

# PV THERMAL SYSTEMS - CAPTURING THE UNTAPPED ENERGY

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## ABSTRACT

PV modules generate electricity, but the electrical output is only one component of the total energy produced by a photovoltaic array. A typical photovoltaic (PV) module has an ideal conversion efficiency in the range of 15%. The remaining energy produced is heat, which is neither captured nor utilized. This heat increases the operating temperature of the PV modules, which actually decreases their overall performance.

Recent scientific testing done in conjunction with the International Energy Agency Task 35 Project at Canada's National Solar Test Facility has shown that it is possible to capture almost two to three times more thermal energy than electricity from a PV array. Panels from various manufacturers were tested under NOCT conditions, and the results showed that when PV modules were mounted on top of SolarWall® transpired collector panels, the total solar efficiency increased to over 50%, compared to the typical 10 to 15% for PV modules alone.

By removing the excess heat generated by the PV modules, the electrical output is increased. Modules can commonly operate at temperatures over 50 degrees C above ambient temperature, resulting in a performance reduction of more than 25%. By dissipating the heat from the module and lowering the operating temperature, significant gains can be made in system performance and the heat can be utilized for practical heating purposes. As a result of these effects, the testing showed that the payback on a PV system that incorporates a thermal component could be reduced by between one third and one half.

This paper will present the test results, and the practical and scientific implications of using a transpired solar collector with conventional PV to create a solar co-generation system.

## 1. INTRODUCTION

The trend with photovoltaic (PV) installations is towards building integrated systems, and while this is advantageous in many regards, there are problems associated with conventional methods of integrating PV directly into a building.

The main problem with building integrated photovoltaic (BIPV) systems is heat buildup under the PV modules. The heat produced can be as much as 50°C (90°F) over ambient temperature resulting in two concerns. The first is the possible structural damage from heat if panels are not vented or if heat is not recovered. The second is the lower efficiency of most PV modules with increasing temperature. Crystalline cells are affected by temperature and the performance drops as cell temperature rises. It has been shown that for each °C increase in temperature, the power production drops by ~0.5%. This means that a BIPV 100 W crystalline module at 65°C is only delivering 80 W of power compared with the 25°C name plate rating.

A PV module can have a stagnation temperature of 50°C above ambient if the heat is not removed. If ambient temperature is 30°C, the actual module temperature can be 80°C, or even higher, on some tiled roofs.

Another issue facing installers and customers is competition for roof space and deciding on which solar technology should have priority. Covering a roof with PV modules only uses 10% to 15% of available solar energy and eliminates the possibility for future solar thermal systems with much higher solar conversion efficiencies. A client may not be able to install solar panels to heat water, a pool or the building when the roof is already covered with a solar electric technology.

Grid tied PV systems have a high initial cost and are generally sold only with generous incentive programs. A possible solution to the long payback situation is to see

whether the "waste" solar heat can be recovered and used to lower heating costs.

## 2. PV THERMAL PROGRAM

The International Energy Agency (IEA) initiated Task 35 "PV/Thermal Solar Systems", a three year research program, on January 1, 2005, as part of the IEA Solar Heating and Cooling (SHC) Program. The objectives of this Task are to catalyze the development and market introduction of high quality and commercial competitive PV/Thermal Solar Systems, to increase general understanding of PV/T and contribute to internationally accepted standards on performance, testing, monitoring and commercial characteristics of PV/Thermal Solar Systems in the building sector.

The definition of PV/Thermal solar system is a combination of photovoltaic (PV) and solar thermal components which produce both electricity and heat from one integrated system from the same surface area exposed to the sun. PV and solar thermal panels which operate side by side and not together are excluded from this definition.

The European members of the Task were focused on liquid collectors as the solar thermal component of the PV Thermal system. Canada decided to investigate air as the transfer medium to remove heat from PV arrays, represented by Conserval's SolarWall transpired solar collector.

Rather than develop a new PV Thermal panel, Conserval took the approach of combining commercially available PV modules on top of the transpired collector and utilizing the unique air balancing features of the transpired collector to remove heat from the back of the PV array. In essence, the PV panel becomes a back pass solar air collector with the PV cells acting as the solar heat absorber with ambient air passing around and behind each PV module, removing heat and then the heated air enters the perforations in the transpired panel. This concept allows for heat removal from most PV modules currently available on the market and avoids the lengthy delays associated with developing a new PV panel and obtaining the associated electrical approvals. It is realized that the thermal performance may not be optimized but some heat should be recovered.

The purpose of the Canadian test program was to quantify the amount of heat that could be readily recoverable from commercially available PV modules.

### 2.1 Testing Program

The trend in PV installations has been to use larger PV modules. To obtain data that is representative of the

systems being installed, the most popular models from each manufacturer were chosen for the testing at NSTF. Arrangements were made with three manufacturers, BP Solar, Evergreen Solar and UniSolar to test their panels on the 10 square metre (108 ft<sup>2</sup>) test panel previously used for certification tests of the SolarWall system.

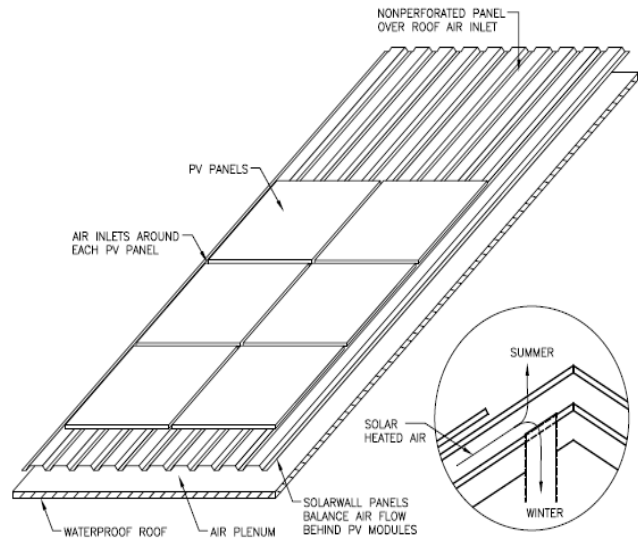


Fig. 1 Schematic of PV modules mounted on perforated metal panels

Special mounting clips were made to mount the BP and Evergreen PV modules approximately 10 mm above the transpired collector to allow air to flow behind the PV panels.



Fig. 2 PV panels on SolarWall® test panel

Evergreen supplied six of their new 170 Watt panels. Two rows of three panels covered 90% of the 10 m<sup>2</sup> test panel.

BP Solar supplied six of their 160 Watt panels which when placed onto the test panel covered approximately 76% of the test panel surface leaving 24% of the transpired panel exposed to the sun.

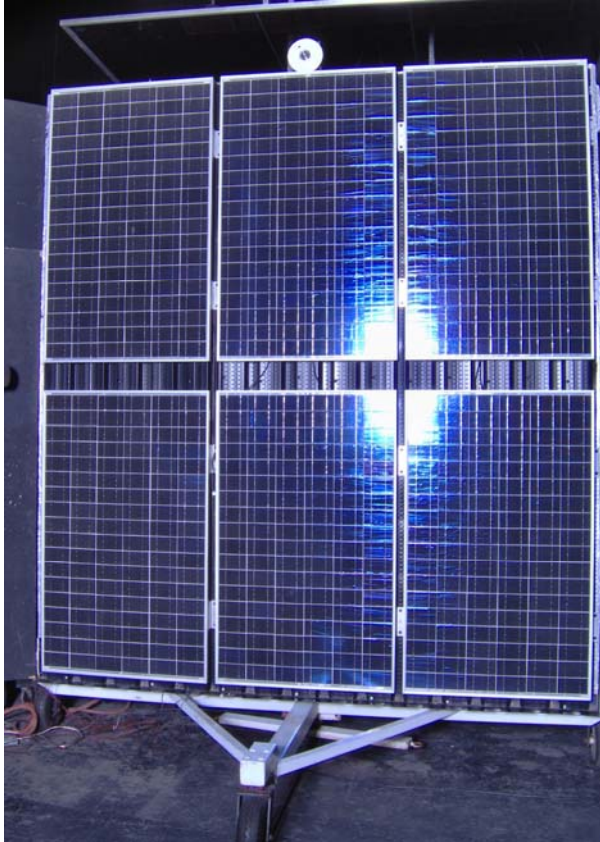


Fig. 3 PV Thermal testing with six Evergreen 170 Watt panels at NSTF

UniSolar supplied eight of their peel and stick 68 Watt modules which fit nicely onto the test panel in a horizontal configuration and covered 90% of the test panel.

The tests were conducted indoors at Canada's National Solar Test Facility (NSTF). One problem identified by the IEA Task 35 working group is which standard test condition should be used to test a PV Thermal system. PV panels are tested with a flash test at 1000 Watts/m<sup>2</sup> and 25 C. NOCT tests use 800 Watts/m<sup>2</sup>, 1 m/s wind and an open back. Thermal panels are generally tested at 900 Watts/m<sup>2</sup> and at 3 m/s wind. In addition, the transpired collector can accommodate a wide range of air flows through the panel.

It was decided to perform two sets of tests at two flow rates for each panel, one set at NOCT conditions and the other at the solar thermal conditions. The air flow heat removal rates selected were 2 cfm/ft<sup>2</sup> (36 m<sup>3</sup>/h.m<sup>2</sup>) and 6 cfm/ft<sup>2</sup> (108

m<sup>3</sup>/h.m<sup>2</sup>) of gross collector surface which represent low and medium air flows typical for heating ventilation air.



Fig. 4 PV/T testing with six BP 160 Watt panels



Fig. 5 PV/T testing with eight UniSolar 68 Watt modules

### 3. TEST RESULTS

The tests were performed over a two week period in October 2006 and the results are summarized in the following tables. Table 1 lists the two primary test conditions. The heat was drawn off at two rates, 2 and 6 cfm/ft<sup>2</sup> of collector surface and results are shown separately for each flow rate.

Tables 2 & 3 indicate the difference in air temperature between ambient and the air leaving the transpired solar panel. Irradiance, wind speed and flow rates are shown to all have an effect on the thermal gain.

TABLE 1: TEST CONDITIONS

Designated #	Test Type	Irradiance [W/m <sup>2</sup> ]	Wind Speed [m/s]
1	PV NOCT	810	1
2	Thermal	910	3

TABLE 2: AIR TEMPERATURE RISE @ 6 CFM/FT<sup>2</sup>

Collector Type	Test Condition	
	1	2
BP PV/T	9	7
Evergreen PV/T	9	6
UniSolar PV/T	11	9

TABLE 3: AIR TEMPERATURE RISE @ 2 CFM/FT<sup>2</sup>

Collector Type	Test Condition	
	1	2
BP PV/T	15	9
Evergreen PV/T	14	10
UniSolar PV/T	20	15

The Evergreen panels and UniSolar panels have similar coverage area of 90% but are significantly different in shape. The Evergreen and BP panels are similar type and shape with the main difference being the coverage area, BP panels only cover 76% of the surface of the transpired panel compared with 90% for the Evergreen ones.

TABLE 4: THERMAL EFFICIENCY @ 6 CFM/FT<sup>2</sup>

Collector Type	Test Condition			
	1		2	
	Eff.	% Ideal	Eff.	% Ideal
BP PV/T	44	63%	28	62%
Evergreen PV/T	40	57%	27	60%
UniSolar PV/T	50	71%	39	87%
Bare transpired panel	70	100%	45	100%

TABLE 5: THERMAL EFFICIENCY @ 2 CFM/FT<sup>2</sup>

Collector Type	Test Condition			
	1		2	
	Eff.	% Ideal	Eff.	% Ideal
BP PV/T	24.1	54%	13.4	45%
Evergreen PV/T	23.2	52%	14	47%
UniSolar PV/T	31.4	70%	21.5	72%
Bare transpired panel	45	100%	30	100%

The thermal results are interesting in that they clearly show a reasonable heat gain and reasonable solar efficiencies. For comparison purposes, the thermal efficiencies of the bare transpired panel are shown, which have been taken from the previous certification test data on the same 10 m<sup>2</sup> test panel.

Transpired collectors are installed for heating or preheating the ventilation air required in buildings. Most applications are designed to preheat air with a temperature rise in the 5°C to 20°C range. The test data shows that the temperature gain from the PV modules is between 6°C to 20°C or well within the typical range for transpired collectors.

It was expected that the bare transpired collector would perform better than with PV modules mounted above it (PV/T). What is surprising is that by resizing the transpired collector or adjusting the air flow rate, the same thermal design target with PV/T is possible as is currently produced in many transpired collector installations.

The NOCT tests are conducted with an open back and PV suppliers typically list a PV panel temperature in the 47°C range. The PV/T tests, (with a closed back) as listed in Table 6, which is typical of a BIPV configuration, show temperatures similar to or lower than the NOCT data.

**TABLE 6: ELECTRICAL AND THERMAL EFFICIENCIES**

	Test	Air Flow	PV Power Watts	PV $\eta$ rated	PV $\eta$ Actual	T avg C	Thermal Power Watts	Thermal $\eta$	T rise C	Total $\eta$
EG	1	2	746	11.4%	10.3%		1878	23.2	14.41	32.4
EG	2	2	858	11.4%	10.5%		1276	14	9.74	23.4
BP	2	2	720	11.9%	10.5%		1220	13.4	9.36	21.3
BP	1	2	637	11.9%	10.4%		1954	24.1	15.12	31.9
US	1	2	477	6.1%	6.6%		2542	31.4	19.68	37.3
US	2	2					1962	21.5	15.06	N/A
US	2	6	557	6.1%	6.8%	41	3573	39.3	9.46	45.4
US	1	6	487	6.1%	6.7%	48	4076	50.4	10.8	56.4
BP	1	6	627	11.9%	10.3%	46	3545	43.8	9.42	51.6
BP	2	6	726	11.9%	10.5%	37	2534	27.8	6.72	35.8
EG	1	6	753	11.4%	10.3%	47	3229	39.6	8.56	48.8
EG	2	6	866	11.4%	10.6%	41	2443	26.7	6.43	36.2

The efficiency data for the PV portion of PV/T in Table 6 is based on the dimensions of the PV modules. The thermal efficiency data is based on the transpired collector area of 10 m<sup>2</sup>. Since the PV modules do not cover 100% of the transpired collector, the column showing Total  $\eta$  (efficiency) is not a straight addition of the PV and thermal numbers but is based on the gross test panel area of 10 m<sup>2</sup>.

**3.1 Practical and Scientific Implications**

The test data clearly indicates that all of the PV modules tested produce more thermal energy than electrical energy under all test conditions. These “off the shelf” panels have not been optimized for thermal gain. In fact, the BP and Evergreen modules, due to their more square shape compared with the UniSolar modules, can be considered the worst case for thermal efficiency. These “poor” thermal collectors still delivered from 150% to 400% more thermal energy than electricity. The UniSolar panels delivered from 400% to 800% more thermal energy than electricity. The long rectangular shape of the UniSolar panels appears to be better suited for heat collection.

These tests were meant to quantify the thermal energy that is possible from conventional PV modules and provide data to allow designers to assess the merits of considering a PV/T system. Using readily available PV modules eliminates the lengthy delays and costs that would be required for approvals if new PV modules were developed to improve the thermal performance.

It is realized that the thermal energy may not be as useful as electricity or be required year round, however, the heat can be used during the heating season to heat and ventilate buildings. During the summer months, the heat can be used to heat swimming pools in residential applications, preheat domestic hot water, dry clothes or crop drying, and for drying desiccants if desiccant cooling is utilized. When heat is not required, it can be vented.

When space on the roof or wall is limited or when the available solar surface becomes a contest for which solar technology will win, PV Thermal offers the designers and customers a solution to solve the dilemma. The generous incentives available in many jurisdictions for PV systems could create long term concerns, especially when additional fossil fuel usage needs to be curtailed and clients have already covered the entire roof with PV, leaving no more space to displace further CO<sub>2</sub> emissions by increasing the renewable energy usage for that building.

The transpired collector costs approximately 25% of a PV system on a per unit area basis. On an economic basis, it makes sense to evaluate the benefits of recovering heat from PV. Lowering the PV cell temperature also increases the electrical output for the modules tested and will undoubtedly do the same for most PV modules currently being installed.

The illustration in Figure 6 shows a simple solution for the integration of PV cooling and thermal recovery on flat roof mounted systems.

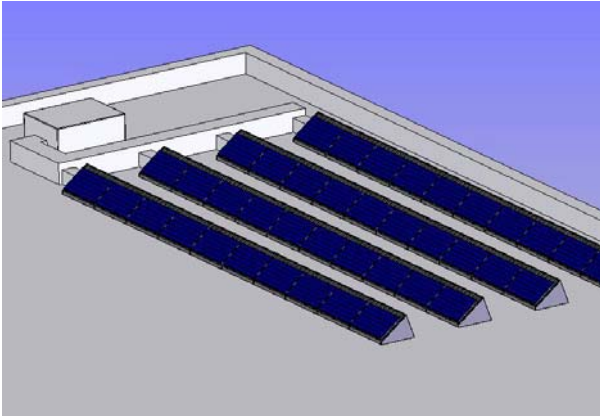


Fig. 6 Concept for typical roof mounted PV/T system connected to rooftop HVAC units



Fig. 7 Photo of PV/T on a residence in California

The economic potential of a PV/T installation could be the subject of a separate study in itself due to the wide range of costs for electricity and heating fuels, weather data, uses for the thermal energy and ease of connecting to existing HVAC equipment.

#### 4. CONCLUSIONS

Test results from the National Solar Test Facility indicate that mounting the PV panels above SolarWall thermal panels will lower the PV panel temperature to an acceptable level. Lowering the cell temperature also increases the power output. The power output for the panels from BP and Evergreen increased at a rate of between 0.4% to 0.5% per degree C of lower module temperature.

The tests confirmed that the thermal energy was much larger than the electrical energy, between 150% to 400% higher

for the crystalline PV panels and as much as 800% higher for the amorphous panels. For example, a 160 Watt PV panel actually produced over 700 Watts of total energy with 540 Watts of thermal energy making up the difference.

The solar heat is normally used during the heating season whereas the electrical output is useable over twelve months. Heating air with the transpired collector is cost effective with only 5 - 9 months of utilization and should also be cost effective with PV/T. When space heating is not required, the solar thermal energy can be easily vented. If however, the summer solar heat can also be used for clothes drying, water heating, pool heating or process heating, then the economics improve even more.

The tests showed a temperature rise of 6 to 20°C above ambient. If a higher temperature is desired, a two stage solar heating system can be designed with the first stage as PV/T panel system and the second stage a glazed solar panel to receive solar preheated air from the first stage.

It is desirable, however, to develop other uses for the heat in the summer months to make a PV thermal system even more cost effective, such as a desiccant cooling system. Utilizing the summer heat will improve the economics of a project and at the same time, recover heat that would otherwise be rejected to the atmosphere.

These test results warrant investigating the application of PV/T systems in various geographical areas and climate zones, with and without the various incentives for PV installations.

All building integrated PV installations should evaluate the benefits of utilizing the rejected heat.

#### 5. ACKNOWLEDGMENTS

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#### 6. REFERENCES

1. IEA Task 35 website: [www.pv-t.org](http://www.pv-t.org)
2. Supplier panel specifications from Evergreen Solar, BP Solar, UniSolar and SolarWall.