Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 48 (2014) 150 – 156

Energy Procedia

SHC 2013, International Conference on Solar Heating and Cooling for Buildings and Industry
September 23-25, 2013, Freiburg, Germany

Performance and economic analysis of hybrid PVT collectors in solar DHW system

Tomas Matuska*

University Centre for Energy Efficient Buildings, Czech Technical University in Prague, Nám. Sítná 3105, 272 01 Kladno, Czech Republic

Abstract

Performance of different concepts of solar hybrid PVT liquid collectors has been analyzed for domestic hot water application in a block of flats. A comparison with conventional installation of photovoltaic (PV) and photothermal (PT) solar collectors with the same total collector area 100 m^2 has been done for identical load conditions. Conventional solar system has been considered with different fraction of PV collector to PT collector area for comparison with the PVT system. Economic analysis based on the performance results, energy prices and conventional PV and PT collector prices has revealed several important facts. Unglazed PVT collector cannot be competitive with conventional PV-PT collectors in given solar DHW system. Competitive price of unglazed PVT collector is negative in most of variants. Competitive price of glazed PVT collector available at the market is about less than half of its real today market price. Competitive price range has been set in advance for solar PVT collectors being under development with novel siloxane lamination: 290-410 €/m^2 for nonselective type and 370-500 €/m^2 for selective type.

Keywords: PVT collector; DHW preparation; economic analysis

1. Introduction

Solar hybrid photovoltaic-thermal (PVT) liquid collectors represent a new technology on the market which combines the electricity and heat production from the same receiving surface in one device. The hybrid PVT

* Corresponding author. Tel.: +420-224-352-481; fax: +420-224-355-606.
E-mail address: tomas.matuska@uceeb.cz

doi:10.1016/j.egypro.2014.02.019

collectors can provide both heat and electricity, while the heat production is several times higher than the electricity. Through the solar electricity and heat cogeneration, the total energy output per unit collector area can be higher than the outputs of conventional photovoltaic (PV) module and photothermal (PT) collector placed and operated separately with the equal total area. Such feature could be effectively used in the building applications with high and constant use of thermal energy through the year but with the limited roof area, e.g. DHW in the multifamily buildings, block of flats, etc. or in the solar active houses with high solar fraction e.g. self-sufficient houses with a seasonal storage.

Because of mature and cheap PV manufacturing process the PVT collectors available on the market are based on standard PV laminates with EVA compound. However, EVA laminate restricts the maximum operation temperature of PVT absorber to 80 °C [1, 2]. Therefore hybrid PVT collectors are mainly the unglazed ones with a poor thermal performance for usual solar thermal applications in buildings. Despite this fact, the market price of solar hybrid PVT liquid collectors achieves extremely high level (450 to 950 €/m^2) in comparison with standard glazed solar thermal collectors and PV modules.

A novel glazed PVT collector concept based on PV laminate with siloxane gel is now under development at Czech Technical University in Prague. Siloxane gel instead of EVA lamination compound offers several important advantages like high temperature resistance, high transparency, compensation of thermal dilatation stresses and good heat transfer from PV to heat exchanger in PVT collector [3].

Presented analysis has to give an answer to basic questions concerning the performance and economic parameters of different hybrid PVT collector concepts considered. The maximum market price for the PVT liquid collector concepts has been determined for combined solar heat and power supply for block of flats in order to be competitive when compared with conventional separate PV and PT collectors installation at given boundary conditions (building heat and electricity load, energy prices, prices of conventional solar collectors).

2. Hybrid PVT liquid collectors

Solar hybrid PVT liquid collectors are the most widely studied configuration thanks to a large potential for the applications in buildings. While solar PVT air collectors have limited use of the heat in summer season, PVT liquid collectors show a good heat usability in the low temperature applications like primary circuits of heat pumps (0 to 10 °C), pool water heating (25 to 35 °C), domestic hot water and space heating (up to 60 °C).

Today, the market of PVT liquid collectors is limited to unglazed types due to problems with standard EVA lamination of PV modules which can decompose to acetic acid (delamination, coloration, degradation of PV cells by acid) at temperatures elevated above 80 °C. Thus the conventional PV laminates cannot withstand the stagnation temperatures in glazed collectors usually ranging from 120 to 180 °C. Moreover, the thermal resistance of back layers in conventional PV laminates is quite high to achieve a good heat transfer rate from PV cell to liquid.

Use of the unglazed PVT collectors with thermal efficiency significantly dependent on ambient conditions (wind, temperature) is restricted to applications with a very low operation temperature (water preheating, primary circuits of heat pumps). The field of solar DHW and space heating applications with the glazed PVT collectors is opened by introduction of new siloxane gel lamination, highly transparent and flexible material which is inert in a wide range of temperatures up to 250 °C [3]. Experimental work on first nonselective prototype of glazed PVT collector has confirmed the excellent performance features of siloxane laminate application for PVT absorber. Glazed PVT solar collector has been built with use of collector frame, 40 mm mineral wool insulation of back side and additional solar low-iron glazing as cover. The developed solar glazed PVT collector is nonselective one due to the nature of solar glass used for absorber laminate (no low-e coating on its surface applied). Thermal insulation has been used only for back side of the absorber. The edge side has been left without insulation due to complicated immersion of PVT absorber prototype into available collector frame box. Figure 1 shows the glazed PVT collector prototype and its thermal efficiency characteristic (with open electric circuit). Despite the excessive edge losses the characteristic show sufficiently high zero-loss efficiency. That means that efficiency factor of the absorber which expresses the ability to transfer heat from PV cell to fluid is high and optical properties of siloxane laminate as well. Because of uncoated solar glass has been used as a front layer of the PV laminate, the significant radiation loss reduces the thermal performance of the PVT collector at high temperatures. Application of laminate glass with a spectrally selective coating highly transparent in the visible region (to maintain good PV efficiency) but with a low infrared emissivity could reduce radiation heat loss and improve thermal properties of the glazed PVT collector. Such novel spectrally selective PVT collector is a subject of further development.

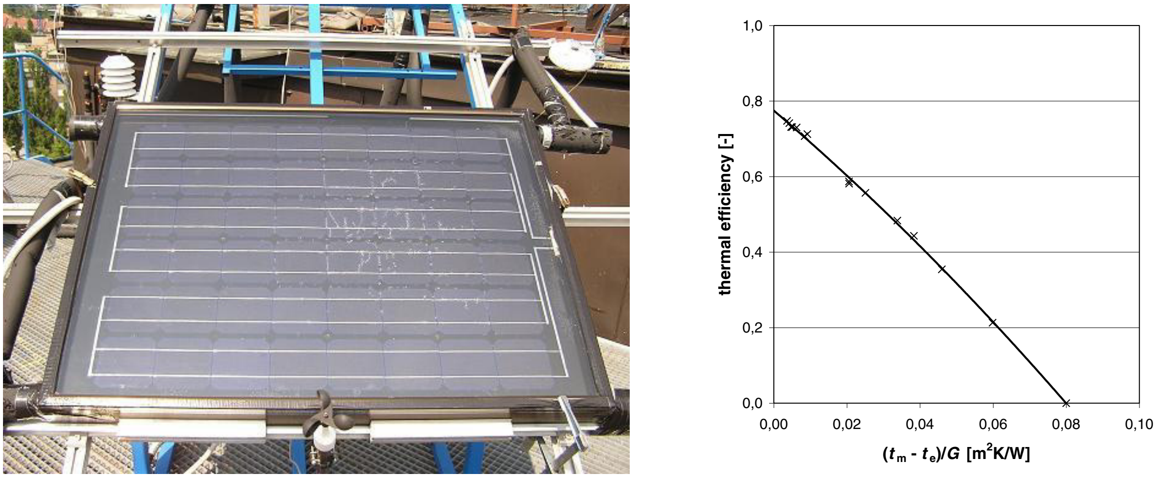

Fig. 1. (a) Glazed PVT collector with siloxane gel lamination; (b) thermal performance characteristic from experimental tests.

Several hybrid PVT collector concepts have been selected for the performance and economic analyses of combined heat and power supply in block of flats. The investigated variants of solar hybrid PVT collectors are:

unglazed PVT collector in the quality available on the market,
glazed PVT collector in the quality available on the market,
glazed nonselective PVT collector with the novel siloxane lamination (under development),
glazed selective PVT collector with the novel siloxane lamination (under development).

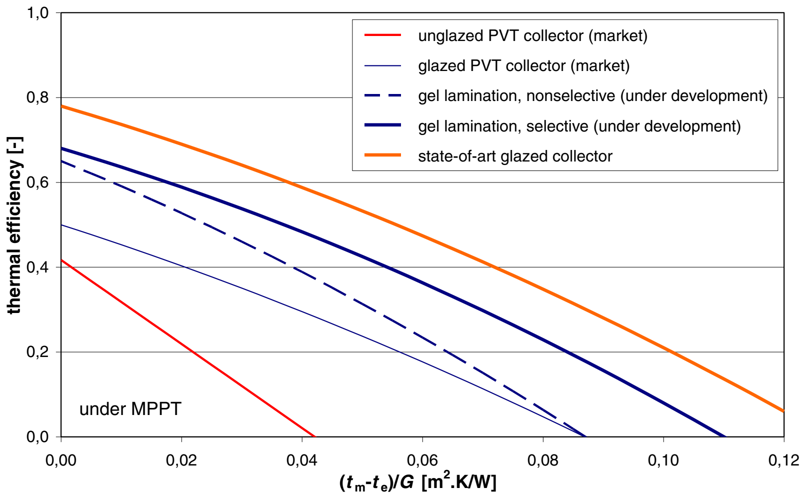

Fig. 2. Thermal efficiency characteristics of PVT collectors used for performance modeling in the analyses.

Thermal performance of the analyzed hybrid PVT collector concepts is represented by thermal efficiency characteristics in MPPT (maximum power point tracking) operation, see Figure 2. Characteristics have been derived from the detailed mathematical model PVT-NEZ [4, 5] originally developed for unglazed PVT collector performance modeling based on optical, thermophysical and electrical parameters of the absorber. The model has been extended for glazed PVT collectors and used to make a fair comparison of the investigated PVT collector concepts with different thermal quality but with the identical quality of PV cells. Polycrystalline PV cells with STC efficiency 15 % and temperature coefficient 0.45 %/K has been uniformly considered for all PVT concepts and also for conventional PV module performance modeling. Figure 2 shows also the thermal efficiency characteristic for state-of-art solar thermal collector with spectrally selective surface used for modeling of conventional glazed solar photothermal collector applied in the performance analysis.

3. Analysis

The performance and economic analyses are based on the solar system with the combined heat and electricity production for a residential building with 45 flats and 100 occupants. Solar heat is used for DHW preparation, solar electricity is used for the building appliances load. Heat demand for hot water use in the building is 96.3 MWh/a. Electricity demand for the building is 112.5 MWh/a. Climate for Wurzburg (Germany) has been considered for the analyses with annual solar irradiation sum 1229 kWh/m^2.a.

The solar system with hybrid PVT liquid collectors in different construction concepts is compared with conventional solar heat and power system consisting of state-of-art solar photothermal collectors and photovoltaic modules with identical polycrystalline cells as considered for hybrid PVT collectors. Available solar collector field area on the building roof 100 m^2 is the total collector area for all systems in the analyses. Conventional solar PV and PT system is considered in 5 variants differing in percentage ratio of PV and PT solar collector area applied. The variants are:

100PV (100 m^2 of PV collector, 0 m^2 of PT collector),
75PV-25PT (75 m^2 of PV collector, 25 m^2 of PT collector),
50PV-50PT (50 m^2 of PV collector, 50 m^2 of PT collector),
25PV-75PT (25 m^2 of PV collector, 75 m^2 of PT collector),
100PT (0 m^2 of PV collector, 100 m^2 of PT collector).

Solar heat and power systems have been modeled in TRNSYS environment. Simplified layout of the system is shown in Figure 3. Solar thermal part of the investigated system variants consists of several main components: solar collectors with slope 45° and orientation to south, insulated pipes of collector circuit, heat exchanger and insulated solar DHW storage tank. Parameters of main components are dependent on collector field area considered in the different variants and are listed in Table 1.

Table 1. Parameters of solar DHW system components considered in variants.

Variant	Collector area [m^2]	Solar tank volume [m^3]	Pipe dimension [mm]	Pipe insulation [mm]
100PV	-	-	-	-
75PV-25PT	25	1.25	22x1	19
50PV-50PT	50	2.50	22x1	19
25PV-75PT	75	3.75	28x1.5	25
100PT	100	5.00	28x1.5	25
PVT systems	100	5.00	28x1.5	25

Dimension of the collector circuit pipes is based on specific mass flow rate 15 kg/h.m^2 of collector area (low flow solar system). Pipes length of solar collector circuit in outdoor environment is 130 m, length of pipes inside the building is 30 m. Solar tank volume has been determined from specific value 50 l/m^2 of collector area. Solar plate heat exchanger has the efficiency 85 %.

PV power system is a conventional grid-on system with inverter. Total system losses are considered 10 %. Whole PV electricity production is assumed to be consumed for the building appliances load.

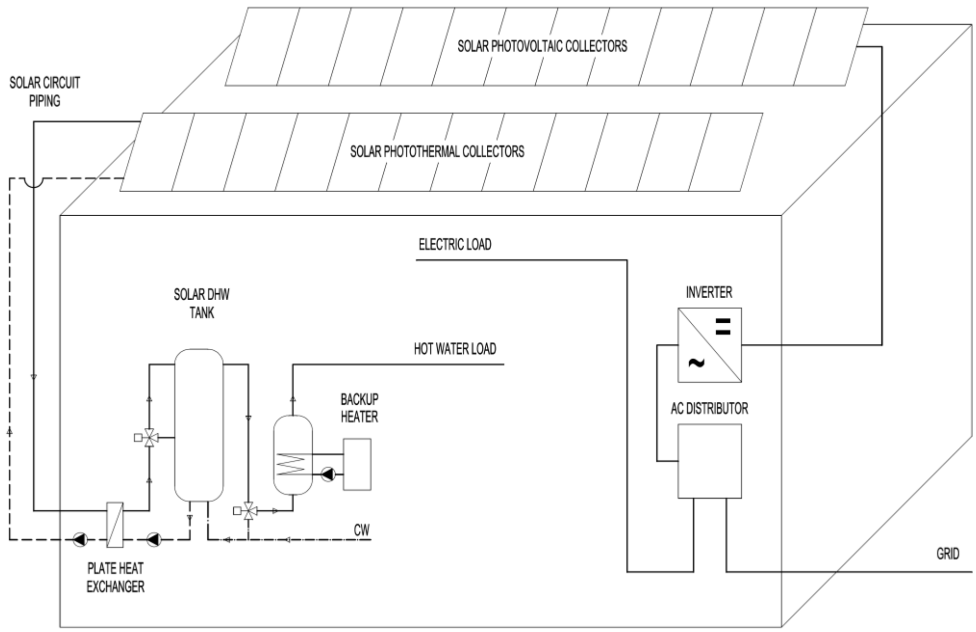

Fig. 3. Simplified scheme of the considered solar energy system for block of flats.

The target of the performance and economic analysis is to find the competitive specific price range for each given concept of solar hybrid PVT collector. Inputs for the economic calculations are the heat and electricity price and costs for solar PT and PV collectors and the system costs. Electricity price for households in Europe varies between 8 €-cents/kWh and 30 €-cents/kWh depending on the region [6]. Similarly, the range of heat price is quite wide between 4 €-cents/kWh and 16 €-cents/kWh dependent on the fuel and technology used for heat production and local legislation, e.g. specific taxes on fossil fuels [7]. Electricity price 16 €-cents/kWh and heat price 8 €-cents/kWh common in Germany have been used for the economic analysis.

Solar collector costs are considered 120 €/m^2 for photovoltaic polycrystalline modules and 350 €/m^2 for the state-of-art spectrally selective solar thermal collectors. Solar collectors are considered that represent 50 % of total system costs in both PV and PT system.

The competitive specific price for given hybrid PVT collectors has been derived from the balance of investment costs and operation costs for 20 years lifetime period for conventional PV/PT system and the hybrid PVT system. The specific collector price is found if total lifetime costs of hybrid PVT system and conventional PV/PT system are equal. Interest rate is considered equal to energy price increase, assuming both at 5% level.

4. Results

4.1. Performance figures

Table 2 shows the performance figures for conventional combined solar PV and PT system variants together with PVT system with different concepts of hybrid PVT collectors. Heat savings in DHW preparation and electricity savings for building supply has been evaluated in Wurzburg (Germany) climate conditions by numerical simulation in TRNSYS.

Table 2. Results performance analyses for investigated solar energy systems.

Variant	Description	Heat savings [kWh/a]	Electricity savings [kWh/a]
100PV	conventional PV only system, 100 % PV	-	13 514
75PV-25PT	conventional system, 75 % PV + 25 % PT	17 608	10 136
50PV-50PT	conventional system, 50 % PV + 50 % PT	31 133	6 757
25PV-75PT	conventional system, 25 % PV + 75 % PT	42 606	3 379
100PT	conventional PT only system, 100 % PT	51 733	-
100PVT-UNGL	unglazed PVT available on the market	12 751	13 361
100PVT-GL	glazed PVT available on the market	35 033	10 859
100PVT-GLNS	glazed PVT nonselective (siloxane gel lamination)	40 966	11 137
100PVT-GLSE	glazed PVT selective (siloxane gel lamination)	46 293	11 016

4.2. Economic figures

Competitive specific price for hybrid PVT collectors has been calculated from the results of performance analyses (energy savings) and the economic inputs presented above. Each solar hybrid PVT system has been economically compared with different conventional PV and PT system variants (ratio between PV and PT collector area). Results are shown in Figure 4.

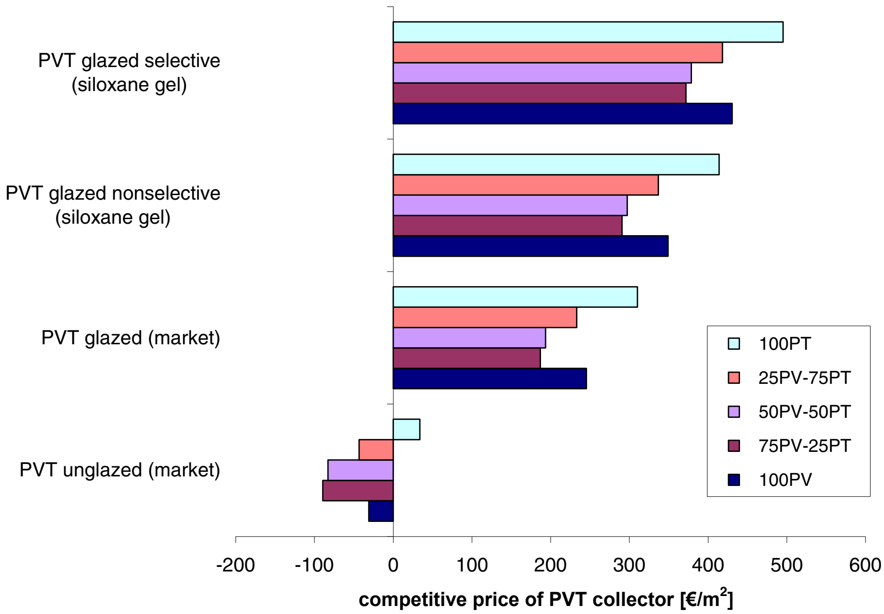

Fig. 4. Competitive specific price of different hybrid PVT collector concepts.

It is clear that solar system with the unglazed PVT collectors cannot compete to conventional combined PV/PT installation for DHW application anyhow because of a negative specific price result in most of cases. When compared with PT only installation the calculated competitive price is lower than price of PV module alone (without heat exchanger) which is not realistic to achieve. It could be stated that unglazed PVT collectors are not economically applicable for solar DHW systems and have a very limited application potential with their high market price today.

Competitive specific price calculated for glazed PVT collector available on the market is less than half of today lowest market price for such type of PVT collector. In addition to problematic PV laminate (EVA compound) the application of this PVT collector for DHW preparation means a clear economic loss when compared with conventional combined PV/PT solar energy systems.

The main purpose of the performance-economic analyses has been to determine the maximum specific price for hybrid PVT collectors being developed with the siloxane gel lamination. Results have shown that for given economic conditions the price could range from 290 €/m^2 to 410 €/m^2 for the nonselective type and from 370 €/m^2 to 500 €/m^2 for the selective type of glazed hybrid PVT collector. This information is an important input in the early stage of the novel glazed PVT collector development.

5. Conclusion

Use of PVT technology in standard solar energy applications requires a new glazed concept of PVT collector with spectrally selective absorber and novel type of PV laminate based on thermally resistant silicone compound. To determine the economic limits the maximum competitive price has been derived from the performance and economic analyses which have compared systems with PVT collectors to conventional systems combining solar PV and PT collectors. The analyses have shown that PVT collectors available today on the market are not competitive with conventional installations of solar energy systems for given block of flats with solar DHW preparation and electricity supply for the building. If the market price of novel spectrally selective glazed PVT collector would be maintained under 420 €/m^2, large application potential opens for standard solar thermal applications in buildings for domestic hot water and space heating systems.

Acknowledgements

The research leading to these results has received funding from the European Union's Seventh Framework Programme FP7/2007-2011 under grant agreement nº 282825 – Acronym MacSheep. The paper has been supported by European Union project OP VaVpI no. CZ.1.05/2.1.00/03.0091 – University Centre for Energy Efficient Buildings.

References

[1] Zondag HA, Van Helden WGJ. Stagnation temperature in PVT collectors. PV in Europe, Rome (Italy). 2002.

[2] Zondag, HA. Flat-plate PV–thermal collectors and systems: a review. Renewable and Sustainable Energy Reviews 12, p. 891–959. 2008.

[3] Poulek V, Strebkov DS, Persic IS, Libra M. Towards 50 years lifetime of PV panels laminated with silicone gel technology. Solar Energy 86, pp. 3103-3108. 2012

[4] Matuska T. Theoretical analysis of solar unglazed hybrid photovoltaic-thermal liquid collector. Proceedings of the Eurosun 2010, Graz (Austria). 2010.

[5] Matuska T, Buchta L. Experimental investigation of solar PV-T/liquid collector. Proceedings of the ISES Solar World Congress 2011 in Kassel (Germany). 2011.

[6] Eurostat Electricity prices for household consumers. Available at http://epp.eurostat.ec.europa.eu. 2013.

[7] Euroheat & Power District heating and cooling statistics – country by country survey. Available at http://www.euroheat.org. 2013.