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SOLAR COGENERATION PANELS

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ABSTRACT

Photovoltaic panels generate heat as well as electricity and the amount of heat is significantly more than the electrical energy. A project, funded by New York State Research and Development Authority, Natural Resources Canada and Conserval Engineering investigated the method of combining photovoltaic cells with the transpired solar air heater, constructed prototypes, measured the combined electrical and thermal energies produced and compared the results with single function reference panels. The results showed that combining the PV cells with the transpired SOLARWALL panels can produce higher total combined solar efficiencies than either of the PV or thermal panels on their own.

BACKGROUND

Photovoltaic solar panels generally produce electricity in the 6% to 12% efficiency range. Most of the remaining energy is thermal energy which is not recovered. By comparison, a solar thermal collector can operate in the 40% to 70% efficiency range. A lot of work is being done to improve efficiency of PV panels, to reduce manufacturing costs and to integrate PV panels into walls and roofs of buildings. Unfortunately, very little effort has been done on recovering the thermal energy. By integrating the PV modules in a design to collect the heat generated, a solar cogeneration system is possible which holds enormous potential for improving the cost benefits of PV integrated roof and wall systems. The PV SOLARWALL project developed and tested an integrated photovoltaic/thermal panel to provide both thermal and electrical energy.

The main drawback to existing PV systems is the high initial cost. Another problem is reduced efficiency at higher temperatures. By comparison, the unglazed perforated plate solar air heating system or transpired collector is very cost effective and operates at lower temperatures than most PV panels. It represents a major breakthrough in solar thermal technology and it incorporates building integration. The transpired collector eliminates glazing, utilizes common wall construction, replaces building cladding normally required, and supplies the ventilation air needed in buildings. In new construction, a major portion of its installation costs can be appropriated to capital budgets that would be spent in any event and only the incremental costs would apply when evaluating solar energy savings.

Conserval developed and currently markets an innovative solar-thermal building cladding called SOLARWALL®. It has been extensively tested and field proven with over 60,000 m^2 in service worldwide. A SOLARWALL panel is coated, perforated, corrugated metal cladding installed over building surfaces. It collects solar energy for applications such as heating ventilation air, combustion air, and process air heating. SOLARWALL® system operating efficiencies are generally in the 50 to 70 percent range.

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Ambient air enters the SOLARWALL® cladding panel through perforations in the corrugated metal. Contact with the solar-heated metal transfers thermal energy to the air. With the integrated photovoltaic/thermal system, a portion of the surface is covered with encapsulated photovoltaic cells or modules, which convert solar energy to electricity. The PV cells are cooled by the air stream, which increases their conversion efficiency and the heated air is captured and utilized.

DESIGN CRITERIA

The principal tasks in the project were the design, fabrication and testing of prototype PV SOLARWALL® panels. The work was performed by Conserval, Bechtel and Canmet, division of Natural Resources Canada.

Several design criteria were developed to aid in evaluating design alternatives and concepts for the PV SOLARWALL® panels, and to aid the development of a practical and viable product. These were arrived at by discussions among personnel at Conserval, CANMET and Bechtel.

The PV SOLARWALL® concept involves integration of the photovoltaics directly with the thermal panels at the factory, rather than mounting PV modules on a finished roof or wall. For reasons of safety and interconnection to attain practical system voltages, the photovoltaic cells and/or modules must be electrically isolated from the metal panels. Therefore , cells (e.g.., amorphous silicon) could not be deposited directly on the metal panels. Adhesives must be weatherproof and durable.

The PV SOLARWALL® panels should be capable of being shipped stacked on pallets, as are the present thermal panels. Also, it is highly desirable that the panels withstand handling by conventional building siding installation crews. This generally precluded modules and photovoltaic technologies that use glass superstrates or substrates.

Additionally, for the roof-mounted configurations, the panel cross section and/or photovoltaic module design should be such as to prevent damage to the modules if people walked on the roofing during installation or maintenance activities.

It was deemed desirable to have a high module efficiency in order to make best use of the area available on the panels. Additionally, at least for the prototype panels, the photovoltaic technology was to be commercially available. Other photovoltaic technologies will be considered as they become available and as they offer an advantage to commercialization of the PV SOLARWALL®.

Panels

The panels currently used for the SOLARWALL® thermal systems are essentially corrugated sheet metal. Both galvanized steel and aluminum sheets are used. The sheets are painted or otherwise finished to provide weather protection and match the aesthetics of the building on which they are to be installed.. The sheets are then perforated. The perforations are approximately 1.5 mm diameter, and are spaced uniformly with the desired porosity, as required by thermal system considerations.

The completed panels are nominally 0.95 m wide and varying lengths. To add structural strength and rigidity, the perforated sheet material is processed through rollers to form corrugations and ridges. The ridges are on the order of 20 - 40 mm tall and spaced 150 - 300 mm apart. A large number of cross sections are available. However, the general configurations of commercially available shapes limited the sizes and shapes of photovoltaic modules that could be easily integrated onto the thermal panels.

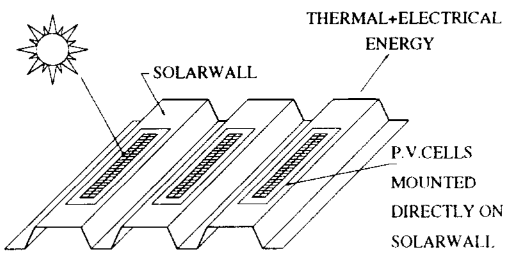

Fig. 1 Sloped Roof Panel Configuration

PV Technology Selection. Several photovoltaic technologies are available but many of the technologies had to be eliminated from serious consideration for the prototype PV SOLARWALL® because they are primarily laboratory devices and were not commercially available at the time. Photovoltaic technology is continually evolving and the selection of an optimum type of cell resulted in changes during this program and no doubt will be reviewed again as the PV SOLARWALL® matures into commercial status.

CANMET prepared a report titled "Thin Film PV-SOLARWALL Hybrid System" to evaluate the various PV technologies. CANMET's research was to investigate thin film systems and it appears that in the near term, amorphous silicone will be cost effective and suitable for use with the PV SOLARWALL®. In the mid term, other thin film technologies such as cadmium telluride (Cd Te) and copper-indium-diselinide (CIS) technologies will also have merit and should be considered when those technologies are more readily available.

The only technology that CANMET rated as a now selection is the crystalline silicone material. Conserval came to the same conclusion from dealing with the various suppliers of PV materials.

TEST PANEL

The criteria for selecting the most appropriate PV technology is as follows:

1. Should have a low cost to performance ratio, dollars to watt and watt per square metre
2. Should possess a long term stability.
3. Should be mechanically flexible.
4. Should be commercially available.
5. Should be easily installed onto SOLARWALL® material.

The only two PV technologies commercially available are the crystalline silicon and the amorphous silicone. The crystalline silicone technology was selected for the test panel due to its overall costs, long term stability, it is readily available, and it allows for substitution for the PV cells to eliminate dependency on one major supplier.

The criteria for selecting the most appropriate SOLARWALL® configuration is:

1. Profile is readily available from roll formers.
2. Surface area for mounting of PV material should be sufficiently wide to accommodate cells and rigid to minimize flexibility.
3. Panel length to be small enough to accommodate modular construction and ease of shipment.

Crystalline silicone cells encapsulated in teflon were obtained from a custom PV assembly company. The cells were cut in half to achieve a width of 50 mm. With the encapsulation edging the overall width was just under 75 mm. The SOLARWALL® panel of 914 mm x 1220 mm has six rib sections suitable for mounting the PV cells. The cells were purchased at a cost of approximately $5 per watt. The test panel is illustrated in figure 1 and shown in the photo in figure 2.

The PV SOLARWALL® test panel was sent to CANMET's lab near Montreal for a flash test which is the standard method of testing PV panels.

The PV SOLARWALL® test panel was then shipped to the indoor solar simulator at the National Solar Test Facility in Mississauga Ontario for the combined thermal and electrical tests. An identical SOLARWALL® panel, without the PV modules attached to it, was also prepared and sent to NSTF to obtain a reference for the thermal characteristics. After the thermal tests were completed, the test reference absorber was removed and replaced with the PV SOLARWALL® absorber.

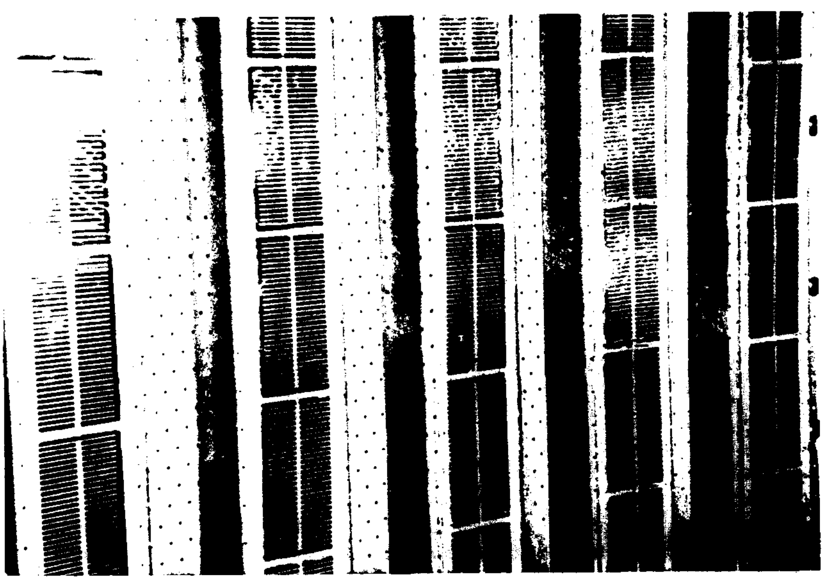

Fig. 2 Photo of test panel

Panel Area Summary

Each PV cell area was 52.53 cm^2.
There were 54 cells on the test panel.
Total PV area = 0.2837 m^2
SOLARWALL® panel area = 1.1664 m^2
Ratio of PV to total area = 0.2428, PV cells covered approximately 24.3% of the SOLARWALL® surface.

Electrical Test Summary

PV cell efficiency was approximately 11% at standard conditions according to the flash test based on cell area.

CANMET developed a model to predict the field installed PV module temperature under different atmospheric conditions. The model closely represented past experimental results. Based on this model and the test conditions used by NSTF (wind speed = 1.5 m/s; ambient temp. = 20C; insolation = 600 or 900 W/m^2), the PV cell temperatures have been predicted. The following table compares the predicted temperatures for the field installed PV cells and the experimentally observed temperatures by NSTF for the PV cells integrated with the thermal panel.

Insolation (W/m^2)	PV ONLY-Predicted (C)	PV/SOLARWALL®-Observed (C)
600	36	32-34
900	45	38-42

The results indicate the temperature of the PV cells with the combined PV SOLARWALL® are lower than a stand alone PV panel.

Lower cell temperatures will improve the efficiency of the PV cells and combining the PV panels with the thermal panel will therefore improve the electrical generation efficiency compared with a stand alone system.

Thermal Test Summary

SOLARWALL® reference panel:
efficiency at 900 W/m^2 and 100 m^3/h.m^2 is 51.8%
efficiency at 900 W/m^2 and 50 m^3/h.m^2 is 34.4%

Reference panel is approximately ¼ the size of Conserval's standard test panel due to the difficulty in obtaining sufficient PV test panels. Smaller panels will report lower thermal efficiencies due to edge losses which are significantly higher in proportion to the panel surface area.

The main purpose of the tests was to determine any changes in the performance in both thermal energy and electrical energy when PV cells are combined with a SOLARWALL® thermal panel.

Discussion of Results

The thermal efficiency of the combined PV/SW was slightly lower than the thermal reference panel. Thermography photos were taken on two of the tests and the photos identified areas where more heat can be recovered. Further work in this area is expected to improve the thermal collection efficiency.

Combined PV/SW Panel

Test #	Irradiance (average) (W/m²)	Airflow Rate (m³/h.m²)	Thermal Efficiency (average)	PV Power (Watts)	Combined Efficiency (average)	PV Efficiency Net Cell Area	Reference Thermal Efficiency
PV1	902	50	0.330	26.6	0.355	0.103	0.344
PV2	596	50	0.329	18.1	0.355	0.107	-
PV3	599	100	0.484	18.5	0.511	0.111	-
PV4	905	100	0.489	27.0	0.515	0.107	0.518

CONCLUSIONS

The test results indicate that combining the PV panels with the SOLARWALL® thermal panel will improve the efficiency of the PV panel and that the overall total efficiency can be greater than the thermal efficiency.

The thermal efficiency of the combined panel is slightly lower than on the standard SOLARWALL but there are methods to improve it. Additional work is necessary to optimize the design and finalize the selection of PV components.

Their is a considerable cost and energy benefit with PV building integrated systems when the thermal energy is utilized. PV efficiencies of 12% have a long payback time. Adding thermal energy can increase the total solar combined efficiency to over 50% with little or no increase in capital cost. The combined PV SOLARWALL will dramatically reduce the payback time and make PV projects more cost effective. When a photovoltaic installation is specified, consideration should be given to integrating solar thermal panels with the PV panels into one combined design.

Monitoring of existing SOLARWALL installations has shown thermal energy savings of between 500 kWh per year per m² to over 1,000 kWh per year per m² of cladding area. With a PV system, attached to the panels, approximately 10% or 50 - 100 kWh per year per m² of electricity could also be generated with the balance being provided as thermal energy.

The heat generated on the thermal side can be used with the ventilation system or processes requiring a continual supply of outside air. The PV panels operate more efficiently when they are cooled and drawing outside air across the panels performs this cooling function. The solar air panels best suited for the PV integration are the unglazed transpired panels as the PV cells will not be under glass.

Buildings with entire PV integrated walls and roofs must make provision for heat removal. Otherwise, overheating of the collector array can occur. It is now common practice to build an entire wall or roof covered with the PV cells. With proper design, the thermal energy can be collected and can be put to useful work within the building.