An Aesthetic Energy Producing Roof with Integration of PV Modules and Solar Thermal Collectors

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Abstract

Aesthetic integration of solar energy products in the roofs of dwellings is important to achieve a good social acceptance and a high market potential. Several solutions for building integrated PV (BIPV) are available on the market, however, a very limited number of solutions for covered solar thermal collectors are available. Currently, covered solar thermal collectors are much thicker and often much larger than PV modules, which complicates aesthetic integration of both PV and solar thermal collectors in the same roof. Therefore, a Dutch collector producer developed a solar thermal collector with the same dimensions and thickness as a framed PV module. The aim was to also achieve the same efficiency parameters. Eight collectors, eleven PV modules and a window were integrated into a dummy roof and measured extensively in a field test.

Keywords: Building integration, solar thermal

1. Introduction

Dutch policy aims to realize a more sustainable built environment in the Netherlands. To achieve a reduction of 49% of greenhouse gas emissions in 2030 (with reference to 1990), a large reduction of greenhouse gas emissions in the built environment is required. Because of a limitation of the available space in the Netherlands, application of solar energy products on buildings is very interesting. When the number of solar energy systems in the built environment increases, aesthetic integration of those systems becomes more important for social acceptance and a higher market potential. It is expected that Building Integrated PV (BIPV) will show a strong growth in the upcoming years. Many BIPV products have been developed in the last five years (Zanetti *et al.,* 2017), however, the number of building integrated solar thermal collectors are very limited. Especially for newly built dwellings with a high insulation, the share of the domestic hot water (DHW) demand can be over 50% of the total heat demand of a dwelling. The DHW demand is at higher temperatures and a large share of it can be supplied by a simple domestic hot water system with covered solar thermal collectors.

The research presented in this paper is part of the ‘Building Integrated Solar Thermal and PV (Building STeP)’ project. The goal of this project is the development of a multifunctional roof, which includes PV modules, a PV-sized solar thermal collector and an integrated window. The focus is mainly on the development of the thinner solar thermal collector, since that was not yet available.

In this paper, we will present the current results regarding the development of the collector. Within the project a field test is carried out with the integration of PV modules, a window and the solar thermal collector in a multifunctional roof. The results of the field test will be presented as well as some simulation results.

2. Nero solar thermal collector

The Dutch solar thermal collector company HRsolar had been producing a high performing solar thermal collector with an area of 1.6 m^2, called HPC-1.6, since 2013. Though the HPC-1.6 collector was easier to include in a side-by-side installation together with PV modules than a standard solar thermal collector, with 94 mm thickness, it was still too thick for the standard PV mounting frames.

The goal of the development of the new collector was to create a thinner and lighter collector with a similar collector performance. The thickness of the collector was set to be a maximum of 40 mm, the same as a framed PV module. Furthermore, the collector should have the same look as an all-black PV module. Therefore, a different absorber coating is used. It was a challenge to decrease the thickness and similar heat losses. To reach this, the insulation on the back of the collector was replaced by insulation with a higher Rc value. Furthermore, instead of air, a noble gas mixture was used between the absorber plate and the glass cover. Also double coated glass was used.

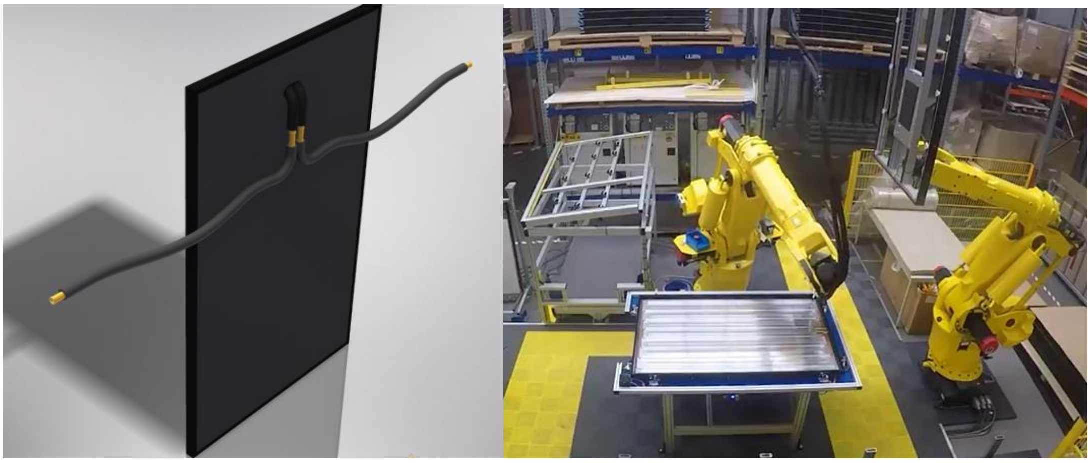

Fig. 1: Left: New solar thermal Nero collector, Right: automated production process (HRsolar, 2018)

Table 1 shows a comparison between some key characteristics of the HRsolar Nero and HPC-1.6 collectors. The heat loss factors a_1 and a_2 are in the same range. The incidence angle modifier is higher. The zero-loss efficiency is lower, probably due to the black absorber coating.

Table 1: Comparison of old and new collector characteristics based on data sheets and Solar Keymark certificates

	Nero (new)	**HPC-1.6 (old)**
Gross area	1.62 m^2	1.63 m^2
Thickness	40 mm	94 mm
Weight	23.8 kg	25 kg
η_0	0.692 (gross area, Solar Keymark)	0.750 (gross area, calculated) 0.837 (aperture area, Solar Keymark))
a_1	4.503 W/m^2K (gross area)	4.61 W/m^2K (gross area)
a_2	0.022 $W/(m^2K^2)$ (gross area)	0.017 $W/(m^2K^2)$ (gross area)
IAM at 50°	0.96	0.91

The collector is commercially available with the name Nero (HRsolar, 2018) and has a Solar Keymark certification since January 2018.

3. Field test building integrated PV and solar thermal roof

3.1. Field test specification and installation

The multifunctional building integrated roof was installed on SolarBEAT, the experimental outdoor research facility of SEAC, as shown in Figure 2. The outdoor facility is located on the roof of one of the buildings of the Technical University of Eindhoven and includes a solar measurement station that measures direct, diffuse and global horizontal irradiance, as well as wind speed and direction and ambient temperature.

The following setup was installed:

- 11 260 Wp mono-crystalline PV modules in SCX Solar Soloroof mounting structure, one string of 11 modules is connected to an SMA Sunnyboy 3600 TL inverter.
- 8 HRsolar solar thermal collectors type Nero (zero-series, 4 with one sided anti reflection coating, 4 with double coating), two series of four collectors.
- Integrated roof window

Furthermore, a thermal loop was designed and installed to allow for measurements on solar thermal collectors and PVT systems. Excess heat produced by the thermal systems is dumped in the university’s aquifer. The liquid is preconditioned to the specified temperature. The input temperature for the systems can be set between 15 and 80°C. A 49 % glycol solution is used.

The following measurement equipment is installed:

- Meteorological measurements: Global tilted irradiance (secondary standard pyranometer), pyrgeometer, in-plane wind speed and direction, ambient temperature.
- PV performance measurements: DC and AC string voltage and current are measured, the PV module temperature is measured with T-type thermocouples.
- 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 from November 2017.

Fig. 2: Field test on the SolarBEAT location

3.2. Thermal performance results

The thermal analysis was carried out for all solar thermal collectors individually. We present the results here of one of the collectors with the quasi-dynamic approach. Since it is a covered collector we only fit the zero-loss collector efficiency factor (η_0), the heat loss coefficient (c_1), the temperature dependent heat loss coefficient (c_2) and the effective thermal capacity of the collector (c_5) (see equation 1). The b_0 coefficient is derived from the solar keymark tests.

$$\dot{Q}/A_g = \eta_0 K_{0b}(\theta) G_b + \eta_0 K_{0d} G_d - c_1(T_m - T_a) - c_2(T_m - T_a)^2 - c_5 \frac{dT_m}{dt} \qquad \text{(eq. 1)}$$

Where $K_{0b}(\theta) = 1 - b_0 \left(\frac{1}{\cos\theta - 1}\right)$ (eq. 2)

The coefficients (Table 1) are in the same range as the ones in the Solar Keymark certificate with a few differences. The zero-loss efficiency is slightly lower, this might be caused by some pollution on the panel, the use of a propylene-glycol mixture as well as a single reflection coating. Figure 3 shows the measured efficiency points versus the reduced temperature. The blue curve is the collector curve where only the zero-loss efficiency and c_1 (of 4.3 W/m^{2}K) are taken into account. The red curves also include c_2 where the reduced temperature is calculated with respectively 500 or 1000 W/m^{2}K. Incidence angle related losses as well as differences due to the thermal capacity of the collector, are not shown in the graph.

	Parameters
η_0	0.66 [-]
c_1	4.3 W/m^{2}K
c_2	0.024 W/(m^{2}K^2)
c_5	2.4 kJ/m^{2}K

Table 2: Fitted collector parameters

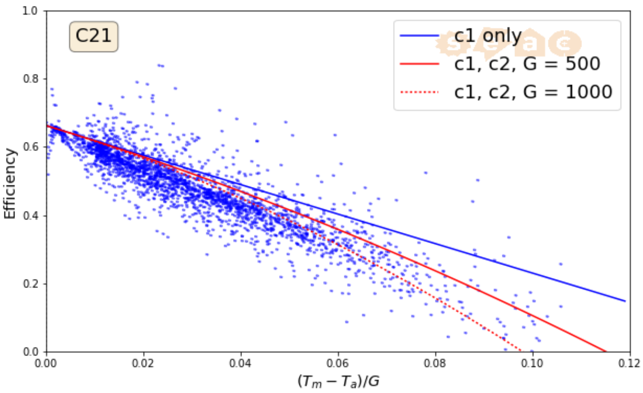

Fig. 3 Collector curve with only c1 from table 2 and c2 = 0 and at G=500 or 1000 W/m^2

3.3 PV performance

The performance of the 11 PV modules is characterized by the Performance Ratio (PR). The performance ratio is defined in Equation 3. The performance ratio is a measure of the realized energy yield in comparison to the performance under Standard Test Conditions. Both AC and DC performance is measured. Using DC or AC output power P we can calculate the performance ratio (PR) and efficiency (η_e) of the PV modules using

$$PR = \frac{G_{\mathrm{STC}}}{G} \frac{P_{measured}}{P_{\mathrm{rated}}} \qquad \text{(eq. 3)}$$

where P_{measured} is the measured AC or DC power output, G is the measured irradiance in the plane of the modules, G_{STC} is the irradiance under standard test conditions and P_{rated} is the rated power of the PV module under standard test conditions (in Wattpeak or Wp).

The performance ratio is usually lower than 100% due to inverter losses, reflection losses, cabling losses and a higher PV temperature than the module temperature under Standard Test Conditions. Figure 4 shows the DC and

AC performance ratio of the system over the measured months (in blue and cyan). The average with irradiance weighted temperature is shown in orange. It can be seen that there is a clear correlation between module temperature and the PV performance ratio. The average PR over the measured period is 83 % (DC) and 79 % (AC).

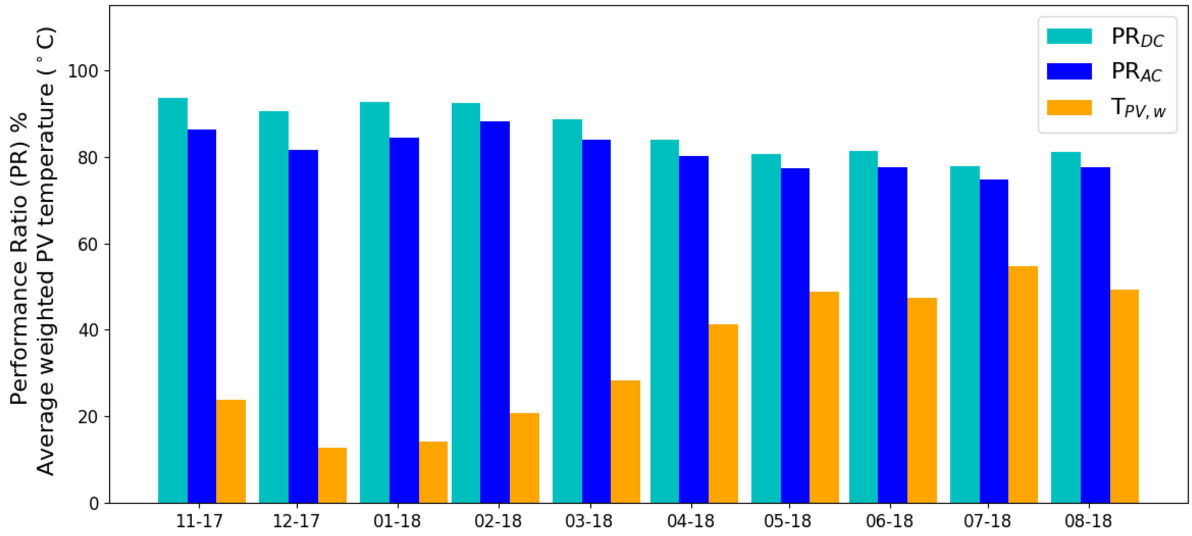

Fig. 4: Monthly PV DC and AC performance ratio and weighted average PV module temperature

4. Simulation of building integrated solar roof

The simulation was carried out for a roof with space for 20 PV modules, thermal collectors or windows. The thermal collector yield for a typical domestic hot water system was simulated with TRNSYS. A DHW profile of 9 GJ (2486 kWh) of the Dutch norm NEN7120 is used with a variation in the number of collectors (1 to 3), the size of the storage (120 or 200 l) and the temperature level of the hot water (45 or 60°C).

The thermal yield is shown in Figure 5 and is between 292 and 530 kWh/m^2 collector area.

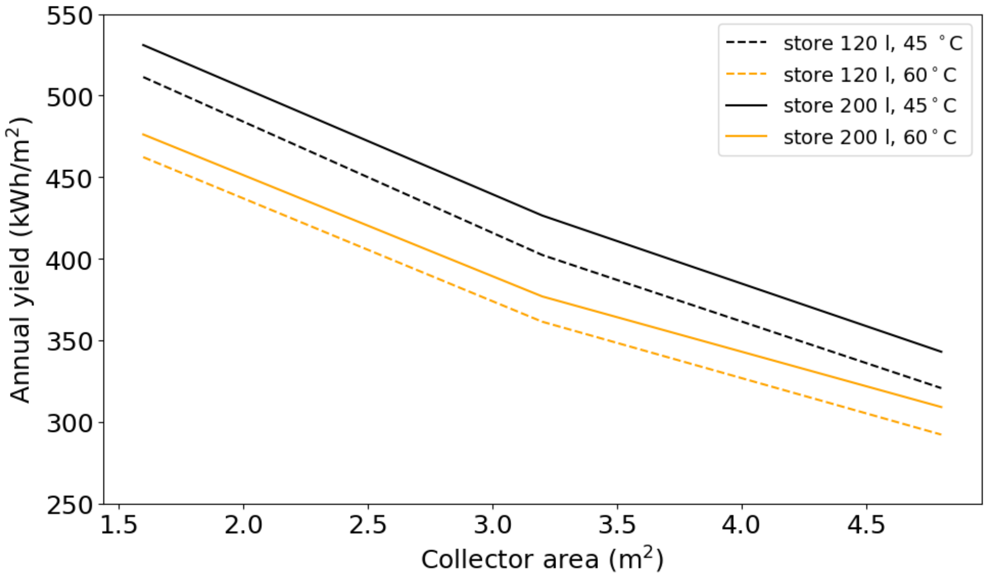

Fig. 5: Annual collector yield for a DHW system with one, two or three collectors, a 120 or 200 l storage and a DHW demand temperature of 45 or 60 °C

The PV yield is calculated with an annual AC Performance ratio of 80% and an STC power of 300 W per module.

Furthermore, it is assumed there is one roof window. The annual irradiation at the location is 1100 kWh/m^2.

Table 3: Annual energy yield of a multifunctional roof

#PVmodules	#collectors	Thermal yield	Solar Fraction	Electrical yield
18	1	0.85 MWh	32%	4.7 MWh
17	2	1.4 MWh	51%	4.5 MWh
16	3	1.6 MWh	61%	4.2 MWh

5. Conclusion

In this project, we showed that it is possible to produce a collector that is the same size and thickness as a standard crystalline silicon PV module. We demonstrated the easier integration of the thermal collectors in a building integrated solar roof. The performance was measured over an eight month period. The collector shows a slightly lower zero-loss efficiency than the previous thick PV sized solar thermal collector due to a different aesthetic coating that was used. Heat loss parameters are in a similar range.

6. References

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7. Acknowledgements

This work was supported by the ‘Netherlands Enterprise Agency’ (Rijksdienst voor Ondernemend Nederland, RVO) and the Dutch Topteam Energy via the project: ‘Building STeP: Building Integrated Solar Thermal and PV with grant number TEUE116177.