PV-ROCK-ROOF

Mock-up test report

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Mock-up test report

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Content

1. PV Rockwool mock-up at DTI

The PV-ROCK-ROOF project aims at developing a combined electricity producing PV roof and thermal energy saving insulation. Several studies and experiments have been conducted as part of Work Package 2, and more mock-ups have been constructed. One of the constructions has been placed at the outdoor test area at DTI for evaluation of its performance during normal weather exposure. The construction, measurement system and results are presented in this WP5 report.

Construction
The mock-up was constructed by Rockwool in Hedehusene using a number already produced PV elements from Danish Solar energy. The PV part consists of 6 red modules on the left side and 6 in different colour on the right side. Three of the modules are electrically connected in series and the cable conducting the power to a small inverter in the laboratory. The rest of the modules are dummy modules that are not electrically connected.

Instrumentation
The instrumentation was partly done during the construction phase, so that the sensors could be hidden in the different layers. The temperature sensors are placed at the positions where the highest temperatures can be expected. Sensor type:

- Temperatures: PT100
- Relative humidity: DOL
- Solar irradiance: Reference solar cell (Soldata)
- PV voltage: direct measurement
- PV current: shunt resistance.

Cable#		Temperature
3		Junction box on module no. 2 (upper)
4		Center of module no. 2
5		Center of module no. 5
6		Air gap temperature, right-top
7		Air gap temperature, right-bottom
8		Relative humidity in air gap
		Solar irradiance
		Ambient temperature

Module array and connected module numbers:

2	
4	
5	

The three active modules were connected in series and feeding a small grid connected inverter.

- Data logger: Grant 2400
- Sampling interval: 30 seconds
- Logging interval: 10 minutes.

1.1. Results with original PV modules form DSE

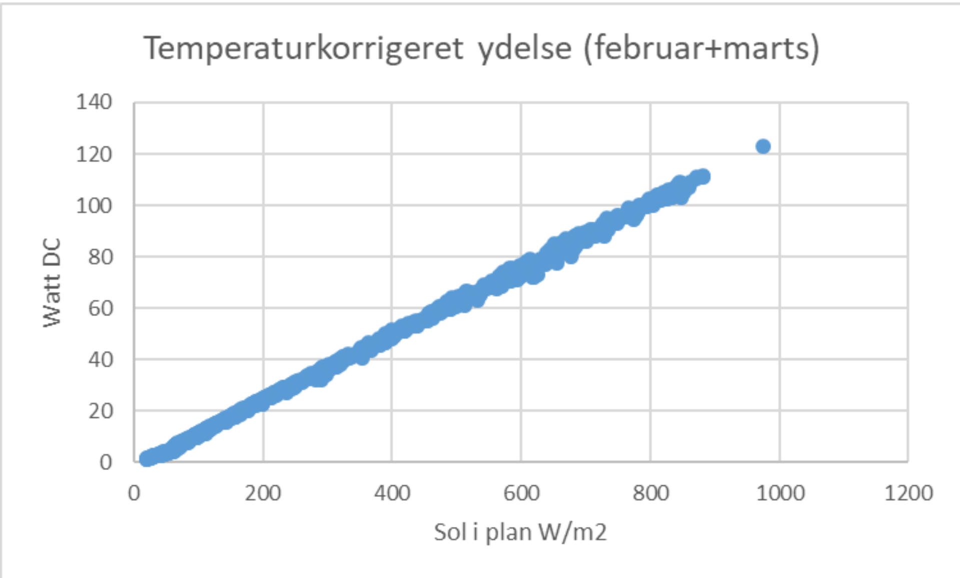

Figure 1 Long term measurements from a former test of the old generation of red modules show a total STC power of 125 Wp.

The initial measurement of the IV-curve shows a total STC power of 120 Wp for the three old modules. However, the IV cure analyzer does not measure the cell temperature directly but use the irradiance sensor temperature as proxy. Because the PV modules are approximately 10K warmer (manual reading) than the sensor, a correction factor of 10K * 0,4%/K= 4% is applied:

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P= 1,04 * 119,9 = 124,7Wp (41,6 Wp per module)

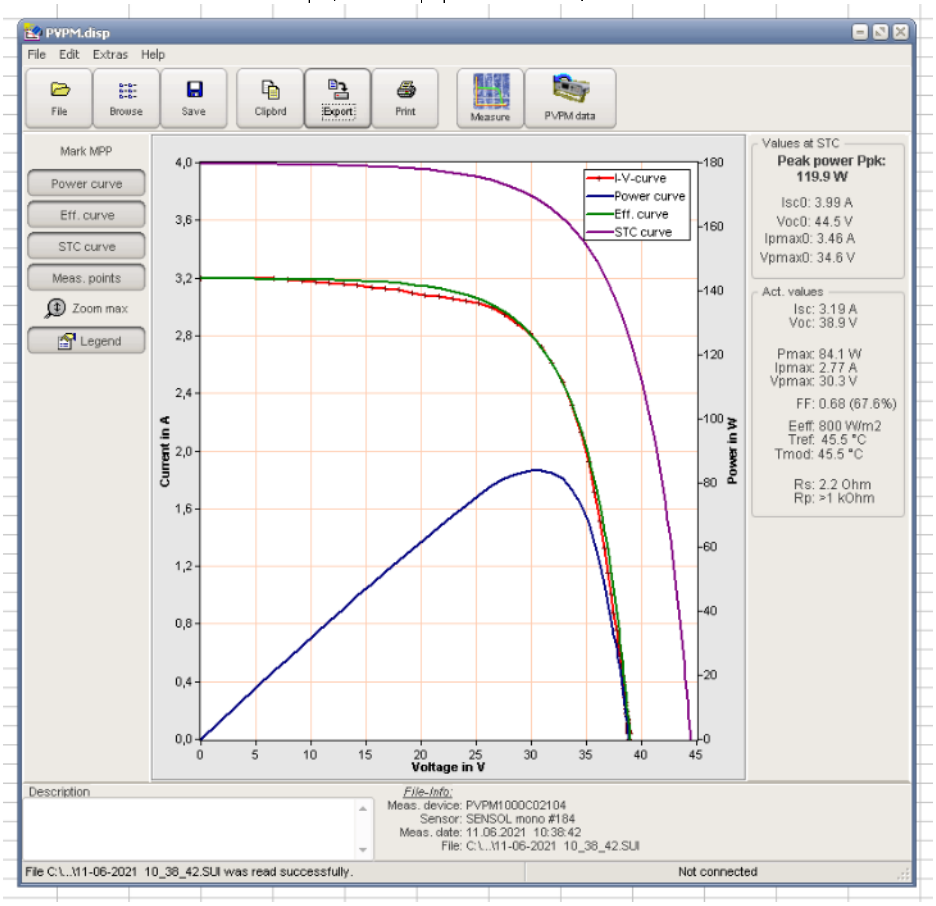

Figure 2 Readout from PVPM6020 IV curve analyzer.

1.2. Thermal imaging

Thermal imaging was conducted on a sunny day to get an overview of the temperature distribution of the roof surface. At first, the modules were not producing power, and thus the solar energy is either reflected or absorbed and converted to heat. The temperature is relatively uniform.

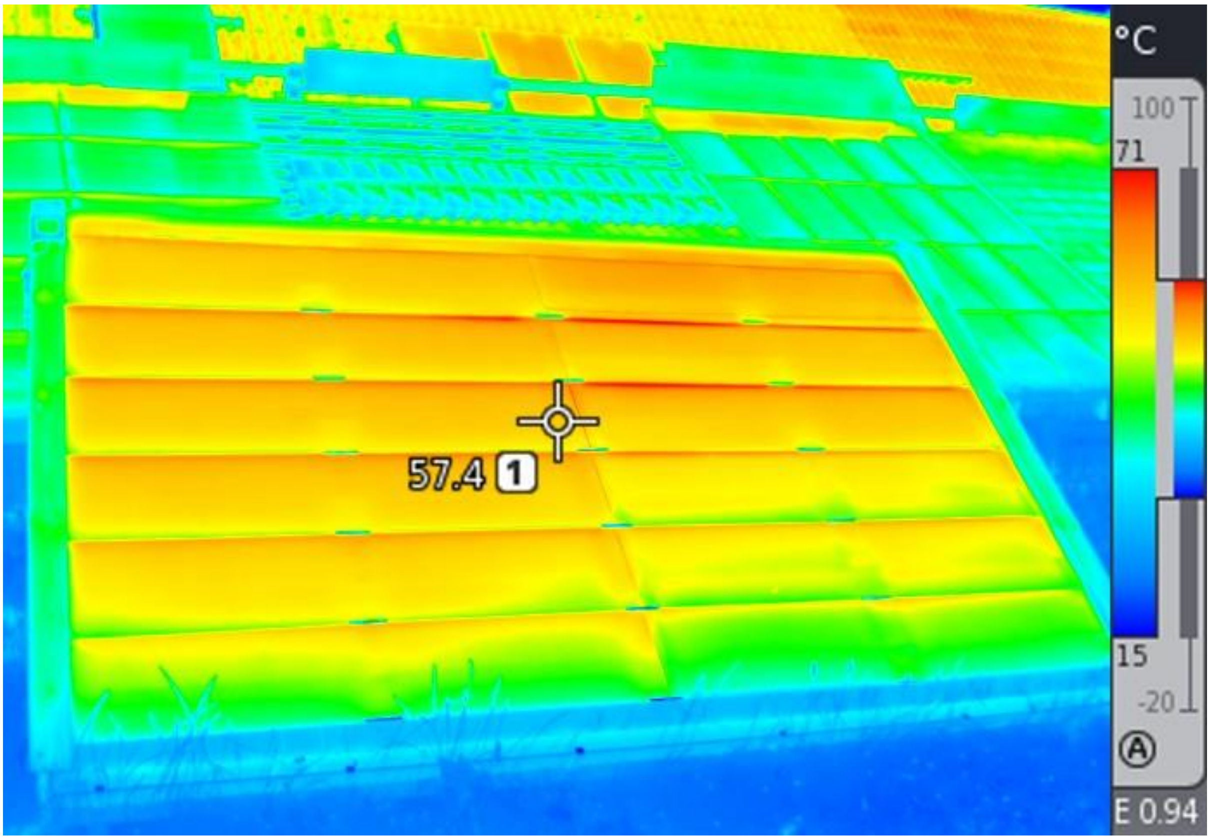

Figure 3 IR photo with idle PV modules.

When the modules are producing power, some of the energy is extracted as electricity, and the modules get colder. There is also some difference between the modules due to different colour and position in the array.

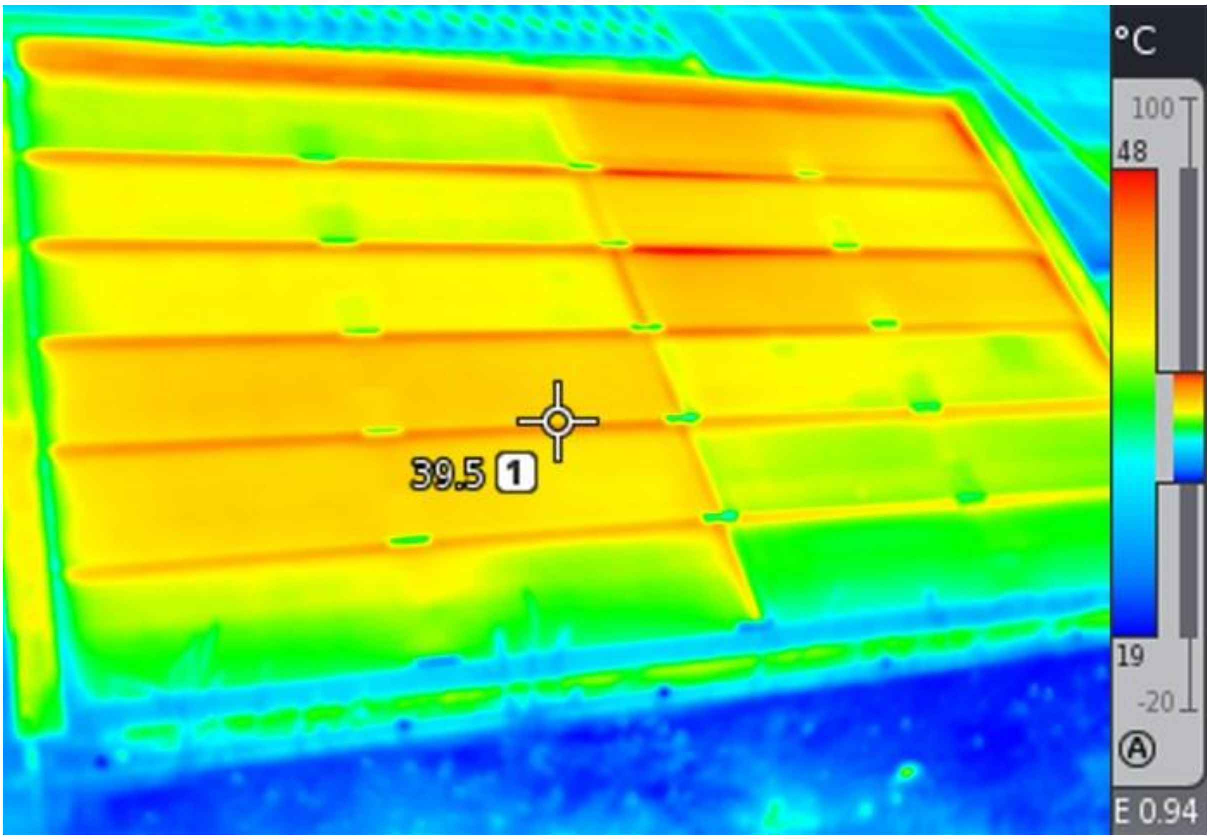

Figure 4 IR photo with active PV modules.

2. Refurbishment with new modules from DSE

Observations:
It was somewhat difficult to loosen the adhesive tape around the edges of the modules, but apart from that disassembly was easy. The construction looked tight and nice:

- No signs of water intrusion or excess humidity
- No signs of temperature damage or deformation of plastic parts
- Sign of corrosion on cable ends in junction boxes. DSE explains it could be because they used a silicone that gasses acetic fumes in the hardening process. Normally they use a neutral silicone.

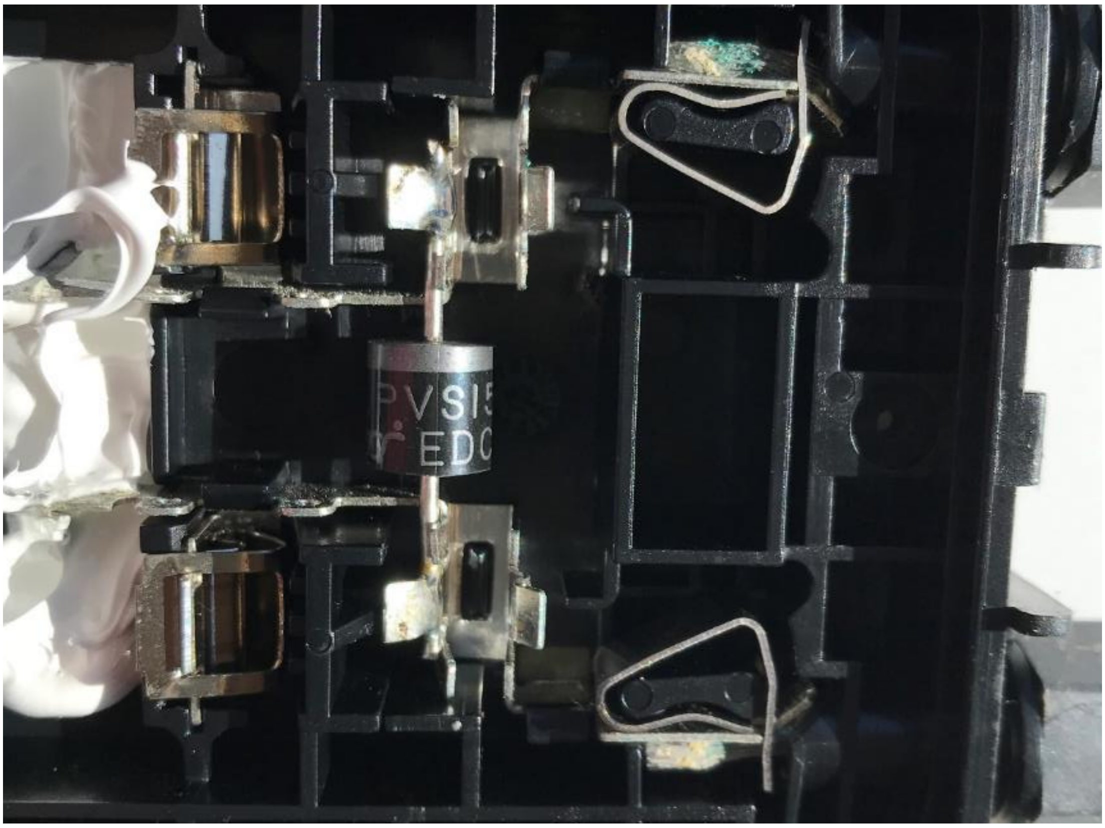

Figure 5 Diode box with visible corrosion products on cable ends.

Figure 6 Disassembly of edge profile and bitumen tape.

Figure 7 Removal of old modules from top and down. A rubber strip can be seen on the old module.

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Figure 8 Two new modules mounted. There is no rubber strip on these.

Figure 9 Due to narrow clearance from the PV cells to the edge of the glass, it was necessary to move the outer profile to avoid shadow of the cells.

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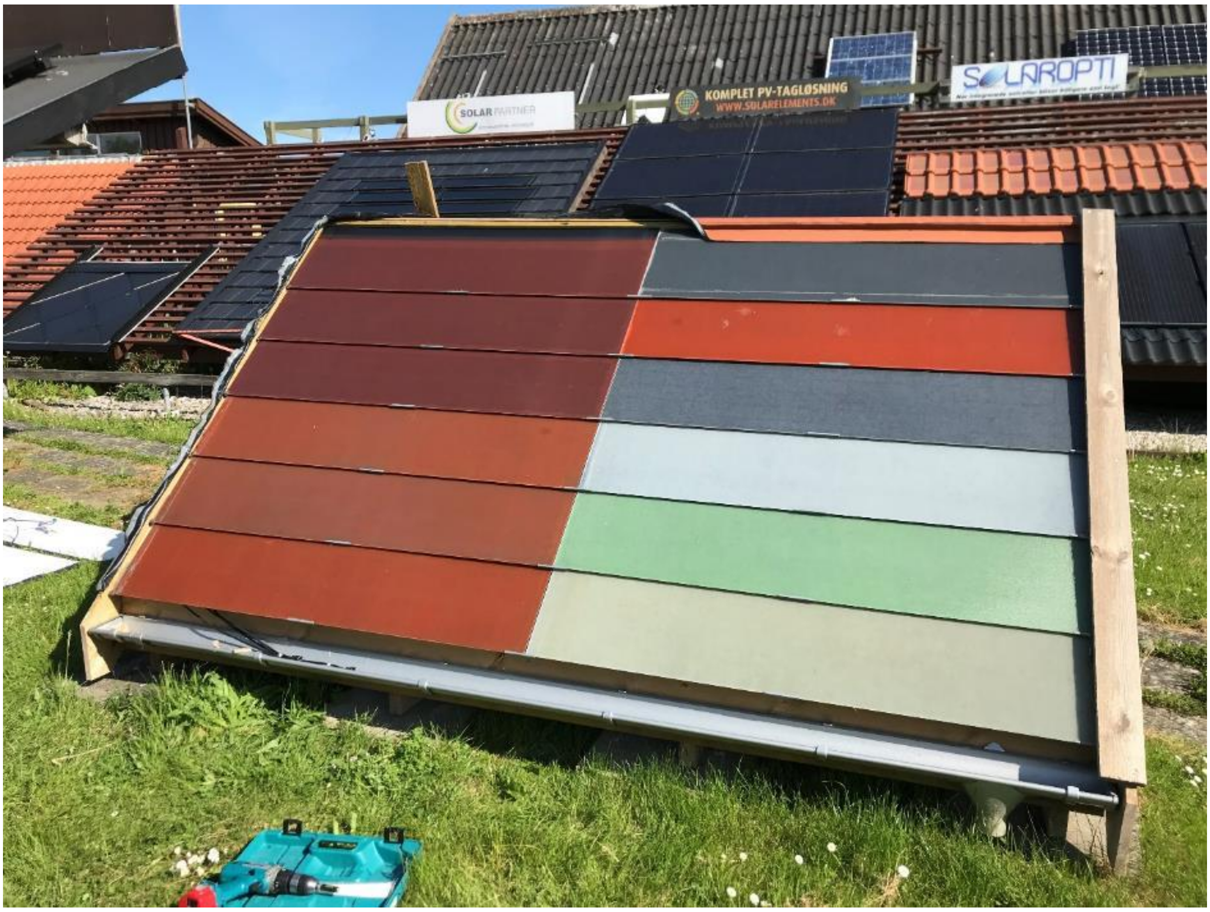

Figure 10 Final result, though the edges not repaired.

2.1. Power measurement of old modules by end of measurement period

23-05-2022:
A new IV curve measurement showed slightly higher values than the originally measured power. Taking a measurement accuracy of 5 % into account, the conclusion is that no degradation was detected after more than 3 years weather exposure at DTI (Last year in the PV-ROCK-ROOF mock-up).

2.2. Power measurement of new modules

23-05-2022:
Before placing the new modules in the mock-up, a measurement was made on each module individually and on all three in series. The measurements show a somewhat irregular curve; however, the power is much higher than for the old modules.


Figure 11 Set up for IV curve measurements with PVPM 6020 analyzer.

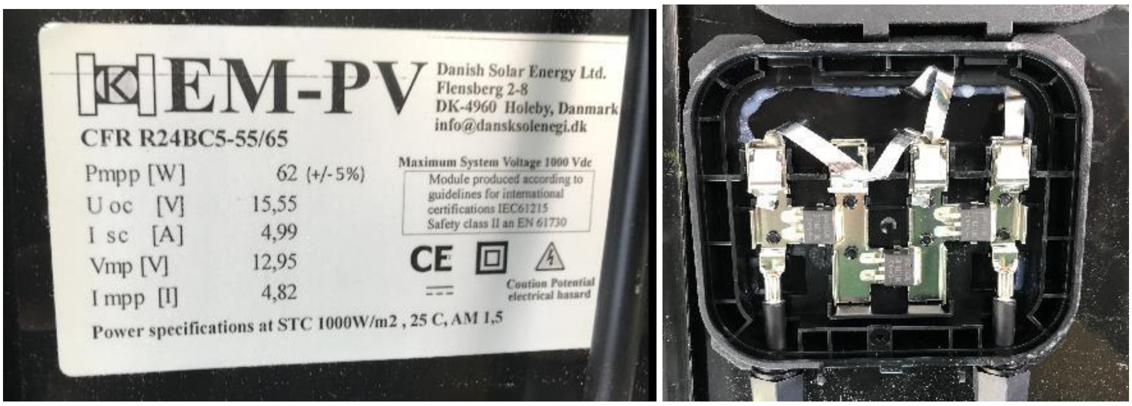

Figure 12 Name plate and junction box of the new modules.

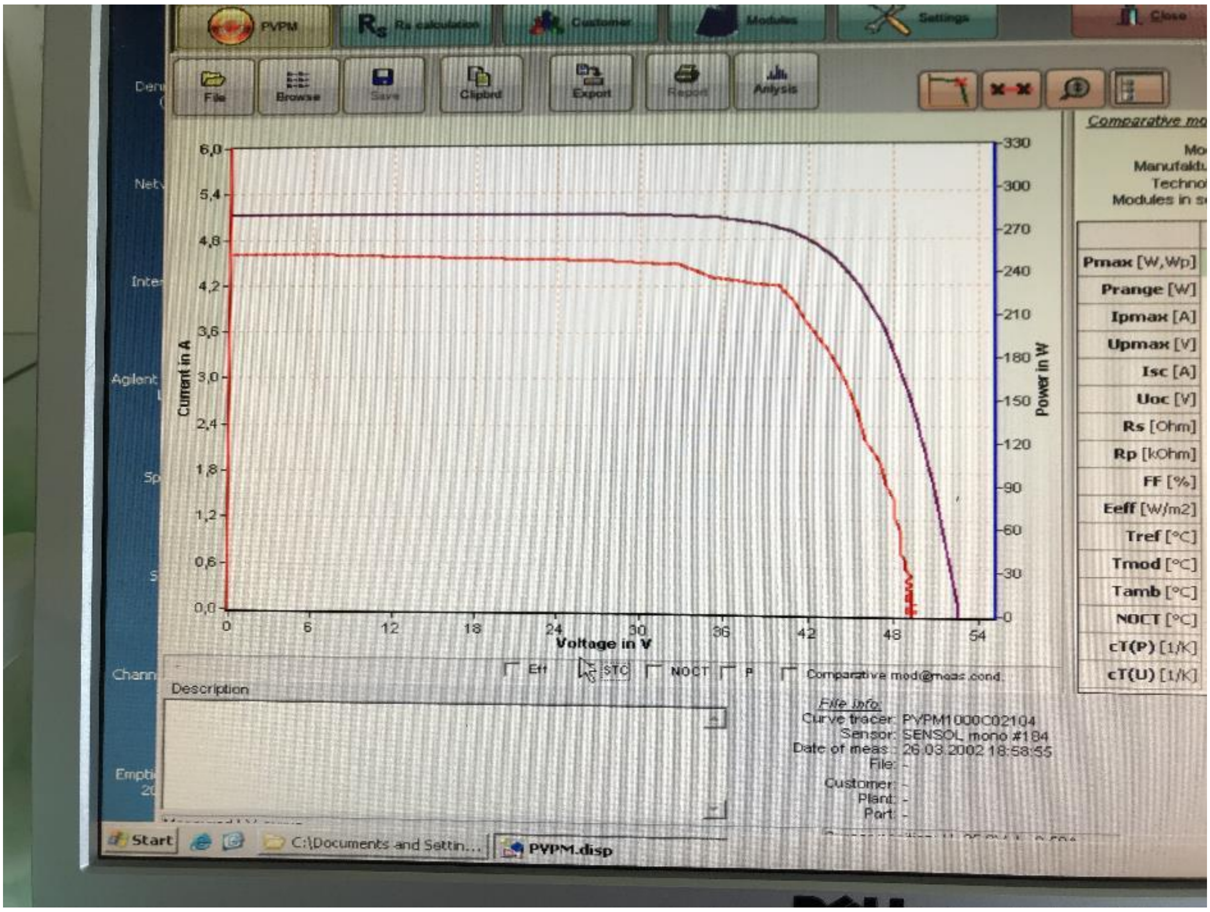

Figure 13 Photo of the measured IV curve for the modules in series connection. The red curve indicates some degree of mismatch, maybe due to variation of light absorption in the coloured interlayer.

The measured and STC corrected values for the new modules are: **198,9 Wp or 66Wp average per module.**

Measurement accuracy is estimated to 5 %.

The old modules are 124,7 Wp, so the new generation is performing 60 % higher for the same area.

3. Long term measurements on the mock-up

After installation, the measurements on the mock-up were continued with an inverter as load. The instrumentation is identical to the instrumentation in the first run.

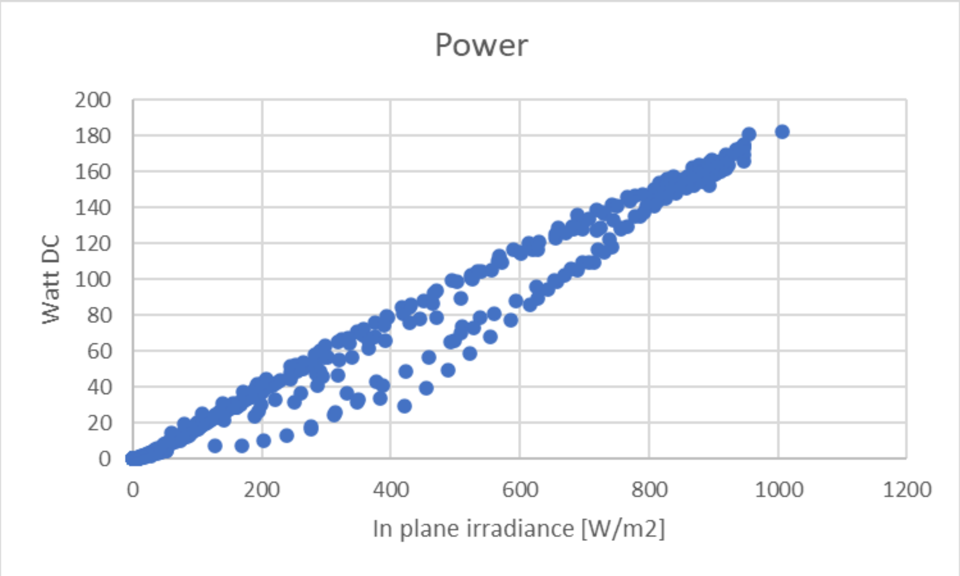

Figure 14 Power as a function of irradiance shows a band where the upper limit is close to the measured STC value. The lower band shows the power limitation due to shading effects in the afternoon.

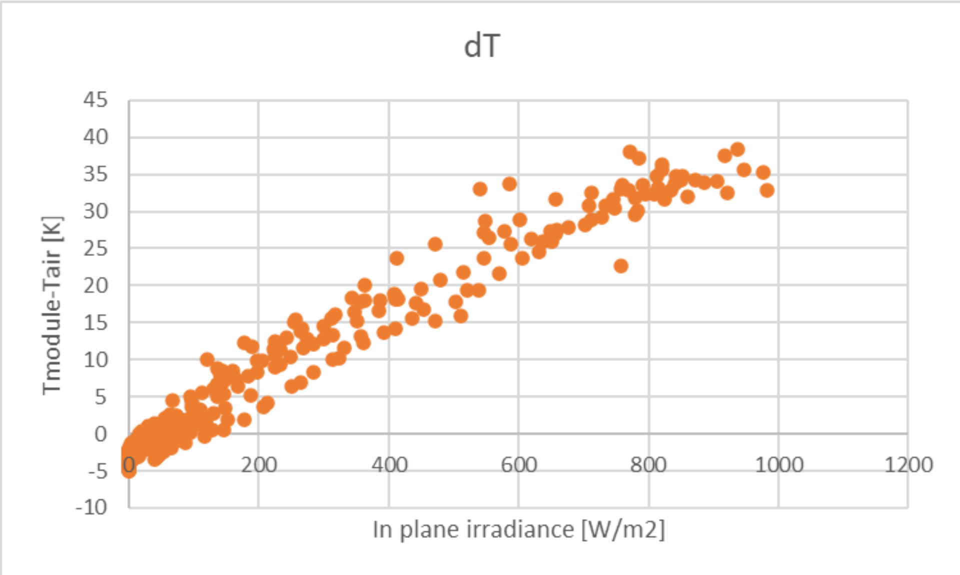

Figure 15 Module overtemperature as a function of irradiance.

As a check of the power level at standard testing conditions, data was selected for times with near perpendicular insolation and power corrected to a module temperature of 25 °C. The result at 1000 W/m^2 is very close to the power measured with the IV curve analyzer.

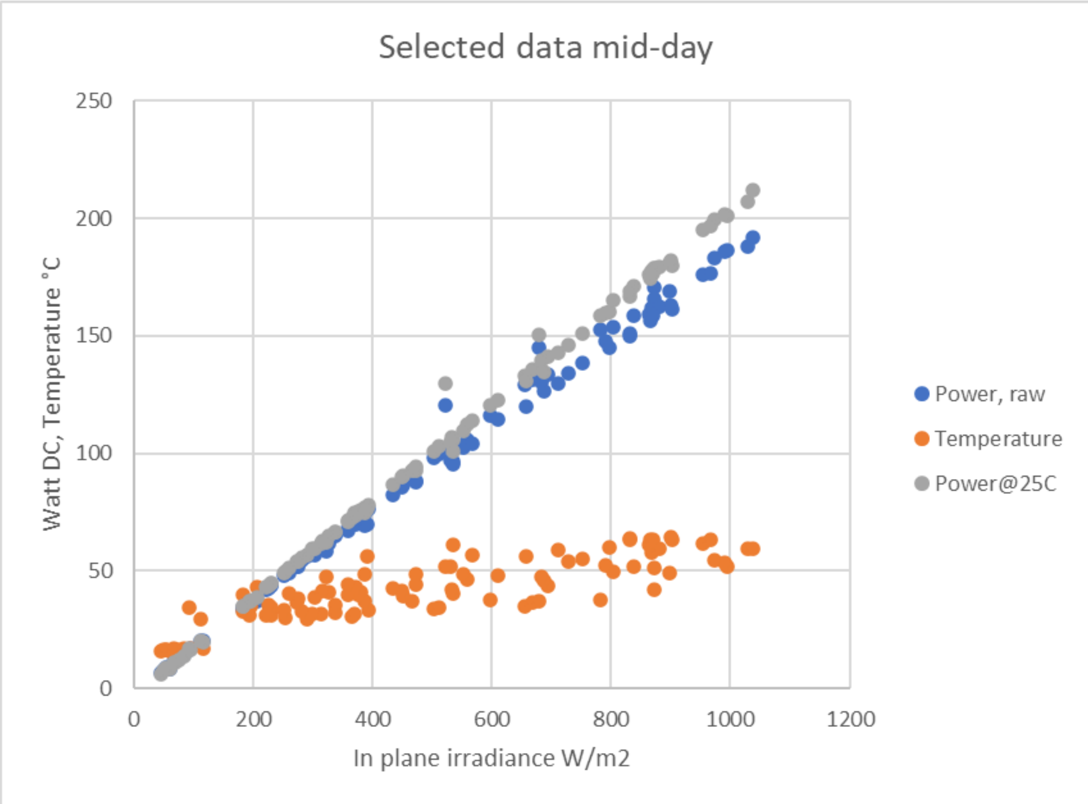

Figure 16 Power as a function of in plane irradiance confirm the nominal power of approximately 200 Wp for all three modules together.

Energy losses due to increased temperature for the whole period are difficult to calculate precisely because there has been some shadow on the modules from the surroundings. Furthermore, a system with rear ventilation would also have a varying temperature. Therefore, the energy loss has only been calculated theoretically.

3.1. Theoretical PV module temperature

In the proposed construction, the entire rear surface of the PV modules will be covered by Rockwool insulation. In practice, all heat loss will then take place from the upper surface of the PV module. This raises two concerns:

1) Increased maximum temperature on the module including bypass diodes, cables, and connect-ors.
2) Loss of energy due to higher average cell temperature.

The instantaneous cell temperature depends on the energy balance, which is mainly influenced by the solar irradiance, the cell efficiency, the module material and the surrounding wind speed and sky and air temperature. A simplified model has been developed using standard values for some common materials.

Heat transfer coefficient to the surroundings by convection and radiation from a surface can be expressed as:

Total thermal resistance R = 1/(Hc+Hr)
Radiation: Hr = Epsion x 4 x StBolz x Tmean ^{3}
Convection: Hc = 4 + 4 x Windspeed
Source: ISO/DS 6946: 2017 Bygningskomponenter og bygningsdele – Termisk modstand og termisk transmission – Beregningsmetoder.

If we assume a wind speed over the surface of 3 m/s and an average temperature of surface plus surroundings of 300 Kelvin, these coefficients become:
Hc= 16 W/m2K
Hr= 5,5 W/m2K
Htotal = 21.5 m2K/W and R total = 0.046 m2K/W

The PVsyst software assume the following values for Htotal:

- No ventilation: 15
- Some ventilation: 20
- Free standing: 29

The value found by ISO 6946 may therefore be a bit too high, but it is also a matter of wind speed, which again depends on building height.

The energy balance for the PV module is:

Solar input = Electricity + heat loss

The electrical efficiency is given by the manufacturer and is typically 15-20 % of the incident irradiance. Since we assume that the rear is completely insulated, the heat loss can only take place through the front.

The calculated cell temperature for some typical constructions, worst case:

- PV disconnected, efficiency = 0
- 1000 W/m2 irradiance
- No wind
- 30 °C air temperature

Results:

- 3 mm glas cover, free standing: 95 °C
- 3 mm glass cover, insulated back: 134(!) °C
- 0,5 mm Tedlar, insulated back: 115 °C.

The theoretical maximum temperatures are significantly higher than the actual measured surface temperatures, probably because there is some ventilation in practice in the mock-up.

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Diode and junction box temperature could be critical, so only products with high temperature tolerance should be used. Mitigation measures could be a colour adjustment towards a higher reflection of sunlight and the use of metal back laminate to distribute heat evenly.

Regarding the reduction of annual energy output, an analysis in Pvsyst results in the following specific performance for a system in Denmark (facing south and 30 degrees tilt angle):

- No ventilation: 975 kWh/kWp
- Some ventilation: 996 kWh/kWp
- Free standing: 1007 kWh/kWp

There is only a 3.2 % reduction in worst case.

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