FIBER-REINFORCED THERMOELECTRIC TILE AS AN ALTERNATIVE SOURCE OF ENERGY

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Abstract: Urban heating in modern cities that raises the temperature by 1℃ to 3℃ than the ordinary environment temperature due to the presence of high thermal mass materials present within the environment is a phenomenon called the Urban Heat Island Effect. These materials tend to store huge amount of thermal energy resulting to more humid environment temperature. This study proposes a method of reducing urban heating by converting thermal heat energy to electrical energy using fiber-reinforced thermoelectric tiles. The design of these tiles makes use of the concept of flywheel effect. Materials that possess high thermal mass can store thermal energy when the ambient temperature is higher than the material and releases it back when the ambient temperature is cooler. The study aims to convert the stored heat energy in materials to usable energy instead of being released back to the environment. This is accomplished by employing concrete cement mixed with carbon and aluminum fibers that act as n-type and p-type material, respectively, arranged in a way that one side is exposed to high temperature and the other side to low temperature. Result showed that a temperature difference between 15℃ and 35℃ can induce voltage and current between 0.75V to 1.80 V and 1.15A to 1.28 A, respectively, for a 305 cm × 305 cm tile. Moreover, result showed that while converting the absorbed heat energy, the ambient temperature cools down faster compared to using typical concrete tiles.

Keywords: *albedo effect*, *cement, concrete, cooling system, thermoelectric fiber-reinforcement, renewable energy, urban heat island*

1. INTRODUCTION

One of the widely discussed topics nowadays is climate change. Global warming and its consequences can be attributed to human activities rather than natural causes (Le Treut et al., 2007). Due to human activities and economic development, Urban Heat Islands (UHIs) are formed in which the temperature of urban areas increases and becomes warmer than the surrounding rural areas. This phenomenon is called the Urban Heat Island Effect (UHIE) (A*STAR, 2015), which happens when temperature shifts by 1°C – 3°C higher than the average within a surrounding. UHIE affects communities and the quality of the environment (Priyadarsini & Wong, 2007; EPA, 2017). Another factor that causes UHIE is the albedo effect. The measurement that is used to determine the amount of reflected sun's energy back into the space is similar to the albedo effect. The term 'albedo' is derived from the Latin for 'whiteness' (Wayne, 2013; Hien, 2002). Naturally, the albedo effect of the earth cools down the environment.

Figure 1 shows the albedo coefficient of each component within a typical urban city. The less the albedo coefficient present in a material, the less energy is being reflected back to space and, thus, more heat is being absorbed from the sun's radiation. As shown in the figure, the concrete used in sidewalks has an albedo factor of 0.1 – 0.35 depending on the color and the type of material. According to *Energy Technologies Area* (ETA), the traditional concrete made of Portland cement, in general, contains albedo, which has a solar reflectance of 0.35 approximately, but this value may vary depending on the concrete properties (Concrete Society, 2003).

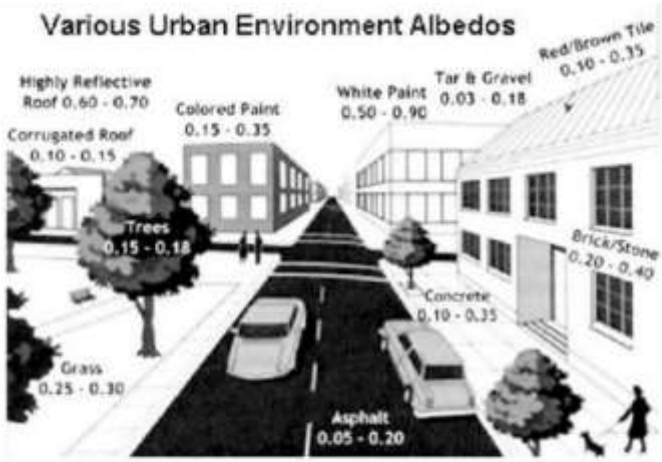

Figure 1. Albedo number street scene (http://www.greenandpractical.com/Albedo. htm).

The recent increase in the earth's temperature is undesirable if compared with the usual timescale that is associated with the natural climate change episodes. The natural climate change of the earth that happens gradually becomes abrupt recently. Through the United Nations, the international communities created special groups to focus on the effects of climate change. It also initiated protocols to organize global response on how to deal with the consequences of global warming. It is predicted that global-mean temperature and sea level would continue to rise (Wigley, 2005).

One of the initiatives of United Nations is the *sustainable development goals* (SDG), which covers 17 specific goals to sustain the planet. One of the goals is to have an affordable and clean energy. Nowadays, the world considers the solar power not only as an alternative source of energy that will meet the increasing energy demand but as a solution in reducing the pollution generated by the non-renewable power plants. The use of energy from renewable sources is becoming a trend as the traditional materials used for energy production become scarce and its harmful effects in the environment become serious. Several sources of renewable energy have already been established and only some are considered viable in the long term because of specific trade-offs. For example, solar panels have been a trend for residential and some commercial infrastructures but these solar panels, which utilize photons from the sun, cannot operate at night-time and they cannot prevent the harmful ultraviolet rays that cause global warming. Neither is there a renewable source of energy that provides a cooling system nor helps the environment at the same time.

Cement is the primary component that is found in almost every infrastructure in the world due to its wide applicability as a structure material. It has remarkable mechanical properties that can be used in constructing different infrastructures such as buildings, bridges, roads and many more. These structures are exposed to a large quantity of solar power, which is stored as thermal energy (Lobaccaro & Frontini, 2014).

In this study, an alternative material for converting heat energy will be considered. Instead of viewing cement as heat storing material only and main cause of UHI, it will be used as an alternative source of electrical energy. This study focuses on constructing a prototype that can perform as a re-modeled Peltier, which will absorb the urban heat and convert it to electrical energy. A Peltier consists of parallel plates that produce a high temperature on one plate and a low temperature on the other plate when a voltage is applied, which is a consequence of Seebeck's effect. The voltage (Le Treut et al., 2007) produced is directly proportional to the temperature difference between the two plates. Peltiers are used as cooling systems for microprocessors and the like. They can convert electrical energy into thermal energy and vice-versa, which means they can also be used as a source of energy, but it is not practical because of its low heat flux. The parallel plates of the Peltier are positioned so close to each to effect heat transfer, which produces a very minimal induced voltage. Peltiers consists of p-type and n-type materials connected in series, which allow the electrons to flow from the hot plate to the cold plate and hence, produce current.

Studies showed that Portland cement with zero cement pastes involved is an n-type semiconductor material. Plain Portland cement can produce an absolute thermoelectric power of 1.99 ±0.03 µv/°C. Fiber reinforcements such as carbon fibers are used on cement matrix to increase the cement stress and strain capability properties such as its tensile and flexural strength. They have high specific heat and can decrease the drying shrinkage (Chung, 2000). Fiber reinforcements are not only used in improving the physical quality of a concrete but are also good in amplifying the Seebeck's effect. Reinforcing the cement paste with carbon fibers increases the linearity and reversibility of heat conversion (Wen & Chung, 1999). Reinforcements on cements were used to achieve higher tensile strength and ductility of concrete (Wen & Chung, 2001). This enhances the thermoelectric power properties of cement once applied.

Finite element analysis was done during the preliminary phase of the work and the prototype was built after the appropriate mixture was obtained. By conducting finite element analysis, the output power generated by the prototype was determined as well as its implications such as its effect on the environment. The projected temperature of the environment was determined and compared with that of the ordinary concrete tile.

2. METHODOLOGY

2.1 Materials

Two types of cement were used, one for creating a p-type and the other for creating an n-type material. For p-type nodules, 17-25 % silica cement was used and for n-type nodules, the high alumina cement with 37-41% alumina was employed. No aggregate (fine or coarse) was used.

To reinforce and increase the potential difference between the nodules, carbon and steel fibers were used. Carbon sheet with 1 mm thickness was cut into 5 mm by 1 mm strips and steel sheet with 0.25 mm was cut into 5 mm by 1 mm strips.

For connecting the p-type and n-type nodules, an aluminum bar with 0.5 mm thickness was employed. This was also used in the output terminals of the tile. To separate the nodules, a 2 mm thickness acrylic plastic (transparent) was used, which was cut into 305 mm by 20 mm strips.

2.2 Procedure

Manual mixing of materials was done. To produce the p-type nodules, 1 bag of silica cement (50 kgs) was mixed with 1 pail of water (50 L). For the n-type nodules, 1 bag of high alumina cement (50 kgs) was mixed with 1 pail of water (50 L).

The cold side interconnection was prepared by cutting the aluminum bar into 10 mm × 30 mm sheet and laid out to form sequence for series connection of tiles. The acrylic glass is then laid atop of the aluminum sheet to separate the p-type and n-type nodules, creating a 25 mm × 25 mm mesh. Steel fibers and carbon fibers were messed inside the 25 mm × 25 mm separation with 5 mm distance; fiber mesh is laid out alternatingly from one mesh to another. The cement mixture is poured with their respective meshes. Another layer of fibers was added and closed the circuit by connecting the mesh using another set of aluminum sheet, then, let dry for 48 hours at 32°C controlled container.

The prototype obtained to exhibit the desired Seebeck effect is a 305 mm × 305 mm × 30 mm tile composed of fiber-reinforced cement blocks. Figure 2 shows the output composition of the prototype. It consists of the p-type (light color) and n-type (darker color) semiconductor cement nodules. Each nodule is electrically and mechanically separated by an acrylic board. They are internally connected in series at the top (N-P) and bottom (P-N) through an aluminum bar. The output power is collected through the end bar of the series connection.

One hundred fifty copies of tiles were produced using the same method. Thirty-two (32) of the produced tiles broke before they have been cured completely. The thermopower of a tile as well as that of cascaded tiles formed from the remaining tiles was tested. Thermopower measurement was performed on the 305 mm × 305 mm × 30 mm tile sample and added series of tiles after each test. The test composed of voltage and power measurements at temperatures from 25°C to 60°C, maintaining the floor temperature at 25°C. The tiles were laid out in a 35-sqm room and tested individually. The highest and lowest readings were recorded. After testing all the tiles, replacement of all the defective ones was done. The researcher then connected two tiles in series and conducted similar tests until 100 tiles in series were tested.

Figure 2. Prototype of the design.

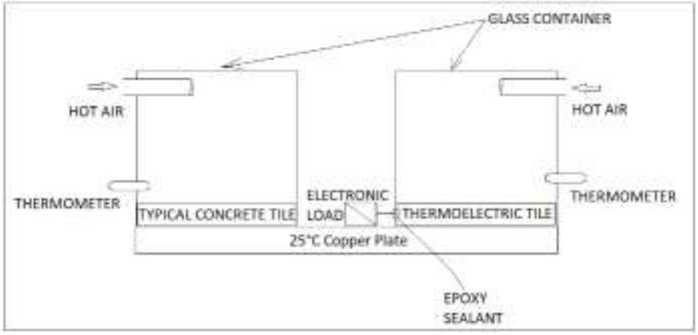

Figure 3. Test setup.

To test the effect of using thermoelectric tile in ambient temperature, the setup in Figure 3 was devised. Using two containers with similar properties, hot air blower, thermometer, electronic load, and a copper plate were setup and tests were performed simultaneously. The container was injected with hot air with temperature from 25°C to 65°C and maintained for 160 minutes and then reduced back to 25°C. Using a thermometer, the ambient temperature inside the two containers was measured and logged. The temperatures were plotted as shown in Figure 4.

3. RESULTS AND DISCUSSIONS

One hundred copies of tiles were tested at temperatures with cold side of 25°C and hot side from 40°C up to 60°C with an interval of 5°C having temperature differences from 15°C up to 35°C, respectively. The voltage was measured using Fluke 87V handheld multimeter and plotted as shown in Figure 4. The response at a temperature difference of 15°C looks like linear but above this temperature difference, the response plot looks like a logarithmic function.

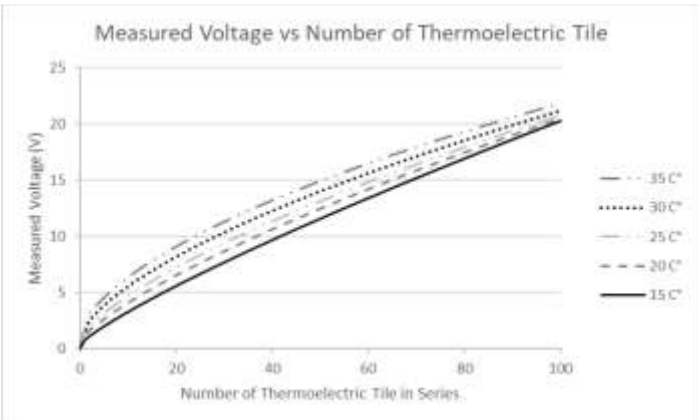

Figure 4. Measured voltage with respect to the number of tiles in series.

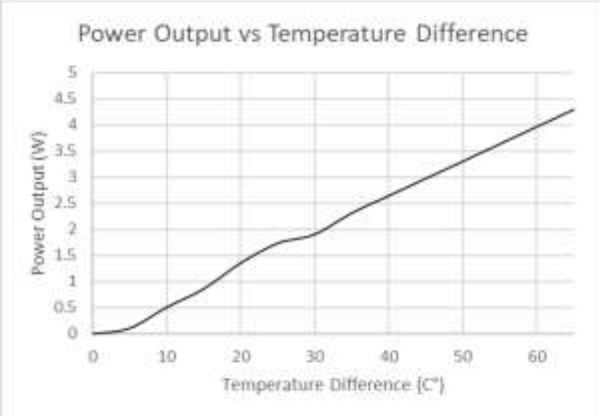

Figure 5. Power generation per tile.

Figure 5 shows the output power produced by a single thermoelectric tile with respect to the temperature difference. In the figure, the relationship shows that as the ambient temperature increases, the power generated by the thermoelectric tile also increases.

Figure 6 shows that when the temperature of injected hot air increases, the temperature of the tiles also increases. The ambient temperature inside Container 1 can be observed to increase faster than in Container 2 whereas Container 2 ambient temperature decreases faster than in Container 1.

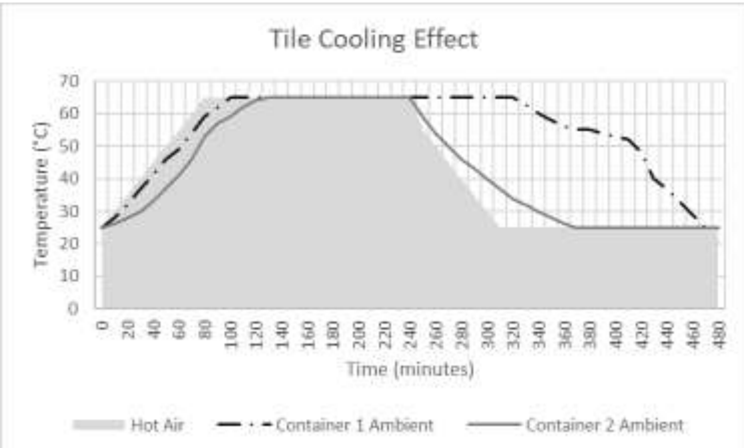

Figure 6. Cooling test result.

4. CONCLUSIONS

The result of this study showed that it is feasible and practical to produce a fiber-reinforced thermoelectric tile that can generate electrical energy from ambient heat and reduce the ambient temperature faster compared to the typical concrete tiles. This was proven by constructing an actual prototype based on gathered data from conducted researches. The 305 cm × 305 cm thermoelectric tile prototype can generate between 0.75 V to 1.80 V of voltage and 1.15 A to 1.28 A of current in 15°C to 35°C temperature difference. In 8 hours of testing, the result showed that ambient temperature decreases as the hot air injected is reduced, which implies that the flywheel effect is decreased by converting the stored heat into usable electrical energy. Also, the ambient temperature normalizes quickly. One of the practical applications of this is in lessening the demand for ACU indoors, resulting to less energy consumption. The use of this fiber-reinforced thermoelectric tile is not restricted outdoor but it can be used also indoors such as rooms that have high temperature as in electrical room. As it cools the environment, it generates electricity from urban heating and thus functions as a new renewable source of energy. This can revolutionize the source of renewable energy in our communities since the tile is made from abundant material. The fiber-reinforced thermoelectric tile can also be used for other applications, for instance, as roof tiles, facade or wall tiles. Moreover, it can be used to induce Peltier effect for the environment with extremely low temperature. It is recommended to conduct further study on the cement matrix to be used to improve the electrical energy generation of the tile and how it can be maximized in terms of absorption of environment heat.

5. ACKNOLEDGMENT

The author would like to acknowledge the family and friends who gave inspiration and contributed in completing the project, particularly, for their help in performing the experiments. Moreover, the author would like to thank the Technological Institute of the Philippines (TIP) for allowing him to use their facilities while conducting the initial phase of the research.

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