

Performance analysis of glazed PVT collectors for multifamily building

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Abstract. The paper deals with performance analysis of potential application of glazed photovoltaic-thermal collector for domestic hot water preparation for multifamily building in European climatic conditions. Two different solutions are studied, glazed photovoltaic-thermal collectors integrated in the building envelope and glazed photovoltaic-thermal collectors fixed on the roof of the building. Moreover, the paper presents a comparison with conventional side by side installation of solar thermal collectors and photovoltaic panels to show the benefit of photovoltaic-thermal collectors. Simulation analysis has been done in TRNSYS with use of developed and validated mathematical model of glazed photovoltaic-thermal collector.

1 Introduction

Glazed photovoltaic-thermal (PVT) collector represents a technology combining the solar thermal collector and photovoltaic module in a single component. Simultaneous production of power and heat from limited area of building envelope (roof, façade) can increase the fraction of renewable energy sources on energy supply for buildings. In contrast to unglazed PVT collectors widely available on the market today, glazed PVT collectors allow sufficient temperature levels for domestic hot water preparation similar to conventional solar thermal systems, while electricity production is reduced due to additional glazing and higher operation temperatures [1]. The principle barrier for the glazed PVT collector application is the low resistance of common ethylene-vinyl acetate (EVA) encapsulation of PV cells to excessive thermal exposure. Maximum operation temperature of EVA laminate ranges around 85 °C [2] while the stagnation temperature for glazed solar collectors could reach 120 °C to 180 °C. At such temperature levels, EVA encapsulation decomposes to acetic acid, which causes the corrosion of PV cell contacts, delamination and degradation of layer transparency. There are several attempts to avoid this problem by increasing heat losses during stagnation period [3,4]. The concept of glazed PVT collector presented in the paper focuses on the temperature resistant encapsulant for PV cells based on polysiloxane gel [5]. Polysiloxane gel offers a large range of operation temperatures (from -60 to +250 °C), high transparency for solar radiation and allows the compensation of thermal dilatation stresses thanks to low modulus of elasticity [6].

A specific option for the glazed PVT collector application comes with the integration into façade

envelope as a prefabricated unit. PVT collector replaces a part of the façade construction and the concept of envelope considered as an energy loss in past turns to energy active envelope. On the other hand, façade integration of PVT collectors becomes also an architectural issue (surface color, texture of component, etc.). Façades are also sensitive to shading by other buildings or trees.

2 Glazed PVT collectors

Glazed PVT collector both in separate and façade integration alternative is based on sandwich unit with monocrystalline PV cells encapsulated in the polysiloxane gel layer between double glazing and copper sheet with pipe register, see in Fig. 1.



Fig. 1. Fabricated PVT sandwich unit

Prototypes of PVT collectors in both alternatives for

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testing have been fabricated. Double glazing with a gap between glass panes 24 mm filled with argon has been used. Absorber has been made from copper sheet (0.2 mm) soldered to pipe register made from risers of 8 mm in diameter. Distance between the copper risers was 50 mm. The sandwich unit can be integrated into standard collector frame made of aluminum profiles or integrated into component of curtain walling façade.

Separate collector unit size is 1.04 m x 1.64 m with gross area 1.71 m². To decrease the heat losses low emissivity coating has been applied at the inner glass of double glazing surface. In total 6 x 11 monocrystalline PV cells at size 125 x 125 mm have been used. The PV cell reference efficiency declared by manufacturer is 18.8 % under STC (standard test conditions, i.e. reference temperature 25 °C and solar irradiance 1000 W/m²). Gross area of the collector has been filled with PV cells for 60 % (packing factor related to gross area). Absorber has been insulated by 30 mm of mineral wool on the back, edge side was insulated by 10 mm of mineral wool.



Fig. 2. Separate PVT collector in standard frame (left) and facade integrated PVT collector (right) at test stand

Size of collector unit integrated into façade module is 1.04 m x 1.46 m with gross area 1.52 m². Monocrystalline cells used were identical with separate alternative, but only 60 cells have been used. Similar packing factor has been achieved. Integration of PVT sandwich unit into curtain walling façade element results in total insulation thickness behind the absorber 160 mm. No low emissivity coating has been applied for glazing in this prototype.

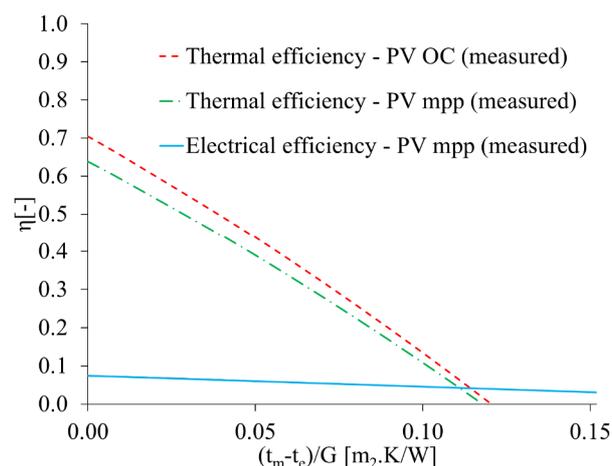


Fig. 3. Measured thermal and electrical characteristics for separate PVT collector (related to gross area)

Prototypes have been tested at Solar laboratory (UCEEB CTU) with use of indoor solar simulator. The thermal performance has been determined according to EN ISO 9806. Characteristic of thermal efficiency has been tested in two modes. In the hybrid mode, the PV part was connected to maximum power point (MPP) tracker with measured load. In open circuit mode, the PVT collector thermal performance was tested without electric load. Thermal and electric characteristics have been related to gross area. Fig. 3 shows the tested characteristics of thermal and electrical efficiency for separate PVT collector module with low-e coating. Fig. 4 shows the efficiency characteristics for façade integrated PVT collector without low-e coating.

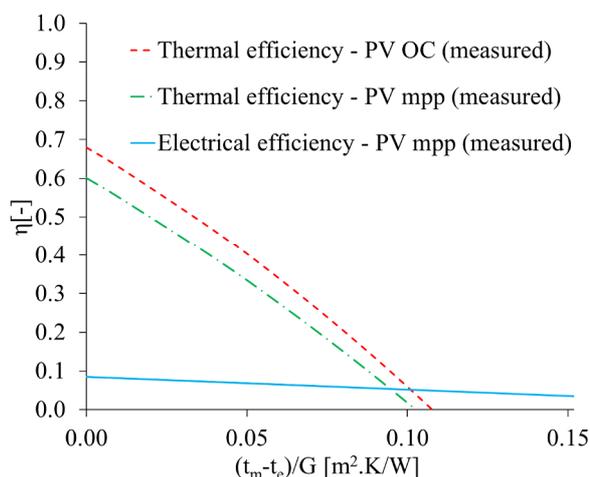


Fig. 4. Measured thermal and electrical characteristics for integrated PVT collector (related to gross area)

2 Analysis for multifamily building

Glazed PVT collectors are convenient for applications with uniform heat and electricity load during the year and also for building with limited space on the roof for installation of solar collectors. Therefore, solar domestic

hot water preparation for multifamily building is target application.

2.1 Modelling of PVT collector

Nowadays, several steady state models etc. [7, 8] and dynamic models of PVT collector etc. [9, 10, 11] are known in scientific literature. In TRNSYS simulation software there is type 50b [12] which does not consider a detailed construction of the collector and change of important collector parameters during the different climate and operational conditions (collector heat loss coefficient, fin efficiency factor, etc.). Due to this fact, mathematical model has been developed with use of Florschuetz approach [13]. The model uses detailed energy flows balance of PVT collector, expanded for photovoltaic conversion. Calculation procedure of the model solves the external and internal energy balance of the PVT absorber. Both balances proceed in the iteration loop, more in [14]. The presented mathematical model does not consider diffuse incidence angle modifier. Undisputed advantage of implemented model is the possibility to define a number of design and physical parameters of collector configuration: geometry, electrical and thermo-physical properties of PV cells, thermo-physical properties of materials used in PVT collector, etc. Thanks to validation of the mathematical model based on the testing, low emissivity coating has been considered for both investigated alternatives: separate PVT collector on the roof and PVT collector integrated into façade. Inputs of the model are conventional: weather and operation conditions. Main outputs of the model are usable thermal and electric power, absorber temperature and outlet liquid temperature.

2.2 SDHW system in multifamily building

The studied multifamily building has 45 flats occupied with 100 occupants. Gross floor size of the building is 25 m x 19 m with height 25.2 m (9 floors). The total floor area of the building is 475 m², south façade area is 630 m². 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 116 MWh/a. Electricity demand for the building is 96 MWh/a.

Analyses have been performed for three different climate zones in Europe with different annual solar irradiation: Madrid (1864 kWh/m².a), Prague (1115 kWh/m².a) and Helsinki (1153 kWh/m².a). Three different solar systems with glazed solar PVT liquid collectors were compared with conventional side by side installation of solar thermal collectors and PV panels. In every studied case 100 % of PVT area was compared with side by side installation of same area (50 % of solar thermal collectors and 50 % of PV panels). Side by side installation combined the state-of-art solar thermal collectors and photovoltaic modules with identical monocrystalline PV cells as used in hybrid PVT collectors. Solar heat and power systems have been

modelled in TRNSYS environment with use of the developed model for glazed PVT collector [14].

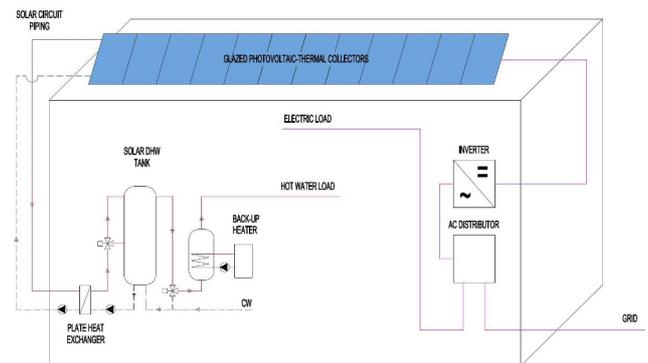


Fig. 5. Simplified scheme of the solar energy system

Simplified scheme of the solar energy system is shown in Fig. 5. Solar thermal part of the investigated system variants consists of several main components specified in Tab. 1. Solar collectors were considered with slope 45° for roof installation and 90° for integration into façade. For side-by-side alternative an inclination 30° has been used for PV panels. Moreover, there were considered following parameters: orientation to south, insulated pipes of collector loop, heat exchanger and insulated solar DHW storage tank. Parameters of main components for the solar thermal systems alternatives are dependent on collector field area considered in the different variants. Dimension of the collector loop pipes is based on specific mass flow rate 15 kg/h.m² of collector area (low flow solar system). Pipes length of solar collector loop in outdoor environment is 80 m, length of pipes inside the building is 80 m. For façade integrated alternative collector loop pipes were considered fully installed in indoor environment. Solar tank volume has been determined from specific value 50 l/m² of collector area (see Tab. 1). Efficiency of solar plate heat exchanger is 80 %. PV power system is a conventional grid-on system with DC/AC inverter. Total system losses are considered 10 %. Whole PV electricity production has been assumed to be consumed for the building appliances load.

Table 1. Solar energy system parameters

Variant	Solar thermal area [m ²]	Solar tank volume [m ³]	Collector loop dimension [mm]	Collector loop insulation [mm]
R - PVT	165	8.3	35 x 1.5	25
R-50PV50PT	82.5	4.1	28 x 1.5	25
F9 - PVT	140	7	35 x 1.5	25
F9-50PV50PT	70	3.5	28 x 1.5	25
F5 - PVT	78	3.9	28 x 1.5	25
F5-50PV50PT	39	1.9	22 x 1.5	19

2.3 Roof installation of the solar energy system

Available solar collector field area on the building roof is 165 m² (35 % of total roof area). 48 collectors with gross area 3.43 m² are considered (see in Fig. 6.). Side

by side installation consists of PV panels (82.5 m²) and solar thermal collectors (82.5 m²) It means, that side by side installation has a same installation area as a PVT alternative. Alternative with PVT collectors uses the whole available roof area 165 m², see Fig. 6.

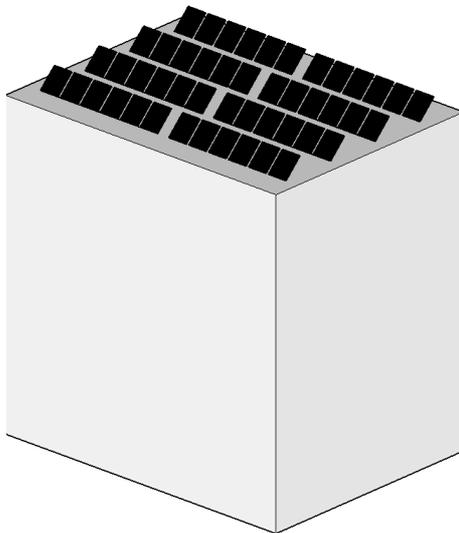


Fig. 6. Roof installation (R)

2.4 Façade installation of the solar energy system

Roof of the building can be very often occupied by technology systems and therefore there is very limited space for solar collector installation in reality. Due to this fact, façade integration of solar energy system is studied as an alternative as well. First sub-alternative of façade installation considers the area 140 m² which is 22 % of total area of the south wall (fully using the opaque part of the facade for 9 floors, see Fig. 7). While side by side installation considers 70 m² of PV panels and 70 m² of solar thermal collectors, PVT collectors

occupy the whole area of 140 m². In fig 7. windows are represented by blue colour and solar installation by black colour. Because of potential green vegetation in the front of south façade in future, only upper 5 floors were simulated as well in second sub-alternative (see Fig. 7). Area of energy-active façade in this case is only 78 m². Therefore only 39 m² of PV panels and 39 m² of solar thermal collectors were considered in side by side alternative, while considering 78 m² of PVT collectors.

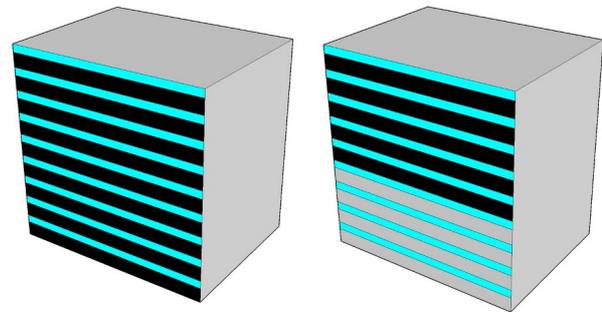


Fig. 7. Façade glazed PVT collectors installed in nine floors (F9) and in five floors (F5)

Results of simulation study for three different climatic location are shown in Fig. 9 and in Tab. 1. It is evident that facade installation of PVT collectors achieves about 25 % lower energy gains compared to roof installation (both heat and electricity). When performance of PVT collectors is compared with side by side installation of PV modules and solar thermal collectors, PVT collectors achieve significantly higher energy gains, especially in case of the heat. The increase of thermal and electrical production thanks to PVT design is shown in Tab. 2.

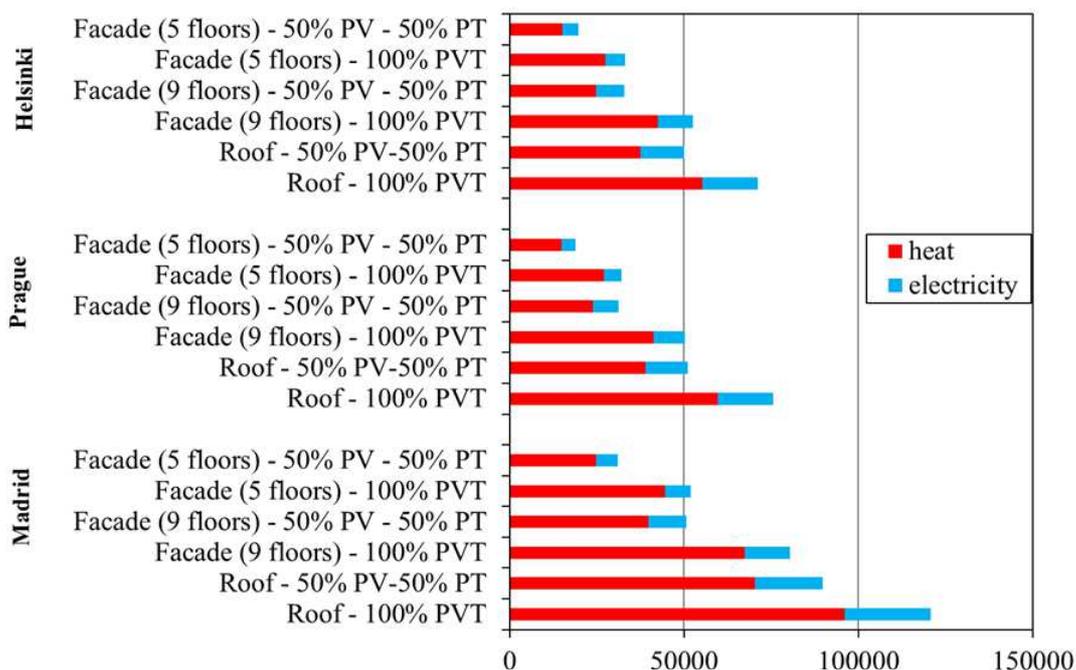


Fig. 8. Results of simulation study

Table 2. Increase of energy production of PVT alternative compared to side-by-side installation

Location	Variant	Heat	Electricity
Madrid	Roof	37 %	27 %
	Façade 9 floors	70 %	19 %
	Façade 5 floors	79 %	22 %
Prague	Roof	53 %	32 %
	Façade 9 floors	72 %	21 %
	Façade 5 floors	81 %	23 %
Helsinki	Roof	47 %	28 %
	Façade 9 floors	72 %	23 %
	Façade 5 floors	81 %	25 %

3 Conclusion and outlook

Simulation analysis was done with a detailed model of glazed solar PVT collector experimentally validated with testing of prototypes. Two alternatives (integrated and separated) of the new concept of glazed solar PVT collector with polysiloxane gel encapsulation of PV cells have been presented.

The results from simulation study of the given multifamily building have shown a large potential for achieving the higher solar fraction compared to separate installation of conventional technologies. Increase of electricity production due to PVT solution vary from 19 % to 32 %. Increase of thermal production differs between façade and roof alternative. Increase of thermal production for roof alternative ranges from 37 % to 53 %. The increase is much higher in the façade alternative and ranges from 71 % to 81 %.

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