Assessing suitable fields of application for PVT collectors with the characteristic temperature approach

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Abstract

PVT collectors co-generate heat and electricity and a single component. There are various PVT collector technologies available, with varying efficiencies and thus varying fields of application. But which PVT collector technologies are suitable for which fields of application?

The characteristic temperature approach is a novel method, which correlates the electrical and thermal yield with the mean operating temperatures T_{char}. Thus, the complexity of the system is reduced to a single temperature. T_{char} is therefore an apt indicator to assess suitable fields of applications for PVT collectors and select the most suitable collector technology. Moreover, the characteristic temperature approach allows a preliminary dimensioning of a PVT system and estimate yields of different technologies.

Keywords: PVT system; system simulations, Hybrid PV/Thermal collector; yield assessment

1. Introduction

PVT collectors can be classified according to their design (unglazed, glazed, concentrating), their heat transfer medium (water, air), and their PV cell technology (Zondag 2008). In Europe, unglazed PVT collectors have the highest market share, but their application is limited to low temperature systems due to high collector heat losses. Glazed PVT collectors offer an enhanced thermal efficiency owing to reduced thermal losses by a transparent front cover. Spectrally selective low-emissivity (low-e) coatings in glazed PVT collectors reduce infrared radiative heat losses, yet at the cost of a drop of electrical efficiency (Lämmle et al. 2016). Concentrating PVT collectors can be realized out from low to high concentration ratios, with the possibility of both stationary and tracked operation. Concentrating PVT collectors potentially achieve very low heat losses and high temperature levels (Chow 2010).

These considerations demonstrate that each collector technology has its specific temperature levels and accordingly suitable applications. From an energetic point of view, the annual electrical and thermal yields of PVT collectors in typical system installations are of major interest.

2. Characteristic temperature approach

2.1. Definition of the characteristic temperature T_{char}

As is generally known, the fluid temperatures have a strong influence on the instantaneous performance of PVT collectors. The electrical efficiency of silicon PV cells drops by approximately 0.4 % per Kelvin of increased cell temperature owing to the negative power temperature coefficient γ. Also the thermal efficiency drops due to higher heat losses at higher absorber temperatures.

To investigate the influence of the annual operating temperatures, a new system indicator was introduced in Lämmle et al. (2017), which characterizes a PVT system based on its mean operating temperatures. The characteristic operating temperature T_{char} is defined as the annual, irradiance-weighted, mean fluid temperature in the collector:

$$T_{char} = \frac{\int G\, T_m dt}{\int G\, dt} \qquad \text{(eq. 1)}$$

with the instantaneous irradiance in the collector plane G, and the mean fluid temperature T_m.

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2.2. Comparison of PVT collector technologies

Different flat plate, water-type PVT collector technologies are included in the assessment:

- a commercially available unglazed PVT collector without rear insulation,

- a glazed PVT collector with an anti-reflectance coated front cover

- a glazed PVT with a low-emissivity coating on the PVT absorber (Lämmle et al. 2016)

- a conventional PV module and a flat plate collector for comparison purposes

Concentrating PVT collector technologies are not included in this analysis. An initial comparison of energy yields revealed no energetic benefit of applying currently available concentrating PVT collector technologies in the central European climate.

Fig. 1 compares the electrical efficiency at standard test conditions and the thermal efficiency curves of the investigated technologies. The detailed efficiency parameters can be found in Lämmle et al. (2017).

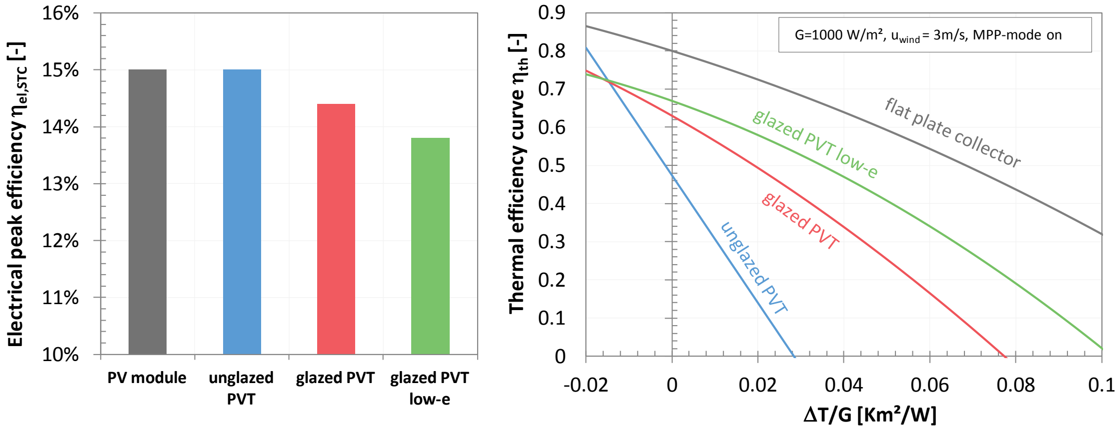

Fig. 1: Comparison of the standard efficiency of PVT collector technologies.

A conflict of interest between a high electrical vs. a high thermal efficiency can be observed, which results from the trade-off between a good optical performance vs. thermal insulation.

2.3. Analysis of correlation between yields and T_{char}

System simulations were carried out to analyze the correlation between collector yields and the characteristic temperature. For this purpose, several different types of PVT systems were analyzed, including systems for domestic hot water (DHW) heating in single and multi-family-homes, as well as combined DHW and space heating systems with and without heat pump. To achieve a wide variation of operating temperatures, the key system parameters of collector area and storage volume were varied. Simulations were carried out for the German location of Würzburg, and the detailed assumptions and results can be found in (Lämmle et al. 2017).

Analyzing the correlation between the characteristic temperature T_{char} and electrical and thermal yields, characteristic curves for each collector technology are found (Fig. 2). In the diagrams, each point represents results of a specific annual system simulation run and different types of PVT systems with varying system dimensions are included therein.

Due to the observed strong correlation between yields and T_{char}, the characteristic temperature describes the effect of the PVT system on yields independent from the system type. T_{char} is therefore a suitable indicator to characterize the thermal operating conditions of PVT systems. Depending on T_{char}, different PVT collector technologies can exploit their specific strengths. Therefore, the most suitable PVT collector technology has to be selected to match the given T_{char} of the PVT system.

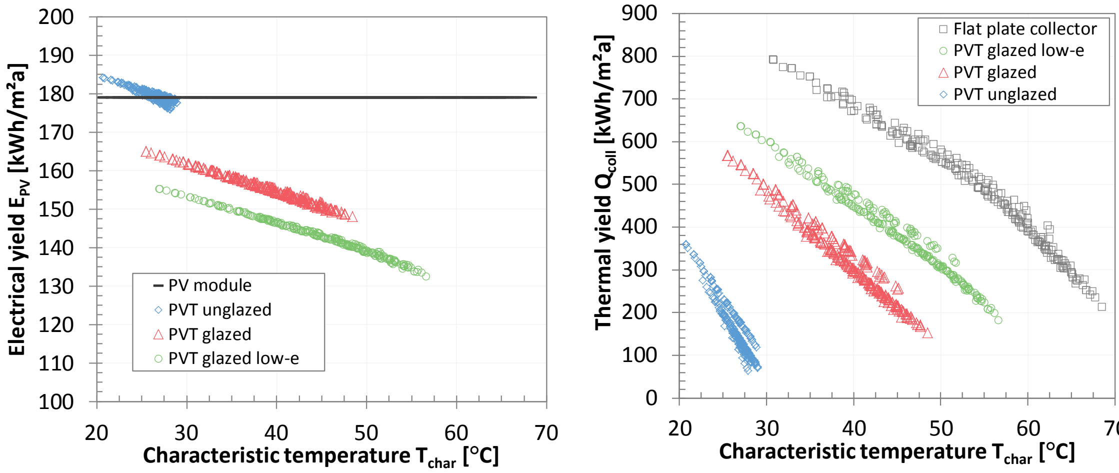

Fig. 2: Characteristic curves of the electrical and thermal collector yield of different PVT technologies as function of the characteristic temperature T_{char} (Lämmle et al. 2017).

2.4. Exemplary application of the characteristic temperature approach

To assess the applicability of PVT collectors in specific systems the following schematic procedure can be applied:

1. Identify T_{char} for the present application. This can be either done by a single annual simulation run or T_{char} can be estimated from operating temperatures of known systems
2. Read specific yields from Fig. 2
3. Size collector field to achieve the required electrical or thermal target output
4. Calculate the total electrical and thermal output of the PVT system

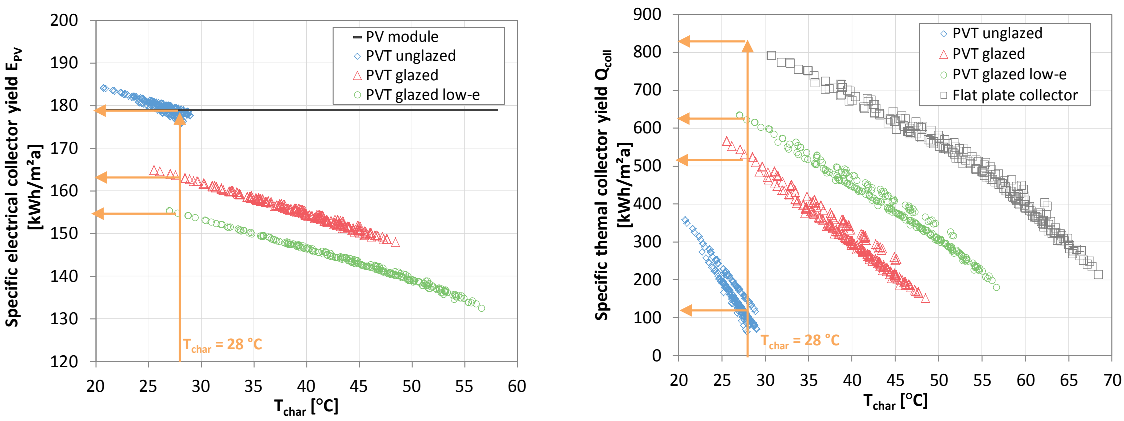

Fig. 3: Exemplary application of the characteristic temperature approach for the preliminary design of a PVT system with a characteristic temperature T_{char} = 28 °C at the location of Würzburg, Germany

Fig. shows the exemplary application of this procedure for a hot water system in an office building with a characteristic temperature of T_{char} = 28.0 °C. With the knowledge of T_{char}, the electric and thermal yields can be read from the graph. While the unglazed PVT collector reaches the highest electrical yields, the glazed PVT collector with low-e coating reaches the highest thermal yields.

Depending on the local energy demand, priority is either given to high electrical or high thermal yields. Typical energetic evaluation criteria include, amongst others, the specific yields per square meter of collector area, the roof area required to meet the required local solar energy demand, or the maximum energetic electricity and heat output a specific roof area can reach. If cost functions are supplied, also levelized costs of electricity and heat can be calculated. All these evaluation criteria can be preliminarily assessed by means of the characteristic temperature approach.

3. Assessing suitable fields of applications for PVT collectors

A central motivation for PVT collectors is the optimization of the overall combined electricity and heat output. As PVT collectors co-generate solar electricity and heat from the same area, potentially highest overall yields can be achieved. To quantify the combined electricity and heat output as a single value, primary energy yields are used. The primary energy yield per square meter of collector area is given by:

$$Q_{PE} = f_{PE,el}\,E_{PV} + f_{PE,heat}\,Q_{coll} \qquad \text{(eq. 2)}$$

with the primary energy factors for electricity $f_{PE,el}$ = 2.0 and for heat $f_{PE,heat}$ = 1.1 (DIN V 18599-1:2013-05), and the specific electrical and thermal yield E_{PV} and Q_{coll}.

Fig. 4 plots the primary energy yield Q_{PE} as function of the characteristic temperature T_{char} for the previously mentioned PVT systems. On account of the dependence of electrical and thermal yields from T_{char}, a strong correlation is also observed between T_{char} and primary energy yields, resulting in characteristic curves for each collector technology.

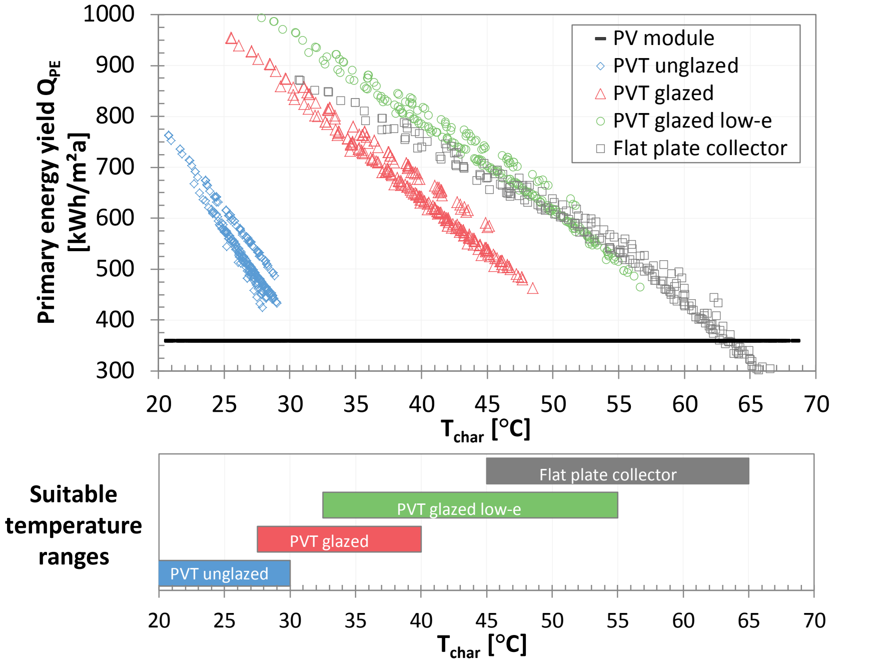

Fig. 4: Primary energy yields and derived suitable temperature ranges per PVT collector technology.

For an optimized utilization of available solar areas, the primary energy yield needs to be maximized.

Firstly, this can be achieved by reducing $T_{char.}$ As both the electrical and thermal efficiency benefit from low operating temperatures, a reduction of the fluid temperatures affects an increase of both electrical and thermal yields. For instance, low characteristic temperatures are achieved by smaller dimensions of the PVT array, larger storage volumes, and lower storage temperatures.

Secondly, the primary energy yields can be maximized by an adequate selection of a suitable collector technology, which matches the characteristic temperature. From Fig. 4, suitable temperature ranges can be derived for each collector technology. The following temperature ranges, and accordingly suitable fields of application, seem recommendable:

- **Unglazed PVT collectors** for very low operating temperatures near or below ambient of T_{char} < 30 °C.
- **Glazed PVT collectors** for low to medium operating temperatures of T_{char} < 40 °C.
- **Glazed PVT collectors with low-e** for medium operating temperatures of T_{char} < 55 °C.
- For higher temperatures, **concentrating PVT collectors** or a side-by-side installation of **flat plate collectors and PV modules** might achieve an optimized primary energy yield.

4. Conclusion

The operating temperatures in PVT systems are of pivotal importance, since both the electrical and thermal performance depend on it. The characteristic temperature approach puts these operating temperatures into the focus by introducing the new indicator T_{char}, which specifies the mean annual operating temperatures of the PVT system.

The characteristic temperature approach can be used to preliminarily design a PVT system and evaluate the technical and economic feasibility. Depending on the temperature level T_{char} of a specific PVT system, the most suitable collector technology can be selected. T_{char} is therefore a good indicator to assess the applicability of different PVT technologies in different PVT systems with varying temperature levels.

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