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Development of a building integrated solar photovoltaic/thermal hybrid drying system

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This work presents a feedback of the main experimental studies performed on a solar PV/T hybrid air collector, from optimization to demonstration. Indoor experimental parametric studies permitted to optimize the system basic configuration consisting in a PV laminate inserted into a metal absorber and comprising an insulated air gap at the underside. The main results showed that the modification of the system configuration leads heat rise in PV laminate and thus to the decrease of its electrical performance. The main solution proposed was the addition of stiffeners at the absorber backside in order to optimize its heat transfer surface with the PV laminate. The optimized prototype was, then, integrated into a roof fodder drying installation in Savoy. First thermal, electrical and aeraulic measurements showed that wind velocity has an important effect on air velocities in the air gap, even in drying periods. Considering the existing air gap and indoor tests results, the system daily thermal efficiency up to 27.7%, the PV field electrical efficiency up to 13% and the maximum air preheating of 7.8 °C indicated that the PV/T system is suitable for fodder drying application. As further studies, technical solutions will be proposed in order to optimize the PV installation.

1. Introduction

In a building integrated solar PV/T hybrid system (BIPV/T), according to the French policy, the PV module ensures the main functions (water and air tightness, weather protection …) of the building construction elements it replaces. Moreover, it is coupled with a heat recovery device for a simultaneous production of thermal and electrical energy. Various research programs aim to optimize the configuration design and the thermal and electrical performance of solar BIPV/T systems comprising PV modules stuck on a metal absorber [1–9]. In 2012, Tyagi et al. proposed a review of design requirements of BIPV/T systems considering their constituting layers properties, as well as an overview of possible applications [10]. In 2013, Moradi et al. performed the study of the effect of influencing design parameters on the performance of solar PV/T hybrid collectors [11]. Yang and Athienitis (2014), demonstrated through indoor tests on a BIPV/T component under a solar simulator that the metal absorber acts as a fin, increasing the thermal efficiency of system [12]. In 2015, Michael et al. detailed performance improvement factors and applications for solar PV/T hybrid collectors, including BIPV/T systems and solar drying applications. They specified that the decrease of thermal efficiency of the PV/T system compared to solar thermal collectors is related to the reduction of absorbed solar energy and to the increased heat transfer resistance between the PV modules and the absorber [13]. Solar drying is one of the few building applications, permitting to obtain a concomitance between energy needs and energy production since it is realized during summertime when PV modules most need to be cooled. Two main kind of solar drying methods exist: the direct solar drying in which the products to dry are exposed directly to the sun through a transparent cover, and the indirect solar drying in which the heat is driven through a solar collector to the drying room [14–16].

Some research projects aim to analyze the performance of direct solar drying applications in which greenhouses are equipped with BIPV/T systems but most of the time PV modules are mainly used to run auxiliary devices [17–23]. In 2010 and 2013, Assoa et al. introduced an innovative prototype of solar PV/T hybrid air collector suitable for integration into an indirect solar drying installation for fodder or industrial products [2] [24,25]. The building integration process consisted in replacing the conventional dark-

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colored roof element by the designed solar PV/T hybrid component [26]. The present work focusses on two main steps of the development of this solar BIPV/T collector, namely, the optimization of its basic configuration and a first feedback of its demonstration into a real application.

The basic prototype patented by Solarezo Company is composed of a conventional PV laminate (frameless PV module) inserted into an aluminum absorber instead of being stuck. This integration structure avoids the problem of gradual separation of PV modules and absorber noticed on various existing solar PV/T hybrid collectors.

During a preliminary comparative experimental parametric study under a solar simulator in natural ventilation, the thermal and electrical behavior and performance of four configurations of PV systems, including the basic prototype are analysed and compared. The impact of each constituting layer on the thermal and electrical behavior of the PV systems is assessed in order to define technical solutions optimizing the cooling of the PV laminate in the basic component. Finally, the hourly and daily thermal and electrical performance of the optimized solar PV/T component are evaluated and validated in real conditions after integration into an operational rooftop solar fodder drying installation in Savoy in order to highlight its suitability for this kind of application. The first experimental studies performed on a partially installed roof air gap are presented. The thermal and aerodynamic behavior of the air gap focusing on air velocities and air preheat, and the impact of metal absorber temperature on the electrical behavior of the PV laminate are investigated considering drying activity periods, natural ventilation periods and wind effect.

2. Experimental parametric study

The basic configuration of the solar PV/T hybrid air collector studied is composed of a PV laminate inserted into a thin aluminum sheet comprising at the backside an insulated air gap which could be ventilated. In order to optimize the thermal and electrical behavior of this prototype with a relevant choice of layers and material properties, various comparative experimental parametric studies were realized on four different configurations of solar PV component at the French National Institute of Solar Energy (INES) site at Le Bourget du Lac.

2.1. Description of the four configurations considered

SILIKEN polycrystalline frameless PV modules (PV laminates) of dimensions 98.5 cm × 163.5 cm were considered for these tests. Each module had a nominal electric power of 230 Wp. The first configuration is composed of a PV laminate mounted on a wooden frame (See Fig. 1.1 and Table 1). The second configuration comprises a PV laminate inserted in a thin metal ribbed panel and mounted on a wooden frame. The dimensions of the metal panel are 129 cm × 184 cm (See Fig. 1.2).

To obtain the third configuration, namely the basic component, a 1.7 cm thick insulated and naturally ventilated air gap was added at the backside of the second configuration (See Fig. 1.3).

In the fourth component, the insulation layer is mounted directly in contact with the backside of the metal panel of the second configuration, resulting in the third configuration without air gap (See Fig. 1.4).

2.2. Description of the experimental setup

The experimental setup was carried out in order to obtain thermal, electrical and meteorological data. The uncertainties on the sensors measurements are presented in Table 2. K-type thermal sensors and PT100 sensors stuck with aluminum scotch enable to measure the temperature at the backside of the PV laminate and at both sides of the metal panel. An Infrared camera permitted to evaluate the temperature of the front side of the PV laminate on 6 defined measurement points. The ambient temperature was measured using a PT100 sensor with perforated and sheltered immersion pocket.

The INES solar simulator consists of eight (8) incandescent lamps of 4000 W providing a solar radiation up to 1200 W/m^2 covering the largest portion of the spectrum and permitting to emit also in the near infrared region (760–1100 nm). The spectral energy distribution of the solar simulation at 1000 W/m^2 is presented in Fig. 2. Above 1000 nm, Fig. 2 shows that the solar simulator provides values lower than the sun (AM1.5). Nevertheless, this share of solar spectrum represents only nearly 0.93% of the total solar energy of the standard AM1.5 spectrum at 1000 W/m^2 (and 0.74% at 800 W/m^2). Thus, the solar simulator used is supposed to be sufficiently representative of solar radiation. Moreover, since standard silicone crystalline PV modules are sensitive in the spectral range between 300 nm and 1100 nm, the solar spectrum covered by the solar simulator is suitable for the analysis of the effect of the PV modules temperature on their electrical production. A pyranometer (Kipp & Zonen CMP21) and a reference PV cell permitted to measure the distribution of solar radiation. During the tests campaign, the radiation distribution obtained by modifying the location of the 8 lamps was not totally uniform on the prototypes surface. Nevertheless, for each PV configuration, the mean values of solar radiation received were very close. Two values of solar radiation were fixed during tests, 800 W/m^2 and 1000 W/m^2 nearly.

Moreover, this solar simulator permitted to represent a sky temperature close to 17 °C. For all case studies, due to technical issues, the artificial sky was switched off.

Measurement of electrical values (such as maximum power, maximum voltage, maximum current, open circuit voltage, short circuit current and IV curve was performed in steady state with an IV tracer.

24 measured data were recorded with a 10s time step using an Agilent HP 34970A datalogger and a program developed on Labview National Instrument software.

Locations of thermal sensors on the four configurations are shown in Figs. 3–5. The instrumentation of the third and the fourth configurations are similar.

The thermal and electrical tests results obtained were analysed in order to optimize the basic configuration of the solar PV/T hybrid air collector.

3. Analysis of results and optimization of system configuration

3.1. Analysis of thermal results

The thermal results obtained on each configuration (see Table 3) were compared considering the PV laminate, the both sides of the metal panel and the front side of the insulation layer at different measurement points (see Figs. 3–5). The impact of each integration configuration on the PV laminate thermal behavior was evaluated.

Since the solar radiation distribution was not uniform, a significant gradient of temperature is noticed along the PV laminate surfaces (See Table 3 (a-b)).

3.1.1. Impact of modification of the integration configuration on PV laminate temperature

Considering the tests conditions, the analysis of Table 3 (a) shows that the modification of the prototype configuration from 1 to 4 leads heat rise in PV laminate with the two values of solar