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Ultra-thin and lightweight photovoltaic/thermal collectors for building integration

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Abstract

Unglazed PVT collector concepts to cover electricity and heat demands of LowEx Buildings have been experimentally and numerically evaluated. Critical aspects affecting electrical and thermal efficiency are identified. A promising solution was found in the direct lamination of thin-film solar cells onto a channel-plate thermal collector resulting in a highly efficient, super-light (<4kg/m^2) and ultra-thin (<4mm) PVT collector. The lightweight design simplifies building integration and reduces the amount of materials and associated costs as well as environmental impacts.

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1. Introduction

Integrating solar thermal collectors and photovoltaic modules into the building envelope plays a key role for the contemporary goal of constructing net-zero and plus-energy buildings [1]. To maximize the energy harvest, photovoltaic/thermal hybrid (PVT) collectors have been proposed. In a PVT collector, the solar cells serve as the

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absorber to capture the incident solar radiation. Part of the radiation (typically 10-20%) is converted to electricity while the remainder is converted to useful heat in an adjacent thermal collector. A PVT collector hence not only is able to provide heat for building systems but simultaneously – by lowering the solar cell temperature – improves the electricity yield of the solar cells. Depending on application (e.g. air/water pre-heating, hot water for domestic/industrial use, etc.) and location-dependent conditions (e.g. climate and orientation), a variety of PVT collector concepts have been proposed in the past [2-4]. The various concepts have been classified in terms of design (e.g. glazing, concentration, degree of integration), type of heat removal (natural/forced fluid/gas flow, evaporative collectors, etc.) and type of solar cell (e.g. monocrystalline/polycrystalline silicon, thin-film solar cells, etc.) resulting in a variety of PVT class definitions such as liquid/air PVT, covered/uncovered PVT or concentrating PVT. More recently, the level of thermal insulation has been proposed as an alternative classification [5]. Generally, improved insulation (e.g. side and rear insulation and additional transparent cover) correlates with increased stagnation temperatures and increases challenges related to temperature resistance of materials, long-term degradation, thermal expansion, overheating protection, etc.

Most PVT collectors are based on a typical glazed flat plate collector design, i.e. a rectangular rear- and side-insulated box of about 2m^2 with a glass cover [6]. From a buildings' perspective, the collectors are rather heavy, thick and available only in standard dimensions which limits the number of areas suitable for installation and confines architectural integration quality [7]. Moreover, they are typically optimized for operating temperatures of >50°C and not necessarily for the seasonally changing energy needs of buildings. For example in the LowEx Building concept – a promising approach for zero emission buildings – moderate supply temperatures are targeted to exploit valuable anergy sources. An example for such a system is the combination of thermally activated building systems (TABS) for low temperature space heating, an efficient heat pump, a borehole thermal storage and solar collectors supplying heat at moderate temperatures around 20-35°C [8]. These low temperatures can efficiently be provided with unglazed collectors e.g. low-cost plastic or channel-plate thermal collectors typically found in pool heating applications [9]. Unglazed solar thermal collectors are simple in construction, cheap and characterized by high heat exchange rates with the ambience and consequently low stagnation temperatures. These properties make unglazed collectors ideal candidates for low-temperature PVT collectors e.g. in conjunction with thin-film solar cell laminates.

In the present study we focus on "unglazed" PVT collectors, i.e. built entirely without glass. Instead, thin-film solar cells encapsulated between thin plastic sheets are used. This results in a significant weight reduction compared to glazed PVT collectors where solar cells – typically crystalline silicon – are imbedded in between two glass layers and/or protected by a glass cover. In addition, to further reduce the weight and thickness, a thermal collector based on rollbond or extrusion techniques is envisaged. The resulting light and thin PVT collector is expected to facilitate installation and improve architectural integration quality.

2. Experimental analyses

To identify critical aspects affecting thermal and electrical performance as well as architectural integrability, two different PVT collector designs, named "channel-plate" and "tube-foil" are studied in detail. The designs are based on flexible 3mm thick CIGS solar modules glued onto (1) a 0.4m wide, 1.8m long and 3mm thick channel-plate collector made from multiport extrusion (MPE) aluminum microchannel profiles with a total of 108 parallel channels; and (2) a 0.6m wide, 2m long and 3mm thick tube-foil collector made from a polypropylene capillary mat with 54 parallel tubes and covered by a thin aluminum foil (Fig. 1). The header tubes, which supply the thermal collector channels/tubes with water, increase the overall thickness to ~20mm at the inlets and outlets of the thermal collector.

The prototypes were installed on a tilted, insulated wooden frame simulating roof or façade integration into a building (Fig. 2). Experimental tests were conducted outdoors, under sunny conditions in Zurich, Switzerland in winter time. A commercial water chiller system was used to supply the PVT collector with water at a constant temperature. Temperature increase across the collector was measured by Pt100 sensors installed at the collector water inlet and outlet, respectively. Water mass flow was manually adjusted and measured with a magnetic flow meter. Irradiance and wind speed were measured by pyranometer and anemometer, respectively. Additionally, surface temperature distributions were measured by IR thermography.