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A novel approach to compare building-integrated photovoltaics/thermal air collectors to side-by-side PV modules and solar thermal collectors

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Abstract

Building-integrated photovoltaics with thermal energy recovery (BIPV/T) shows great potential for integration into net-zero energy buildings. This technology is still not widely used, however. One of the reasons is that its advantages compared to traditional PV modules and solar thermal collectors are unclear. This study addresses the lack of a methodology on how to perform such comparison. It also presents a case study on how this novel approach can be used to demonstrate the actual energy and economic benefits of BIPV/T air systems compared to side-by-side PV modules and solar thermal collectors for residential applications. In this methodology, the thermal energy produced by both systems is transferred into water using a heat exchanger and the concept of annual equivalent useful thermal energy production is used to combine thermal and electrical energy. To perform the analysis, a detailed model of a BIPV/T system was developed and validated against experimental data. Then, the following systems were modeled in TRNSYS: a BIPV/T air system and side-by-side PV modules and liquid solar thermal collectors (PV + T). A case study was performed by simulating the performance of both systems on a 40 m^2 south-facing roof located in Montreal, Canada. The total energy produced by both systems was assessed by converting electricity into heat with various conversion factors. For a factor of 2, the BIPV/T system was found to produce 5–29% more equivalent useful thermal energy than the PV + T system for a water temperature at the heat exchanger inlet corresponding to 10 °C. Under similar operating conditions and for systems operating all year long, the acceptable cost to recover the heat from the BIPV system in order to break even with the cost of the PV + T system was found to be 7000 CAD.

Keywords: Building-integrated photovoltaics; Heat recovery; Hybrid collector; Conversion

1. Introduction

In the next 5 years, building-integrated photovoltaics (BIPV) is set to become one of the fastest growing segments of the solar industry worldwide with a predicted capacity growth in the range of 50% or more from 2011 to 2017 (PikeResearch, 2012). This growing interest in BIPV is due, in part, to the fact that many countries are now establishing specific targets related to net-zero energy buildings (NZEBs). In order to achieve this goal, building designs must incorporate three essential concepts: energy conservation, energy efficiency and the optimal integration of renewable energy technologies. For this last aspect, BIPV offers significant advantages compared to standard rack-mounted PV modules because it does not only generate electricity, but also acts as an active component of the building envelope.

In recent years, building-integrated photovoltaics with thermal energy recovery (BIPV/T) has shown great

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potential to be integrated into NZEBs. In such systems, the heat generated by the PV module is recovered by a heat transfer fluid that can be either air or a liquid, producing both thermal and electrical energy simultaneously. BIPV/T offers the same advantages as BIPV, but in addition, it provides a more aesthetically pleasing look than side-by-side PV modules and solar thermal collectors and generally produces more energy for the same surface area. Although valuable for NZEBs, these benefits are often considered insufficient when the building's architectural aspect is not a primary design criterion or when a large amount of building surface area is available for mounting solar energy technologies. Thus, many building designers still prefer to implement traditional solar energy technologies such as side-by-side rack-mounted PV modules and liquid solar thermal collectors. For this reason, this article aims at identifying the actual energy and cost benefits of BIPV/T residential systems using air as the heat transfer fluid compared to more traditional solar energy technologies, i.e. side-by-side rack-mounted PV modules and liquid solar thermal collectors. In particular, the objectives are:

- To develop a methodology allowing the energy and cost benefit comparison of a BIPV/T air system with side-by-side PV modules and liquid solar thermal collectors.
- To use this methodology in a case study to compare the amount of energy produced by a BIPV/T air system to that generated by a system consisting of side-by-side PV modules and liquid solar thermal collectors.
- To identify the required cost to convert a BIPV system into a BIPV/T system so that the cost of the BIPV/T system breaks-even with the cost of side-by-side PV modules and solar thermal collectors.

2. Literature review

Quantifying the performance of combined photovoltaic/thermal collectors (PV/T) or BIPV/T is a challenge because these systems produce two types of energy: thermal and electrical. In most applications, thermal and electrical energy do not have the same value. Thus, it is not straightforward to compare the performance of two PV/T or BIPV/T systems that have different electrical and thermal yields. When comparing a BIPV/T air system to a more traditional system such as side-by-side PV modules and liquid solar thermal collectors, an additional challenge occurs because thermal energy stored in air must be compared to thermal energy stored in a liquid. This section presents a review of studies that have looked at comparing PV/T or BIPV/T with PV modules, solar thermal collectors or other PV/T collector designs. It focuses on the performance indicators that have been used to encapsulate the performance of PV/T or BIPV/T collectors and on the main results obtained with these performance indicators.

2.1. Combined energy or exergy efficiency

Some studies have used a combined efficiency, η_T, as a performance indicator for PV/T collectors defining it as the sum of the electrical and thermal efficiencies (Garg and Adhikari, 2000; Huang et al., 2001; Othman et al., 2007; Sopian et al., 2000):

$$\eta_T = \eta_{th} + \eta_{el} \tag{1}$$

Using this definition, Garg and Adhikari (1997) compared single glazed and double glazed PV/T air collectors. They concluded that the reduced heat losses of the double glazed system were not worth the transmission losses, and thus, that a single glazed system was more appropriate. Chow et al. (2009) compared the performance of glazed and unglazed thermosyphon PV/T collectors. They found that the thermal efficiency of the glazed collector was greater than that of the unglazed collector (50.4% vs 40.8%), but that the electrical efficiency was lower for the glazed than for the unglazed collector (9.3% compared to 12.1%). When considering the combined efficiency as defined in Eq. (1), they concluded that the glazed collector generally had a better performance. Using the combined exergetic efficiency of the collector as a performance indicator, however, they found that the unglazed configuration usually performed better except at high levels of radiation and ambient temperature.

Hegazy (2000) used the net combined efficiency, $\eta_{T,net}$, as a performance indicator to compare different PV/T collector designs:

$$\eta_{T,net} = \eta_{th} + \eta_{el,net} \tag{2}$$

In Eq. (2), $\eta_{el,net}$ is the net electrical efficiency defined as:

$$\eta_{el,net} = \frac{\eta_{PV,system} P_{PV,DC} - P_{flow}/\eta_{fan}\eta_{motor}}{A_g G} \tag{3}$$

In Eq. (3), A_g is the collector gross area, G is in the in-plane irradiance, $P_{PV,DC}$ is the DC PV system power, P_{flow} is the flow pumping power and η_{fan} and η_{motor} are the fan and electrical motor efficiencies, respectively. The PV system efficiency, $\eta_{PV,system}$, accounts for balance of system (BOS) losses (batteries, cables, inverter, etc.) and was estimated at 56% by Hegazy. This performance indicator was used to compare 4 designs of glazed PV/T air collectors using monocrystalline solar cells on a daily basis: with the air flowing over the absorber, the air flowing below the absorber, the air flowing on both sides of the absorber in a single pass configuration and the air flowing on both sides of the absorber in a double pass configuration. The best net combined efficiency was obtained with the air flowing on both sides of the absorber in a single pass configuration regardless of flow rate. Daily combined efficiencies for the Egyptian climate ranging from 32% to 54% were obtained for flow rates between 18 kg/(h m^2) and 144 kg/(h m^2).