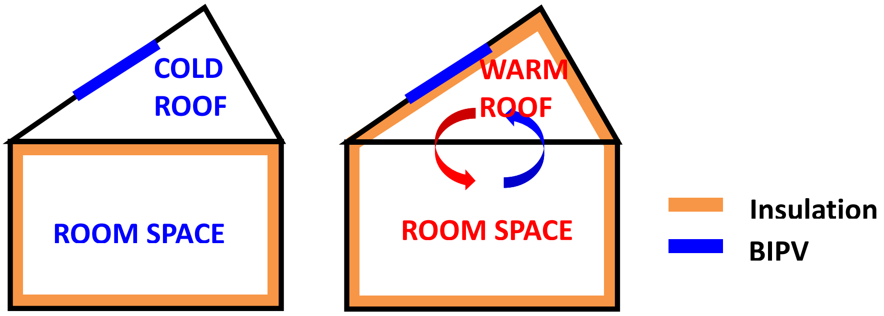

Fig. 1. Building model concept

As shown in Fig. 1, the system consists of a low-rise residential building with a pitched roof configuration. Two types of pitched-roof configurations were considered in this study, namely:

- Cold roof: roof construction where the insulation is laid immediately the flat ceiling. This means that everything above the insulation such as rafters, is colder than the living (room) space beneath.
- Warm roof: roof construction where the insulation is beneath roofing, in between roof rafters, thus the roof space and living space are both at conditioned space temperature because air flow occurs between roof and living spaces.

The BIPV was modelled on the south facing façade of the building; sloped at an angle of the pitched-roof at 30^{o}. General zone specifications used in the study are listed in Table 1. The zone temperature was controlled to 20 ^{o}C and 26 ^{o}C for heating and cooling, respectively; depending on occupancy schedules.

Table 1. Zone specifications

	Space	Volume
Zone	Room space	321.6 m^3
	Roof space	123.8 m^3
	Component	U-Value [W/m^2K]
Building component manager	External	0.304
	Ceiling	4.180
	Floor	0.330
	Cold roof	2.617

2.2. BIPV system modelling

The system was modelled with TRNSYS program, using BIPV type 567 as depicted in Fig. 2. It was assumed that the building was situated in Daejeon, South Korea; thus typical hourly weather data conditions for Daejeon, was used. As can be seen in Fig. 2, the main components included BIPV, data reader, radiation processor, multi-zone building model, and inverter. It was assumed that the back surface of the BIPV had the same temperature conditions as the roof space beneath. Specifications of the BIPV system are shown in Table 2.

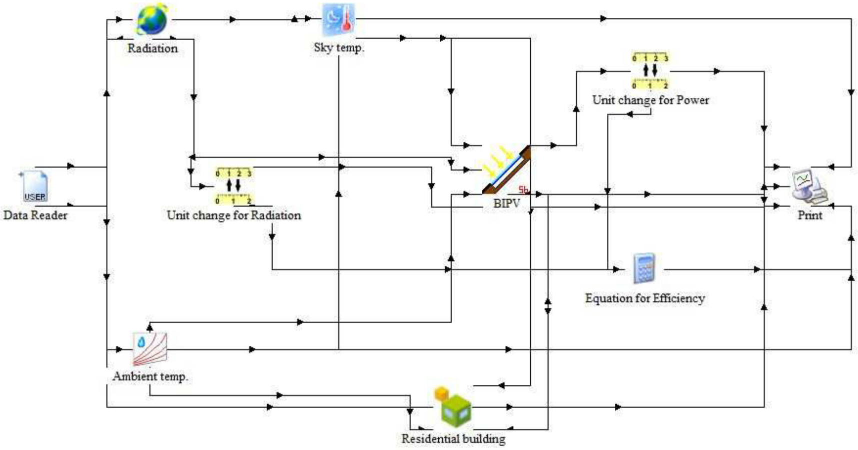

Fig. 2. TRNSYS information flow diagram for the BIPV system

Channel height of 0.0005 m means no ventilation. The total rated power of the BIPV was 4 KW.

Table 2. Type 567 BIPV system design parameters

PV parameter	Collector length	6.608 m
	Collector width	3.976 m
	Cover thickness	0.04 m
	Channel height	0.0005 m
	Reference PV efficiency	0.152
Input	Incidence angle	30^o
	Collector angle	30^o

3. Result and discussions

Output can be provided by TRNSYS on a daily or monthly basis. The results for particular days, as well as monthly values are presented in this study. Whereas daily results depict characteristic behavior of the system, monthly results show a long duration outcome.

3.1. Temperature description of system

The temperature of room space, temperature roof space, and PV temperature for cold and warm roofing configurations, as well as the ambient temperature and irradiation are illustrated in Fig. 3. Sampled results for three days each in spring (7th-9th May), summer (12th-14th August), autumn (4th-6th November) and winter (4th-6th January), respectively, were used to plot the graphs. The results show that the PV temperature was closely related to the irradiance on the PV surface. The higher the irradiance, the higher the PV temperature was. Depending on the magnitude of irradiance, the difference in temperature between PV and ambient environment varied. At lower irradiance, difference in temperature between PV and both roof configurations was small. Likewise, at higher irradiance, difference in temperature between PV and both roof configurations was large. Depending on ambient temperature, temperature change across the layers (PV, roof and room spaces) was large or small. For instance, at lower ambient temperature such as during winter, temperature change across each layer was large. Also, higher ambient temperature such as during summer resulted in a smaller temperature change across the each layer. Mostly, lower ambient temperature resulted in higher temperature difference across each layer, and vice versa. Notable from Fig. 3, the mean ambient temperature was about, 25 ^oC, 35 ^oC, 20 ^oC, and -5 ^oC in spring, summer, autumn, and winter, respectively. Generally, PV temperature was higher than roof temp, which was in turn higher than room temp. In particular, PV temperature for warm roof was always higher than cold roof regardless of the season provided irradiance was greater than or equal to one. Also, PV temperature of warm roof was similar to the ambient temp regardless of the season when irradiance was zero. This is because there is no heat exchange in the night (zero irradiance), thus, thermal equilibrium or heat balance. Further, at the said zero irradiance, PV temperature of cold roof was higher than PV temperature of warm roof. This is primarily because of the PV back surface is in cold roof space and volume of cold roof equals air gap on PV aspects. Throughout a year, PV temperature ranged between -2 ~52 ^oC and -9 ~ 69 ^oC for cold roof and warm roof respectively. PV in warm roof has a predominant influence of the ambient temp than roof temp. The PV temperature for each roof configurations rose by 52 ^oC (cold roof) and 69 ^oC (warm roof), when the irradiance was 800 W/m^2 or more. PV temperature of warm roof rose to nearly 70 ^oC during peak summertime. The maximum difference in PV temperature (ΔT) between cold and warm roof was 20 ^oC. PV temperature has a direct effect on the PV generated. Higher power generation is expected when applied to cold roof and will be discussed in Section 3.2. Except for summer season when roof temperatures of both cold and warm roofs are quite similar, roof temperature of cold roof was always higher than that of warm roof. It's worth noting that roof temp affects building energy demand. Thus, expectations are that heating demand of warm roof will be smaller than heating demand of cold roof. Room temperature was mainly determined by occupants schedule input factor; indoor temperature was higher or less than set temperature according to outdoor temperature when the building was unoccupied. Maximum and minimum room temperature in summer and winter were 28 ^oC and 17.5 ^oC, respectively.

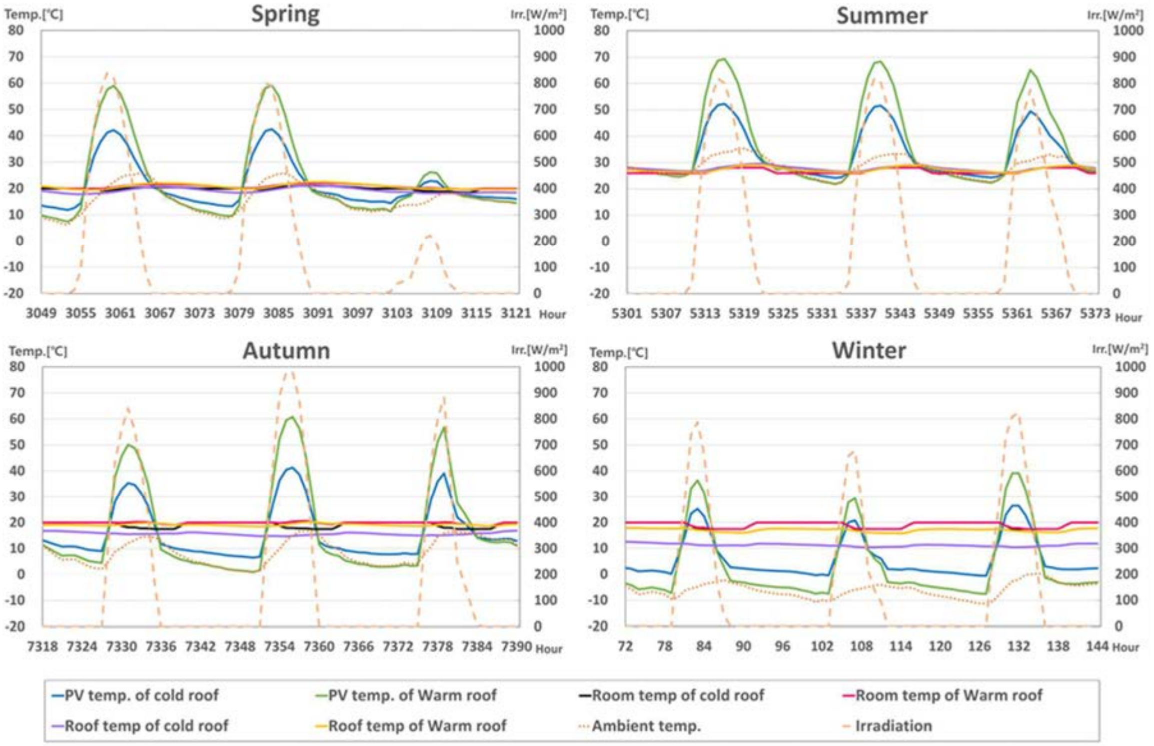

Fig. 3. Temperature profiles.

3.2. Monthly power generation

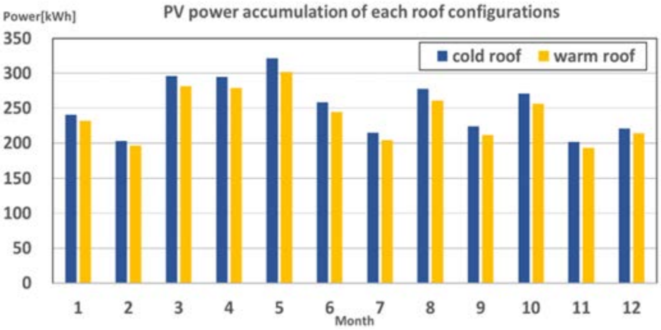

Fig. 4. Monthly power generation of the cases.

From Fig. 4, PV power generation for cold roof was entirely greater than that of warm roof. The total power for a year was 3 MWh for cold roof and 2.8 MWh for warm roof, thus about > 7% more power generated by cold roof.

3.3. Heating and cooling energy demand

The heating and cooling loads for both roofing configurations are shown in Fig. 5. Energy demands for heating cold roof was greater than warm roof. Heating energy saving of 47 % and 45 % was realized in winter (December, January and February specifically) and throughout the year, respectively, for warm roof. This was attributed to the insulation between roof and room. That is, PV absorbs irradiance in winter and insulation reduces heat loss from outdoor to warm roof. In the case of the warm roof, heat is transferred to roof through absorbed irradiation in winter. Moreover the heat warms indoors and reduces heating demand. However, in the case of cold roof, heating demand is huge because of heat transfer to indoors less than warm roof with applied insulation between roof and room. Mostly, cooling demand for cold roof lower than that of warm roof. For instance in June, cooling demand savings on cold roof was about 20 % and 7 % in July. However in August, the heating demand of cold roof was higher than that of warm roof because of difference between the amounts of irradiance.

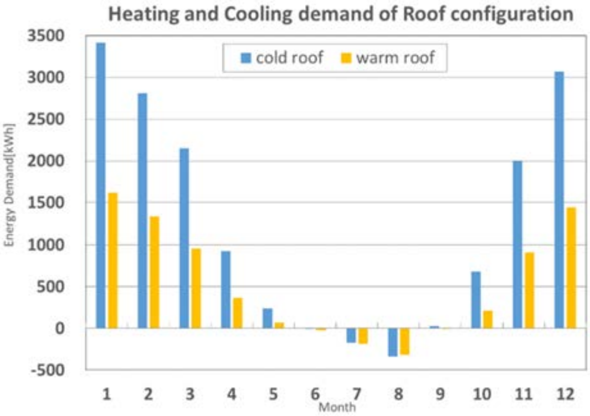

Fig. 5. Variation of the monthly heating and cooling loads of building.

4. Conclusion

BIPV installed on cold and warm roofing configurations has been investigated in this study, using TRNSYS. Generally, the PV temperature for warm roof was generally higher than for cold roof. Also, results showed that cold roof generated 7% more power in a year, as compared to warm roof. Furthermore, from building energy demand perspective, cold roof required more energy to heat and cool conditioned spaces as compared to warm roof. Thus, cold roof has advantage on PV generations aspect whereas warm roof is advantageous on whole building energy demand.

Acknowledgements

This research was supported by Basic Science Research Program through the National Research Foundation of Korea (NRF) funded by the Ministry of Education and the Human Resources Program in Energy Technology of the Korea Institute of Energy Technology Evaluation and Planning (KETEP) granted financial resource from the Ministry of Trade, Industry & Energy, Republic of Korea.

References

[1] Jelle BP, Breivik C, Røkenes HD. Building integrated photovoltaic products: A state-of-the-art review and future research opportunities. Solar Energy Materials and Solar Cells, 2012; 100: 69-96

[2] World Energy Council. World Energy Resources - 2013 Survey. ISBN: 978 0 946121 29 8, 2013.

[3] Garmston H, Pan W. Non-Compliance with Building Energy Regulations: The Profile, Issues, and Implications on Practice and Policy in England and Wales. Journal of Sustainable Development of Energy, Water and Environment Systems, 2013; 1: 340-351.

[4] Iwaro J, Mwasha A. A review of building energy regulation and policy for energy conservation in developing countries. Energy Policy, 2010; 38: 7744-7755.

[5] Yoo SH, Lee ET, Lee JK. Building integrated photovoltaics: a Korean case study. Solar energy, 1998; 64:151-161.

[6] Bahaj AS. Photovoltaic roofing: issues of design and integration into buildings. Renewable energy, 2003; 28: 2195-2204.

[7] Feng C, Zheng H, Wang R, Yu X, Su Y. A novel solar multifunctional PV/T/D system for green building roofs. Energy Conversion and Management, 2015. 93: p. 63-71.

[8] Kalogirou SA, Tripanagnostopoulos Y. Hybrid PV/T solar systems for domestic hot water and electricity production. Energy Conversion and