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Study of the thermal and electrical performances of PVT solar hot water system

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ABSTRACT

Photovoltaic-thermal (PVT) hybrid collectors are co-generation components that convert solar energy into both electricity and heat and represent in principle one of the most efficient ways to use solar energy.

The aim of the study presented in this paper is to assess the performance of this type of collector as part of a solar thermal system. First of all, the development and the test results of an experimental flat plate PVT collector are described. Then, in the second part, the performance of this hybrid collector being part of a solar thermal system in a building is determined and compared to that of systems operating with standard solar devices (i.e. solar thermal collector and PV panel), through simulations using TRNSYS. Comparisons according to various evaluation criteria were made assuming the same surface area and under the same climatic conditions.

The results show that in configuration of limited available space for solar collector area, the use of efficient PVT collectors in the building envelop can be more advantageous than standard PV and solar thermal components, not only from an energetic point of view, but also considering the exergy and the primary energy saving.

1. Introduction

In the prospective of positive energy buildings in a near future, the envelope plays and will play a key role for energy production. Nowadays, efficient generation of energy, thermal or electrical, in the building envelope is currently done through solar thermal collectors or PV panels. These solar active devices need, of course, a well-oriented surface, usually towards the equator. However, these surface areas on roofs or facades with suitable orientations are limited. In order to maximize the energy yield, each available square meter with suitable orientation for solar applications should be used in the most efficient way possible. This is one of the reasons behind the large amount of research underway on the development and integration of solar active devices into the building envelope.

Two main types of solar active devices for energy production can be integrated into the building envelope: solar thermal collectors for the conversion of solar radiation into useable heat, and photovoltaic (PV) panels for the conversion of solar radiation into electricity.

Besides the, relatively low, conversion efficiency of PV cells (typically in the range of 10–20%), the cells have high absorption for all solar radiation, leading to the situation that most of the solar radiation absorbed by PV cells is converted into heat, increasing the cell temperature and as a result reducing its efficiency.

To estimate the share of the solar radiation absorbed by a c-Si solar cell and also to estimate the share of solar radiation converted into electricity, we carried out measurements on a commercial solar cell. The spectral reflection and the spectral response of the cell were measured and are summarized in the Fig. 1.

Roughly 90% of the incoming radiation is absorbed by the cell, whereas only 15% is converted into electricity. The potential of heat recovery (about 75% of the incoming radiation) is then huge for the same solar energy collecting area. The development of co-generation components like PV-thermal collectors (PVT), consisting of a combination of photovoltaic (PV) cells and solar thermal absorber components, can offer an more effective solution by usefully capturing the heat produced in the PV cell.

PVT collectors represent in principle one of the most efficient ways to use solar energy. That is the reason why many investigations on flat plate PVT collectors have been carried out theoretically as well as experimentally since the late 1970s [1–3]. As reported by different authors in recent reviews [4–7], many types of flat plate PVT collectors have already been developed. Flat-plate PVT collectors can be divided into several categories, for example according to the nature of the heat transfer medium (air or water) and the presence of an additional glass cover (covered and non-covered collectors). The focus in this paper is on collectors with water as the heat transfer fluid.

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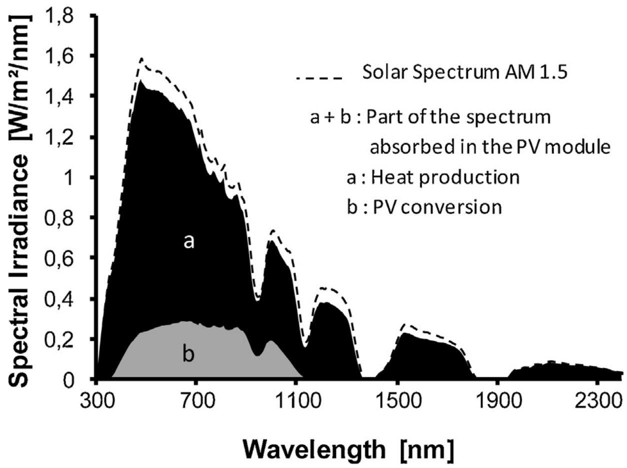

Fig. 1. Spectral representation of the absorption, reflection and PV conversion of a real c-Si solar cell.

The design of non-covered PVT collectors consists mainly of heat removal pipes on the back of a PV module. This allows primarily for the reduction of the operating temperature of the PV module. In the case of covered PVT collectors a specially designed PV module/absorber assembly is placed in a conventional collector housing consisting of a frame with transparent front-cover and insulation at the back and sides in order to reduce heat losses. The essential difference between covered and non-covered PVT collectors is the absence of an (static) air layer between front-cover and the PV cell/absorber assembly for the non-covered collectors (see Fig. 2).

Although the presence of an additional glass cover can reduce slightly the optical and PV performance of the module, it increases strongly the thermal performance of the collector, leading to a better overall energy conversion in comparison to non-covered collectors.

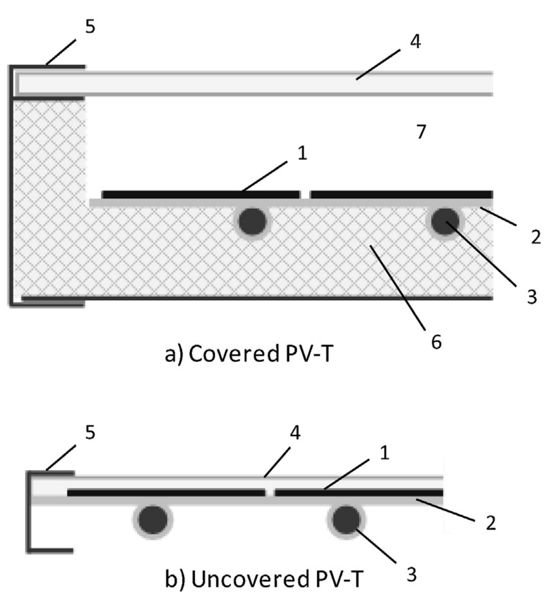

Fig. 2. Cross-sections of the two common PVT collector designs using water as heat transfer fluid: a covered (a) and a non-covered (b) PVT collector, consisting of: laminated solar cells (1), heat exchanger construction (2), heat removal fluid (3), glass cover (4), aluminum frame (5), thermal insulation (6) and static air layer (7).

Fig. 3. Picture of the developed prototype during the measurement in the indoor solar simulator.

2. Experimental development of a PVT collector

Through the ‘dual’-use of the solar radiation the PVT collectors represent in principle one of the most efficient ways to use solar energy. However, the concept of PVT is not new and in spite of continuous interest for this field, PVT is still a controversial technology which has not been able to enter the solar market successfully yet. Its main problem is its low thermal performance.

Through considering the PVT collector as an integrated technology in itself a redevelopment of both PV and solar thermal technologies specifically for PVT applications was made. Experimental investigations on materials and manufacturing processes were carried out merging both technologies optimally [8,9].

By modifying the PV lamination process, structure and the materials used, significant improvements in (solar) thermal properties (i.e. an increase of the absorption coefficient from 0.85 to 0.93 and a strong improvement of the heat transfer coefficient between the PV cell and the heat exchanger) as well as in the electrical efficiency (i.e. an increase in current density above 2 mA/cm^2) were achieved [9].

Following this new approach, a full-size (aperture area: 1.01 m^2) PVT collector was built (see photo in Fig. 3).

The single-crystalline silicon cells were laminated onto the surface of a specially coated metal absorber and covered by a high transmission polymer film. This absorber was built into a collector and tested with and without glass cover. Thermal and electrical measurements on this prototype were carried out in a solar simulator at the indoor testing facility of Fraunhofer ISE. The thermal efficiency curves were measured in maximum power point tracking PV mode (mpp or ‘hybrid’ mode, i.e. production of both electricity and heat) and in PV open-circuit mode (oc, or pure thermal mode, i.e. production of heat only). Results of the measurements are plotted as a function of the so-called reduced temperature (Fig. 4). The reduced temperature corresponds to the difference between the fluid mean temperature (T_m) and the ambient temperature (T_{amb}), divided by the solar radiation (G). The figure also shows the performance of a standard solar thermal single covered collector with a selectively coated absorber which was measured at the same facility.

The thermal efficiency of the covered PVT collector at zero reduced temperature is 72% with a corresponding electrical efficiency of 11%, whereas the thermal efficiency of the non-covered PVT collector at zero reduced temperature is 67% but with much