Measurement Report – Test of PV/T-module ”PVtwin”

A Report of IEA SHC - Task 35

PV/Thermal Solar Systems

Report DC4-1

December, 2006

Ivan Katic

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

Measurement Report –
Test of PV/T-module ”PVtwin”

by

Ivan Katic

A technical report of Subtask C
Report DC4-1

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SHC
SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

IEA Solar Heating and Cooling Programme

The *International Energy Agency* (IEA) is an autonomous body within the framework of the Organization for Economic Co-operation and Development (OECD) based in Paris. Established in 1974 after the first “oil shock,” the IEA is committed to carrying out a comprehensive program of energy cooperation among its members and the Commission of the European Communities.

The IEA provides a legal framework, through IEA Implementing Agreements such as the *Solar Heating and Cooling Agreement*, for international collaboration in energy technology research and development (R&D) and deployment. This IEA experience has proved that such collaboration contributes significantly to faster technological progress, while reducing costs; to eliminating technological risks and duplication of efforts; and to creating numerous other benefits, such as swifter expansion of the knowledge base and easier harmonization of standards.

The *Solar Heating and Cooling Programme* was one of the first IEA Implementing Agreements to be established. Since 1977, its members have been collaborating to advance active solar and passive solar and their application in buildings and other areas, such as agriculture and industry. Current members are:

Australia
Austria
Belgium
Canada
Denmark
European Commission
Germany
Finland
France
Italy
Mexico
Netherlands
New Zealand
Norway
Portugal
Spain
Sweden
Switzerland
United States

A total of 44 Tasks have been initiated, 33 of which have been completed. Each Task is managed by an Operating Agent from one of the participating countries. Overall control of the program rests with an Executive Committee comprised of one representative from each contracting party to the Implementing Agreement. In addition to the Task work, a number of special activities—Memorandum of Understanding with solar thermal trade organizations, statistics collection and analysis, conferences and workshops—have been undertaken.

To find Solar Heating and Cooling Programme publications and learn more about the Programme visit **www.iea-shc.org** or contact the SHC Executive Secretary, Pamela Murphy, e-mail: pmurphy@kmgrp.net.

The Tasks of the IEA Solar Heating and Cooling Programme, both underway and completed are as follows:

Current Tasks & Working Group:

Task 35	*PV/Thermal Solar Systems*
Task 36	*Solar Resource Knowledge Management*
Task 37	*Advanced Housing Renovation with Solar & Conservation*
Task 38	*Solar Thermal Cooling and Air Conditioning*
Task 39	*Polymeric Materials for Solar Thermal Applications*
Task 40	*Net Zero Energy Solar Buildings*
Task 42	*Compact Solar Thermal Energy Storage*
Working Group	*Daylight Research Group*

Completed Tasks:

Task 1	*Investigation of the Performance of Solar Heating and Cooling Systems*
Task 2	*Coordination of Solar Heating and Cooling R&D*
Task 3	*Performance Testing of Solar Collectors*
Task 4	*Development of an Insolation Handbook and Instrument Package*
Task 5	*Use of Existing Meteorological Information for Solar Energy Application*
Task 6	*Performance of Solar Systems Using Evacuated Collectors*
Task 7	*Central Solar Heating Plants with Seasonal Storage*
Task 8	*Passive and Hybrid Solar Low Energy Buildings*
Task 9	*Solar Radiation and Pyranometry Studies*
Task 10	*Solar Materials R&D*
Task 11	*Passive and Hybrid Solar Commercial Buildings*
Task 12	*Building Energy Analysis and Design Tools for Solar Applications*
Task 13	*Advance Solar Low Energy Buildings*
Task 14	*Advance Active Solar Energy Systems*
Task 16	*Photovoltaics in Buildings*
Task 17	*Measuring and Modeling Spectral Radiation*
Task 18	*Advanced Glazing and Associated Materials for Solar and Building Applications*
Task 19	*Solar Air Systems*
Task 20	*Solar Energy in Building Renovation*
Task 21	*Daylight in Buildings*
Task 23	*Optimization of Solar Energy Use in Large Buildings*
Task 22	*Building Energy Analysis Tools*
Task 24	*Solar Procurement*
Task 25	*Solar Assisted Air Conditioning of Buildings*
Task 26	*Solar Combisystems*
Task 28	*Solar Sustainable Housing*
Task 27	*Performance of Solar Facade Components*
Task 29	*Solar Crop Drying*
Task 31	*Daylighting Buildings in the 21st Century*
Task 32	*Advanced Storage Concepts for Solar and Low Energy Buildings*
Task 33	*Solar Heat for Industrial Processes*
Task 34	*Testing and Validation of Building Energy Simulation Tools*

Completed Working Groups:

CSHPSS, ISOLDE, Materials in Solar Thermal Collectors, and the Evaluation of Task 13 Houses

IEA SHC Task 35 PV/Thermal Solar Systems

Objective

The objectives of the Task are to catalyze the development and market introduction of high quality and commercial competitive PV/Thermal Solar Systems and to increase general understanding and contribute to internationally accepted standards on performance, testing, monitoring and commercial characteristics of PV/Thermal Solar Systems in the building sector.

The Task is organized in 5 subtasks:

- Subtask A: Market and Commercialization of PV/T
- Subtask B: Energy Analysis and Modeling
- Subtask C: Product and System Development, Tests and Evaluation
- Subtask D: Demonstration Projects
- Subtask E: Dissemination

Organisation

IEA SHC Task 35 "PV/Thermal Solar Systems" is a three year Task initiated by the International Energy Agency (IEA) Solar Heating and Cooling (SHC) Programme in January 2005.
The Danish Energy Authority, acting through Mr. Henrik Sørensen, Esbensen Consulting Engineers A/S, Denmark, is designated as Operating Agent for the Task.

Task 35 is a so-called "minimum-level" collaboration task with IEA PVPS (Photovoltaic Power Systems Programme). At this level, experts selected by the PVPS Executive Committee participate in experts meetings of the Task managed by the SHC Executive Committee. The Task is fully defined and managed by the SHC Executive Committee with appropriate input from the PVPS Executive Committee. In this project Israel participated as a PVPS country member.

The official participants in the Task are listed in the table below:

Country	**Organization**	**Person**
Canada	Dept. of Mechanical Engineering, University of Waterloo, Waterloo, Ontario, Canada	Mike Collins
Denmark	Esbensen Consulting Engineers A/S	Henrik Sørensen
	Solar Energy Center, Danish Technological Institute	Ivan Katic
Israel	Millennium Electric	Ami Elazari
Sweden	Lund Technical University	Björn Karlsson Johan Nilsson Bengt Perers
The Netherlands	ECN (Energy Research Centre of the Netherlands)	Wim van Helden Herbert Zondag Marco Bakker

Apart from the above mentioned a number of manufacturers, universities, and research institutes from the countries Germany, Greece, Hong Kong, Italy, South Korea, Thailand, and Spain have been involved in the work.

Visit the Task 35 website: http://www.iea-shc.org/task35 for more details on activities and results.

IEA Task 35

Measurement report:

Test of PVT module “PVtwin”

Ivan Katic
Solar Energy Center
Danish Technological Institute
December 2006

Table of Content:

0. Foreword

This measurement report was produced as part of the Danish contribution to the IEA co-operation on photovoltaic/thermal solar energy conversion (Task 35). The measurements took place at Danish Technological Institutes outdoor test facility in Taastrup, Denmark in the period June-September 2006. The results are valid for the tested prototype exclusively.

1. Product identification

PVtwins
P.O.Box 9308
1800 GH Alkmaar
the Netherlands

Product:	PVtwin 422 (prototype)
Dimensions:	190 x 190 x 16 cm^3
Aperture area	2.56 m^2
Absorber type:	Flat copper plate with serpentine tubes (copper)

2. Test conditions

Mounting:	45 deg slope, facing south
PV modules	4 sections, 2x2 series connection
Load:	Gridfit LV Inverter (integrated MPPT function)
Fluid:	Water
Flow rate:	3 l/min (ca 1 l/min pr m2)
Wind:	Constantly running fan giving a minimum wind speed of 1 m/s

3. Preparation of measurements

The PVT collector was received in June 2006, and after opening the box there were no visible transport damages. However, just after mounting on the test rig, it was discovered that one of the fluid exits had become loose. Therefore the rear insulation was carefully removed for tightening of the T-joint compression fitting

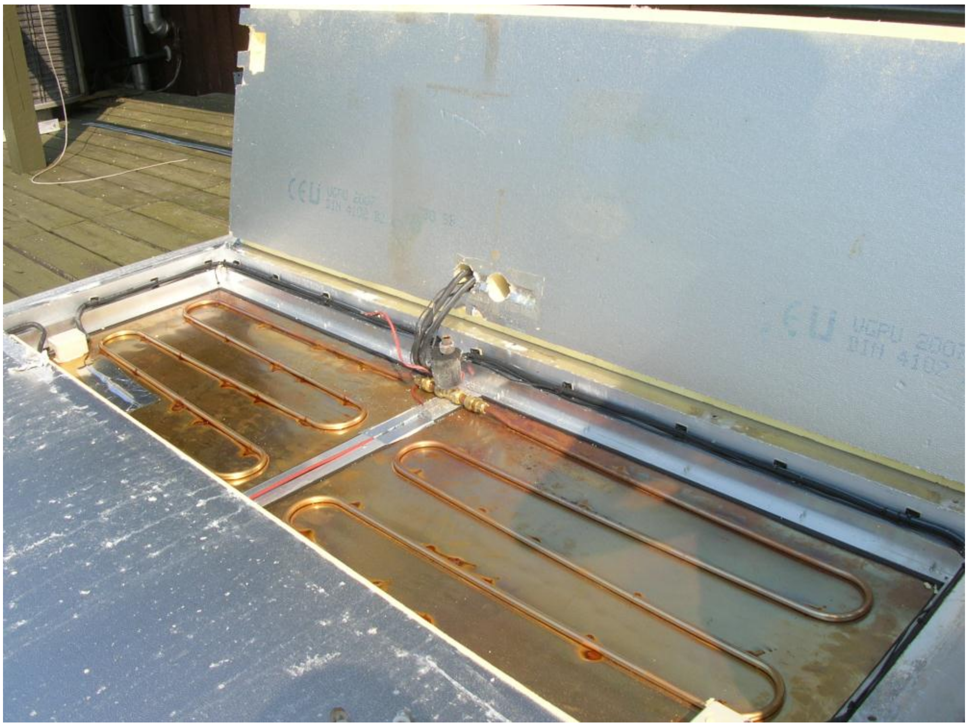


Figure 1. Rear insulation removed for repair.

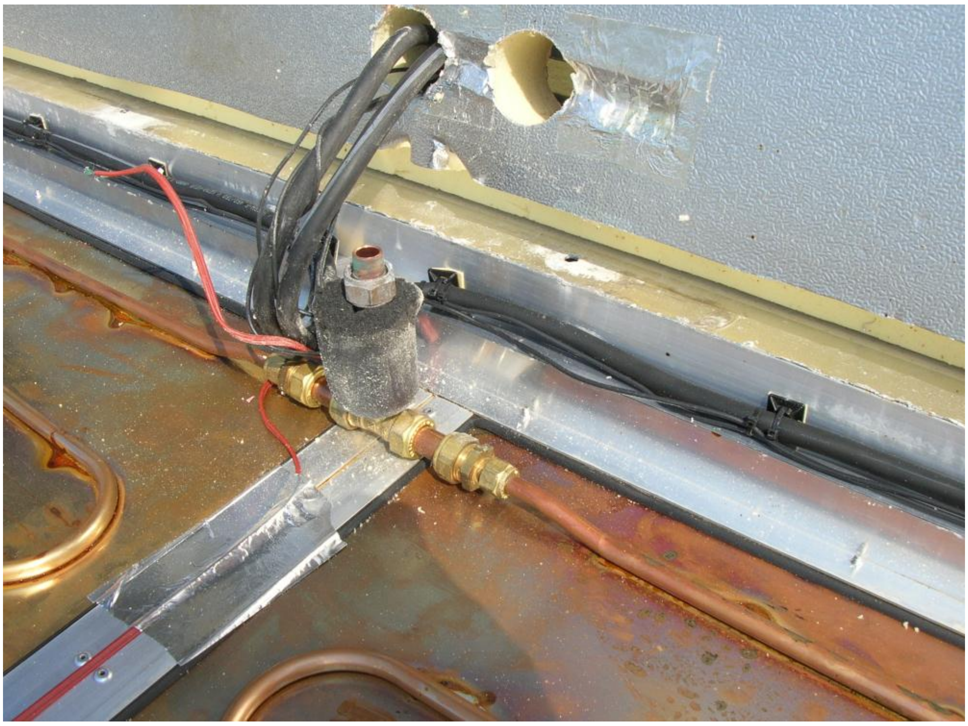


Figure 2. Compression T-joint and cabling details

After repair, the fluid circuit was connected and pressurized, and the thermal measurements could begin. The electrical circuit consists of four PV panels, of which two and two are internally connected in parallel. In order to achieve a reasonably high voltage for the load (inverter), it was decided to connect the two halves in series in the external junction box.
The nominal open circuit voltage would then be 42-43 Volt, short circuit current 9,3 A, which is suitable for a Gridfit LV inverter. The inverter´s only function is to keep the PV panel on its MPPT all the time. Inverter data is found in Annex 1.

4. Data acquisition system

The thermal measurements were carried out on the standard data logger system normally used for thermal solar collectors, consisting of Pt 100 temperature sensors, irradiance sensors, anemometers, and induction flow meters. Data are logged every 10 seconds and saved for every 5 minutes

Temperature at the collector inlet is controlled by mixing water from a cold and a warm tank. Flow is controlled by a regulated motor valve. See Annex 3 for a drawing of the test rig.

For the electric output, a separate data logger was used with the same set up of scan and storage intervals. DC current was measured with a shunt resistor, voltage with voltage divider.

5. Thermal performance results

The thermal performance was measured continuously during the period, but only those data from quasi-stationary operation and G >700 W/m^2 have been selected, according to EN-12975. Data has only been taken for a few hours around solar noon, in order to avoid any edge shading or increased reflection losses.
The data points used for generation of the linerarised efficiency curves have been obtained as the mean value of 16 data records taken from as stationary periods as possible. First a series of data was collected without connection of the PV module (idle). In this case the thermal efficiency can be expressed as:

Start efficiency:	0.67
Heat loss coefficient:	8.20 W/m^2 pr K

It was not possible to find any good data points at high temperature during the measurement period, as it can be seen on the graph. After connection of the PV module to a grid connected inverter, thermal data were again selected for various inlet temperatures of the collector. When the maximum amount of power is extracted from the PV panels, the thermal performance can be expressed as:

Start efficiency:	0.60
Heat loss coefficient:	7.37 W/m^2 pr K

The efficiency was calculated based on the transparent area of 2.56 m^2.

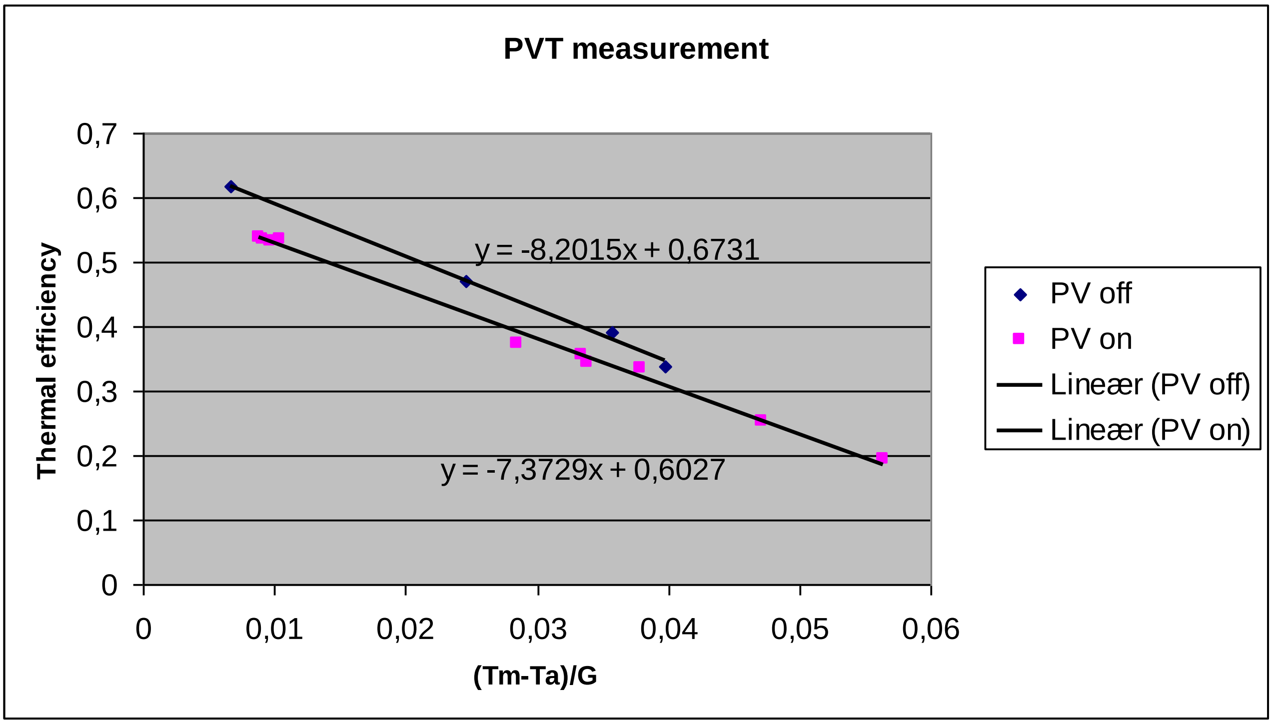


Figure 3. Thermal efficiency results with linear trend curves. T_m = mean fluid temperature. T_a = ambient temperature. G = Total irradiance (W/m^2)

A linear expression seem to fit very well to the data, presumably because the collector has a non-selective absorber surface, where the heat loss coefficient is not very temperature dependent.

The thermal efficiency curve is characterized by a rather high heat loss coefficient, which is to be expected by a non-selective collector. However, it could probably be reduced if the cooling of the absorber surface was improved by a better thermal conductance between cupper tube and absorber sheet.

The data set with the PV module in operation are listed in the table below:

Tm≈	Data 1		Data 2		Data 3		Data 4	
ºC	Tred	η	Tred	η	Tred	η	Tred	η
40	0,0105	0,54	0,0097	0,53	0,0088	0,54	0,0091	0,54
60	0,0333	0,36	0,0285	0,37	0,0338	0,34	0,0379	0,34
80	0,0564	0,19	0,0472	0,25				

6. Electrical performance results

Short term measurements have been carried out by using a special I-V curve tracer PVPM 6020C developed for this purpose. The graph below shows the measured I-V curve as well as the curve corrected to STC conditions (1000 W/m2 and 25 degC cell temperature) for the entire array of 2 x 2 sub modules.

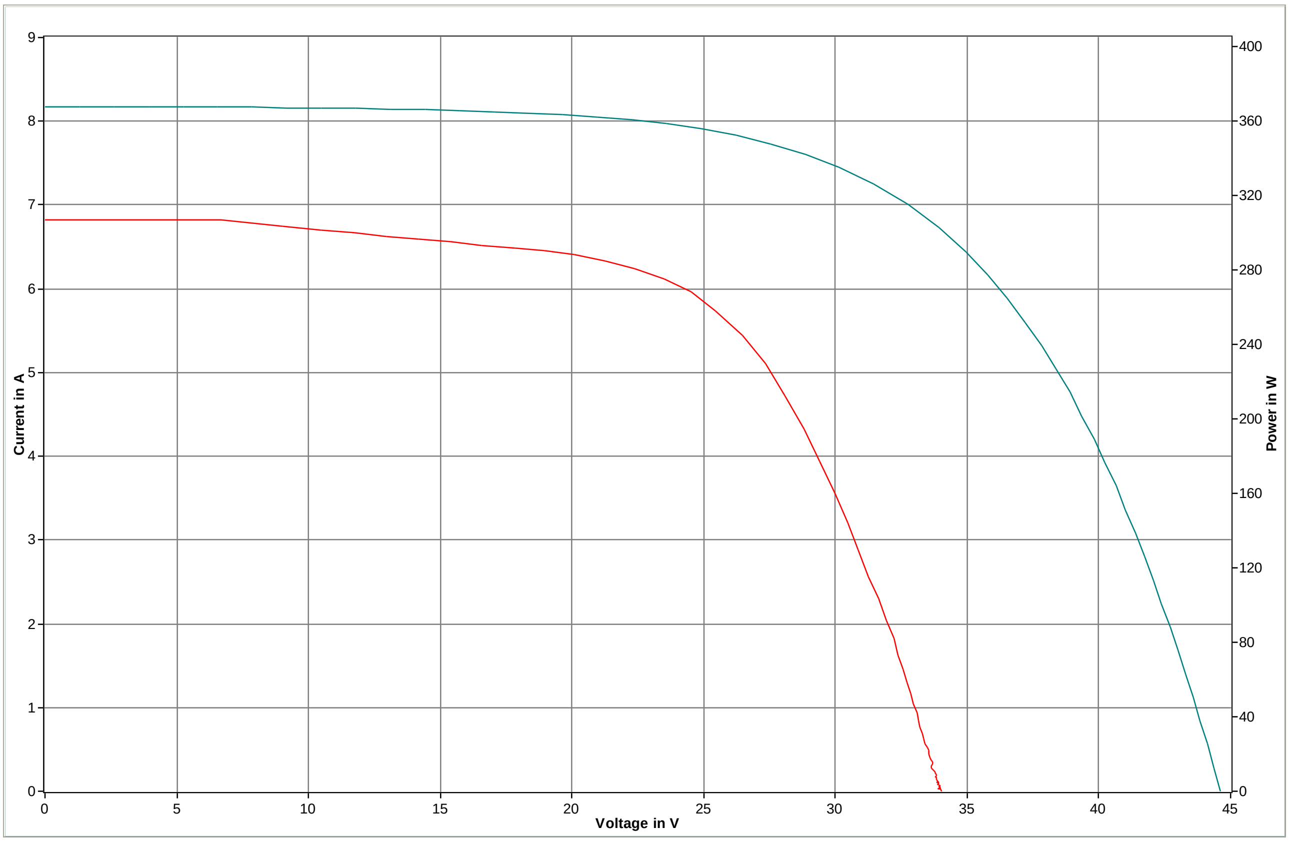


Figure 4. Measured IV curve (lower) and converted to STC conditions (upper)

Data corrected to STC					Measured values									
Im0 / A	**Um0 / V**	**Ppk / W**	**Isc0 / A**	**Uoc0 / V**	Ipmax / A	Upmax / V	Pmax / W	Isc / A	Uoc / V	Rp / kOhm	Rs / Ohm	FF /	T / °C	E / W/m2
7,00	**32,8**	**229,6**	**8,17**	**44,6**	5,85	25,0	146,3	6,83	34,0	>0,21	1,6	0,630	77,0	835

The electric performance is slightly affected by a partially defective module in one of the quadrants. The measured peak power of 230 W at STC is about 20% lower than the flash test result of 287,6 W given by ECN, but since that was before integration under an extra glass cover and before interconnection (involving mismatch losses) it is a reasonable result.

It can be seen that the optimum operating voltage is around 33 V at STC, but considerably lower (25 V) at the actual temperature of 77 degC as measured with the built-in NTC sensor.

Long term measurements were collected with the inverter connected to the PV modules, together with the measurement of thermal performance. A linear relation is found for the DC power as a function of irradiance, as it should be expected. However, for irradiance values higher than 900 W/m^2, data have been rejected because the inverter reduces power input as overload protection. The data have been sorted in bins according to the absorber temperature, and as expected there is a reduction in power as temperature rises.

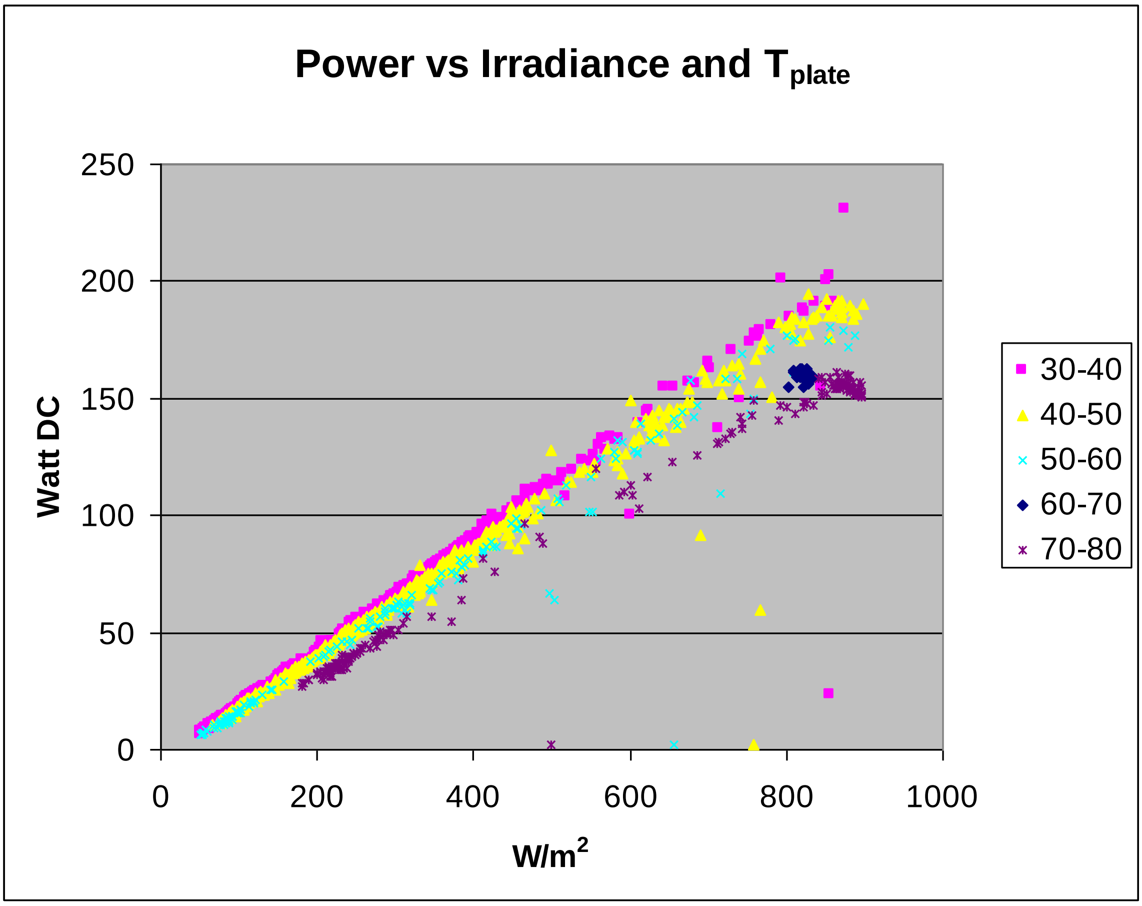


Figure 5. Electric power as a function of irradiance and temperature (Raw data). Some erratic data points due to non-stationary conditions.

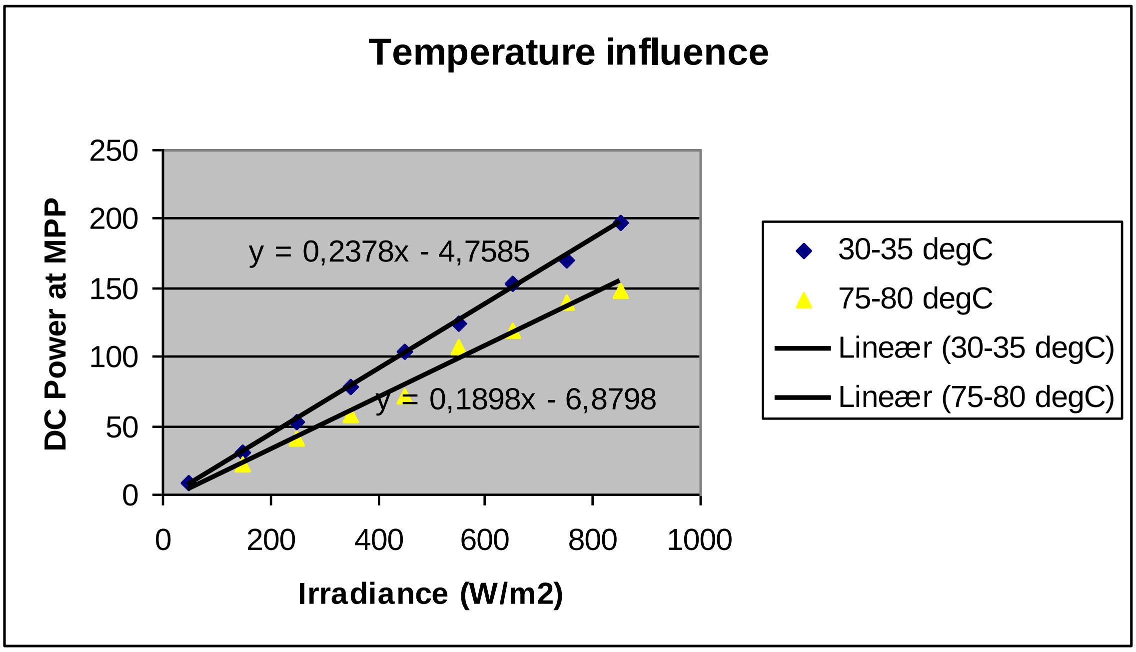


Figure 6. Electric power as a function of irradiance and temperature (Sorted in irradiance bins)

Based on these data, the temperature coefficient of module power is found to *-0.48 % per K*

Power matrix based on mean values of sorted raw data:

Temp. range	*25-30*	*30-35*	*35-40*	*40-45*	*45-50*	*50-55*	*55-60*	*60-65*	*65-70*	*70-75*	*75-80*	*80-85*
G (W/m^2)												
0-100	12	12	10	15	14	12	6					
100-200	23	25		30	27	22					28	22
200-300	56	48	64	50	50	52	50			41	38	31
300-400	80	83	74	75	71	69	64				57	51
400-500	102	98	102	94	95	89				97	72	63
500-600		123	124	123	120	112	116				113	100
600-700		150	145	143	139	138	139				116	231
700-800		170	173	154	155	155				145	138	127
800-900		197	192	189	184	176	176	161	160	157	152	141

The table shows the DC power at MPP for each of the data bins, empty fields meaning no data. In some cases the mean value of the irradiance can be quite far from the middle of the bin, so in order to correct for this, the power was corrected to P_{corr} = Power x Bin mean value(G)/Mean($G_{measured}$)

Power matrix with correction to mid of irradiance bin:

Temp. range	*25-30*	*30-35*	*35-40*	*40-45*	*45-50*	*50-55*	*55-60*	*60-65*	*65-70*	*70-75*	*75-80*	*80-85*
G (W/m^2)												
0-100	8	8	8	9	8	7	6					
100-200	29			29	28	27					22	18
200-300	55	53	55	52	51	50	48			44	40	34
300-400	79	79	77	75	73	71	66				57	52
400-500	103	103	102	98	96	91				94	71	68
500-600		125	124	123	118	113	113				107	97
600-700		154	146	145	140	139	147				118	113
700-800		171	173	156	155	154				141	139	128
800-900		197	194	187	185	180	172	169	165	154	148	138

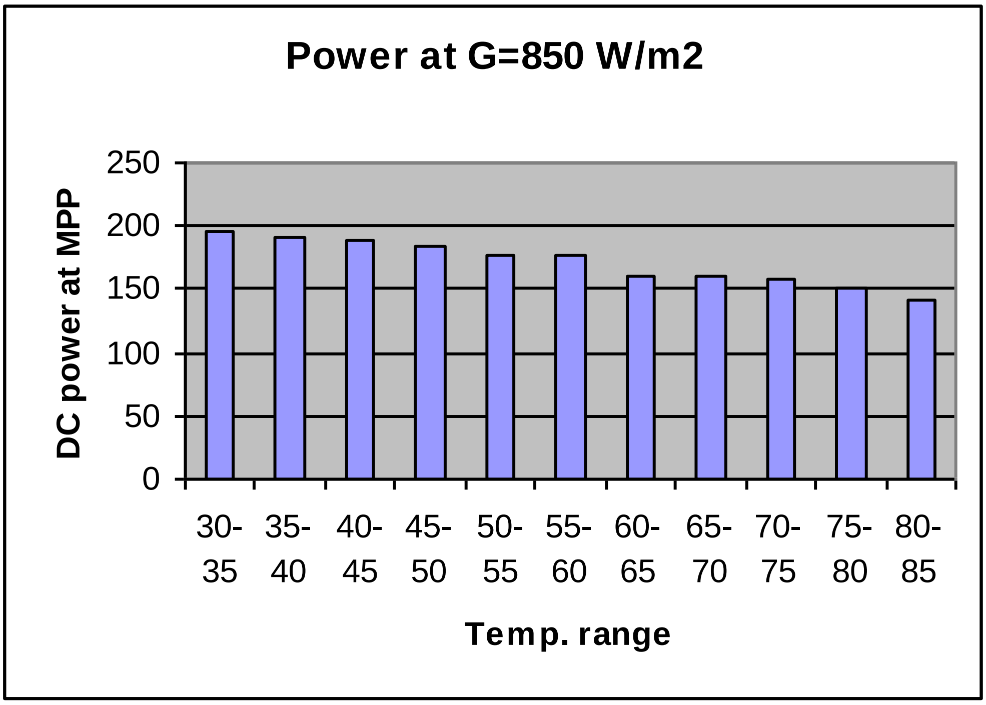


Figure 7. Temperature effect on module performance

7. Experience with the test method:

The procedure in *"D8-6:PVT performance measurement guidelines"(PV-Catapult)* for simultaneous PV and thermal test was only followed part of the time, since the test circuit for the thermal part was ready first, and the weather was good for testing. The thermal test was first carried out without the PV panel in operation, i.e. as a normal solar collector test. Apart from the usual problems with selection of periods with steady-state operation, this test ran smoothly.

After connection of the PV circuit (with its own measurement system), the thermal test was repeated. It is assumed that the load connected to the PV panel (a Gridfit inverter) keeps the voltage at the MPP all the time. This approximation was found not to be valid at high power levels, most likely because the room where the inverter was installed became warm during the test, and the inverter protected itself from overheating by reducing power throughput. Therefore, all data recorded at irradiance levels over 900 W/m^2 were rejected.

The claimed MPPT efficiency for the inverter of more than 98% could not be verified directly, but current and voltage was measured continuously. Together with a measurement of the power curve, the operating voltage could be cross checked for discrete temperature and irradiance levels, and seemed to be within the expected range.

The temperature of the modules was measured with one of the internal NTC sensors (no 338a) and the resistance signal converted according to the table and approximate conversion formula below:

T (degC)	R (Ohm)
0	43240,2
10	25599,2
20	15608,4
25	12319,1
30	9783,86
40	6288,92
50	4138
60	2782,89
70	1909,47
80	1335,4
90	949,56
T = -25,246Ln(R) + 261,45	

The temperature was checked against the Pt100 sensors at the fluid inlet and outlet. The result is listed in the table below:

Resistance	Tplate	Tfluid,h	Tfluid,l	dT	Irradiance (W/m2)
1259,4	81,2	78,8	76,6	3,5	870,1

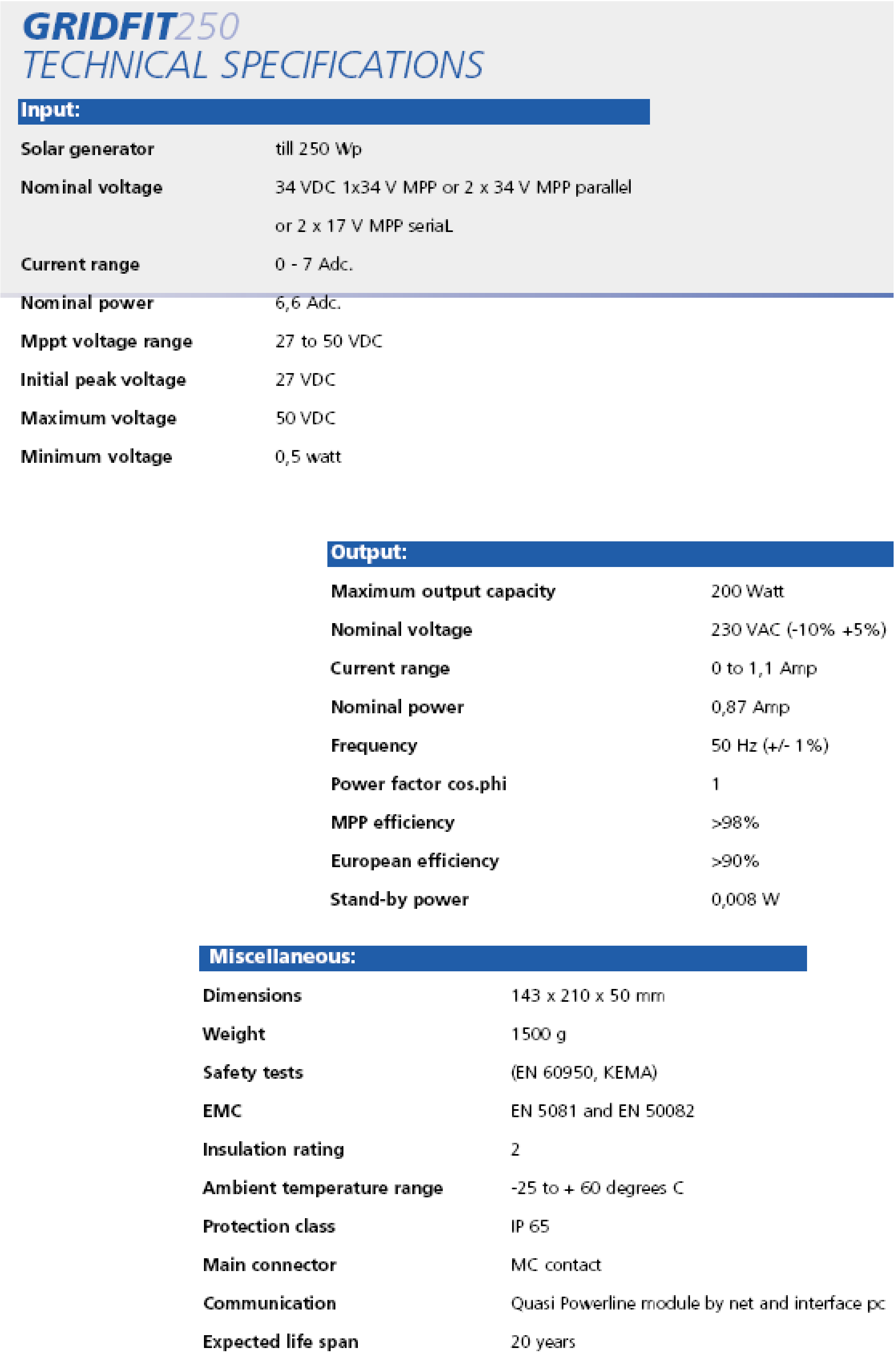
The error is in this case 3.5 K if the mean fluid temperature is used instead of the rear PV module temperature. In practice this temperature can be difficult to measure if a sensor has not been installed during fabrication.

The automatic long term data acquisition has the advantage that one can cover a wide range of operation conditions, but it takes time to sort the data, and many data have to be rejected as out of range or because they have been collected under unstable operating conditions. Even after sorting the data, there are some scatter in the results, that may have been avoided with a better control of the operating conditions, e.g. manual surveillance.

In summary, the method worked reasonably well, but a few practical changes could be:

- the number of data could easily be reduced, it is better to have a few good data over a wide operating range than a huge amount around same conditions. Automatic sorting of data before saving could help this.
- Given the unpredictable weather and long time constant of PVT collectors, it was not easy to select periods with energetic equilibrium. Again automatic sorting would help.
- The load on the pv module was not 100% precise with respect to MPP tracting at very low or very high irradiance. A specialised MPP load had been helpful.

Appendix 1 Gridfit Inverter (MPPT load):



GRIDFIT250
TECHNICAL SPECIFICATIONS

Input:	
Solar generator	till 250 Wp
Nominal voltage	34 VDC 1x34 V MPP or 2 x 34 V MPP parallel or 2 x 17 V MPP serial.
Current range	0 - 7 Adc.
Nominal power	6,6 Adc.
Mppt voltage range	27 to 50 VDC
Initial peak voltage	27 VDC
Maximum voltage	50 VDC
Minimum voltage	0,5 watt

Output:	
Maximum output capacity	200 Watt
Nominal voltage	230 VAC (-10% +5%)
Current range	0 to 1,1 Amp
Nominal power	0,87 Amp
Frequency	50 Hz (+/- 1%)
Power factor cos.phi	1
MPP efficiency	>98%
European efficiency	>90%
Stand-by power	0,008 W

Miscellaneous:	
Dimensions	143 x 210 x 50 mm
Weight	1500 g
Safety tests	(EN 60950, KEMA)
EMC	EN 5081 and EN 50082
Insulation rating	2
Ambient temperature range	-25 to + 60 degrees C
Protection class	IP 65
Main connector	MC contact
Communication	Quasi Powerline module by net and interface pc
Expected life span	20 years

Appendix 2 Manufacturer's specifications

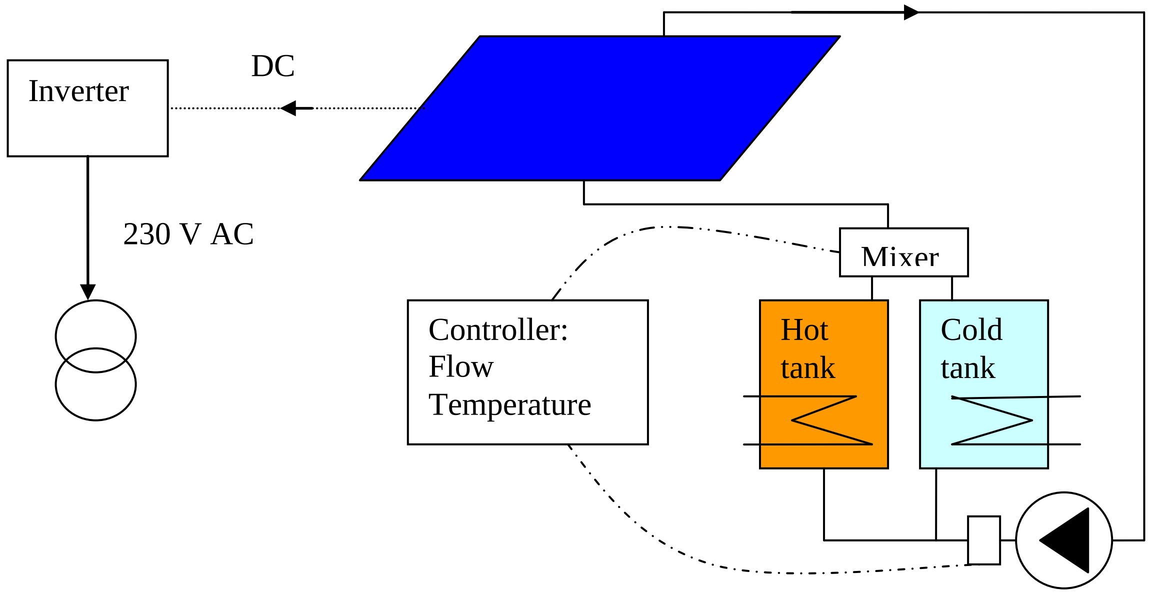
PVT-collector	Dimensions Collectorbox *(m)	Aperture (m2)	Nom. Electrical output **(W)	Nom. Thermal output **(W)
PVTWIN 212	1.050 * 1.895	1.28	150	765
PVTWIN 313	1.050 * 2.760	1.92	220	1150
PVTWIN 422	1.895 * 1.895	2.56	295	1535
PVTWIN 515	1.050 * 4.245	3.20	370	1920
PVTWIN 616	1.050 * 5.325	3.84	440	2300
PVTWIN 623	1.895 * 2.760	3.84	440	2300
PVTWIN 824	1.895 * 3.615	5.12	590	3072
PVTWIN 1025	1.895 * 4.245	6.40	735	3840

** The outer edge is 8 cm wide and covered with roof tiles when the collector is integrated in the roof.*

*** Component power at STC (irradiance 1000 W/m2 and ambient temperature 25°C). Depends on the type of solar cells.*

Photo of the absorber (from PWtwins homepage)

Appendix 3 Experimental set-up:



Measurement points:

Location	**Quantity**	**Sensor**
Collector inlet	Temperature	Pt100
Collector outlet	Temperature	Pt100
Ambient	Temperature	Pt100
Collector loop	Flow	Inductive
Plane of array	Total irradiance	Eppley pyranometer
Plane of array	Diffuse irradiance	Eppley pyranometer
Plane of array	Wind speed	Cup anemometer
PV module outlet	DC current	Shunt resistor
PV module outlet	DC voltage	Voltage divider
PV rear, mid of lower module	Temperature	NTC (integrated)