Glazed PVT collector integrated into façade module

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Abstract

The paper presents the results of the outdoor measurement of glazed photovoltaic-thermal (PVT) collectors integrated into façade modules. Outdoor measurement of two different façade modules has been carried out under real climatic conditions. The paper analyses thermal and electrical performance of glazed PVT collector with and without highly transparent spectrally selective coating. Test cell for long-term tests of energy-active façade has been built and used for the test of integrated PVT collectors.

Keywords: solar energy, glazed PVT collector, building integration, energy-active façade, solar heat

1. Introduction

Solar energy utilization on the south oriented façades is rational way and step further to solar energy active buildings. Area on the roof of residential buildings is usually limited by other HVAC facilities. Therefore significant potential in innovative solar devices for building envelopes exist (dual collectors, daylighting, heat and electricity production). Combination of solar thermal and photovoltaic (PV) technology is very promising. Research and development in the PVT collector area have increased last years. More investigated PVT technology is based on systems using liquid as heat transfer fluid instead of air. Thermal energy from air PVT collectors is difficult to utilize during summer time. Different design construction of liquid PVT collectors exist which is possible divide into unglazed, glazed, and concentrating collectors. Unglazed PVT collectors are now available on the market but the usage is only for applications where low temperatures are needed (preheat for heat pump primary circuit or preheat of cold water). Unglazed PVT collectors can achieve slightly higher electrical efficiency for low operational temperatures due to cooling of PV part. On the other hand glazed PVT collectors are represented on the market only by two manufactures. Glazed PVT collectors have stagnation temperature from 150 °C to 200 °C but maximum operation temperature of ethylene-vinyl-acetate (EVA) lamination is 85 °C (Zondag et al., 2002). Lack of available manufactures of glazed PVT collectors on the market is caused by the restriction with the degradation of EVA lamination during high temperatures which has not been solved yet. The research in glazed PVT area is now separated into overheating protection way (Harrison & Cruickshank, 2012; Lammle , 2016) and usage of thermal resistance material instead of EVA laminate (Matuska, 2015). Main advantage of glazed PVT collectors is the big potential in the most common application in Europe which is preparation of domestic hot water. Glazed PVT collectors have comparable thermal efficiency with conventional thermal collectors. It is necessary to apply low emissivity (low-e) coating on the glazing at the top of PVT absorber so that heat output could be similar to conventional solar thermal collector. Some studies exist which investigated potential of application of spectral selective low-e coating in solar thermal area (Giovannetti, 2014).

Glazed PVT collector presented in this paper has PV cells encapsulated by means of polysiloxane gel instead of EVA lamination. This paper presents developed and tested integrated PVT collector into building envelope. Façade modules have been tested under steady state and real dynamic climatic conditions. Two different PVT collector designs were compared to confirm better thermal performance thanks to spectral selective coating on the PVT absorber. One integrated PVT collector was with standard solar glass (transmittance 0.91, emissivity 0.85) on the top of the PVT absorber and second collector has spectrally selective low-e coating on the top of the absorber. Due to the low-e coating on the absorber heat radiative losses are decreased. Today low-e coatings have high transparency for visible range but unfortunately significantly reduced transmittance for near infrared region of solar radiation spectrum where is not negligible amount of energy. The presented glazed selective PVT collector has been made with low-e coating with optimized of the emissivity (0.3) and transmittance (0.85). Thermal performance should be significantly higher due to low-e coating and at the same time electrical power should be

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slightly lower according to reduced transmittance. One of the purpose of this paper is to present measurement results of the comparison of two different PVT collector design related to thermal and electrical performance.

2. Integrated glazed liquid PVT collector

Developed glazed PVT collector is based on sandwich structure (see Fig. 1). PV cells are encapsulated between a double glazing and the copper heat exchanger by means of polysiloxane gel. Polysiloxane gel as PV encapsulant 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 (Poulek, 2012). The absorber is copper sheet with soldered pipe register (common technology). Sheet and tube absorber consist of 18 riser pipes with distance 50 mm. Double-glazing consists of low-iron solar glazing 6 mm thick with a gap 16 mm filled with argon. Two prototypes of façade modules were constructed. One prototype has commercial available glazing from Euroglas attached to absorber with low emissivity coating (30 %) with transparency for solar radiation 85 %. Second prototype has low-iron solar glazing attached on the absorber with emissivity 85 % and transparency for solar radiation 91 %. The front glazing is solar glass with transparency 94 % for both prototypes. The PV part of the collector has 60 cells at size 125 x 125 mm in three parallel strings. Nominal efficiency of PV cell is 16.3 % under standard test conditions. Area of PV part is 60 % of gross area. Gross area of PVT collector part in the façade element is 1.56 m^2, aperture area is 1.4 m^2. On the back side is 14 cm insulation.

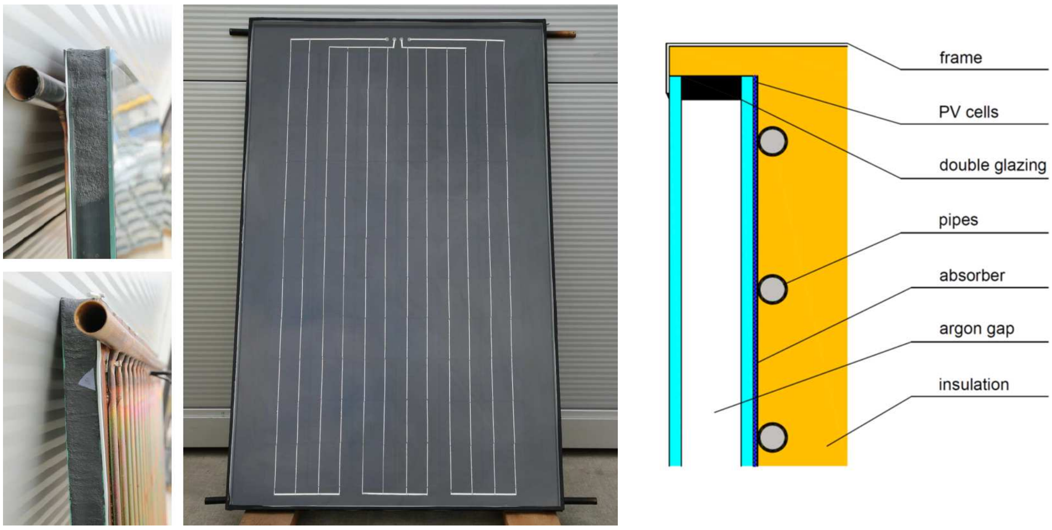

Fig. 1: Glazed PVT collector component prepared for building envelope integration

Integrated PVT collector for the administration building was constructed (see Fig. 2). The façade module consist of glazed PVT collector, window with triple glazing, and glass rasters. Thanks to glass rasters is possible to decrase heat gains during summer and to increase during winter. Glass rasters reflects beam radiation during summer months a during winter months rasters allow radiation entry to the indoor environment (Jirka, 2017). Glass rasters are not subject of this paper further. The whole façade module size is 1,501 x 2,175 m. Glass raster size is 1,463 x 1 m. The weight of the module is 120 kg.

Fig. 2: Tested facade module with PVT collector

Integrated PVT collector only without selective coating was tested under steady state conditions according to EN ISO 9806. The collector was tested at Solar laboratory (UCEEB CTU) with use of indoor solar simulator. Required accuracy of measurement according to EN ISO 9806 was respected. Characteristic of thermal efficiency has been tested in two modes (see Fig. 3). On the axis y there is thermal and electrical efficiency which is determined as a ratio of the heat and electrical power divided by incident irradiance on the gross area. On the axis x there is reduced temperature difference which includes influence of ambient temperature T_a [°C], mean fluid temperature T_m [°C], and incident irradiance G [W/m^2]. In the hybrid mode, the PV part was connected to 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 of the PVT collector which is 1.56 m^2.

Open circuit test conditions were following: the global irradiance was kept at the average value 924 W.m^{-2} during the test. The collector tilt angle was set up to 45°. Ambient temperature was fixed at 16.4 °C. Collector zero loss thermal efficiency was evaluated 68 % (related to gross area). Stagnation temperature was determined 161 °C.

Hybrid mode conditions were following: the global irradiance was kept at the average value 988 W.m^{-2} during the test. The collector tilt angle was set up to 45°. Ambient temperature was fixed at 18.2 °C. Collector zero loss thermal efficiency was evaluated 60 % and the electrical efficiency 8.4 % (both related to gross area). Stagnation temperature was determined 156 °C.

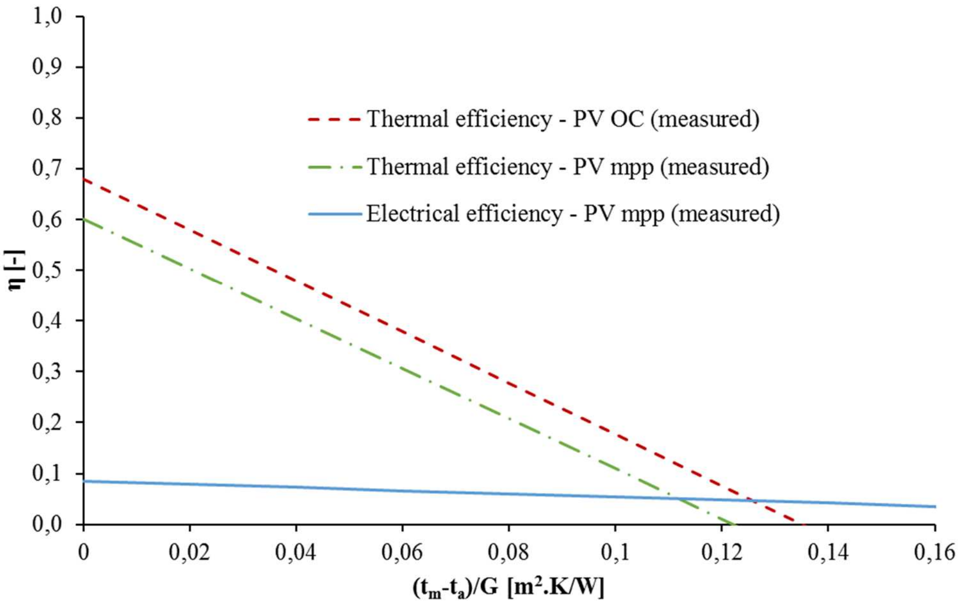

Fig. 3: Measured thermal and electrical characteristics for integrated PVT collector (related to gross area)

3. Test cell for energy-active facades

Test cell for long-term testing of energy-active façade modules was built (see in Fig. 4) on the experimental area of the UCEEB CTU in Bustehrad. Two different facade modules were installed on the south wall (azimuth -15°) of the test cell. Test cell is divided into two parts. First part is for necessary HVAC facilities, second part is testing room with controlled indoor temperature. Thermal energy from PVT collectors is stored in 160 l solar tank. Electrical energy from PVT collectors is stored in battery and subsequently discharged.

Fig. 4: Experimental test cell for energy-active façades

4.2. Electrical part

Measurement of the electrical performance was done separately for both PVT collectors according to the scheme in Fig. 5. It was not possible to connect PVT collectors directly with inverter and then waste the electrical energy in the grid. Therefore the connection with charging by collectors and discharging battery by resistance was chosen. Control of the discharging battery is based on maintaining voltage in range from 11,8 V to 13,8 V (BATT – 12 V x 140 Ah = 1680 Wh) to avoid full charged battery and reduction of useful PV electricity generation. Then it is certainty that the PVT collectors are working in the MPP mode. Voltage and current on the collector is measured separately according to scheme.

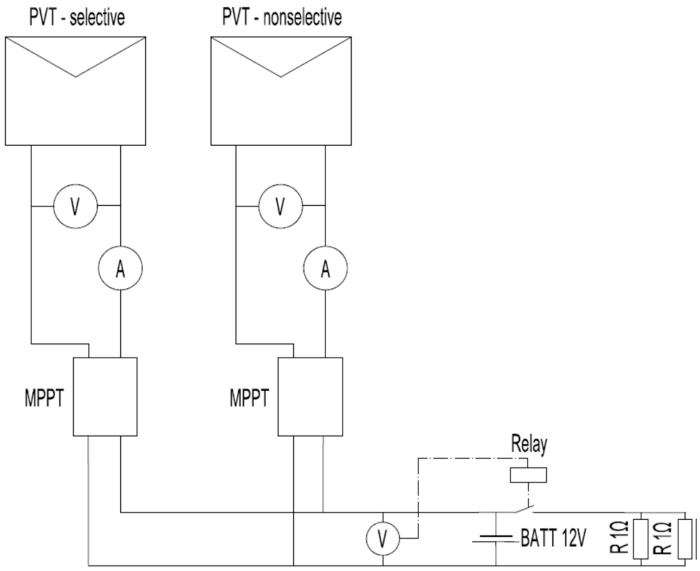

Fig. 5: Electrical scheme

4.2. Thermal part

Solar PVT system is dedicated to the preparation of domestic hot water in 160 l tank. Conventional controller has been installed with the monitoring of the temperature difference and switching on and off the circulation pump of the system. Mass flow in the collector loop was set to 90 $l.h^{-1}$. Hot water load has been emulated by pump between solar tank and cold water tank. Every night was the solar tank discharged till the temperature in the top of the tank was 20 °C. In near future it will be desirable to create simple hot water load profile consisted from at least 4 loads. Cooling unit above the roof is for cooling of 200 l cold water tank. This cooled water is used for cooling in the testing room and for controlled cooling of the solar tank. Second part of the test cell is isolated testing room where ambient temperature is controlled by the electric heater and air cooler. Both cooling power and heating power are measured. For measurement 4 x pyranometer (type CMP 3) has been used for solar irradiance. For measurement of electric consumption 2 x wattmeter has been used. For measurement of thermal output in testing loops 3 x magnetic flowmeters and temperature sensors Pt100 has been used. 2 x voltmeter and 2 x ammeter has been used for measurement of PV power.

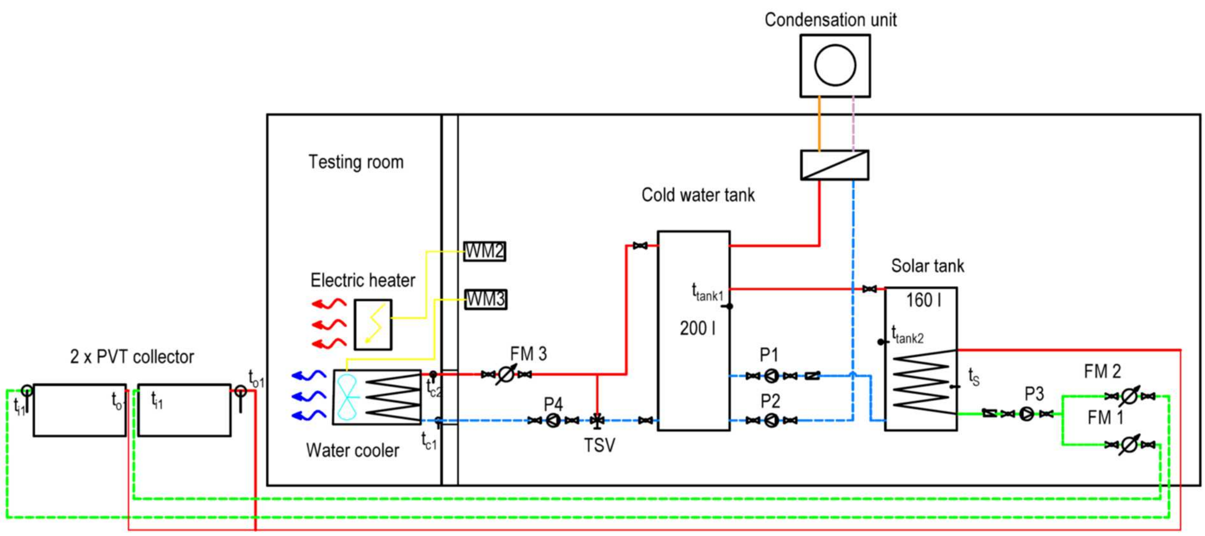

Fig. 6: Scheme of the thermal part of the system

4. Measurement results

Measurement started at the beginning of the year 2018. Many changes of the measurement have been done during the year. Therefore for the comparison only some periods were chosen. In Tab.1 there is a comparison of thermal and electrical gain for both type of PVT collectors. Eleven days in February were chosen for OC mode because it was a period without any electric load. July was chosen for hybrid mode because there were not any changes in electrical measurement.

Tab. 1: Comparison of the thermal and electrical gain for are 1.56 m^2

Time range	Incident solar irradiation	Measured heat gain (selective)	Measured electrical gain (selective)	Measured heat gain (nonselective)	Measured electrical gain (nonselective)
	kWh	kWh	kWh	kWh	kWh
February 2018 –from 10.2. to 21.2. (OC mode)	43,4	23,0	-	20,2	-
July 2018 (MPP mode)	163,4	90,4	9,8	81,9	11,8
Sunny day 3.7.2018 (MPP mode)	6,42	3,26	0,37	2,94	0,45
Cloudy day -1.7.2018 (MPP mode)	5,83	2,82	0,34	2,46	0,41

In Fig. 7 and 8 there is a comparison of thermal and electrical performance for cloudy and sunny day. Comparison of thermal performance for OC mode is shown in Fig. 9.

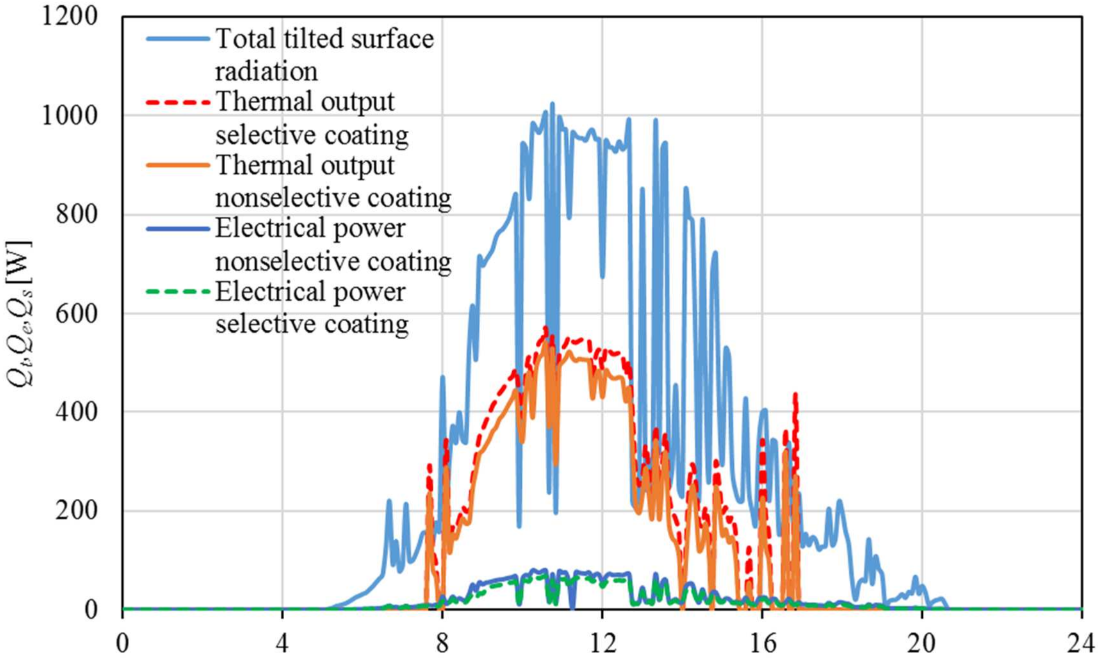

Fig. 7: Comparison of the thermal and electrical performance for cloudy day

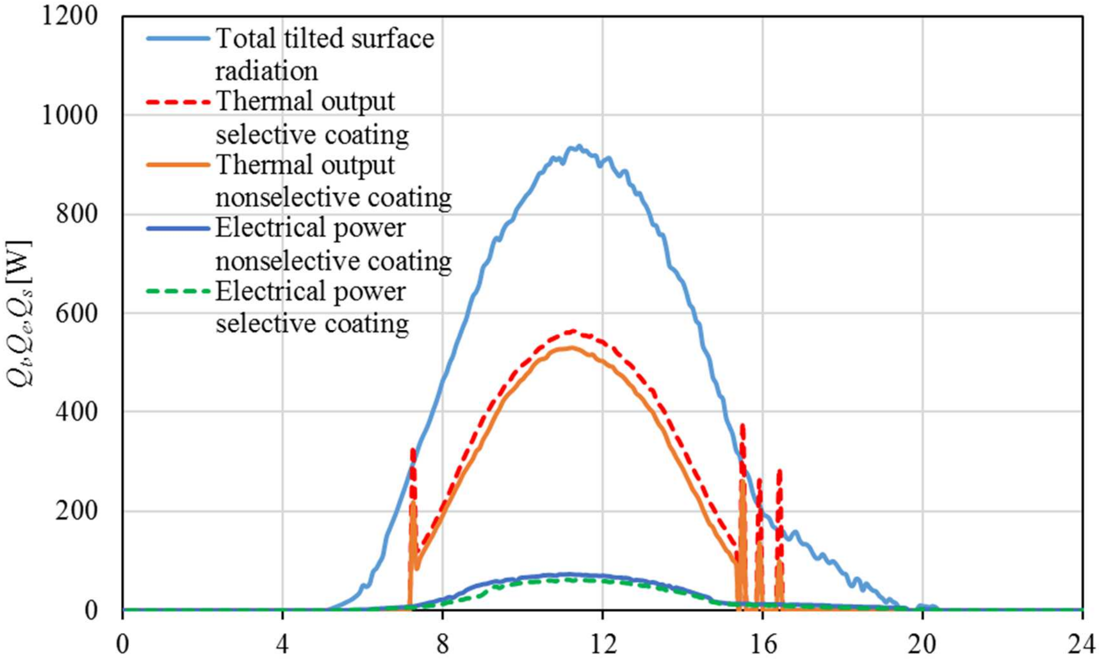

Fig. 8: Comparison of the thermal and electrical performance for sunny day

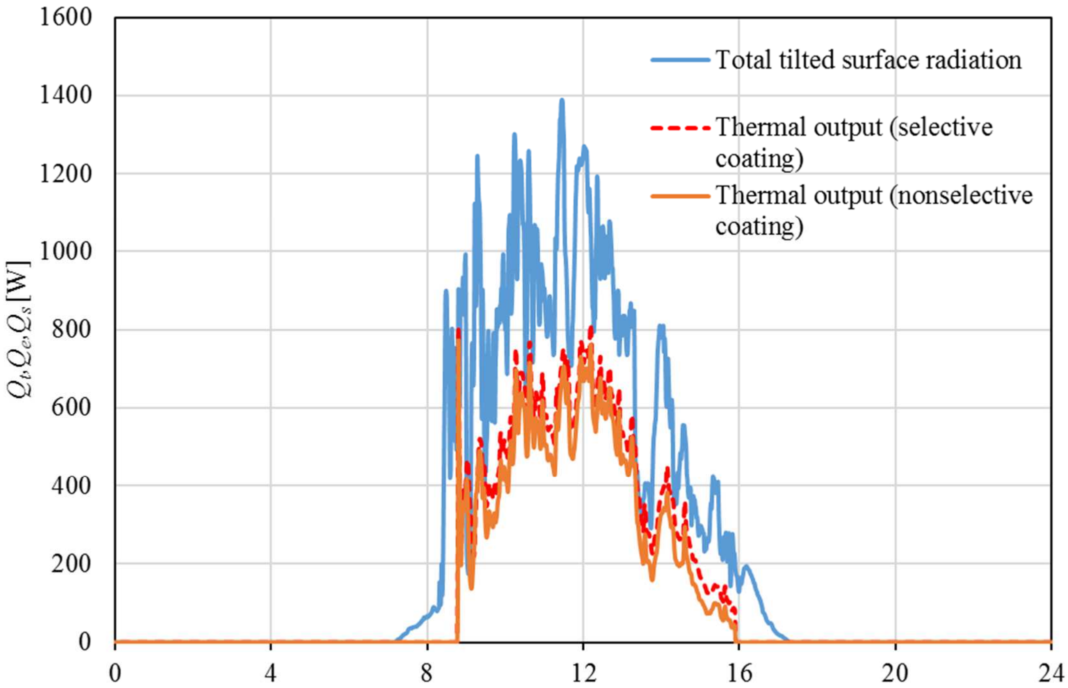

Fig. 9: Comparison of the thermal performance during OC mode

Moreover *U-I* characteristics were measured under outdoor conditions (see in Fig. 10). Total tilted surface radiation was 675 W.m^{-2}, ambient temperature 25 °C, mean fluid temperature 35 °C, angle of incidence was 54°. These conditions are not standard but sufficient to show the difference in short circuit current between selective and nonselective absorber. The selective coating has 17 % lower short circuit current for mentioned outdoor conditions.

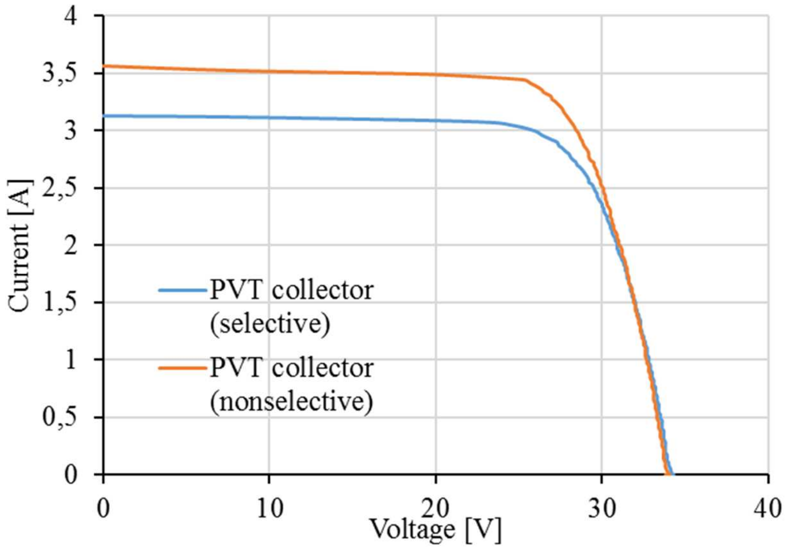

Fig. 10: *U-I* characteristic for both collectors (G = 675 W/m², t_m = 35 °C)

In Fig. 11 infrared image of the front side of the façade module is shown. On the left hand side there is nonselective PVT collector which has higher temperature. On the right hand side there is selective PVT collector. Double glazing does not allow to measure temperature distribution on the PVT absorber unfortunately. Therefore it is not possible to identify eventually defects in PV part.

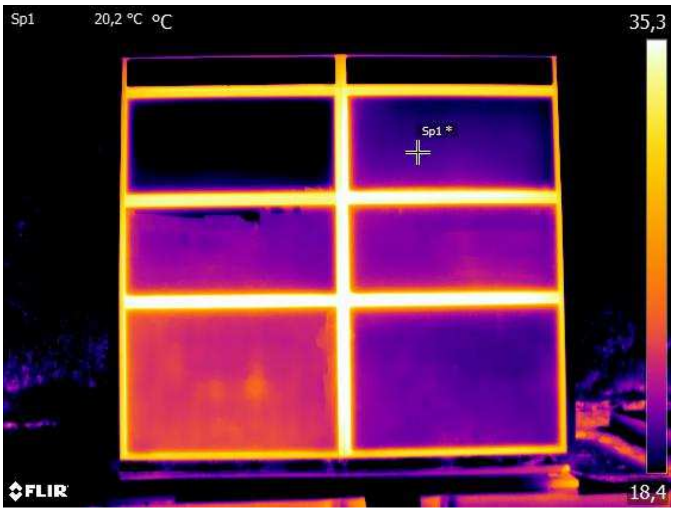

Fig. 11: Infrared image of the front side of the façade modules

5. Conclusion

New prototype of integrated PVT collector into façade module was developed and tested. Application of low-e coating enhanced thermal output and decrease electric power. Comparison of nonselective and selective PVT collector has been carried out under real climatic conditions. Advantage of low-e coating is disputable in this case. The increase of thermal production is approximately 10 % which was anticipated. The increase of thermal energy production is even higher (14 %) in OC mode. However decrease in electrical production was measured around 17 %. Decrease of electrical production was expected around 2 %. Therefore expected overall positive influence of energy output by application of low-e coating on the absorber was not achieved. One possible reason of such a decrease of electrical energy production are micro cracks of PV cells. Electroluminescence analysis should be done in the near future to ensure that there are not micro cracks on the PV cells. Moreover the spectral optical properties of glazing with low-e coating for real climatic conditions will be necessary to measure separately.

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