Performance Test of Racell PVT Modules

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1. Introduction

This test performed at DTU Byg is part of the project “Development of PVT module for multi apartment buildings”. The aim of the project, which is supported by the Danish Energy Agency within the EUDP programme, is to develop a Building Integrated PVT. (BIPVT). The BIPVT has a multifunction design to produce electricity, as well as thermal energy and additionally act as thermal insulation of a building. This can be achieved at the same time when the innovative product is installed on a wall or roof. Architects, consultants and building companies are also involved to get a pleasant, practical and safe design of the whole installation.

Four PVT modules from the company Racell [7] have been tested at DTU during the summer and autumn 2014. Only thermal performance has been analyzed. The modules were tested without the PV part active. This gives slightly higher measured thermal performance but in the annual calculations the derived parameters have been corrected for the PV part being active. This is done by reducing the thermal zero loss efficiency by the nominal cell efficiency (18% assumed). The equations behind the test and calculation model are described in detail in [1]. This modelling is also based on work within IEA SHC Task 35 about PVT systems [2]. The test procedure closely follows the QDT method in the DIN EN ISO 9806:2014 standard [3].

The collector prototypes tested, are shown in figure 1. Collector 4 is heavily insulated (10 cm mineral wool) on the back side. Collector 1, 2 and 3 to the left, only have an air space and a wooden board on the back side. The extra wind and long-wave sky radiation sensors close to the collectors are also indicated.

Figure 1.The prototype collectors tested. They are connected in series and have the same flow rate. The collector size is 2 m^2 respective 6 m^2.

By means of pyranometers the total and diffuse solar radiation on the modules were measured. Also the ambient temperature was measured. The volumetric water flow through the modules was measured with an ultrasonic flow meter. The inlet and outlet temperatures of each module along with temperature difference across each module between inlet and outlet were measured with thermocouples and specially designed thermopiles. Thermopiles have extra high accuracy, at low temperature differences that occur frequently during this kind of test.

The collector loop was connected to a 735 liter tank. Normal hot water draw offs were applied at 7:00 12:00 and 19:00 to get a low inlet temperature for the collectors.

The heat transfer fluid used in the modules is water which was separated from the water in the tank with a heat exchanger. Pumps were set to run 24 hours to get a continuous flow and a slow temperature swing up and down in the PVT collectors, out of phase with the solar radiation and ambient temperature each day.

This meant that the inlet temperature to the collectors in series was slowly increasing during the day and then going down in the late afternoon and night until the next morning.

The large thermal inertia of the tank meant that a time lag was introduced between solar radiation and operating temperature. This gave good conditions for evaluation of collector parameters.

On top of this also night time data were used to get the heat loss parameters more reliable. The night time losses are not exactly the same as during day time, but the special aluminum absorber used here, has a very high heat transfer efficiency factor F' making the error small in heat loss evaluation at night, even if the thermal flow is going the other way leaving the collector then. For cost optimized finned solar collector absorbers the error can be significant though, when using night data and separate loss parameters are needed for day and night.

The PVT collectors are designed to be installed in a demonstration project at Nørrebro in Copenhagen. The whole concept also includes an integrated insulation of the old brick walls of the facades. Therefore the PVT collector gets a multiple function of 1) heat production, 2) electricity production and 3) wall insulation.

Figure 2 shows an architect view of the finished installation on two facades southwest and southeast.

The DTU test was primarily a thermal performance test, but also a short durability test, especially of the PVT module lamination and new aluminum absorber design. The aluminum alloy is developed by Hydro Aluminum. The aluminum extrusion is made by SAPA and the prototype absorbers were made by the collector manufacturer Savosolar:

SAPA http://www.sapagroup.com/en/precision-tubing/solar/applications-in-solar/mpe-absorbers/
Savosolar. http://www.savosolar.fi/

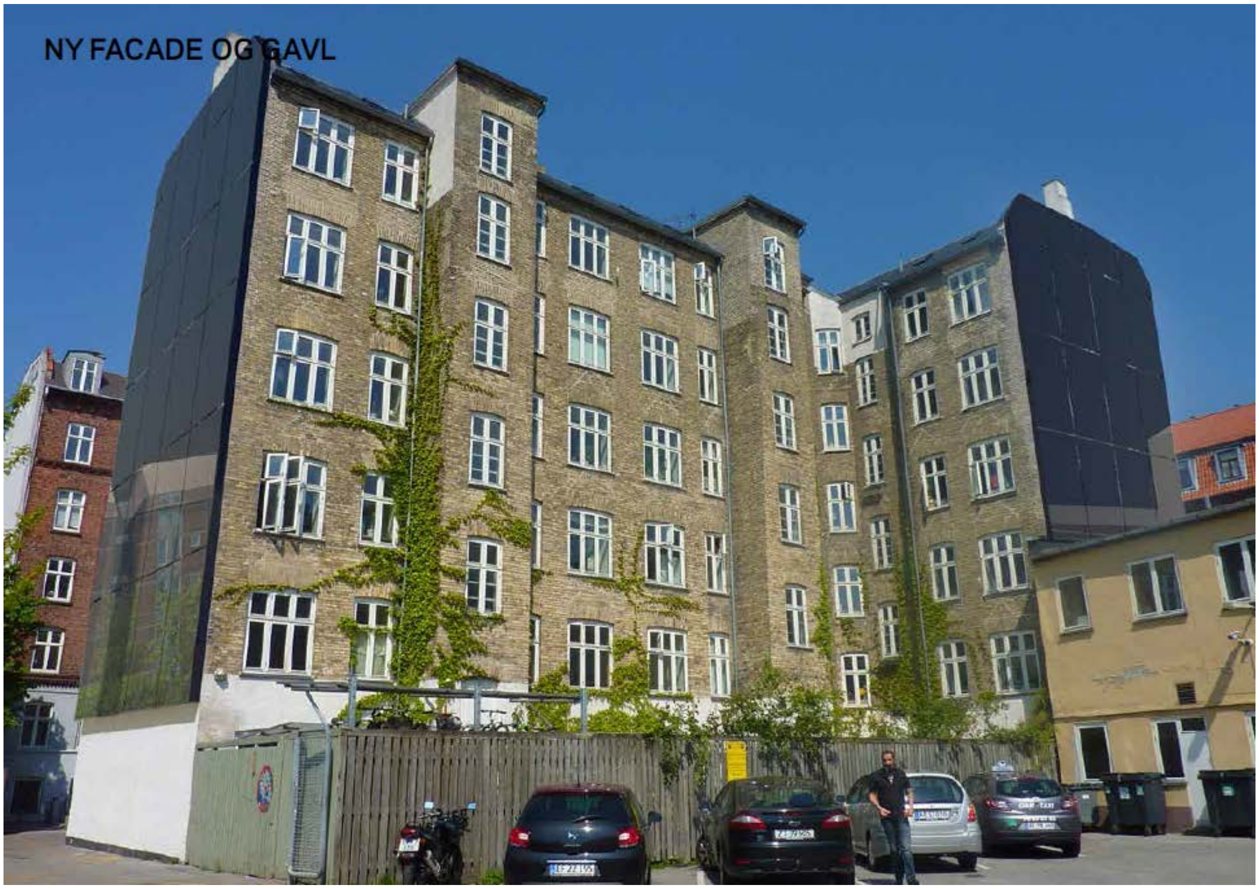

Figure 2. An Architects view of the demonstration installation, on two walls in Nørrebro Copenhagen.

2. Test results

Based on analysis of all day performance measurement data from July 2 to July 6 at DTU, the PVT collector parameters and a thermal collector model for annual performance prediction, has been determined for module 4.

A Standard QDT all-day model and parameters from test have been used to create a standard test efficiency diagram, figure 3. The full all day QDT model and parameters are used to derive the curves but the input variables are set to clear weather conditions at noon given below:

Beam radiation (900 W/m^2), Diffuse irradiation (100 W/m^2), Incidence angle (0^o) , Wind speed in steps 0-5 m/s and long wave net radiation (-100 W/m^2).

The strong wind and temperature dependence on the thermal performance can be seen in both figure 3 and figure 4. This is due to the unglazed design.

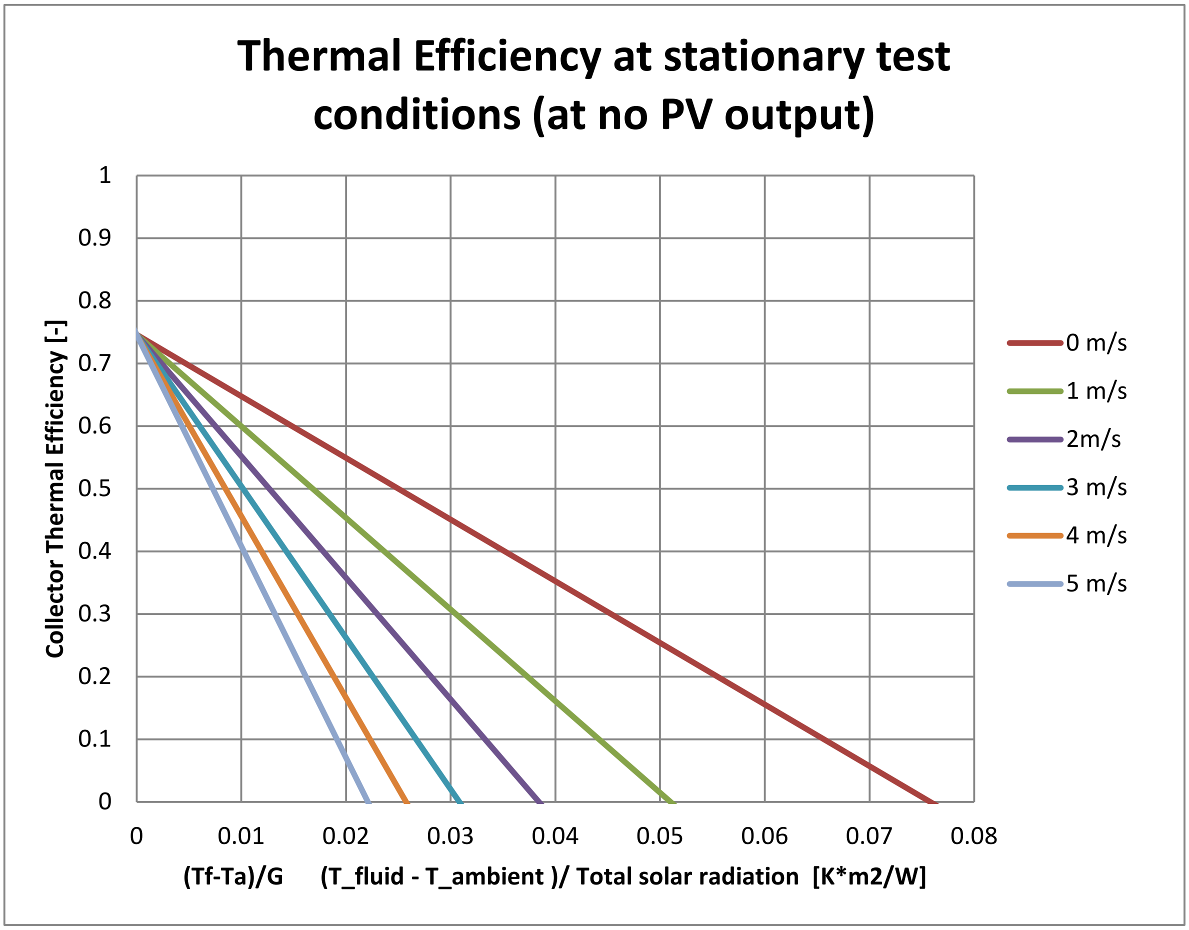

Fig 3. Collector thermal efficiency diagram. Calculated from the model with fixed clear weather variable values. The model parameters used, are from July.

The same information and variable settings can also be used to show results as peak power output per m^2 at standard test conditions, see figure 4.

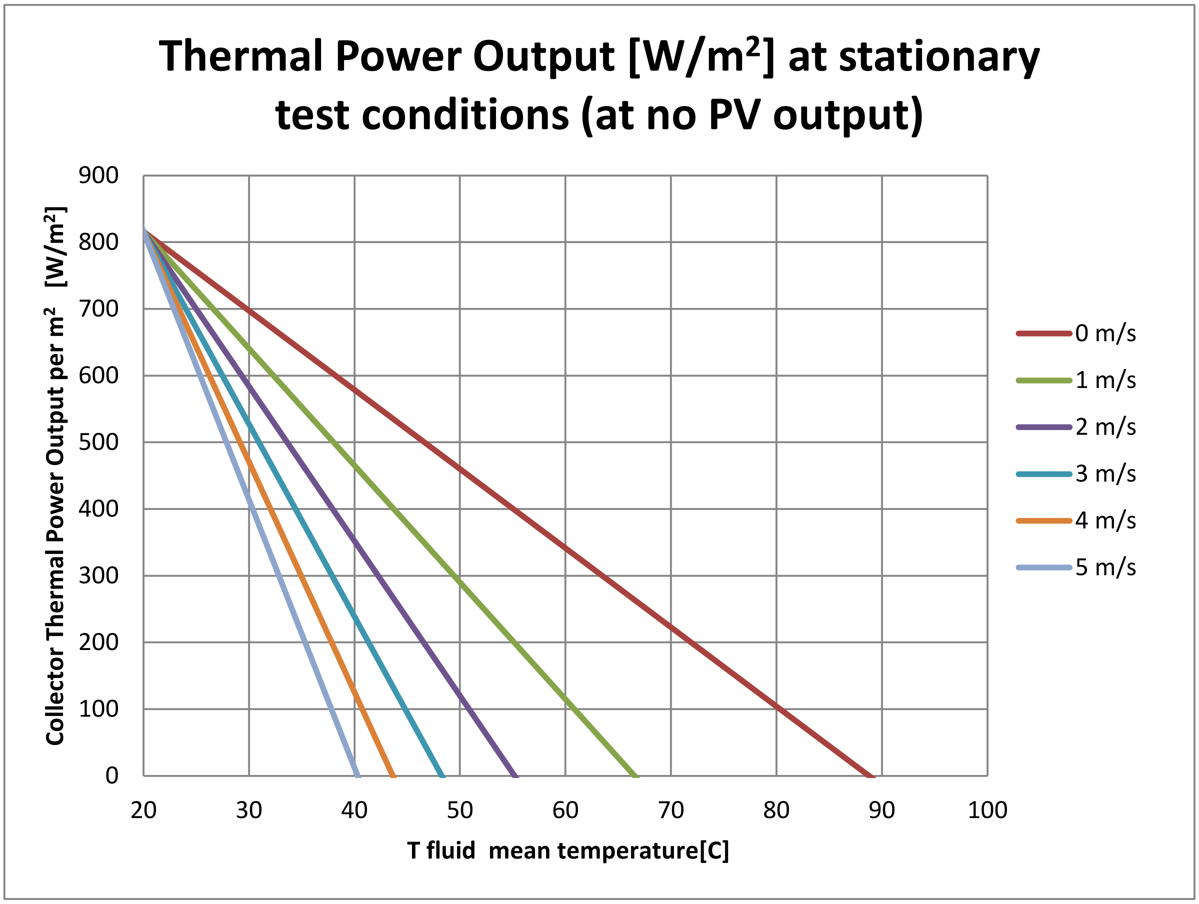

Fig 4. Power output per m^2 aperture area versus mean operating temperature, at different wind speeds. The diagram is calculated from the full QDT model with fixed clear weather variable values. Model parameters used, are from July 2014.

2.1 Thermo vision camera check

A thermo vision camera was used to check the surface temperature of all 4 prototypes. This was done to reveal any problems with flow distribution or delamination of the cells from the special aluminum absorber. This could otherwise reduce the performance significantly.

As can be seen in figure 5 the surface temperature only varies slightly. No significant cold- or hot spots are visible.

The temperature resolution is magnified for each picture to still give color changes. Therefore the color scales are not the same for the different collector thermal images.

The main reason why there is a temperature gradient visible in collector 4 and not for the other collectors is that the flow per m^2 is much higher (3 times) for the small collector prototypes due to the series connection.

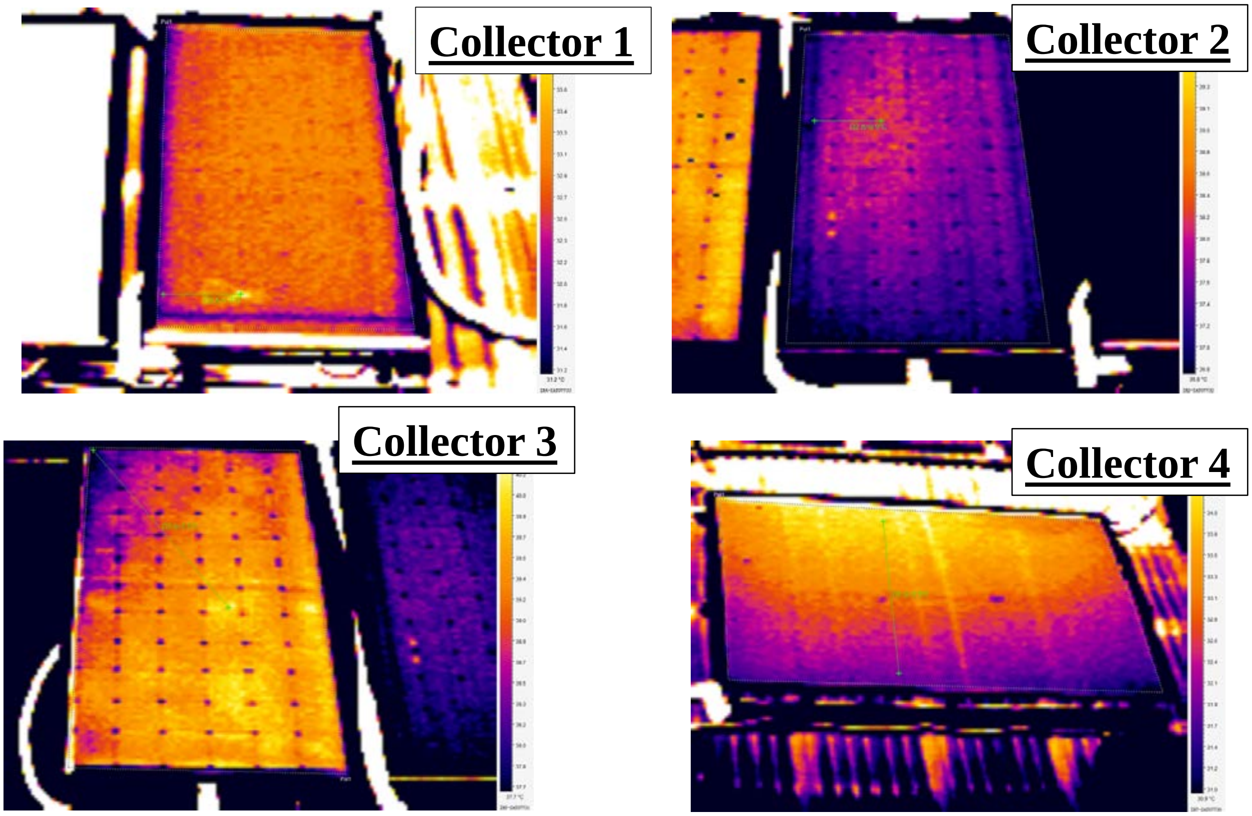

Figure 5. Thermo vision camera pictures indicating that there are no problems with delamination or flow distribution or air enclosures, that can affect the performance results.

2.2 Model and parameter validation

A comparison of all day power output is shown in figure 6 for module 4. Measurements are compared to the QDT model with a complete parameter set and all measured input variables active in the modelling.

The diagram indicates a reasonable match for all days and also 24 hours around the clock.

The night time measurements are used to separate the heat loss parameters from the zero loss efficiency parameters more accurately.

The heat loss parameters are theoretically not perfectly equal during day and night in general, but for this very good absorber and PVT design, this can be justified as the heat transfer between fluid and collector surface is so good and the error will be small.

This diagram is important to give confidence in the annual performance calculation as the same model and parameters are used in the ScenoCalc tool.

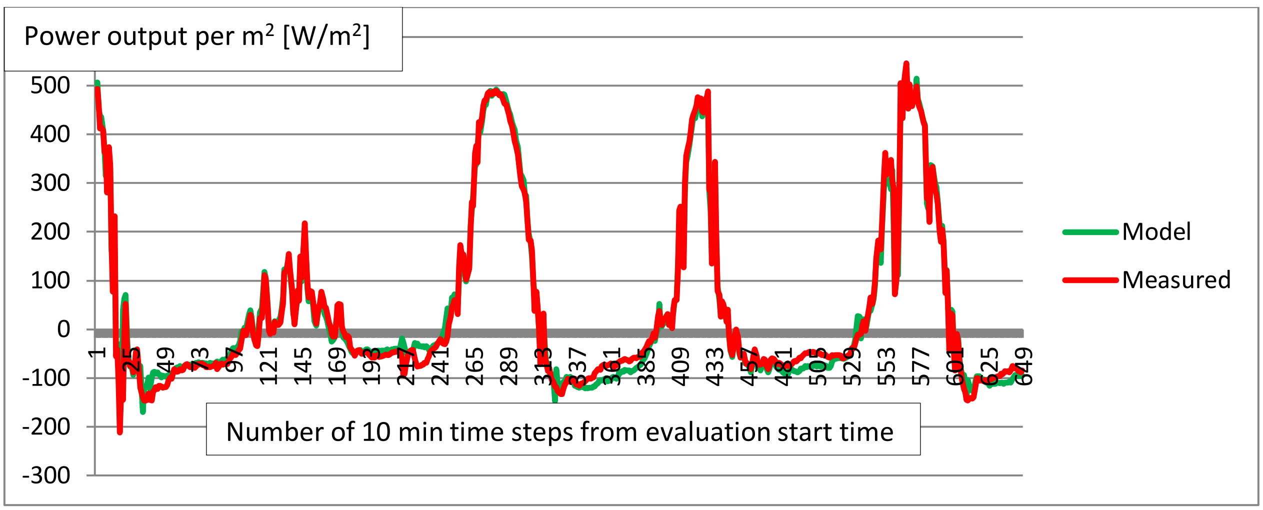

Fig 6. Model validation for the test period in July 2014. The same model and parameters are used in the annual performance calculations using ScenoCalc PVT.

2.3 Comparison of thermal output between the PVT modules

To give an experimental impression of how close the different PVT modules perform, some data are shown from the end of the season in October, when the power output is most sensitive to design differences. The absorbed thermal solar energy and heat losses gets closer to each other or even negative over the day and as the net output is the difference in between it gets more sensitive.

Figure 7 shows thermal output per m^2 of aperture area, to be directly comparable between differently sized modules. There is a small difference in power output, due to the increasing operating temperatures, when the collectors are connected in series. It can be seen that collector 3 (green curve) that is first in the flow order, has the highest performance during day and lowest during night. This is as expected. The opposite happens for the last collector 4 (dark blue curve). If the collectors were exactly the same in performance the curves would differ like this. A red curve is also shown for the total energy going into the tank. This is a double check that no strange measurement errors are present.

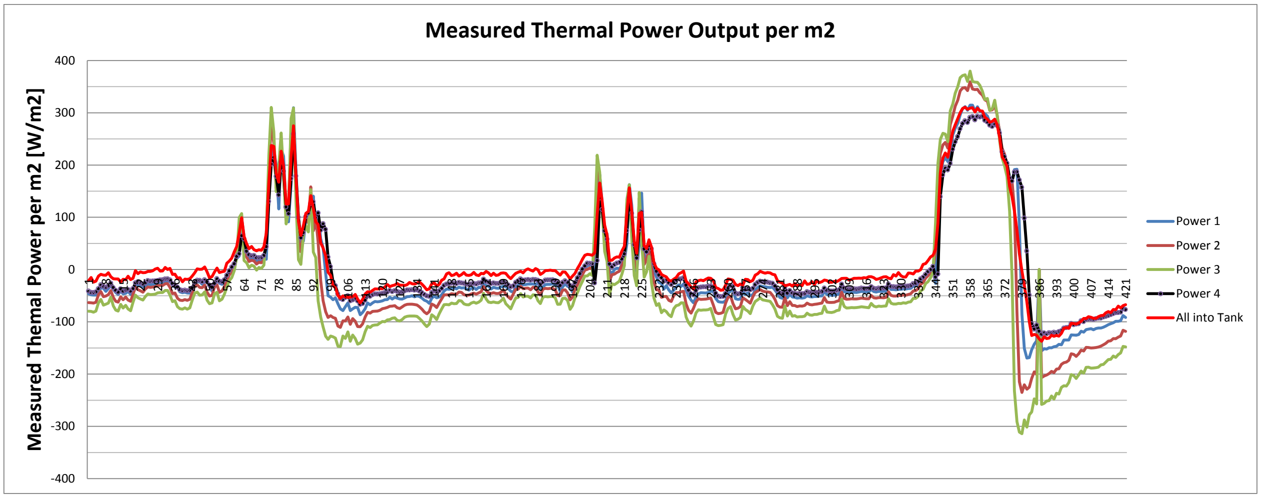

Figure 7. Measured thermal power output, for all PVT collectors for October 26-28. Also the total power going into the cooling (heat sink) tank is shown. All results are presented as power per m^2 aperture area. Note no correction, for different mean operating temperature in the collectors, is done in this diagram.

In figure 8 the modelled collector output power (Y-axis) versus measured output power (X-axis) for collector 1, 2, 3 and 4 are shown. This is for a period in late October using the exactly the same model and parameters determined for module 4 from the July data evaluation.

A small difference can be seen between the collector prototypes. But the difference is very close to the measurement accuracy. The scattered points come from partial shading of the collectors from trees around the test site. The small solar sensor detector area may be fully illuminated but the collectors partly shaded. It could generally be the opposite producing low points but here the solar sensor is high up on the test roof where the shade only may reach in winter .

The model will predict normal performance as if they were fully illuminated, but the collectors do not receive full solar radiation part of the afternoon and produce much less net thermal power output than normal for shorter periods giving scattered points.

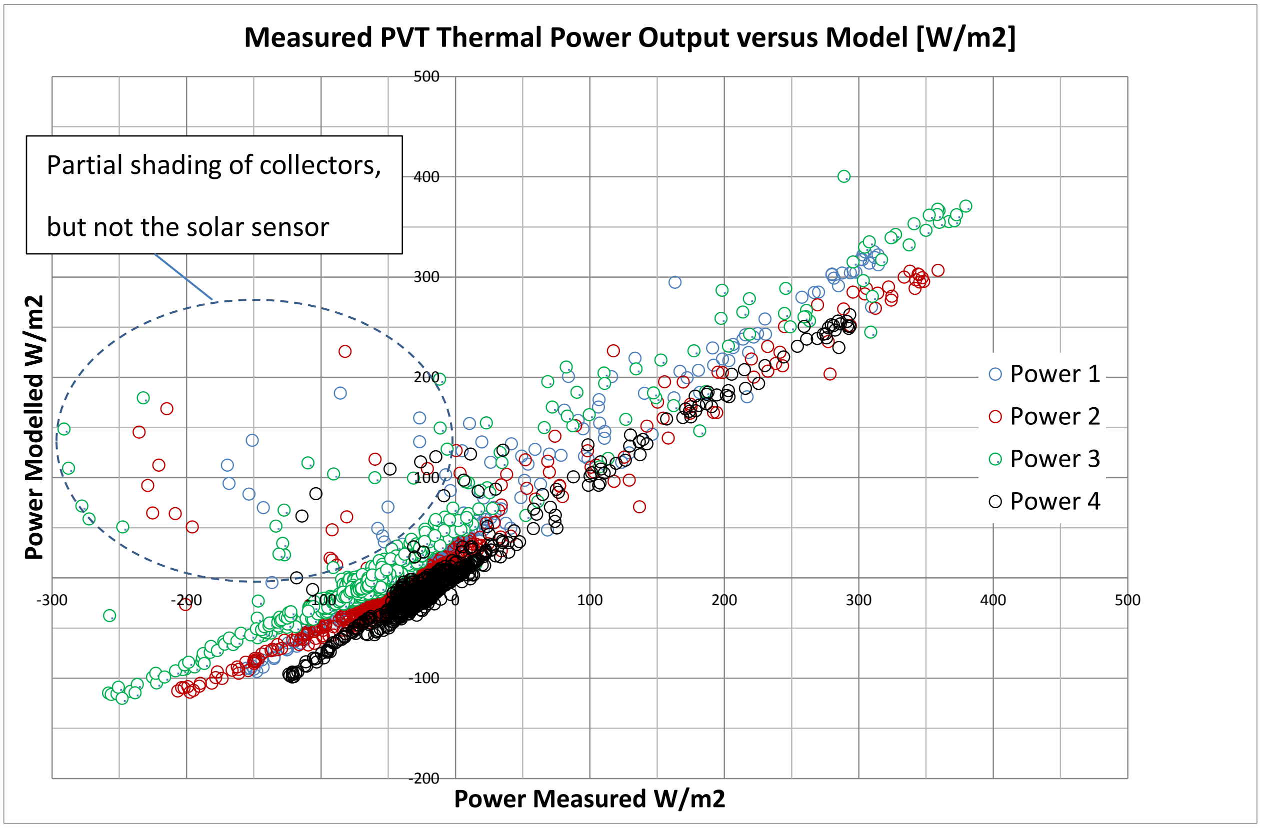

Fig 8. Modelled collector power (Y-axis) versus measured power (X-axis) for collector 1, 2, 3 and 4 for a period in late October with the model and parameters from the July data evaluation. A small difference can be seen between the collectors but it is very close to the measurement accuracy.

From the measurements it is concluded that the thermal efficiency curves are almost the same for the four modules.

3. Annual Performance calculations for the Copenhagen climate

The model and parameters derived from July data, were used in the ScenoCalc PVT tool [4], to estimate annual energy output both from the PV and Thermal part of the prototype PVT design. The PV aperture area based STC (Standard Test Conditions) module efficiency, was set to 18% corresponding closely to the high performance PV cells usually used by Racell. This STC efficiency was subtracted from the thermal zero loss efficiency, as the thermal test was done without the PV part active.

The chosen PV input STC efficiency level 18%, based on module aperture area, can later be adapted to the real STC efficiency in an installation to derive more precise results.

In figure 9 it can be seen that the thermal performance is extremely sensitive to the system temperature demand. Full hot water temperatures are not attainable in practice in the Danish climate. But preheating and Swimming pool heating is completely possible in a good system with low temperature losses in heat exchangers for example. Connection to a heat pumps system is also a possible system solution.

It can also be seen that there is a significant difference due to tilt. A façade installation gives much less energy per year than a 45 degree tilted roof installation at the same operating temperature. A reduction of the operating temperature by 5-8 K, can compensate for the tilt disadvantage in thermal performance for a façade. The PV electrical output is always around 30-40% lower for the façade almost independent of operating temperature.

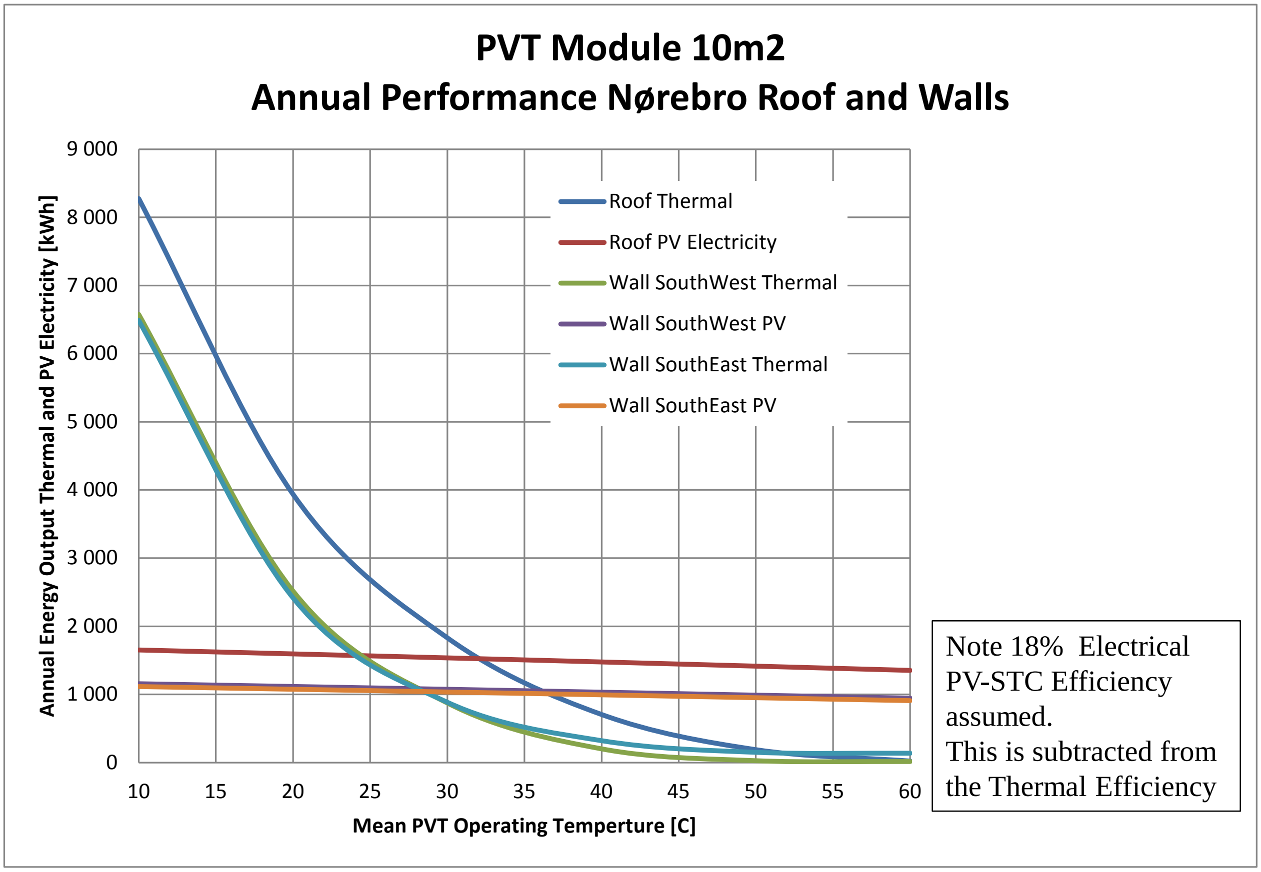

Figure 9. Annual performance, at different operating temperatures. Both electrical and thermal outputs are shown. A 10 m^2 module and 18% STC PV module efficiency is assumed. The calculations are done with the ScenoCalc-PVT tool .

4. Conclusions

The experimental investigations at DTU showed that:

- The thermal efficiency is almost the same for all four prototypes.
- The zero loss efficiency is high
- The heat losses are high due to the unglazed front surface.
- Simple back insulation is enough for thermal performance (for an unglazed design).
- Low temperature system operation is important for high annual output.
- Hot water preheating, ventilation air preheating, pool heating or connection to the cold side of a heat pump system, are some possible applications.
- No durability or corrosion problems were observed, but the testing time is very short compared to the required life time in an installation.

References

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