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Renewable Energy for People and Planet

PHOTOVOLTAIC MODULE HEAT RECOVERY USING REFRIGERANT

—Combined Heat and Power

White Paper
June 2010

Photovoltaic Module Heat Recovery Using Refrigerant

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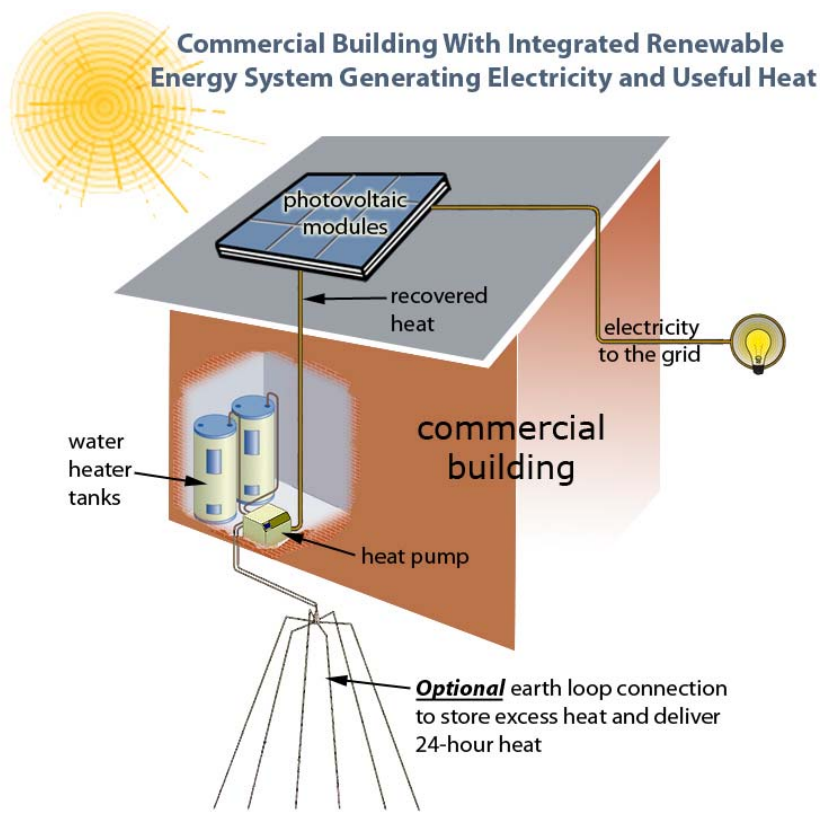
Introduction

New electrical and thermal efficiencies are attainable by using photovoltaic modules with a heat pump system for increased photovoltaic (PV) energy output and the delivery of large amounts of recovered heat for useful purposes. The PV module is a system component that is capable of performing more than one function (ie. producing power and heat).

The hybrid system is unique because it can combine two renewable energy sources: direct solar energy and stored solar energy. The result is increased generation of electrical power by the photovoltaic system by the removal of undesireable heat and the delivery of that heat for useful purposes or storage. Because the two energy systems are now commercially available, the integrated system can be marketed in the near future to provide valuable energy and environmental solutions.

The system can operate 1) independent of the earth and serve to remove unwanted heat from PV modules, improve module efficiency and deliver heat to a building, a water tank, a thermal storage system or a combination of them; or 2) the system can also be coupled with the earth for full- time energy delivery using the PV system or using the earth when the sun is not shining; or 3) can operate independent of the electric grid in remote locations that otherwise lack power and water heating.



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The Challenge

- Photovoltaic systems convert direct solar energy into DC power but most modules lose as much as 15-25% efficiency in the heat of the day (0.5% in output power for every degree Celcius increase in cell temperature). Even in cool weather, a cell typically operates at 50-70°C (122°F-158°F) during full sun.

  If the detrimental heat is removed, operating efficiency and power density are improved. A cell that could remain near 75°F (24°C) would produce 15-25% more energy than an uncooled cell. The space available for module installation can then be better utilized or the required panel surface can be reduced.
- Detrimental heat can be removed from PV modules and delivered for use in heating fluids, heating buildings or stored in a thermal storage device or the earth for later use.
- Current methods of removing heat from modules and rejecting that heat into water heaters is limited by the capacity of the water heater to accept heat, which also results in the module remaining at high temperatures when it would otherwise be cooled.

The Solution

- Backing the PV module with a flat panel heat exchanger containing liquid refrigerant cooling channels adhered to the undersurface with a thermally conductive material to remove heat (and ultimately, a heat exchanger that is an integral part of the manufactured module).
- Circulating a refrigerant fluid to remove heat through phase-change by evaporation and condensation.
- Transporting the energy (heat) by use of a compressor and a closed circuit with delivery and return lines.
- Providing for the circulating compressor to be driven by grid power to allow sale of all PV-generated power to the grid (at a premium “green power” price) and the compressor also to be operated during hours that the PV system is not producing power. Alternatively, when the installation is not grid-connected, supplying PV generated power to operate the compressor.
- Providing an appropriate closed-loop heat pump design for coupling the module heat (and optionally, the inverter heat) with a building to deliver the recovered heat for useful purposes.

- Providing an optional geothermal closed-loop heat pump design for also coupling the heat pump system to the earth where excess heat can be rejected, stored, accessed and delivered by the heat pump for later use.

All elements of this system are used in existing products and designs. However, it is not known that any previous attempt has been made to integrate and optimize these renewable energy resources into a high efficiency co-generation system having multiple uses.

EarthLinked Technologies, Inc. (ETI) is the global technology leader in direct geoexchange heat pump systems. It developed the patented refrigerant flow controls that are essential to this project, and the simple, lower cost, low impact earth coupling technique for the optional geothermal 24-hour application.

The Advantages of the Described PV Hybrid Method

- The **co-generation of electrical and thermal energy** with the PV hybrid system optimizes the productivity and value of available roof space, eliminates the need for the addition of a solar thermal collection system and reduces the weight on the roof structure. This has the advantage of saving cost, space and weight, increasing the solar yield and the aesthetic benefit of uniformity.
- **Increased electrical output** can increase Return on Investment or reduce the needed module surface, thus reducing installed cost and the required space.
- Increased electrical output can increase the revenue from the sale of power to the grid and **reduce the cost of PV generated power**.

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- Major efforts and millions of dollars are expended to **improve PV module efficiency** by just a few percent. The described method can bring an average improvement in PV system output of 15-20%. That equates to a 20%± drop in the cost of PV energy (currently a reduction of about 6 cents/kWh); or alternatively, a 20%± increase in the power produced per square foot of roof space and for sale to the grid. Likewise, the installed cost (today, a decline of about $1.60-$2.00/watt); or more power per square foot of panel space.
- Because the described system uses ETI's proprietary Adaptiv™ refrigerant flow controls, it can 1) efficiently accommodate to **constantly changing temperature** in the refrigerant evaporator and condensor, 2) **deliver heat to alternate locations** when it is needed (water tank or building or divert heat for storage in the earth, a dessiccant cooling system or a thermal storage bank when it is not currently needed), 3) efficiently **accommodate to the various distances** to several heat sinks, and 4) it is believed that these characteristics make the system a good candidate to cool Concentrated PV panels and deliver the undesired heat for beneficial use or storage.

PV and wind energy are intermittent, lack storage and often do not match the load. The earth is a heat battery that is warmed by the sun daily and never runs out of thermal energy.

- The single greatest contributor to the physical end-of-life for any PV cell is prolonged operation at high temperatures. Nearly every negative mechanism (oxidation, delamination, encapsulation failure) is accelerated by high temperatures— exponentially in some cases. By cooling the panels, the described system reduces stress due to heat and increases durability.

- Water cooled systems are limited by the **capacity of the heat sink** (water tank) to accept heat and by the ability of the host structure to **support the additional weight of the water** circulating system. This system does not have those limitations.

- Even though inverter efficiency does not decline so greatly with operating temperature, it is certain that mean time before failure is negatively affected by high operating temperatures.

- With a simple thermostat, the earth coupled heat pump can be brought on during very cold nights to maintain the PV array at a desired temperature to prevent exececessive thermal stresses (from cold nights to full sun) on the contacts, modules, encapsulation and other elements of the expensive PV array. Thus, **module reliability can be increased** and life can be extended. Also, in **heavy snow zones** this method of heating during snowstorms would allow PV systems to be ready to operate as soon as the skies clear. Presently, these PV systems are essentially useless for long periods of time during the winter months, even though significant sunlight is available on cold, clear days after a snowfall.

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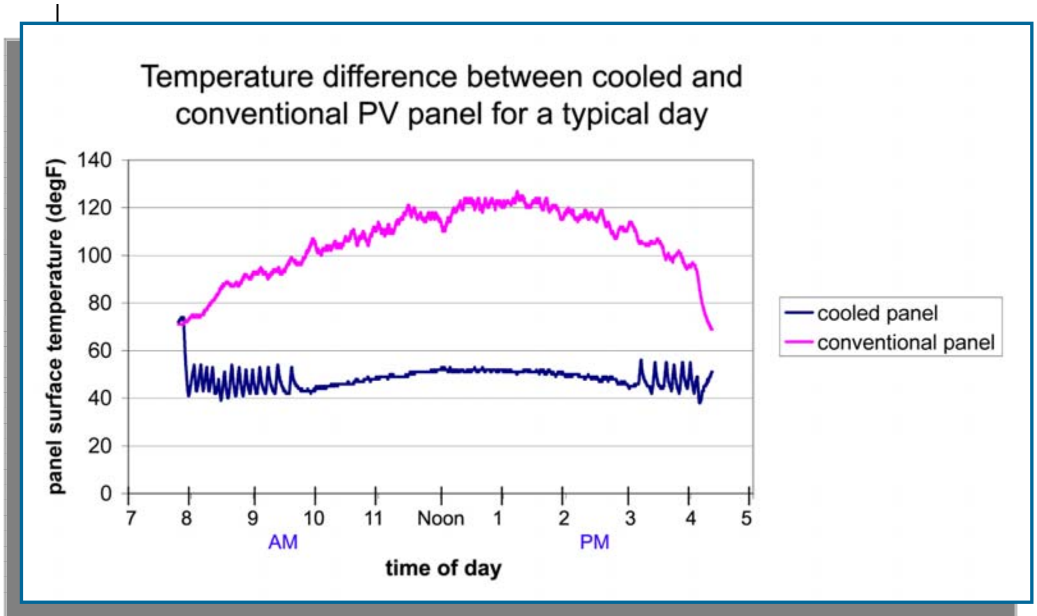
- Although PV is currently more expensive to install than fossil fuel energy systems, the price of fossil fuels fluctuates and is rising, while the cost of solar fuel will remain as the cost to convert and deliver that energy for use.

- The system has the capacity to operate **off the grid** to supply electricity and water heating and break the hardship and health risk of isolation in the poorest communities in remote areas. Thus electrification can **leapfrog the grid** as telephony is doing in India and China. One-third of humanity does not have electricity or basic hygiene. Tele-medicine can cover the world, but medical care is dependent upon electricity for communication, an on-line connection, to refrigerate medicines, pump clean water, and heat water to provide sanitation.

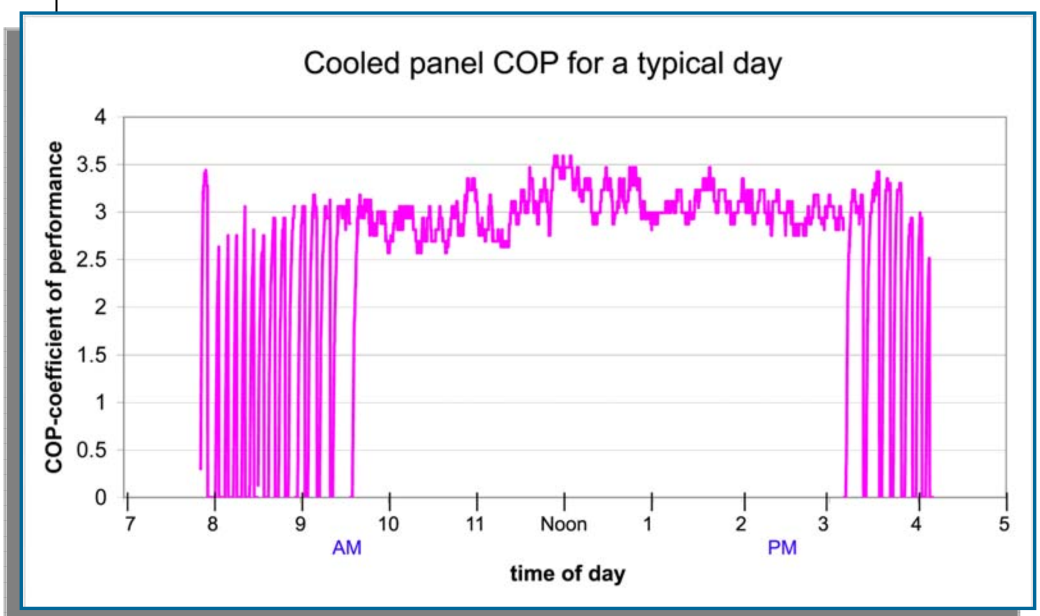
Demonstration Setup

One PV panel was modified by the addition of a simple coil system with an intricate pattern and manifold. One PV panel was cooled and the heat was transferred for heating water.

The second panel was not cooled and was used for electrical power output comparison.



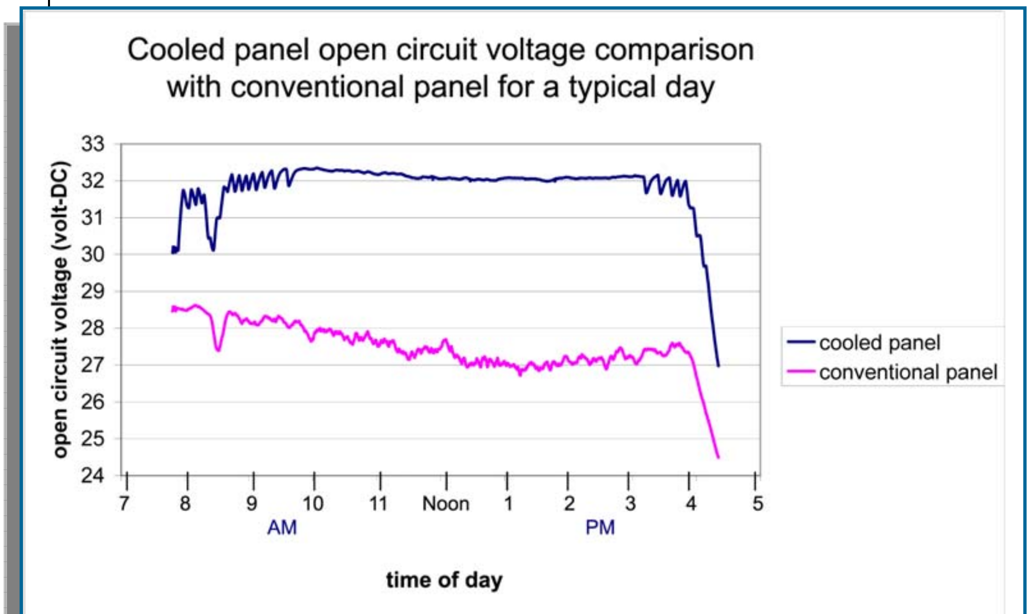
The cooled panel had an average temperature of 10°C (50°F).

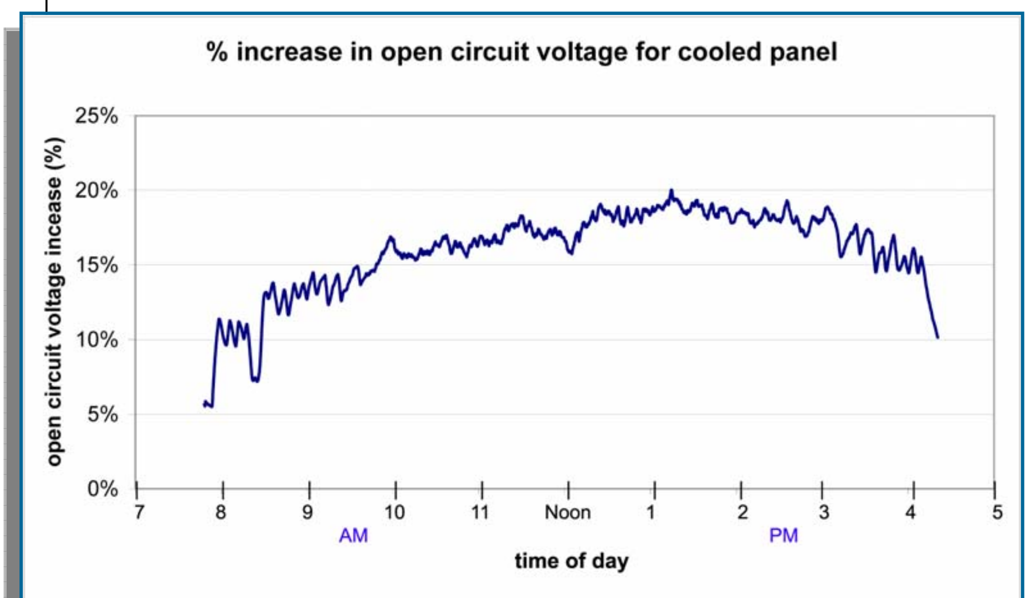


The relatively large heat output occurring between 7 a.m. and 8 a.m. was due to the initial cooling of the panel after being inside the heated warehouse all night.

PV Power Output Comparison Testing

The cooled panel demonstrated up to a 19% increase in Open-Circuit Voltage output over the un-cooled panel, and an average 12% daily increase. Open-Circuit Voltage output varied with solar incidence on these stationary panels.





The water temperature was monitored to determine the heat recovered from the one panel that was being cooled. The following data shows the discharge water temperature and Coefficient of Performance (COP) for three different flow rates:

Gallons per Minute	Water Temperature	COP
0.25	60°C (140°F)	2.3
0.5	49°C (120°F)	3.5
1.0	38°C (100°F)	3.6

By reducing water flow, higher temperatures can be achieved, but operating efficiency is reduced. Even on an overcast day, water temperatures of 100°F were achieved.

Conclusions

1. With the addition of the refrigerant circuit the Open-Circuit Voltage output increased up to 19% over the comparison un-cooled Panel, with an average daily increase of 12%. The temperature was uniform over the majority of the panel except the extreme edges were not cooled. It is believed that further improvement in heat exchanger coverage on the underside of the PV panel will result in a further increase in voltage output.

2. The by-product of removing heat from the panels with an improved heat exchanger is thermal energy that can be delivered by the circuit for various useful purposes with a COP in excess of 4.

3. It is believed that the cost of the hybrid system and its installation can be greatly reduced while its voltage and thermal output can be increased by manufacturing the heat exchanger as an integral part of the underside of each module.

About EarthLinked Technologies

ETI is the manufacturer of simple, small and energy-efficient geothermal systems that provide affordable heating and cooling to enable people to hedge against soaring electricity prices, lower their energy bills, reduce their carbon footprint and improve their quality of life. More information is available at *www.earthlinked.com*.

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