Evaluating the thermal and electrical performance of several uncovered PVT collectors with a field test

Citation for published version (APA):
de Keizer, C., de Jong, M. M., Mendes, T., Katiyar, M., Folkerts, W., Rindt, C. C. M., & Zondag, H. A. (2016). Evaluating the thermal and electrical performance of several uncovered PVT collectors with a field test. In *Proceedings of the 4th International Conference on Solar Heating and Cooling for Buildings and Industry (SHC 2015)* (pp. 20-26). (Energy Procedia; Vol. 91). Elsevier. https://doi.org/10.1016/j.egypro.2016.06.166

DOI:
10.1016/j.egypro.2016.06.166

Document status and date:
Published: 01/06/2016

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
• The final published version features the final layout of the paper including the volume, issue and page numbers.

Link to publication

General rights
Copyright and moral rights for the publications made accessible in the public portal are retained by the authors and/or other copyright owners and it is a condition of accessing publications that users recognise and abide by the legal requirements associated with these rights.

- Users may download and print one copy of any publication from the public portal for the purpose of private study or research.
- You may not further distribute the material or use it for any profit-making activity or commercial gain
- You may freely distribute the URL identifying the publication in the public portal.

If the publication is distributed under the terms of Article 25fa of the Dutch Copyright Act, indicated by the “Taverne” license above, please follow below link for the End User Agreement:

www.tue.nl/taverne

Take down policy
If you believe that this document breaches copyright please contact us at:

openaccess@tue.nl

providing details and we will investigate your claim.

Download date: 16. Nov. 2023

Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 91 (2016) 20 – 26

Energy Procedia

SHC 2015, International Conference on Solar Heating and Cooling for Buildings and Industry

Evaluating the thermal and electrical performance of several uncovered PVT collectors with a field test

Corry de Keizer[a]*, Minne de Jong[a], Tiago Mendes[a], Munish Katiyar[b], Wiep Folkerts[a], Camilo Rindt[b], Herbert Zondag[b,c]

[a]*Solar Energy Application Centre (SEAC), High Tech Campus 21, 5656AE Eindhoven, the Netherlands*
[b]*Technical University Eindhoven, Eindhoven, the Netherlands*
[c]*ECN, Petten, the Netherlands*

Abstract

Recently, there has been a lot of interest in PV thermal systems, which generate both heat and power. Within the WenSDak project, several companies and research institutes work together to (further) develop several uncovered PVT collectors. The outdoor performance of prototypes of these collectors is being evaluated in an outdoor test setup. The three types of uncovered PVT collectors in this paper can be distinguished as an un-insulated add-on PVT collector, a PVT collector with insulation at the back and a building integrated PVT collector.

In this paper, we will describe the experimental outdoor field test facility used for measuring the electrical and thermal performance. Furthermore, the results of the steady state analysis and typical collector curves are presented. In the next phase of the project, results of this field test will be used for dynamic simulations of the annual electrical and thermal energy yields for typical system designs and heat loads in the Netherlands.

Keywords: PVT systems; PVT performance

---

* Corresponding author. Tel.: +31 (0)88 5154953
E-mail address: dekeizer@seac.cc

doi:10.1016/j.egypro.2016.06.166

Nomenclature

A_G	Gross collector area (m^2)
b_1	heat loss coefficient (W/m^2K)
b_2	wind dependence of the heat loss coefficient (J/m^3K)
b_u	collector efficiency coefficient (wind dependence) (s/m)
c_p	Specific heat capacity (J/kgK)
E_L	Long-wave irradiance (W/m^2)
G_{POA}	Global irradiance in plane-of-array (W/m^2)
G''/G_{eff}	Net irradiance (W/m^2)
T_a	Ambient temperature (K)
T_m	Mean collector temperature $(T_{in}+T_{out})/2$ (K)
T_{in}	Input temperature (K)
T_{out}	Output temperature (K)
P_{PV}	Power produced by PV panels (W)
$\dot{Q}_{th}$	Heat flow (W)
u	Wind speed (m/s)
$\dot{V}$	Volume flow (l/s)
α	Solar absorptance (%)
ε	hemispherical emittance (%)
$\eta_{0,th}$	Peak collector efficiency (η_{th} at$T_m = T_a$)
η_{th}	Thermal collector efficiency, with reference to T_m
ρ	Density (kg/l)
σ	Stefan-Boltzmann constant (W/m^2K^4)

1. Introduction

The market for PV systems has been growing rapidly in the last years. However, PV systems only convert 10-20% of the incoming solar radiation in electricity [1]. Part of the remaining absorbed radiation can be converted to heat by a PVT collector. Furthermore, PV temperatures can potentially be reduced, thereby increasing the electrical yield.

Hybrid PV-thermal (PVT) systems have been around for several decades [2]. Up to now, there have not been many commercial successes. Currently, there is a renewed interest in the development and application of PVT systems in the Netherlands, the main focus is on uncovered or add-on PVT systems, which are used in combination with a (ground source) heat pump.

The renewed interest for PV-T collectors is, besides declining PV prices, related European regulations aiming towards (near) zero-energy buildings in the near future; there is a limited roof area available and several full-roof (BI)PV solutions have been developed. Since a large share of the energy demand in the built environment in continental Europe consists of heat, PVT systems may result in higher energy and exergy yields and a more aesthetic unified appearance of the roof.

In the Dutch ‘WenSDak’ project several companies and research institutes work together to (further) develop five different PVT roof concepts and to evaluate their performance. The main aim is to further develop these systems and to evaluate how much these systems can contribute to a sustainable built environment. The outdoor performance of these systems is measured by the Solar Energy Application Centre (SEAC) on the outdoor research facility SolarBEAT, while also indoor performance tests using a steady state solar simulator are carried out by the Technical University Eindhoven. The measured performance results will be used as input for annual system simulations for typical residential systems.

In this paper, we will focus on the three uncovered PVT systems in the project that are developed by three different companies. This paper will focus on results obtained with the outdoor field test facility that is used to measure the performance of prototypes of these uncovered PVT collectors.

2. Experimental field test set-up

2.1. SolarBEAT field test infrastructure

The SolarBEAT facility, see figure 1, is an outdoor Research & Development infrastructure for innovation on BIPV(T). The facility is a cooperation between SEAC and the Technical University Eindhoven and is located on a large flat south oriented roof with an almost clean horizon. The roof is equipped in order to investigate all key topics of BIPV(T) research in a realistic outdoor setting. The main use is to measure the performance of BIPV, PVT and solar thermal systems in dependence of several variables (a.o. weather related). Other topics of research involve:

- Building integration aspects of BIPV in roofs and facades (water tightness, ventilation, condensation);
- Partial shading effects;
- Architectural customization of BIPV (colour, size, shape, patterns);
- Operation and Maintenance aspects (pollution, repair & replace);

A solar measurement station from EKO is installed that measures: global horizontal irradiance, diffuse irradiance, direct normal irradiance, wind speed and direction and ambient temperature.

The facility was extended to be able to measure the performance of PVT and solar thermal systems in 2015. A thermal loop was designed to be able to set the input temperature and flow rate for several systems. Excess heat produced by the thermal systems is dumped in the university's aquifer. A combination of heaters, valves, chillers and control technology make sure the liquid is preconditioned to the specified temperature. The input temperature for the systems can be set between 7 and 80°C. A 25 % glycol solution is used in the PVT loop.

Fig. 1. Field test facility Solar BEAT. The middle dummy building in the front row contains the three types of uncovered PVT systems.

2.2. WenSDak field test set-up

The three uncovered PVT systems that are discussed in this paper are installed on the middle dummy building in the front row (Figure 1). Because of confidentiality reasons, we will not describe the PVT collectors in detail, however, they can be characterized as follows:

- System A: c-Si PV with uninsulated absorber clamped to the back of the module
  - Analysis of 2 PVT collectors, gross area of 3.3 m^2, flow rate 74 l/m^2h
- System B: CIGS panel with clamped absorber and insulation
  - Analysis of 4 PVT collectors, gross area of 4.4 m^2, flow rate 24 l/m^2h
- System C: building integrated c-Si PV with in-roof absorber and insulation
  - Analysis of 2 PVT collectors, gross area of 3.5 m^2, flow rate 18 l/m^2h

The collectors of each system are thermally connected in series. For every system, different flow rates are defined. However, the inlet temperature of the first collector of each system is the same. The flow rates were decided upon by the supplier of the system, to match the flows that are used in real systems. Each PVT panel is electrically connected to a DC/DC SolarEdge power optimizer. The power optimizers are in series connected to the SolarEdge AC/DC inverter. Therefore, the electrical and thermal performance of the PVT modules is measured at maximum power point.

The following measurement equipment is installed:

- *Meteorological measurements:* Global tilted irradiance (secondary standard pyranometer), pyrgeometer, in-plane in-plane wind speed and direction, ambient temperature.
- *PV performance measurements*: Measurements are done in MPP (maximum power point). DC voltage and DC current (via a shunt) are measured for every PVT collector separately.
- *Thermal performance measurements*: input and output temperature of each collector (Pt100, 1/3B) and flow rate (Electromagnetic sensor, one per series of collectors).
- *Datalogging*: All sensors are connected to a Yokogawa MW100 datalogger. Data is recorded every minute and uploaded every night to a database.

The field test is running since the middle of May 2015.

3. Field test results

3.1. Qualitative results

PVT collectors produce both heat and power. The yield depends on different factors, of which the most important are irradiance, ambient temperature, average fluid temperature and wind speed. Figure 2 shows the produced power (heat and electricity) in W/m^2 for every collector for different days. We chose three sunny days with different inlet temperatures for the solar thermal collector and two days with bad weather.

Figure 2a shows the in-plane irradiance in green; this is a very sunny day with a high average ambient temperature. The thermal heat is depicted by continuous lines, while in the dotted lines the electrical power is added. System A (black) does not have any insulation at the back and therefore acts as a heat exchanger at night and produces heat, when the ambient temperature is higher than the collector temperature. Please note, that the average collector temperature is very different for the different collectors. Figures 2c and 2e on the left also show days with sunny weather and higher collector inlet temperatures. The produced heat declines when the input temperature increases. Figure 2f shows the input temperature in black and the output temperatures of system A (black), B (red) and C (blue) and the ambient temperature for the same day as in figure 2f, 10 July. It is clear that system C operates at higher temperatures and therefore, produces more useful heat. System B and C perform better at higher temperatures due to the insulation at the back. Figures 2b and 2d show, that less heat and power is produced on days with bad weather.

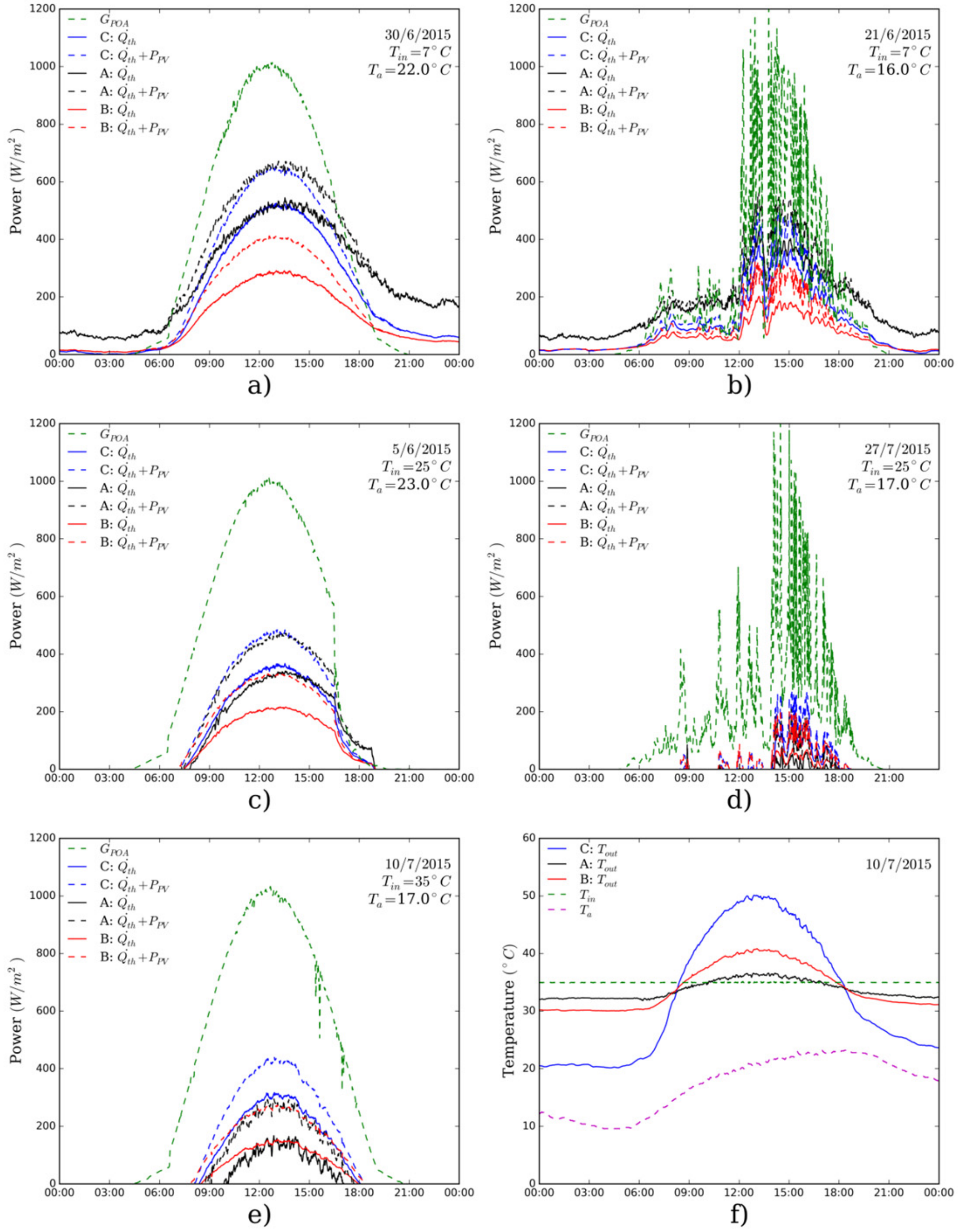

Fig. 2. Graphs 2a to 2e show the in-plane irradiance (green dashed lines), the heat flow (continuous lines) and the heat flow plus PV power (added with dashed lines) for five different days with different return/input temperatures (a&b) 7°C, (c&d) 25°C and (e&f) 35°C. Figure 2f shows the ambient temperature (purple), the input/return temperature and the flow/output temperature for each system. The colours refer to: Blue: system C, Black: system A, Red: system B. The average ambient temperature is written in each subfigure.

3.2. Steady state performance analysis

The thermal efficiency is calculated based on measured data from June to October 2015. We analysed the data by following the method for steady state analysis for unglazed collectors as described in the ISO 9806 norm [3], though there are some differences , like building integration and the flow rate. The thermal efficiency is calculated by Equation 1. The effective irradiance is calculated by equation 2, with the in-plane irradiance as an input. Furthermore, the pyrgeometer is used to calculate the long-wave irradiance (E_L). The absorption of the different PVT panels was measured by ECN with an integrating sphere and was between 0.90 and 0.94 for the different panels. The emission is approximately 0.9. The coefficients η_{th}, b_u, b_1 and b_2 are fitted by using a least squares method and equation 3.

$$\eta_{th} = \frac{\dot{Q}}{A_G \cdot G''} = \frac{\rho \cdot c_p \cdot \dot{V} \cdot (T_{out} - T_{in})}{A_G \cdot G''} \tag{1}$$

$$G'' = G_{POA} + \frac{\varepsilon}{\alpha}(E_L - \sigma T_a^4) \text{ with } \varepsilon/\alpha = 0.98 \tag{2}$$

$$\eta_{th} = \eta_{0,th}(1 - b_u u) - (b_1 + b_2 u)\frac{(T_m - T_a)}{G''} \tag{3}$$

The thermal collector efficiency curves for collector A, B and C are shown in Figure 3 for a wind speed of 0 and 3 m/s, with the PV in MPP. The PV efficiency (approximately 13.6 – 14.8 %) is additional. The collectors show very different performance features. Collector C performs the best of the three measured collectors. The other collectors can also perform well in system configurations that have a low demand temperature. E.g. systems that are used for the regeneration of a borehole, often operate below ambient temperatures. The coefficients and the average electrical efficiency are shown in Table 1.

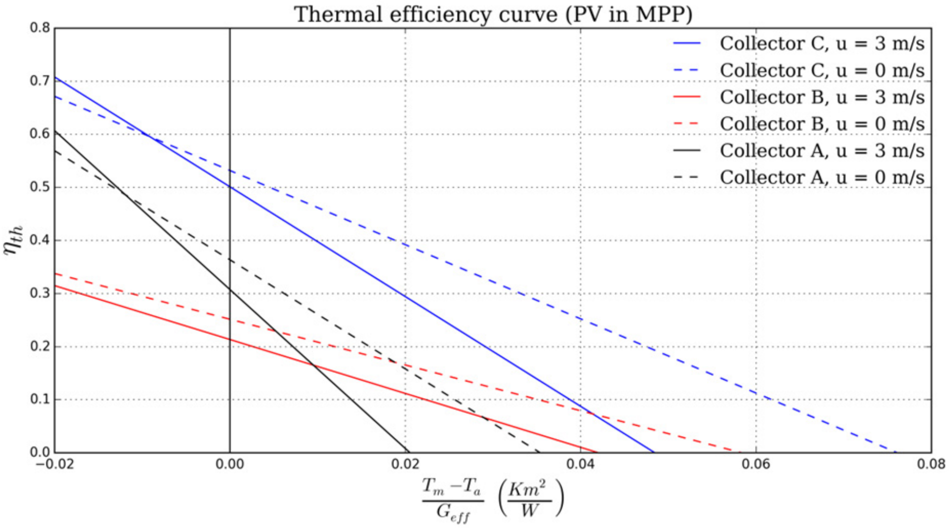

Fig. 3. Collector curve for PVT collector A, B and C with a wind speed of 0 or 3 m/s, based on measured data from 4June to 20 November 2015, with PV operational and measured in MPP.

Table 1. Thermal and electrical coefficients of system A, B and C.

Collector	η_{th}	b_u (s/m)	b_1 (W/m^{2}K)	b_2 (J/m^{3}K)	η_{el} (DC)
A	36 %	0.05	10	1.6	14.2 %
B	25 %	0.05	4.3	0.3	12.2 %
C	53 %	0.02	7.0	1.1	12.9 %

The electrical average efficiency of the three uncovered PVT systems is between 12.2 and 14.2 %. The difference is partially caused by a different peak power per square meter. The thermal efficiency parameters are for a large part caused by the thermal contact between PV and the thermal collector together with the insulation on the back of the system. A better thermal contact leads to a higher η_0, but also to higher heat loss (b_1) and wind dependency of the heat loss (b_2) parameters, also if the back of the panel is insulated or integrated in the roof.

4. Discussion, conclusion and further work

In this paper, we evaluate the performance of three different PVT collectors. There is quite some difference between the collectors. This can for a large part be explained by the collector architecture. Within the WenSDak project, options for improving the performance are analysed. Some measures, like applying a heat conducting paste, come at a certain cost that may not lead to the most cost-effective system solution.

Future work in the project is to determine the performance of a solar collector as part of a solar thermal system. To this end we will set up simulations in the TRNSYS environment. We will use TRNSYS to simulate the annual performance of a full-roof solar energy solution for a typical Dutch row house. Several options will be considered, regarding type of PVT collector, share of PVT and PV collectors and a comparison to a standard side-by-side system.

Acknowledgements

This work is supported by the ‘Netherlands Enterprise Agency’ (Rijksdienst voor Ondernemend Nederland, RVO) and the Dutch Topteam Energy via the project: WenSDak with grant number TEZG113008.

References

[1] Dupeyrat, P. *et al,* Study of the thermal and electrical performances of PVT solar hot water system, Energy and Buildings
[2] Zondag, H.A., Flat-plate PV-thermal collectors and systems: a review, Renewable and Sustainable Energy Reviews 12 (4) (2008) 891–959
[3] EN ISO 9806, Solar energy - Solar thermal collectors - Test methods (ISO 9806:2013)