Measurement Report – Test of PV/T-module ”SolarWall PVT”

A Report of IEA SHC – Task 35

PV/Thermal Solar Systems

Report DC4-2

June, 2007

Ivan Katic

SOLAR HEATING & COOLING PROGRAMME
INTERNATIONAL ENERGY AGENCY

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by

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A technical report of Subtask C
Report DC4-2

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

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 "SolarWall PVT"

Ivan Katic
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Danish Technological Institute
June 2007

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 May-June 2007. The results are valid for the tested prototype exclusively.

1. Product identification

SolarWall PVT prototype by

Multisol ApS
Lysmosevej 13
8670 Låsby
Denmark

Tel.: 70 212 777
Fax: 70 212 877
E-mail: multisol@multisol.dk

Data for SolarWall elements:

Type	Trapezoid profile of galvanized steel (Black paint)
Length	344 cm
Width	104 cm
Exit pipe diameter	Ø 125 mm

Data for PV modules type ES-190 from Evergreen Solar:

Standard Test Conditions (STC)[1]
Tolerance on rated power of 98 to 104% (-2 to +4%)

		ES-170 RL	ES-180 RL	ES-190 RL
P_{mp}[2]	(W)	170	180	190
$P_{mp, max}$	(W)	176.3	186.1	195.9
$P_{mp, min}$	(W)	166.6	176.4	186.2
V_{mp}	(V)	25.3	25.9	26.7
I_{mp}	(A)	6.72	6.95	7.12
V_{oc}	(V)	32.4	32.6	32.8
I_{sc}	(A)	7.55	7.78	8.05

Temperature Coefficients

$\alpha\ P_{mp}$	(%/ °C)	-0.49
$\alpha\ V_{mp}$	(%/ °C)	-0.47
$\alpha\ I_{mp}$	(%/ °C)	-0.02
$\alpha\ V_{oc}$	(%/ °C)	-0.34
$\alpha\ I_{sc}$	(%/ °C)	0.06

Module size 951 x 1571 mm2

Two PV elements have been mounted directly on the SolarWall elements, leaving an uncovered area at the lowest part of the elements.

2. Test conditions

Mounting:	45 deg slope, facing south
PV modules	4 sections, 2x2 series connection
Load:	No electric load (Open circuit)
Fluid:	Ambient air
Flow rate:	Variable speed fan
Wind:	No control
Fans:	LINDAB 70-140 W

3. Preparation of measurements

System configuration
System 1: SolarWall with two PV modules on top, variable flow (high)
System 2: SolarWall with two PV modules on top, variable flow (low)
System 3: SolarWall alone, variable flow (thermal reference)
System 4: PV module alone, natural ventilation (electrical reference)

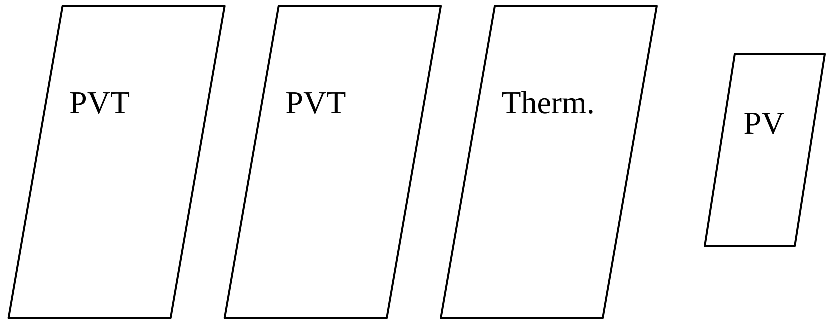

Fig.1 Side-by-side configuration of solar converters #1-4

Each of the SolarWall elements have been fitted with a 125 mm duct and a fan as shown in figure 2.

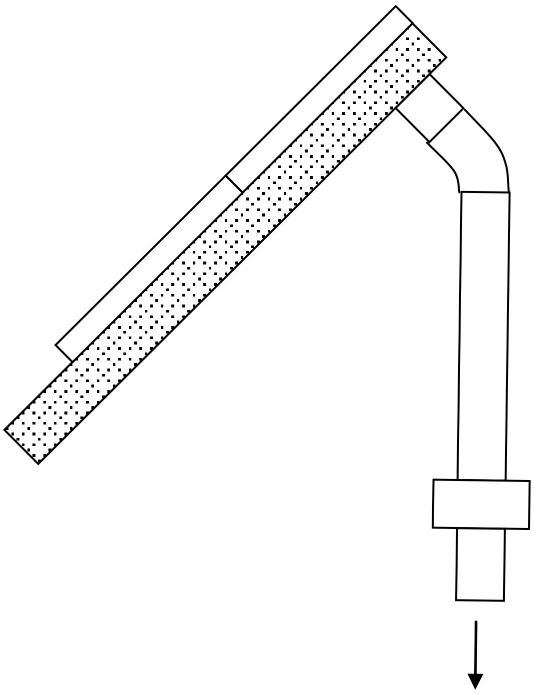

Fig.2 SolarWall PVT panel with two PV modules and exhaust fan.

Fig.3 Photo of the mounted PVT collectors

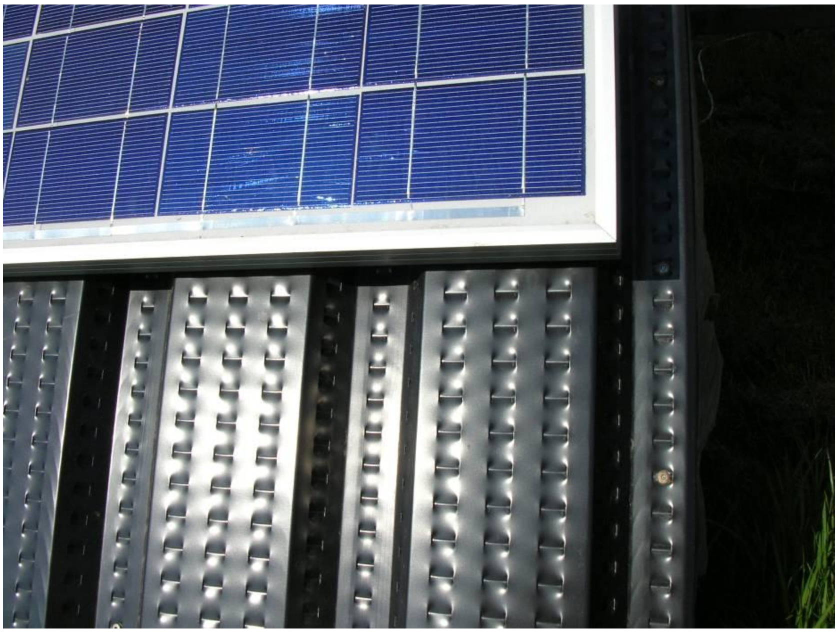

Fig.4 The frame of the PV modules are mounted directly on the SolarWall element. Air is transpired through all the small holes in the black metal profile.

Fig.5 Iris damper with pressure ports used in the flow sensor calibration. The flow sensor is covered by the T-joint.

Test method

The test is carried out in open air at variable insolation and wind speed. The data must therefore be sorted, and periods of quasi-stationary operation identified, according to the guidelines for test of uncovered PVT collectors.
Side-by-side testing eliminates errors due to different ambient conditions, and it is therefore possible to see the effect of additional cooling of the pv modules directly. Nominal flow rates according to the supplier are:

#1: 140 m^3/h pr m^2
#2: 75 m^3/h pr m^2
#3: 75 m^3/h pr m^2

The last PV panel#4 is only cooled by natural convection and should represent an ordinary roof or ground mounted PV system with open back surface.

4. Data acquisition system

A PC and a rack of A/D converters from Analog Devises were used to collect data as 1 minute mean values based on 5 second scans. In the table, all sensors are listed. The Pt 100 sensors are flat surface sensors, which have been taped to the respective surfaces. The wind speed is indicative only, and is measured in the plane of array with a cup anemometer. The air flow sensors are of the heat flux type VentCap.

Measurement	**Sensor**	**Channel**	**Device**	**Cable+wire no.**
Weather data				
Irradiance (in plane)	Soldata solarimeter	1	6B11	2
Ambient temperature	Pt100	2	6B13	2
Wind speed (in plane)	Thies Anemometer 0-4.67 mA	3	6B11	2
				2
System 1				2
Velocity 1	Air speed sensor 4-20 mA	4	6B11	2
Tout 1	Pt100	5	6B13	2
Tplate 1	Pt100	6	6B13	2
Tpv1	Pt100	7	6B13	2
				2
System 2				
Velocity 2	Air speed sensor 4-20 mA	8	6B11	2
Tout 2	Pt100	9	6B13	1
Tplate 2	Pt100	10	6B13	1
Tpv 2	Pt100	11	6B13	1
				1
System 3				1
Velocity 3	Air speed sensor 4-20 mA	12	6B11	1

Tout 3	Pt100	13	6B13	1
Tplate 3	Pt100	14	6B13	1
				1
System 4				1
Tpv 4	Pt100	15	6B13	1

Flow calibration:
The air speed sensors only measure the air speed at a specific point of the air flow. In order to find the volume and mass flow, one has to measure the air speed across the entire velocity profile, and integrate the parts of the flow. A hot wire anemometer is used for this purpose.
The actual flow is obtained by speed control of the fans.

PV output:
The power from the PV panels is directly proportional to the temperature – the cooler the better. The cell temperature of each module is therefore taken as an indicator of the possible power output from that specific module. Temperatures are measured near the middle of the arrays. No actual electric power is tapped from the modules, and this introduces a small error. If some of the solar power was converted to electricity, the modules would be slightly cooler.

5. Measurement results

Flow rate settings:
PVT hi: ca. 0.155 kg/s (139 m^3/h per m^2 absorber)
PVT lo: ca. 0.087 kg/s (78 m^3/h per m^2 absorber)
Thermal ca. 0.070 kg/s (63 m^3/h per m^2 absorber)
PV reference: Natural ventilation (open back surface)
The efficiency and flow rate is calculated based on the area of 3.5 m^2.

Thermal efficiency

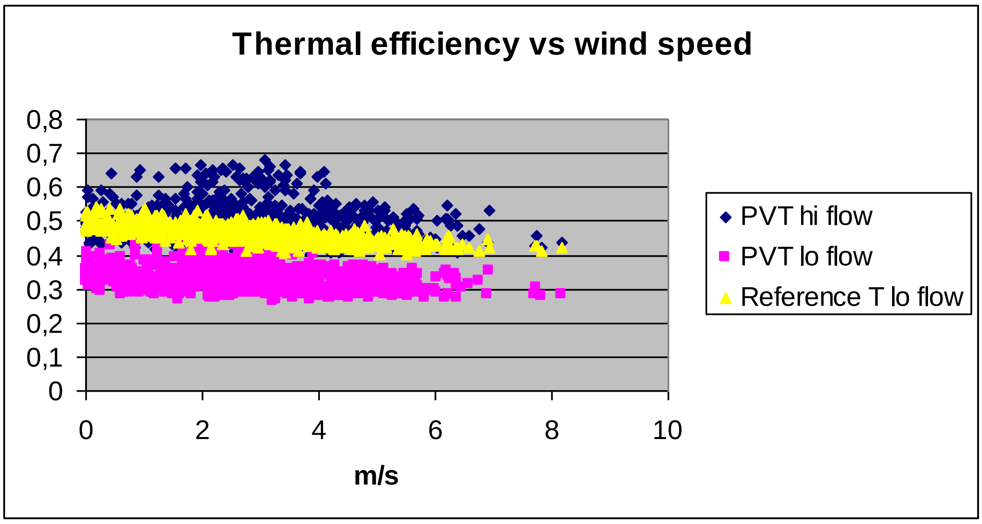

Fig.6 Influence of wind speed on the thermal efficiency of system 1(hi), 2(lo) and 3(ref,lo)

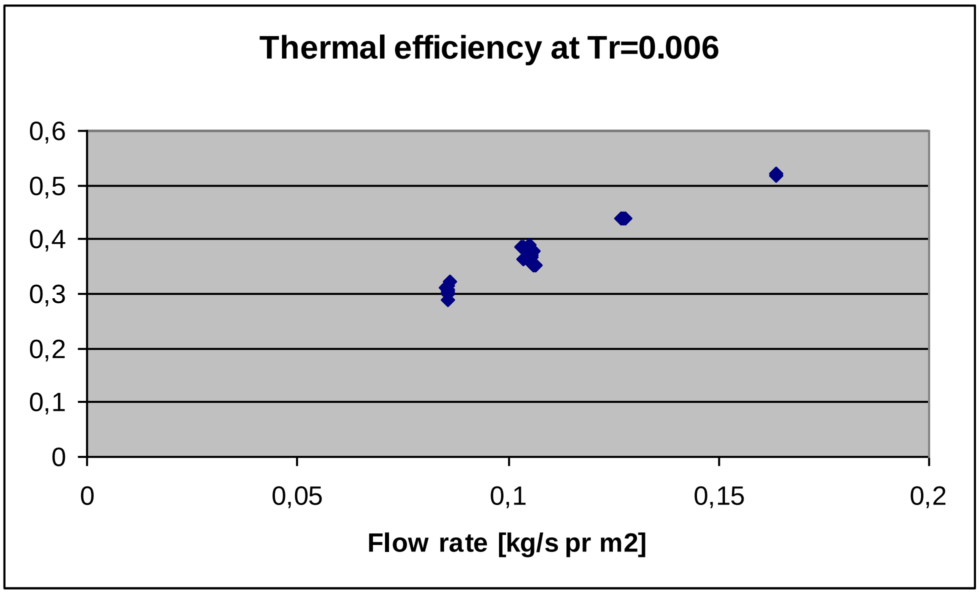

Fig.7 Thermal efficiency for system 1, measured at four mass flow rates

Measured PV module back surface temperature for three different modules

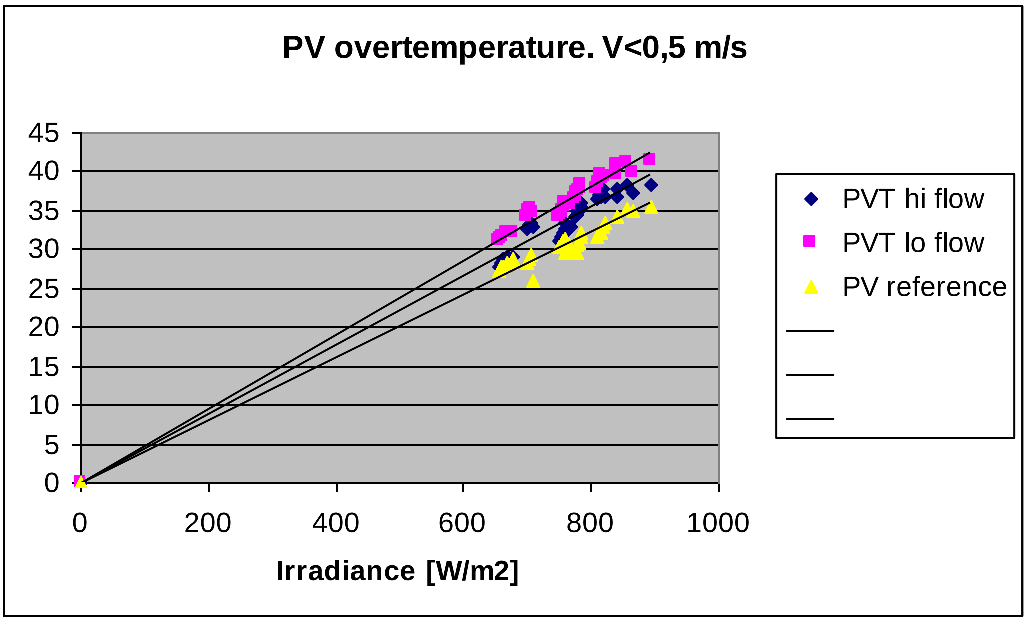

Fig.8 Data points from 04 May 09.00-15.00

The higher temperature of the PV modules mounted on top of the SolarWall elements, may be explained by a poor heat transfer from the modules to the air, despite a rather high flow rate. The reference module is cooler because the back surface is fully open, and can exchange heat by convection as well as by radiation. If the reference was mounted on a solid surface, things would look different.

At high flow, the PV modules become about 3K cooler than at low flow, and this would cause the PV power to rise with 3 * 0.49% = 1.5% at an irradiance level of 800 W/m^2.

The next graph shows the same experiment another sunny day with little wind, but in this case the flow in system 1 has been blocked.

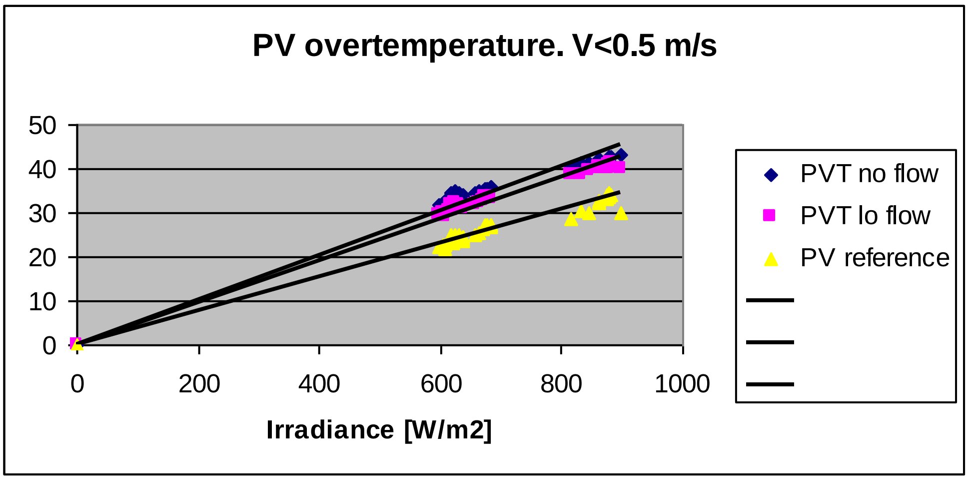

Fig.9 Data points from 10 June 2007 09.00-15.00

The linearised correlation between irradiance and over temperature relative to ambient (at low wind speed) can be expressed as:

Flow rate in m3/h pr m2	**PVT module**	**Back side temperature at 800 W/m^2 / 25 ^0C**	**Corresponding PV power [W]**
0	T = 0.050 * G + Ta	65.0	122.2
78	T = 0.048 * G + Ta	63.4	123.4
139	T = 0.044 * G + Ta	60.2	125.8
	PV reference module		
Not defined	T = 0.039 * G + Ta	56.2	128.8

It is evident that the improvement of the electrical performance due to forced convection is not very significant for this particular construction, even at the highest of the tested flow rates.

The cell temperature has been estimated by measurement of the open circuit voltage of the modules. It seems that the actual cell temperature is up to 10 degrees higher than the temperature measured by the sensors taped to the surface of the module, but this does not change the relative difference between the modules.

Flow rate in m3/h pr m2	**PV open circuit voltage[V]**	**Theoretical cell temperature [^0C]**
0	26.6	80,3
78	27.3	74,5
139	Not measured	
	PV reference module	
Not defined	28.0	67,7

Measured 11 June 2007 13:19

The reason for the different temperature results obtained by this method may be explained by variations from the nominal open circuit voltage for the individual modules.

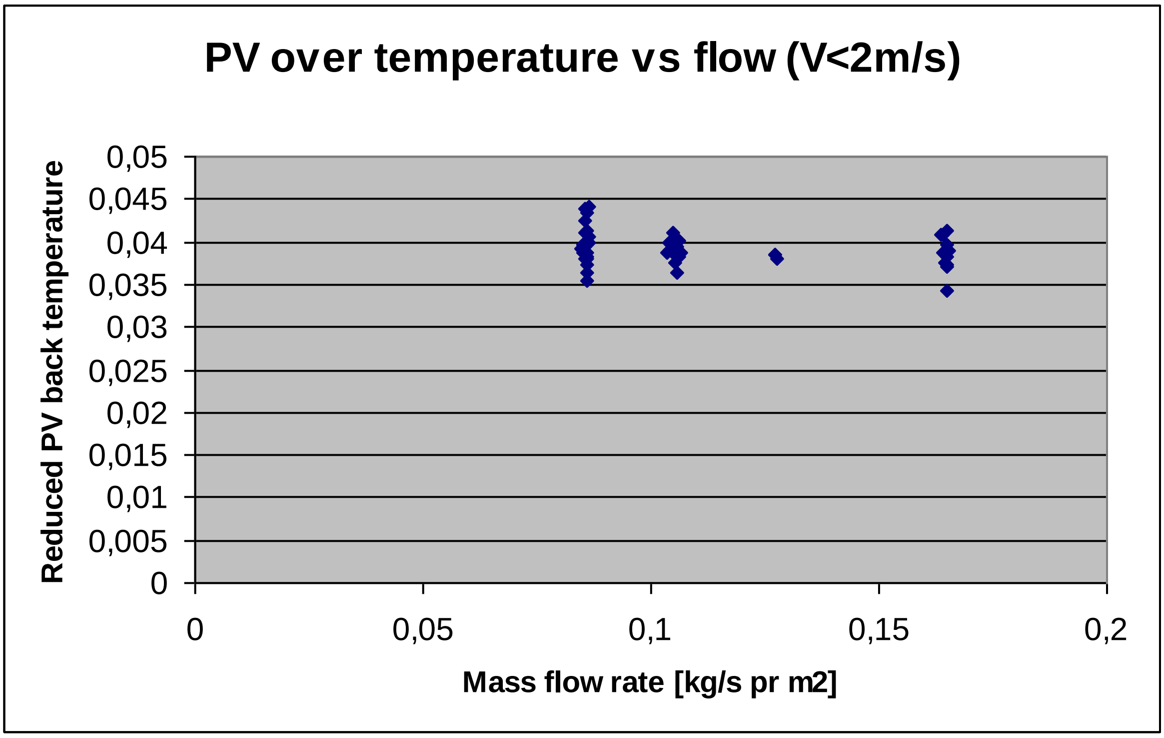

Fig 10. Measurements from 12 June 2007, where the fan speed of system #1 was adjusted in four steps. T reduced = $(T_{pv}-T_{amb})/G$

6. Summary

The test results of this study are in line with other measurement results of air PVT collectors, and the main conclusion is that it is difficult to achieve a significant cooling effect with the tested design under the specific measurement conditions, when comparing with a free-standing PV module with natural ventilation. The most likely reason is that heat transfer from the PV laminate to the underlying air is limited due to a very low air speed along the surface of the module, and that the natural cooling by the surrounding wind supersedes the forced ventilation. The conclusion may possibly be different for higher flow rates with larger fans.

If the measured PV power output is compared with a roof-mounted PV module without forced ventilation, the result is an increase of the performance of 2-4% with PV/T, depending on the weather conditions and ventilation rate. The annual increase for a specific PV plant must be simulated with the actual weather data in order to estimate this effect on an annual basis. For information, a PVsyst simulation for a mulicrystalline PV system in Münich gives additional yield of 2.2% and 3.2% for a partly and fully (naturally) ventilated PV system. For warmer climates the benefit of ventilation could be higher.

The thermal efficiency of the SolarWall absorber was found to be somewhat reduced when a PV module is mounted on top of it, which was expected, but the combined efficiency of PV and thermal energy conversion is higher than for side by side system configuration.
Outdoor testing means that the quality of the measurements is highly depending on the stability of the weather, and it was therefore necessary to discard most of the data.

Log:
02-05-2007 Fans adjusted as close as possible to nominal flow, measurements started
07-05-2007 Fan #1 stopped
12-06-2007 Experiments with variable flow
Fans stopped