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Harvesting Energy through Piezoelectric Tiles: A Comparative Study of Wood, Porcelain, and Ceramic Tiles

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Abstract

This study investigated the feasibility of using piezoelectric tiles in harvesting energy from the footsteps of people. The piezoelectric tiles were made of three materials, namely wood, porcelain, and ceramic tiles, where five piezoelectric plates were attached to each corner and center of individual tiles. A voltmeter was then attached to the piezoelectric tile system to determine the voltage output when people step on the tiles. Study findings revealed that the wood tile produced a mean voltage of 0.711V, the porcelain tile, 0.698V, and the ceramic tile, 1.018V. Analysis of variance results showed that there were significant voltage output differences among the three tiles, and the post-hoc analysis revealed that the voltage outputs of wood and porcelain tiles were comparable with one another, while the voltage output of ceramic tiles was the greatest among the three. The study concluded that the mechanical energy coming from the footsteps could be harvested using the piezoelectric tile, where mechanical energy could be converted into an electrical source. Furthermore, the researchers recommended having a wider variety of sample tiles to see the difference between the tiles and have a wider variety of data that could establish the positive results of this study.

Keywords piezoelectric tiles, wood, porcelain, ceramic, voltage outputs

INTRODUCTION

Electricity has played a vital role in civilization since it makes living more convenient and increases business efficiency [1]. According to the Institute for Energy Research, fossil fuels account for 67% of all sources of electricity. The remaining 16% comes from renewable sources, 13% from nuclear power, and 3% comes from biofuels. This demonstrates how the globe is dependent on non-renewable energy sources like fossil fuels. Fossil fuels are exhausting faster than they can be replaced by nature [2]. As a result, there is a significant need for alternative energy.

Biomass, wind, solar, hydropower, and geothermal energy are all energy sources that can be used in place of dwindling fossil fuel reserves [3]. These alternate sources, particularly in the Philippines, originate from traditional dams like Angat in Bulacan, run-of-river sources like Pulangi IV in Bukidnon, and geothermal energy (e.g. Tiwi in Albay). Only some regions of the nation could utilize the advantages offered by these sources due to their geographic limitations. Consequently, a non-geographically dependent energy source gains attention in science and engineering.

The energy provided when people walk and run through people's footsteps is one potential energy source that has attracted a lot of interest in recent studies [4]. According to calculations, a person uses 20% of his energy for walking for 9 hours each week and much more for 21 hours [5–6]. Given the amount of energy used by the body during walking, a substance that might transform this energy into usable and consumable electrical energy should exist. The idea of the piezoelectric effect could be used to achieve this conversion of mechanical energy to electrical energy.

Due to the accumulation of charges in response to compression or tension stress, the piezoelectric effect is a feature specific to materials that enables the conversion of mechanical energy to electrical energy in materials [7-9]. Bone, for instance, is discovered to display the effect [10] and as a result, can be exploited in the resorption and formation of bones in living matter [11]. Natural piezoelectric materials (PEMs) can be created from biological matter and crystals. Polymers, ceramics, and their composites are examples of man-made PEMs [8]. PEMs are widely used in many areas of science and society [12], and as a result, there is continued interest in PEM-based power generation in the scientific community.

Numerous studies have been done on the creation of PEMs as well as using these materials to generate energy as a result of the PEMs' promising effects. Ceramic PEMs with volcanic dust are promising alternatives, according to Ratnasari [9], to meet the rising need for electricity. A prototype energy harvester tile and power conditioning circuit were created by Kumar et al. [13], who came to the conclusion that the tile's output was rising and that it might be applied to low-powered electronic equipment. According to Hwang et al. [14], one PEM tile can provide 350 W RMS of power, and four tiles can produce an output that is 203% greater than the harvester that is installed on shoes. Finally, Elhalwagy et al. [16] reported that apartments can use the tiles as a way to generate and save energy, and that the electrical energy output could drive wireless data transmitting devices like wireless routers. Siddapa and Ahmed [15] revealed that different loads require different clearance values to attain optimal voltage, that static loading for two seconds yielded a maximum voltage of 4.1 V, and that dynamic loading resulted in a maximum voltage of 3.79 V. Comparing the voltage outputs of three PEMs, namely wood, porcelain, and ceramic materials, has been lacking in the literature, according to these investigations.

The study evaluated the viability of using wood, porcelain, and ceramic tiles to harvest energy from the footsteps of students, instructors, and staff inside the school campus and used the piezoelectric effect concept to create PEM tiles. Since mechanical energy may be converted into useful electrical energy, the study's findings might be important to the general population. Additionally, this can increase Filipino researchers' rising enthusiasm for the hunt for dependable, environmentally friendly alternative energy sources. In order to undertake the study, it was necessary to collect data from this examination that could be used as a baseline for future investigations on piezoelectric tiles.

MATERIALS AND METHODS

The goal of the study was to determine whether it was feasible to gather mechanical energy using piezoelectric tiles and convert it to usable electrical energy. The study mainly focused on 1) building piezoelectric tiles out of wood, ceramic, and wood, 2) figuring out each tile's voltage output, and 3) figuring out which tile provided the highest voltage output.

Prototypes of ceramic, porcelain, and wood-based piezoelectric tiles were created for the study using the project development research design. This style is specifically utilized for research on design and development processes that involve actual object handling as opposed to simulation [17]. The paper specifically used the Research on Product and Tool design, in which the tiles were created, reported, and analyzed, and the finished items were assessed using power outputs.

Piezoelectric plates, a piezoelectric transducer, a capacitor, a diode, wires, a digital voltmeter, and boards made of wood, porcelain, and ceramic tile were the materials used in the study.

On each of the tile boards, there were five piezoelectric plates attached to the corners and one in the center (wood, porcelain, and ceramic). To conveniently monitor the output of the piezoelectric plates, one diode and one capacitor were connected to the five plates. The piezoelectric tile system had a digital voltmeter linked to it (Figure 1). Sixty individuals weighing between 50kg and 70kg stepped on the wood, porcelain, and ceramic piezoelectric tiles in order to test their effectiveness. After that, voltage outputs were monitored and examined.

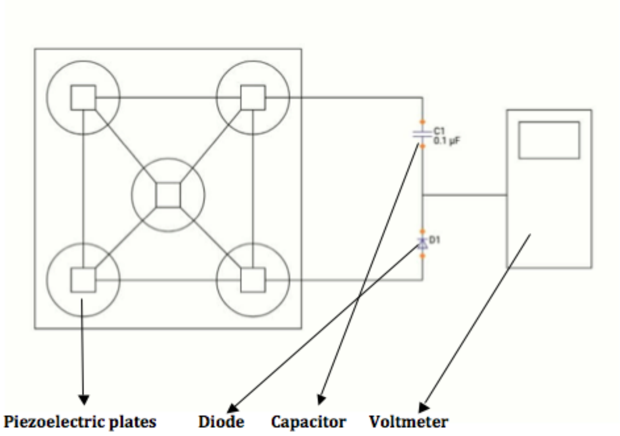

Figure 1. The piezoelectric tile system

The mean and standard deviation of the voltage output from each tile were calculated to assess the findings. Analysis of variance (ANOVA) was used to compare the voltage outputs of wood, porcelain, and ceramic piezoelectric tiles. To ascertain which tile generated the highest mean voltage, a post-hoc analysis utilizing the Tukey HSD test was also used.

RESULTS AND DISCUSSION

Voltage Outputs derived from the Piezoelectric Tiles

To analyze the results, the mean and standard deviation of each tile's voltage output was derived. To compare the voltage outputs between wood, porcelain, and ceramic piezoelectric tiles, analysis of variance (ANOVA) was utilized. A post-hoc analysis using the Tukey HSD test was further employed to determine which tile produced the greatest mean voltage.

Table 1. Voltage Outputs from Piezoelectric Tiles

Piezoelectric Tile	Mean Voltage (V)	SD
Wood	0.711	0.445
Porcelain	0.698	0.531
Ceramic	1.018	0.391

Based on the results presented above, the sixty participants generated energy upon stepping on the three piezoelectric tiles constructed for the study. A mean voltage output of 0.711 V is harvested from the wood tile, 0.698 V from the porcelain tile, and 1.018 V from the ceramic tile. The results above mean that harvesting energy is possible through the use of the energy derived from stepping on the different piezoelectric tiles. This could be because when the tiles were stepped on, compression stress is generated. Once this stress is done, the arrangement of the electrically neutral atoms in the plates and tiles changes. As the arrangement changed, the charge of the plates and tiles also changed – from being neutral to electrically charged. These charges derived from the compression and tension forces caused by the steps of the participants provide the voltage output generated by the three piezoelectric tiles. The generation of such voltage exemplifies the application of the piezoelectric effect [7, 9].

Comparison among the Voltage Outputs of Wood, Porcelain, and Ceramic Tiles

Table 2. ANOVA Results of the Comparison among the Voltage Outputs of Wood, Porcelain, and Ceramic Tiles

Group	SS	Df	MS	F-value	*p*-value
Between groups	3.94	2	1.97	9.313	.000*
Within groups	37.40	177	0.21		
Total	41.24	179			

Note. *Significant at α=.05

Results of ANOVA show that the F-value obtained from the test is 9.313, and the p-value derived is 0.000. Since the calculated p-value is less than that of the confidence level at 0.01, then it can be said that there is a significant difference among the voltage outputs of the three tiles. This means that the voltage outputs among the three piezoelectric tiles are significantly different.

The significant difference among the three tile outputs could be because each of the piezoelectric tiles is composed of different materials, namely wood, porcelain, and ceramic. Different materials have different compression and tension stresses when stepped on, and thus, they have different voltage outputs [7, 9].

Post-hoc Comparison of the Voltage Outputs of the Piezoelectric Tiles

Further analysis is done since the results of ANOVA show that there is a significant difference in the voltage outputs among the three piezoelectric tiles. The post-hoc analysis done is called the Tukey HSD test, and the results of the test are shown in Table 3.

Table 3. Post-hoc Comparison among the Piezoelectric Tiles

Tiles-Pairs	**Q-value**	***p*-value**
Wood and Porcelain	0.229	.900
Wood and Ceramic	5.167	.001*
Porcelain and Ceramic	5.397	.001*

Note. *Significant at α=.05

Tukey HSD test reveals that voltage outputs derived from wood and porcelain are not significantly different. This means that their outputs are comparable with one another, and the two materials have the same efficiency. Wood and porcelain may be considered to be crystalline to some extent, but the structure of these two materials may be a little amorphous or a little not crystalline. Since these materials have a crystalline structure, atoms and molecules still exhibit a piezoelectric effect and can generate comparable voltage output.

In the case of the voltage outputs between wood and ceramic, and between porcelain and ceramic, the mean voltage outputs are significantly different from one another, leading to note that ceramic tiles produce the greatest amount of energy harvested. This could be because ceramic materials have a polycrystalline structure that consists of numerous crystallites and a plurality of elementary cells [18]. These crystallites realign themselves when squeezed in by steps, in such a way that positive charges are on one face and negative charges are on the opposite face. In this way, realign crystallites become "little batteries” [19]. Since there are many crystallites or “little batteries” in the ceramic structure compared to wood and porcelain, the ceramic piezoelectric tile generates the greatest voltage output among the three tiles.

CONCLUSION

Based on the findings of the study, the project concluded that energy could be harvested from the footsteps of the people through the use of harvesting tiles. Piezoelectric tiles are innovative means of harnessing the energy and converting the energy obtained into stored energy, which can be used in the future. In the study, the prototype harvesting tiles can give as much as 1V of available energy per footstep for persons in ceramic tiles, and 0.70V in wood and porcelain tiles. This available energy could be utilized as one of the alternative energies in the future to meet the demands of energy in the future.

In light of the findings and conclusion of the study, the following actions are recommended for the study:

- improve the construction of the piezoelectric harvesting tiles to incorporate cheaper and more powerful components in the tile circuit, and enhance the energy generation process to minimize energy wastage and achieve power optimization;
- test the piezoelectric harvesting tiles to more respondents and for a longer time, so to determine the approximate amount of voltage and power output derived from the tiles;
- conduct more studies on piezoelectric harvesting tiles that focus on the application of static or dynamic loads to the tiles, on the relationship between compressive/tensile stress and voltage and power output, and on the type of environment that the tiles are exposed like indoor and outdoor experimentations; and
- Search for more alternatives for non-renewable sources of energy.

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