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The Use of Thermoelectric Peltiers to Recapture Waste Heat

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Abstract:

Peltier devices are a method of converting differences in temperature into electrical energy. Using data from a supplier of these devices, calculations were made to determine the efficiency of these devices in conjunction with a residential solar hybrid electric system. The initial calculations show efficiencies less than 2% with the temperature differences experienced during the springtime. While this efficiency doesn't sound stellar, taking into account the current efficiency of residential solar cells, this would be an appreciable addition to the power output of a residential solar system.

Introduction:

Residential solar power systems are currently expensive for many reasons, the chief among these being a low energy output per dollar when compared with traditional energy generation. While the efficiencies of solar panels are increasing, augmenting this power by some other means is an attractive option. One particular energy source present that is often overlooked is heat. Using a thermoelectric generator, one could conceivably add additional power to the generation unit without significant cost increase.

According to Paul E. Gray, thermoelectric generators, here referred to as Peltier devices, work on the basis of the Seebeck effect. The Seebeck effect, discovered in the early 1800s, is the production of electricity from a thermal gradient applied across two dissimilar materials[1]. Goldsmid says that if current is applied to a Peltier, then a heating or cooling occurs. This is called the Peltier effect. The Thomson effect, a related thermoelectric effect, occurs in a single phase conductor and was discovered in an effort to explain the connection between the Peltier and Seebeck effects[2].

Using the waste heat created due to solar heating in a Solar Thermal/Electric Panel (STEP) system, a Peltier would be able to utilize this otherwise useless energy. While the thermal system does heat water and provide some radiant heat in a home, there is more heat than needed at times. Thus the addition of a Peltier could prove to be a useful addition to residential solar systems. This study looks at the feasibility and theoretical possibilities of such a system.

Procedure:

Data Collection:

The main portion of data used for the experimental calculations was collected by Joel Lamson during the spring of 2006. The apparatus for the data collection was an array of six Solar Electric Thermal Panels (STEPs). The STEP, as it's acronym implies, is a combination of thermal and electrical solar collection systems. Readings were taken on the available radiation using a pyranometer, and temperatures from the thermal solar unit were measured using thermocouples in the water lines of the test setup. Ambient temperatures were measured throughout the day and averaged for the calculations. The measurements were done for approximately five hours on five different occasions.

Calculations:

From the data collected, the efficiencies of the Peltiers could be calculated using the data provided by Hi-Z, a manufacturer of Peltiers. Assuming a negligible Thomson effect, the following equations from Goldsmid were used to determine the efficiencies of the Peltiers[2]:

$$Z = \alpha^2 \frac{\sigma}{\kappa} \tag{1}$$

Where:

Z = Figure of merit
α = Seebeck coefficient
κ = Thermal conductivity
σ = Electrical conductivity

$$\eta = \frac{\Delta T}{T_h}\left[\frac{\sqrt{1+Z(T_m)}-1}{\sqrt{1+Z(T_m)}+\frac{T_c}{T_h}}\right] \tag{2}$$

Where:

η = Efficiency
ΔT = Temperature gradient
T_h = Temperature of heat source
T_c = Temperature of cold sink

As the Peltier is constructed out of two slightly different types of material, it was necessary to calculate the efficiency of each part of the device and then multiply the efficiencies together to find the total efficiency. Failure to do this can result in abnormally high calculations in efficiency. Having neglected to do this in the initial calculations, the first results showed efficiencies an order of magnitude higher than expected.

Results and Discussion:

Table I : Temperature Difference and Electrical Output

Day	Average Temperature Difference (K)	Watt-hours/m^2 (cumulative)	Average Radiation (W/m^2)	Standard deviation Radiation (W/m^2)
3/26	37.89	45.33	926.70	134.83
3/30	27.38	12.27	495.09	303.26
3/31	34.44	38.47	950.00	82.40
4/1	44.83	53.31	853.15	261.02
4/8	31.80	34.84	939.46	92.19

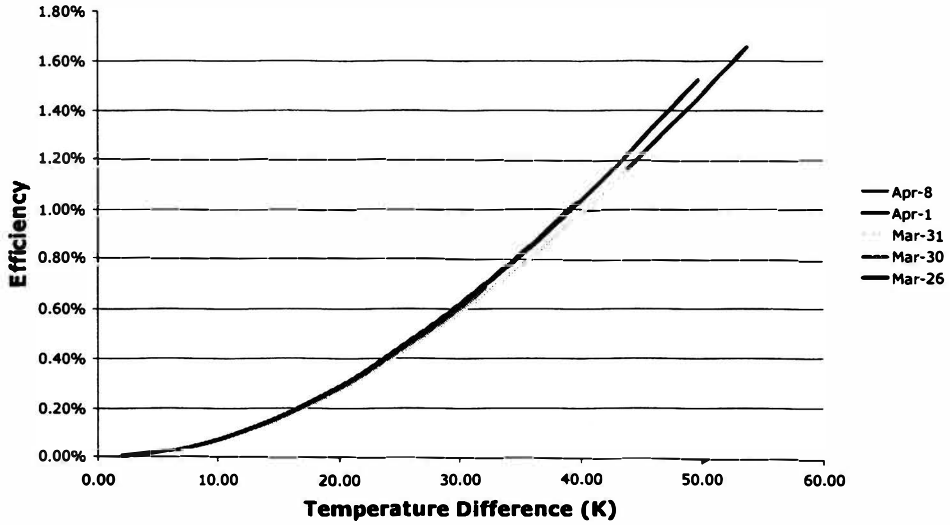

Figure 1: Efficiency vs Difference in Temperature

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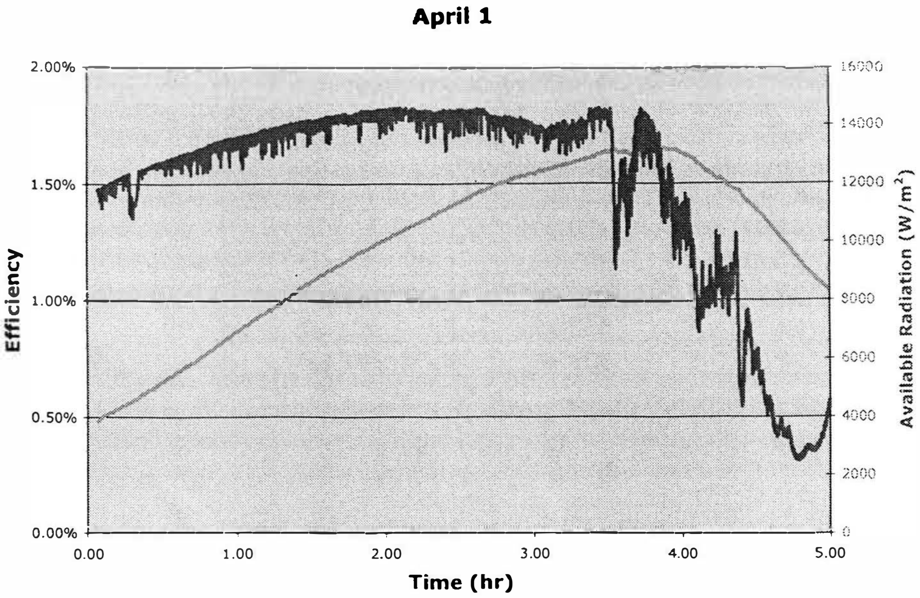

Figure 2: Efficiency vs Time

Temperature difference:

Temperature difference in the Peltiers is the single most important aspect of their performance. As can be seen in Figure 1, the higher the difference between the hot source and cold sink. This is to be expected as the efficiencies should follow the tendencies of any heat engine. The information in Table 1 confirms this as the days with higher temperature differences typically have a higher total amount of energy produced throughout the day. This is exemplified by the highest readings occurring on the 1st of April, when the highest average temperature differences occurred.

Available Radiation:

While temperature difference is what influences the efficiencies of the Peltiers, the temperature difference is highly dependent on the amount of radiation available. The solar radiation is what causes the temperature difference to begin with in the solar system, and thus the more available radiation, the greater the temperature difference. The greater the temperature difference, the higher the efficiency, and also the higher the amount of power to convert into electricity. As the Sun and weather are in control the amount of available radiation, there is little that can be done to increase the amount of radiation that goes into the system. Cloudy weather, such as that indicated by the March 30 data, indicates a significant reduction in energy production due to the irregularity of available radiation. The lack of a constant radiation source results in a lower temperature difference and lower efficiency. Figure 2 shows the dependency of the efficiency of the Peltiers on the available radiation.

Relevance:

Currently, residential solar systems typically have efficiencies between 8% and 12%. While the Peltiers only have efficiencies on the order of 0.5% to 1.5% for the operating temperature differences, this can still have an effect on the overall power output of the unit. Assuming a 10% efficient solar array, one could get 500 watt-hours per square meter in a five hour period at full solar irradiation. Depending on temperature, one could presumably get up to 50 watt-hours per square meter from the Peltiers, a 10% increase in total power. This 50 watt-hours per square meter would allow a homeowner to run a 3-15 watt compact fluorescent light (CFL) for approximately four hours per square meter of array with a few watts to spare. Conceivably, the Peltier system could take over the task of lighting a home while the power produced by the array could be used for other tasks.

Error and issues:

All the data here has been run for a thermal system with no draw from heating water or a home through radiant heat. This would have a significant effect on the amount of power that could be drawn from the Peltiers. Heat drawn from the system by household tasks would act like a liquid cooling system for the STEP, and thus would reduce the high end temperature. As the amount of daily temperature drop in the fluid is unknown at this time, it would be advisable to test the Peltier system on a home using a STEP system in the future.

Possible Improvements:

There are several possibilities for improving the output of a thermoelectrically equipped STEP system. The first of these is the possibility of utilizing a solar tracker in order to track the Sun and thus increase the available radiation to the exposed surface absorbing heat. This system would possibly be helpful, however, it is likely that thermal absorption is not as dependent on incident angle to the extent that electrical energy production in solar panels is as the material should absorb heat evenly regardless of its incident angle. Also, a solar tracking mechanism is potentially heavy to mount and maintain, especially for a rooftop residential solar system. To fully appreciate its usefulness a real world test model would need to be built.

Another possibility commonly used in the solar industry is the solar concentrator. The concentrator would effectively increase the effective area the panel covered. The entire panel itself is the heat sync in the STEP system, so the use of a concentrator would benefit both the electrical and thermal portions of the system. Concentrators have their own set of issues, and would also be something needing real world testing to see their applicability.

Trying to increase the amount of absorbed solar radiation is just one method of increasing power output from Peltiers on the STEP system. Integrating either an air or water based cooling system on the cold sync could increase efficiencies further. How exactly this would be implemented, and whether the energy required to run the coolant would be greater would need to be studied further, but could be another possibility for increasing system efficiencies.

The last option that comes to mind for increasing efficiencies is a better thermoelectric device. Increasing the figure of merit (Z) of the material would lead to an overall more efficient device, and make the system produce more power. Currently Peltiers are relegated to relatively small efficiencies when compared to solar power, however, recent advances in nanotechnology and materials science may lead to newer thermoelectric devices that can bridge the gap. Future couple systems could be significantly more efficient than solar alone, however, this particular option does require the greatest deal of research and development, and therefore is likely the furthest away and most expensive.

Future Plans:

In order to see how real world inefficiencies affect the utilization of the Peltier devices, it would be logical to construct a real world experiment utilizing the STEP system and the Peltier system. In order to get both theoretical and expected values, setting up a system in one of the solar houses on campus as well as a test box would be ideal. The test box would collect data on a fluid system with no heat loss due to household use, and the house system would be able to simulate what a real life situation would be like. Having both sets of data would allow a better understanding of the issues preventing a system like this to go to mass market.

The test box would likely be a test bed for a couple of different options for the Peltiers. Some of the previously mentioned methods for increasing efficiency and available radiation could be demonstrated in the test box. Sectioning the test box off into several sections would be possible, with each of the sections doing something different. The first section would be a control of the STEP without any Peltier system in place. The second would be a STEP with a Peltier. The other sections would demonstrate a liquid or air cooled cold sink, and a concentrator or tracking system. This would allow the comparison of all the systems, and provided the test apparatus were built appropriately, it could serve as an educational outreach tool as well, showcasing the various types of solar collection. The initial results of this study seem promising enough to continue researching the feasibility of using the devices in conjunction with the STEP system.

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Norbert Elsner. Hi-Z Technology, INC.. President of Hi-Z. Provider of high efficiency thermoelectric module data.

References:

(1) Gray, Paul E.. The Dynamic Behavior of Thermoelectric Devices. New York, London: The Technology Press of The Massachusetts Institute of Technology & John Wiley & Sons, Inc., 1960.
(2) Goldsmid, H. J.. Applications of Thermoelectricity. London: Methuen & Co LTD, 1960.