

ECBA -16**Self-energy Home without Compressor Hot / Cold Air Conditioning Power Unit Development for the Micro Energy Harvesting System of A Smart House**B. J. Tsai^{1*}, C. Y. Li², K. C. Cheng³^{1, 2, 3} Chung Hua University, Taiwan

Abstract

The laboratory heating electric generator (TEG) combine plus the phase change material (PCM) via solar panels, to achieve the integration of the temperature in the power generation and architectural environments. In fact, low-power circuitry can now be combined with energy-conserving power management methods to create “perpetually” powered sensor nodes that enable to harvest of required energy from heat, vibration, thermoelectric, rotating energy, passive flapping foils, piezoelectric and even RF signals and so on. A simulated smart room coupling the thermoelectric and latent heat effects, call thermoelectric generators (TEG) combined with phase change materials (PCMs) (TEG/PCM), the work unit can harvest micro-energy day and night, thanks to the heat storage function of the PCM which is placed behind the TEG. But their work was just as a subsystem. In here, we would expect this system to work non-stop, day and night to generate the output current. This power can be used to actuate the fan for adjusting household cool/heat air as well in a 6.5m x 4.5m x 3.2m smart building. Comparisons of the power consumption with/without installation the TEG/PCM module, and then coupling or without coupling a new wireless “on-off” control technique to sustain a comfortable indoor temperature $22\text{ C} \pm 1.5\text{ C}$.

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Keywords— Solar Panel, Thermoelectric Generator, Phase Change Materials(PCM)

Introduction

This study investigates, experimentally, the use of thermoelectric generators with phase change materials (PCM) to harvest micro-renewable energy. Experimental results in the laboratory and in real loading conditions show that the coupled effects of heat flux (solar radiation), external temperature and convection (wind) significantly influence the micro-energy harvest. Unlike other approaches, the proposed system is able to produce micro-energy by day and by night, thanks to the release of solar heat stored in the PCM during the day. With optimized thermal loading, power generation of 0.8 mW was achieved by one work unit. The experimental results also show the sensitivity of the proposed work unit to variations in solar radiation and wind, and this indicates that the system (consisting of many work units) would be suitable for use as a sensor and actuator in wireless applications in buildings, reported by (Zhang, Agbossou, Feng and Cosnier 2010).

1. Semiconductor devices: Polarized solar cells were used to convert photovoltaic-solar energy directly into electrical energy. According to (Cook-Chennault, Thambi and Sastry 2008).
2. Thermal methods: Thermal energy (temperature gradient) is converted into electrical energy using, for example, the Seebeck effect (Rosi 1968); alternatively, time temperature variation is converted through the thermo electric effect. PCM was installed where the sunlight did not irradiate that is the cooling end of TEG (Agbossou, Zhang, Sebald & Guyomar 2010).

Literature Review

The system (consisting of many work units) would be suitable for use as a sensor and actuator in wireless applications in buildings (Zhang et al. 2010) and (Agbossou, Zhang, Amen & Guyomar 2010). Semiconductor devices: Polarized solar cells were used to convert photovoltaic-solar energy directly into electric energy. According to (Cook-Chennault et al. 2008). Thermal methods: Thermal energy (temperature gradient) is converted into electrical energy using, for example, the Seebeck effect (Rosi 1968); alternatively, time temperature variation is converted through the thermo electric effect. PCM was installed where the sunlight did not irradiate that is the cooling end of TEG (Tsai, Huang & Lee 2010). At almost the same time, Tzern T Toh, Paul D Mitcheson, Andrew S Holmes and Eric M Yeatman published “A continuously rotating energy harvester with maximum power point tracking” (Toh,

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Mitcheson, Holmes and Yeatman 2008). A micro motor attached to a driver motor was used to provide electrical power to a wireless tachometer used to control the driver motor (Toh, Mitcheson and Yeatman 2009).

Methodology-Physical Model

Smart house model (Fig. 1) is long 6.6 m, width 3 m, high 2.65 m, the main structure of the concrete wall 0.1 m thick. Sandwich a thick interval 0.05m in the floor and ceiling, the upper mezzanine place a long 1.6m, width 1.9m, 0.04m thick of PCM with long 1.8m, width 2m, 1.4m thick thermoelectric generator. And a long 2.1m, 0.07m width 2.1m thick solar panels (Tsai, Huang and Lee 2011) and (Tsai, Jhang and Liao 2012). Fig.1 gives the introduction of components and equipment of the smart model house. On the right hand side of the building placed a radius 15cm duct, duct elbows, long 0.45m, duct long 1.68m, placed a fan within a radius of 0.05m duct. Disposed within the housing in four different types of micro-energy harvesters, respectively, the thermoelectric generator + energy collection phase change material (TEG+PCM), solar ventilation glass (rotational energy of the collector), stainless steel door (rotational the energy harvester), a thermoelectric power generation energy harvester and plumbing harvesting system to collect the energy, etc. these micro-energy harvesting system generated and converted into electrical energy in order to facilitate the monitoring system to provide a sufficient self-energy capability. With the ambient temperature control system can more accurately detect the indoor temperature changes and in here, we would expect this system to work non-stop, day and night to generate the output current. This power can be used to actuate the fan for adjusting household cool/heat air as well in a 6.5m x 4.5m x 3.2m smart building to reach and maintain at a comfortable temperature of 24 degrees C or so. Therefore, we made use of scaling roughly 1:10 acrylic model (see Fig. 2) as a simulation of a real house, placed on top of a standard model house for 30cmx30cmx3cm (length x width x height) of PV solar panels with 20cmx16cmx2cm (length x width x height) thermoelectric generator (TEG) and 19cmx15cmx1.5cm (length x width x height) of a phase change material (PCM), and installed in the right model house with a diameter of 5cm length duct 28cm and installed in duct inside diameter of 3cm small fan, the other at the top of the acrylic model of a house erected induction halogen as a light source to provide a stable source of solar irradiation in order to simulate a solar panel in day and night time changes in the indoor temperature inside the house. This study with ANSYS Fluent used numerical approach to simulate this smart house. In addition, the whole simulation analysis system will be reported in the next Part B.

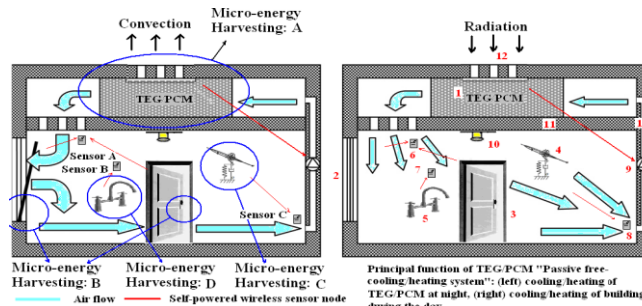


Figure 1: The Simulated Smart House

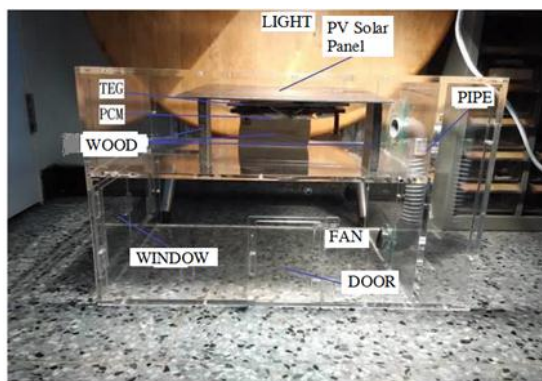


Figure 2: 1:10 Model Test House

Self-energy Air Conditioning Device

The self-energy home without compressor hot/cold air condition power unit consists of Solar panel/ Thermoelectric generator (TEG)/ Phase change materials (PCM). Receiving energy from sunlight by solar panel to

generate electricity, then in addition, as a hot end; heat source of TEG to generate electricity and produce the cooling sink. By using thermoelectric effect, the temperature difference generates electricity. One more technique is using PCM to keep and maintenance of cooling temperature effect of PCM as a cooling sink which can increase the thermal efficiency to reach energy-saving objective.

Solar panel

The size of solar panel is 33x33x0.5 cm (range of electricity generation 30x30x5), properties of electricity: Voc:23V, Vmp:19V, Isc: 460mA, Imp:420mA. In this experiment, using a Multi-meter to measure voltage and current every hour, the power generation capacity of this panel is 8W (see Fig. 3).

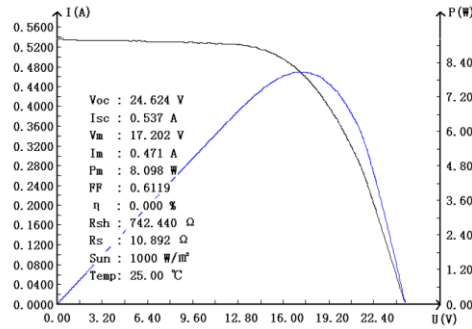


Figure 3: Diagram of PV Solar Panel

TEG/PCM

This module of TEG which made up of Bi2Te3 was produced by the ITRI. Its volume is 20x16x2cm, and consists of 6 units of TEG chips inside the module. On its top installing end cooper tube with water inside as cooling sink, on its bottom side has a heater as heat source. Through the temperature difference, electrons will accumulate on the hot end resulting in different Fermi level, then produce electricity. This experiment used a heater and water to generate temperature difference, then using Multi-meter to measure the voltage and current. In this integration module of TEG/PCM, PCM was embedded in cooling sink of TEG, and maintain a temperature of -5°C. Heater will add heat to different pointed temperature.

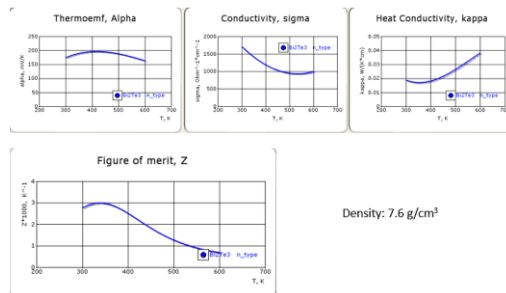


Figure 4: Characteristics Chart of Bi2Te3.

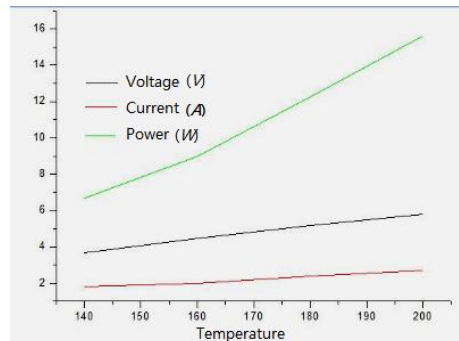


Figure 5: Unit power (I and V) vs. temperature of TEG

Solar panel/TEG/PCM

The above integration of TEG/PCM which PCM was embedded in the cooling side of TEG and maintain a temperature of -5°C. Heater will add heat to different temperatures. In this concept of new design becomes a Solar

panel/TEG/PCM module, Solar panel replaced the heater as heat source. Receiving energy from sunlight by solar panel to generate electricity, then in addition, as a hot end; heat source of TEG to generate electricity and produce the cooling sink. Then by using a Multi-meter to measure voltage and current every hour and using Infrared thermograph measured temperature distribution of each layers of the Solar panel/TEG/PCM module. Fig.6 and Fig. 7 shown temperature distribution comparisons between each layers, and the highest current of the Solar panel/TEG/PCM module was recorded.

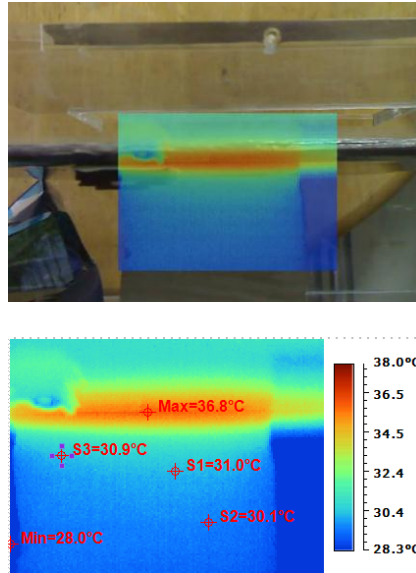


Figure 6: Temperature Measurement of TEG/PCM With the Heater

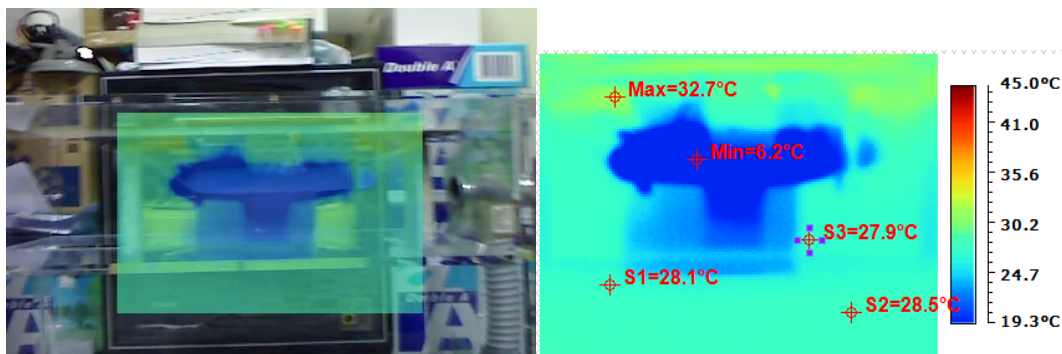


Figure 7: Temperature Distribution of the PV Solar Panel and Model House (by Infrared Thermograph)

Methods of Measurements and Analysis

Methods of measurements and analysis in this experiment can be divided into 3 portions: Solar panel, TEG/PCM and Solar panel/TEG/PCM. Equipment includes: Multi-meter, illuminator, Infrared thermograph; type of Multi-meter is EXCEL DT-9205, Illuminator is UYIGAO UA1010B and Infrared thermograph is A-J Co. IRC4. These equipment measure voltage, current, power and temperature fields for the above three arrangements individually, in especial, the measurement for Solar panel/TEG/PCM module.

Using Halogen light with illumination 1200 irradiated the Solar panel 10 minutes until the temperature of backside solar panel reach to 50°C under the indoor temperature 27°C, then put the hot end of TEG under the backside of solar panel, and PCM installed under the cooling end of TEG, its temperature maintains a temperature of -5°C. In final, wait the illumination to 1200 (corresponding to the sunlight illumination under the daytime temperature 32°C, connect their power generation cathode together and using Multi-meter to measure their voltage and current.

Results and Discussion

Experimental results show power measurements of the Solar panel, TEG/PCM and Solar panel/TEG/PCM. Comparisons between them, the highest measurement value of power is voltage 1.5V and current 8.1A. That is to say the highest value of current is the Solar panel/TEG/PCM with 8.1 A. On the contrary, the simple Solar panel generated current 1.79A and TEG/PCM generated current 1.6A. By integrating original Solar panel with thermoelectric effects of TEG and PCM to generate electricity has high power value is clear, then increasing temperature difference will rise the voltage and current, Measurement of power is higher too. In this investigation, the key factor is the keeping and maintenance of cooling temperature effect of PCM as a cooling sink. And from the result reveals PCM receiving heat from the higher temperature ends which are Solar panel and TEG will result in rising temperature, then narrow down temperature difference will lower the power generation capability and affect temperature level of each layers, therefore matching issue of each layers; Solar panel, TEG and PCM need to redesign more seriously.

Fig 6 and 7 indicated the temperature of each layer of the Solar panel/TEG/PCM. To observe how the installing PCM affect unit environmental temperature, an experiment was set by using Halogen light with illumination 1200 irradiated the Solar panel 10 minutes under the indoor temperature 27°C.

Solar panel

Fig. 6 indicated the temperature of Solar panel is 36.8°C; the average unit environmental temperature is around 29、30°C because receiving sunlight energy from the Solar panel rising temperature and causing the temperature of unit environmental temperature increasing too.

Solar panel/TEG/PCM

Fig. 7 shown the temperature of Solar panel is 32.7°C, and the temperature of PCM is 6.2°C, the average unit environmental temperature is around 26, 27°C, no big difference from indoor temperature. It is not affected by the heat from Solar panel. Main reason is the thermoelectric effects of TEG and PCM, the keeping and maintenance of cooling temperature effect of PCM as a cooling sink heat conduction to all layers including ambient, Solar panel, and decrease their temperatures. Resulting in the average unit environmental temperature is around 26, 27°C lower than that of the simple Solar panel.

Airflow and Thermal Analysis

The forced convection of the night time. Ambient conditions: Atmospheric pressure is 1044.8Pa, the temperature is 20°C and wind speed is 6.6m/sec. The numerical simulation approach was using when time $t=$ 1 minute, 5 minutes, 10 minutes, 20 minutes, 30 minutes and 60 minutes to analyze the change of temperature fields of the simulated smart house respectively.

The temperature fields of the building when $t=$ 1 minute in the night time was shown by Fig. 8. The driven fan of ambient temperature monitoring system has been turn on to blow the cold air through the wind pipe. Temperature of the right hand side of the solar panel begins decreasing. The average temperature is 306.5K (33.5°C). The average temperature on the left hand side of solar panels is 331.2K (58.2°C), the average temperature of surrounding is around 316.8K (43.8°C). The middle of the TEG (thermoelectric generator) temperature is 312.4K (29.4°C). PCM average temperature of 252.8K (-20.2°C), near the PCM, the average temperature is 298.9K (25.9°C). Because of the air flow rate is not too much into the indoor room. There is no significant cooling effect of the indoor temperature is 306.7K (33.7°C). Temperature distribution of case iii was listed in Table 2. It also shows the using wireless environment temperature monitoring system to drive the fan started to adjust the environment temperature inside the room so that the average temperature dropped 5 ~ 10K to reach a comfortable temperature. Temperature vs. time for indoor temperature of the house with natural/forced convection (fan) in day/night time was shown in Fig. 9

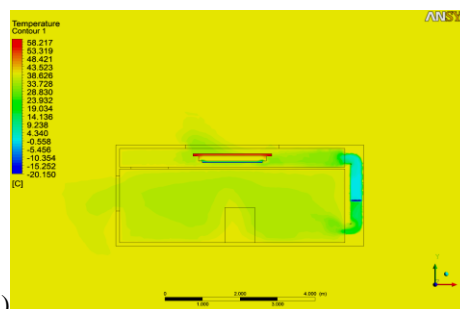


Figure 8: Temperature Distribution of Forced Convection (day) for $T=$ 1 Minute (with Fan)

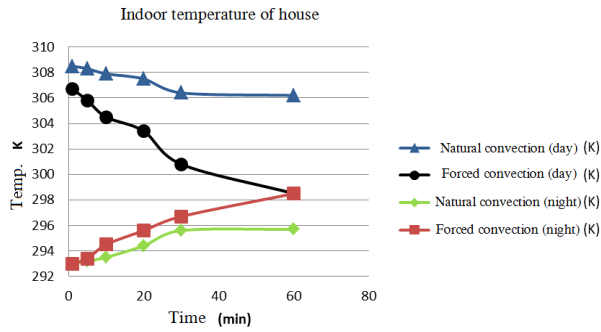


Figure 9: Comparisons of T Temp. Changes for Natural Convection/Forced Convection and day/night

Rotation Energy Harvesting Device and Control

There is a common on-off control method based on room temperature deviations in the air conditioning system (on-off control). In the beginning, deviation around the set point is set in the controller. When the temperature is lower than the “set point - deviation”, the fan is closed and the cooling is stopped. When the temperature is higher than the “set point + deviation”, the fan is open and the cooling started.

In accordance with the difference between the actual room temperature and the set point, the open ratio of the fan in a single cycle (the fan’s open time over the control cycle) can be calculated using the intelligent algorithm, and to control opening and closing the fan in accordance with the open ratio is the last procedure of this intelligent on-off adjustment method. The schematic of the control scheme is shown in Fig.10.

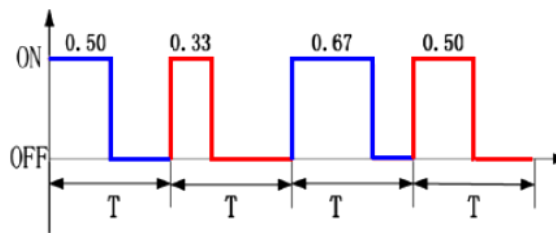


Figure 10: Schematic Diagram of Time On-Off Regulation Based Upon Predicting the Fan Duty Cycle

Conclusion

This investigation proved the unit of Solar panel/TEG/PCM not only generated high power including voltage and current but also can affect unit environmental and indoor temperature of the house. The power can be used to actuate the fan for adjusting household cool/heat air as well in a 6.5m x 4.5m x 3.2m smart building. Comparisons of the power consumption with/without installation the TEG/PCM module, and then coupling or without coupling a new wireless “on-off” control technique to sustain a comfortable indoor temperature $22^{\circ}\text{C} \pm 1.5^{\circ}\text{C}$. This unit becomes self-energy home without compressor hot/cold air condition power unit. This study shows that, in a properly designed system, the instant fragmented rotation mechanic energy harvested by the micro motor generates sufficient electrical power to operate the MEMS. This application can reduce the need for batteries and can reduce the waste and pollution generated by producing batteries. The findings are also meaningful for the Taiwan micromechanical industry, which does not currently produce micro motors designed to harvest energy. Hopefully, the combined efforts of universities, the government, and manufacturers will establish a new green industry. Four micro-energy harvesters A-D, three self-powered wireless sensor nodes A-C and a fan, and testing a new wireless control technique (Wireless “on-off” control technique) for adjusting household cool/heat in a smart building, let its energy savings technology to save around 39% thermal energy and make the dream of healthy, smart and comfortable room come true.

Table 1
Measurement IV of TEG/PCM

Measure time/PCM Temp.	Hot plate setting temp.	Pmax voltage (V)	Pmax Current (A)	Output power Pmax (W)
17:48/5°C	50	2.6	1.6	4.16
17:50/15°C	50	1.8	1.37	2.466
17:52/25°C	50	1.3	1.03	1.339
17:54/30°C	50	0.7	0.55	0.35

Table 2
PV solar panel/TEG/PCM IV measurement_o

Back side temp. of PV /PCM temp.	Illumination (X100)	Voltage (V)(200)	Current (A)(10A)
50.8 / -5(°C)	1203	1.5	8.1

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