HYBRID PV/THERMAL COLLECTORS

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Abstract – This paper focuses on hybrid Photovoltaic/Thermal Collectors which can provide both electrical and thermal energy from the same system. The paper briefly reviews known manufacturers of commercial PV/T collectors and some example projects.

1. INTRODUCTION

Over the last few years there has been a growing interest in PhotoVoltaic/Thermal Collectors (PV/T Collectors). Two kinds of PV/T Collectors are considered here.

1. Combination of a solar *water* heating collector and PV cells.

   Example: A conventional flat plate solar heat collector with integrated PV cells on the absorber, to produce both thermal and electrical energy.

2. Combination of a solar *air* heating collector and PV cells. These can be facade or roof integrated PV cells with ventilation air passed behind or in front of the PV cells.

   Example: PV panels integrated in a ventilated solar wall for preheating of ventilation air.

A survey was carried out to locate and question as many manufacturers of PV/T systems as possible. This paper gives a short description of the identified manufactures of PV/T Collectors and of existing and future building projects with PV/T Collectors. At the end of this paper a reference list is presented which covers references and homepages about PV/T Collectors known at the present stage.

2. SURVEY RESULTS

During the survey 23 examples of PV/T projects or products were found. Of these 4 appear to be commercially available products, the remainder appear to be either one-off designs for specific building projects or else products under development. Table 1 shows a breakdown of the systems identified broken down into the main categories.

Heat transfer medium	Mounting location-method	Number identified	Commercial products
Air	Roof integrated	9	1
	Facade integrated	6	1
	Separate module	5	None
Water	Roof integrated	2 (under development)	None
	Facade integrated	1 (under development)	None
	Separate module	5	3
	Total	28	

Table 1: Breakdown of PV/T systems identified

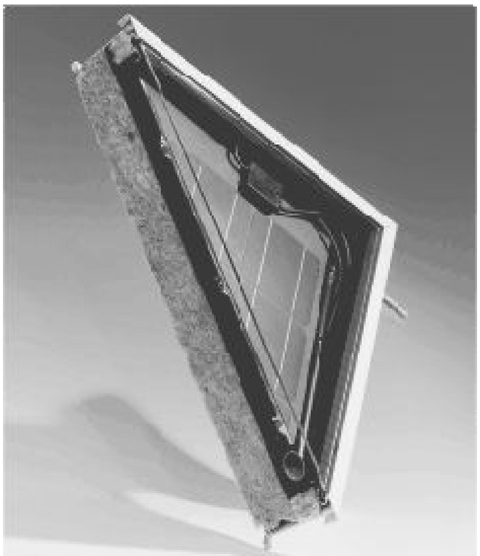
The total given in the table above is greater than the total number of products found because some products can be mounted in more than one manner. Two products are suitable for both roof and facade mounting, 5 are suitable for roof integrated systems or as separate modules and 1 system is suitable for integrating into a facade or as a separate module.

Three of the four commercial products identified were water based separate modules made by: Chromagaen Solar Energy Systems in Israel, and by SolarWerk and SolarWatt in Germany. The only commercially available system for building integration found is an air based system suitable for either roof or facade mounting made by Conserval Engineering in Canada.

3. MANUFACTURERS OF COMMERCIAL PV/T COLLECTORS

In Israel PV/T Collectors have been developed by the company "**Chromagen**" since 1991. The commercially available PV/T Collector is a flat plate solar heat collector with PV cells integrated on the absorber. Chromagen first tested their PV/T Collector in several locations in Israel, finding that the PV/T collector could provide an apartment's electricity and hot water demand. The system was developed in such a way that additional generated electricity could be sold to the local Electricity Company. The average cost for the PV/T Collector, named "Multi Solar System", was about US $1940/m^2 collector. The system can be grid-connected or stand-alone. It is sold with a minimum of 2 modules with a total collector area of 4.64 m^2. The daily thermal and electrical output is about 1.5 kWh/m^2 heat and 0.4 – 0.8 kW/m^2 electricity in Israeli climatic conditions. The product is marketed commercially and about 20 systems have been sold in Israel [A3].

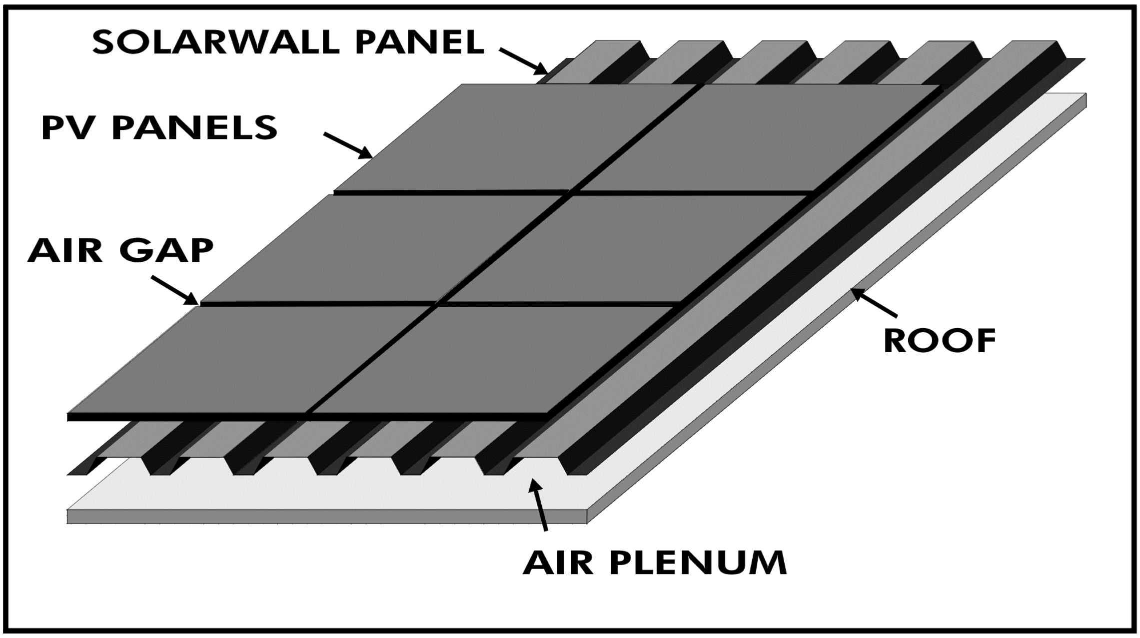
Two German companies, “SolarWerk” and “SolarWatt” have developed a similar kind of PV/T Collector. Both systems are flat plate solar heat collectors with PV cells integrated on the absorber. “SolarWerk” developed their system in cooperation with the Institut fur Solarenergiforschung (ISFH) Gmbh in Hameln, Germany. The product developed is named “Spectrum” and is sold as modules with a collector area of 2.2 m^2. It can be installed either as a stand-alone or a grid-connected system. [Information received from SolarWerk Homepage at www.solarwerk.de/spectrum-b.htm.]



The other German Company “SolarWatt” developed a product named “MultiSolar” which is also a flat plate solar heat collector with PV cells integrated on the absorber. It is

sold as a stand-alone or a grid connected system with a minimum of 1 module of 1.92 m^2 [A5].

A Canadian company "Conserval Engineering Inc.", has developed a PV solar wall product where PV panels can be mounted onto a perforated absorber. This building integrated PV/T Collector can be used as a facade or roof element and is named "PV SolarWall". The PV panels are mounted in such way that cool ambient air is allowed to pass behind the PV panels in a uniform way. Heat generated from the PV cells will be transferred to the air which can then be used for heating ventilation air. The PV Solar Wall is a variation of their standard SolarWall which collects thermal energy using the sameperforated absorber plate without the PV panels. [A6 and Information received from Conserval Engineering at their homepage www.solarwall.com/system.html#12c.]



4. EXISTING BUILDING PROJECTS WITH PV/T COLLECTORS

A "PV SolarWall", made by the Canadian Company "Conserval Engineering", has been installed at the **West Prep School in Toronto**, Canada. The 15 m^2 SolarWall, with two 60-Watt UNISOLAR PV panels, was installed to improve the indoor air quality in the classrooms. The heat generated from the conventional SolarWall and from the PV panels is transferred to cooler ambient air, to provide fresh air to the classrooms and thereby improve the indoor air quality and reduce the heating costs. The electricity generated from the two 60 Watt PV panels is used for running two ventilation fans which provide between 0 and 680 m^3 of air per hour [A6].

In 1993, the Japanese government invested about 1,224 million yen on PV demonstrations. An area of interest was the development of PV/T Collectors for buildings in Japan. One prototype was developed for residential applications and was tested on a **test house in Japan**. The PV/T system consists of PV cells backed by a thermal absorber and it produces daily about 3.2 kW of electricity and 25 kW of thermal energy. [Information received from www.romulus.ultranet.com/~sda/worldreport/japan.htm]

Richard Komp and Terry Reeser of SunWatt Corporation [A1] have constructed and operated an Air PV/T Collector for a **passive solar house in Louisville**, Kentucky. It is built into the roof structure of an attached sunspace and uses natural convection to extract excess heat from finned module assemblies, and delivers that heat into the house during the winter. During the summer, the heat is exhausted from clerestory windows, creating a draft of cooler air into the lower part of the building. The electrical output is delivered through a battery to low voltage lights and other appliances in the house.

The US Department of Energy has initiated the "Building Opportunities in the US for Photovoltaics", abbreviated to "PV Bonus II", program. The program aims to develop technologies and foster business arrangements that integrate photovoltaics, or PV/T solar systems, into buildings cost-effectively. The program supports work to develop PV/T Collectors carried out by Solar Design Associates, Inc., Innovative Design, Energy Conversion Devices, Inc, and United Solar Systems Corporation among others [A4].

Solar Design Associates, Inc. is currently involved in the development of a combined PhotoVoltaic / Thermal Collector. They are in the early stages of product definition. The PV/T Collector will incorporate a liquid-based heat transfer medium and thin-film amorphous silicon PV and will closely resemble a conventional liquid solar thermal collector in appearance. The work is being supported in part by a cost-shared collaborative R&D agreement with the US Department of Energy. In addition, the company was involved in a roof-integrated array of PV/T Collectors at the **Montana State University Research Center** that delivers both thermal and electrical energy to the building. [Information received from www.solardesign.com/PromoArch.htm]

PV BONUS II has also supported Innovative Design from North Carolina, in developing integrated PV systems that use the waste heat from a PV array to heat up water [A2]. A roof-integrated example has been installed on an **Applebee's restaurant** that uses 32 amorphous PV modules. Eight of the modules are connected to a fan that circulates air through a series of passages underneath the 32 modules. About 7 % of the total area of the system is clear glass between the PV cells, facing a black-painted high-absorbing metal pan. As the solar insolation increases and the temperature goes up, a fan switches on to circulate the heat away from the PV modules towards a heat exchanger. The heat flows through a closed loop and is thereby not wasted as it is in conventional PV modules. Since there is a big demand for hot water in the building, all the hot water produced from the solar energy system is used. As it is a roof-integrated system, the costs for conventional roof finishing were saved.

The US Company "United Solar Technologies, Inc." is, with support from US PV BONUS II, developing a PV/T Cogeneration Energy System. US PV BONUS II is also supporting the US company "Energy Conversion Devices, Inc." in the development of two new PV/Thermal roofing systems. One system provides hot water and electricity while the other provides hot air and electricity [A4].

In 1994 in Ispra, Italy**, the ELSA building** had its 25 m high south facade covered by an area of 505 m^2 of amorphous PV cells with an electrical output rating of 21 kWp. The PV cells were mounted onto an insulated wall with an air gap behind the PV cells. The heated air behind the PV cells is used for ventilation purposes [A7].

Similarly PV/ T energy systems are installed at the **Library of Mataro** in Spain and at **the Yellow House** in Aalborg, Denmark. At the Library of Mataro in Spain, PV cells are mounted onto the facade and on skylights on the roof. In chambers behind the PV cells air is heated and is then used for preheating the water in the conventional gas-fired heating system of the building [A8]. The Yellow House in Aalborg, Denmark has 5 different groups of PV installations in the facade for demonstration purposes. [A9]

During the last 10 years, Atlantis Energy Systems, Ltd. from Switzerland, has made several PV/T systems around the world. One system, installed in 1991 at the factory building "**Aerni**" in Arisdorf, Switzerland, has a ventilated PV facade and ventilated PV skylights with a total electrical output of 62 kW and a thermal output of 115 kW. Atlantis Energy Systems Ltd. also developed a PV/T shingle roof, two of them are named “**Brig**” and “**Rigi**” where PV panels are installed on the roof with ventilation air passed behind the PV cells. Both systems have been in operation since 1993 without interruption and have shown good results [A10].

At **the City Archives in Rotterdam**, Netherlands some 1840 m^2 of PV cells are installed on the roof. Beneath the PV cells heat is generated. During the summer this heat is stored in the ground to provide heating in the winter. During the winter, cool air is stored in the ground to provide cooling during the summer. [Information received from www.dubo-centrum.nl and A11]

5. CONCLUSIONS

Interest is currently growing in PV/T systems however the number of commercial products available is limited. The majority of the commercial products currently available are water based modular systems. The majority of the air-based systems installed to date have been one-off building projects.

The water-based systems are typically based on a commercial solar thermal collector, where the absorber is modified to integrate solar cells. When designing PV/T-collectors the question of optimizing the overall performance is always important. For solutions with mono- or polycrystalline silicon solar cells the electrical performance is reduced with increased temperature, which means the best performance will be obtained by optimizing the system to operate with as low a temperature as possible. A low temperature also means high thermal efficiency of the collector. However when systems are designed for heating domestic hot water, where the useful temperature is around 50°C, a higher temperature is required in the absorber. When designing PV/T-collectors the most important parameter to consider is therefore the temperature level at which the collector should operate and the thermal and electrical load the collector must meet.

PV/T-technology is still very new and there is a strong need for R&D and demonstration efforts in the following areas:

- Maximization of heat transfer from the solar cell to the heat transfer medium and maximization of the electrical yield from the solar cells for different temperature-levels.

- Durability testing of collectors and solar cells, especially for laminated solutions and solutions where the solar cells operate at a high temperature.

- A standardized method of assessing the energy performance of PV/T systems needs to be defined and calculated, monitored and evaluated both for the commercial products and for the best solutions demonstrated as one-off systems in buildings.

Architecturally the technology is very appealing and has the potential to develop into a range of standardized and aesthetically uniform products. When developed into mass produced commercial products the price of the systems will be primarily dependent on the amount of material used for the collector. These systems could then provide a very efficient and cost effective way to gain both thermal and electrical energy from the sun even in highly urbanized areas, where the systems might replace other building components.

REFERENCES

All references used in this Working Document are listed here. In addition, a list of homepages containing information about PV/T Collectors is presented.

A. References used in the Working Document

[A1] Richard Komp and Terry Reeser, (1998) *Design, Construction and Operation Of A Site Built PV/Hot Air Hybrid Energy System*, Article obtained from Richard Komp at SunWatt Corporation at +1 207-497-2204.

[A2] K. Sheinkopf, *PV System With Thermal Heat Recovery*, Article of the work of the IEA, obtained from *www.caddet-re.org/re/html/body_298art2.htm*

[A3] Dr. A. Elazari, *Multi Solar System, Field Experience In Israel*, Several articles obtained from Dr. Elazari at Chromagen in Tel Aviv, fax: 972 - 3 - 525 - 6305.

[A4] *Building Opportunities In The U.S For Photovoltaics (PV:BONUS), Two*, Article obtained from Robert J. Hassett, U.S. Department of Energy, Tel: +1 202 586 8163.

[A5] *MULTISOLAR*, Multisolar is a registered trademark of KRUSE Gmbh Technik.

[A6] *Hybrid Solar Collectors for Portable School Classrooms*, Article obtained from Per Drewes, Ontario Hydro Technologies.

[A7] *"Thermal and Power Modeling of the Photovoltaic Facade on the ELSA Building, ISPRA", "Thermal Aspects of PV Integration in Buildings", "Analysis of Fluid Flow and Heat Transfer within the PhotoVoltaic Facade on the ELSA Building, JRC ISPRA",* 3 papers from the 13th. European Photovoltaic Solar Energy Conference, October 1995.

[A8] *The Library of Mataro description and first results of monitoring,* Article by Dr. Antoni Lloret, Labotatoire des Interfaces et des Couches Minces Ecole Polytechnique, 91128 Palaiseauu cedex, France.

[A9] *Improved Solar Renovation Concepts* (1997) A report of IEA Task 20 – Subtask B. January, pp. 136-137.

[A10] *The Importance of Hybrid PV-Building Integration*, Paper by M. Posnansky, Atlantis Energy Ltd. 3012 Bern, Switzerland, Tel: +41 031 300 3220 Fax: +41 031 300 3230.

[A11] *City Archives Rotterdam*, Paper received by email from Siard Hovenkamp at *S.Hovenkamp@ecofys.nl*.

[A12] *Hybrid Collectors, Theoretical Developments and Performance Evaluation of PhotoVoltaic Thermal Collectors*, Master Thesis by Bruno Nielsen, Esbensen Consulting Engineering Ltd. Copenhagen.

C. Web pages about BIPV and PV/T Collectors

[C1] http://www.chromagen.com/

[C2] http://www.doe.gov/html/eren/eren.html

[C3] http://www.chromagen.co.il/

[C4] http://www.jxj.com/dir/wdress/index.html

[C5] http://iamest.jrc.it/est/hello.htm

[C6] http://www.solarinfo.de/links.html#Solar_Energy

[C7] http://www.eren.doe.gov/millionroofs/

[C8] http://www.solarwerk.de/

[C9] http://www.ovonic.com/unisolar

[C10] http://www.solarwall.com/

[C11] http://www.solarex.com/

[C12] http://www.nrel.gov/ncpv/documents/seb/

[C13] http://www.ecw.org/projects/bipv.html

[C14] http://www.etde.org/

[C15] http://www.eren.doe.gov/RE/solar.html

[C16] http://www.caddet.co.uk/

[C17] http://www.solarinfo.de/de/site/product/start.html