JISSE
ISSN: 2636-4425

Journal of International Society for Science and Engineering

Vol. 4, No. 1, 01-11 (2022)

JISSE
E-ISSN:2682-3438

Application of Pv-Piezohybrid Energy Floorin Egypt

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A R T I C L E I N F O

Article history:
Received:18-01-2022
Accepted:01-03-2022
Online: 01-03-2022

Keywords:
Electricity, solar photovoltaic, PV, piezoelectric energy, renewable energy, hybrid energy floor.

A B S T R A C T

This paper proposes the application of a hybrid floor tile that generates electricity from two renewable energy resources. This dual-resource tile uses solar PV energy as well as piezoelectric energy. The surface of the tile is formed of solar PV panel that converts sunlight into electricity during daytime. A piezoelectric device is installed within the tile to convert mechanical energy from footsteps into electrical energy at any time according to foot traffic in the place. These tiles can create energy to be used instantly in real time or it can store that energy to be used afterwards. The tile platform design can be used as a sidewalk or pathway placed in areas with high amounts of foot traffic. The main objective for the research is to investigate the implementation of this hybrid tile design in the International Cairo Stadium of Egypt. The research aims to study managing a low-cost, efficient, and clean energy tile design. The research studied the economic and the environmental aspects for the implementation of this hybrid tile over a 1600m2 of the athletics track in International Cairo Stadium of Egypt. The results showed that it is a worthwhile technology to be deployed

1. Introduction

Electricity is a basic necessity of life. Many of the available natural resources are non-renewable, requiring us to resort to other efficient and innovative ways that provide constant energy. Harvesting energy from renewable energy resources is a growing trend to produce electrical energy worldwide. This is done to overcome the challenge of depletion of conventional energy resources and to reduce the emissions from fossil fuels energy generation. This research aims to investigate the implementation of an energy floor tile that uses dual renewable energy resources to produce electricity in the International Cairo Stadium of Egypt. The two technologies that will be incorporated in this floor tile is the solar PV technology and the piezoelectric technology. The solar energy is the most dominant and prevailing renewable resource of energy used for electrical energy generation all over the world. The solar PV technology has been widely integrated in roof tiles to generate electricity [1-8].In this research the proposed application is for a floor tile that uses PV solar power rather than a roof tile. PV floor tiles have emerged recently and they are manufactured by some companies[9, 10]as will be shown in this paper. The second renewable resource that is proposed for this hybrid energy floor tile is an electromechanical one which is the piezoelectric. The piezoelectric technology converts mechanical/kinetic energy from the motion of humans over this tile into electrical energy. This technology has grabbed increased attention lately and it was investigated and tested in several research works [11-22]. Moreover, it was fabricated, manufactured, and commercialized by some companies. Some design samples of these piezoelectric tiles are depicted in Figure (1).This work investigates implementing and utilizing this dual-energy floor tile to obtain a reliable efficient clean source of power that is generating electricity almost for free.

2. Technology of Hybrid Floor Tile

In this section the evolution of the proposed hybrid PV-Piezo tile is described. The technologies used and implemented commercially by companies are shown. Afterwards, simulation of a small scale of these technologies using Matlab® Simulink® is presented.

2.1. Piezoelectric floor tile

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a. Piezoelectric tile technology

The piezoelectric effect is the generation of electric charges when pressure is applied to a certain type of crystalline material. This effect has been utilized to convert kinetic/mechanical energy into electrical energy. A piezoelectric component as that illustrated in Figure (2) is composed of 2 metal plates with a crystallized material such as the lead zirconatetitanate (PZT) in-between. The electrical charges are formed on the two plates when squeezing the crystallized material. Piezoelectric sensors/transducers are used with regulators and converters to form an energy harvesting platform that produces energy with the required high voltage. The amount of the voltage produced corresponds to the amount of pressure applied on the PZT.

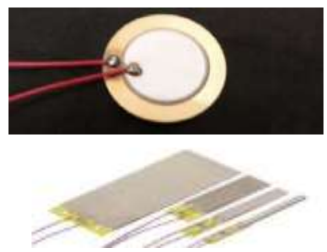
1- Waynergy Floor .source: 	**2- Sustainable Energy Floor (SEF).**source:[10] 
3- Pavegen tiles.source:[24] 	**4- Drum Harvesters - Piezo buzzer Piezoelectric Ceramics.** source:[25] 
5- Sound Power. source:[26][27] 	**6- POWERleap PZT.** source: [28] 

Figure 1: Design samples of piezoelectric floor tile[10][23-28]

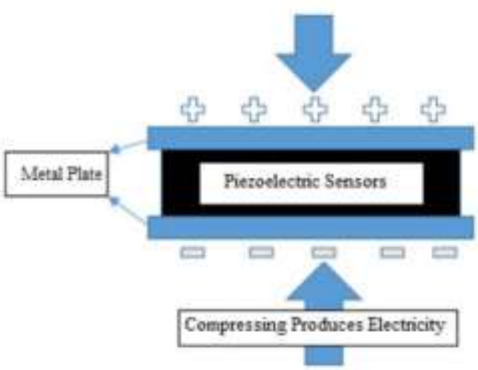


Figure 2: Piezoelectric mechanism and effect[18]

b. *Pavegentile*

The aim here is to produce electrical energy from the kinetic energy of the motion of humans over these piezo-tiles. Several companies have worked on designing and implementing such technology[27]. The most successful company in commercializing its piezoelectric tiles is Pavegen[24]. Pavegen managed to design a solid piezoelectric floor that when walking over it, the pedestrians will not feel that they are falling down. The structure of the tile is depicted in Figure (1), where Figure (3)a shows the triangle shape of the tile and Figure (3)b presents the different components of the piezoelectric floor. The three corners of the triangle are connected to piezoelectric transducers, assuring that stepping on any part of the tile distributes the weight efficiently such that the three transducers are triggered and a force is created over them. The limitation of this smart tile is that it produces energy from one resource only which is the kinetic energy of the motion of people. If no one is stepping over it no electric energy is produced.

c. Simulink model built for the piezoelectric system

A Simulink® model adopted from[29, 30]is built and tested using Matlab® Simulink® environment. Figure 4 illustrates this electro-mechanical model. The model basic unit is the piezo stack element representing the piezoelectric transducer. The circuit consists of two parts: the electric part (presented in blue) composed of the piezoelectric transducer and a voltage sensor to sense the output volt of the piezo stack, and the mechanical part (presented in green) with a mass, string and damper system to simulate the motion over the piezotile. The output voltage waveform is depicted in Figure 5. Afterwards, different masses in kilograms are tested to detect the output voltage obtained for different weights and the results are illustrated in Figure 6. It is mostly observed that an increase in the mass of the body moving over the piezoelement produces an increase in the output voltage and accordingly an increase in the output electrical power.

(a) (b)

Figure 3: (a) Pavegen floor composed of triangular tiles (b) The structure of the triangle tile mounted on 3 piezoelectric transducers

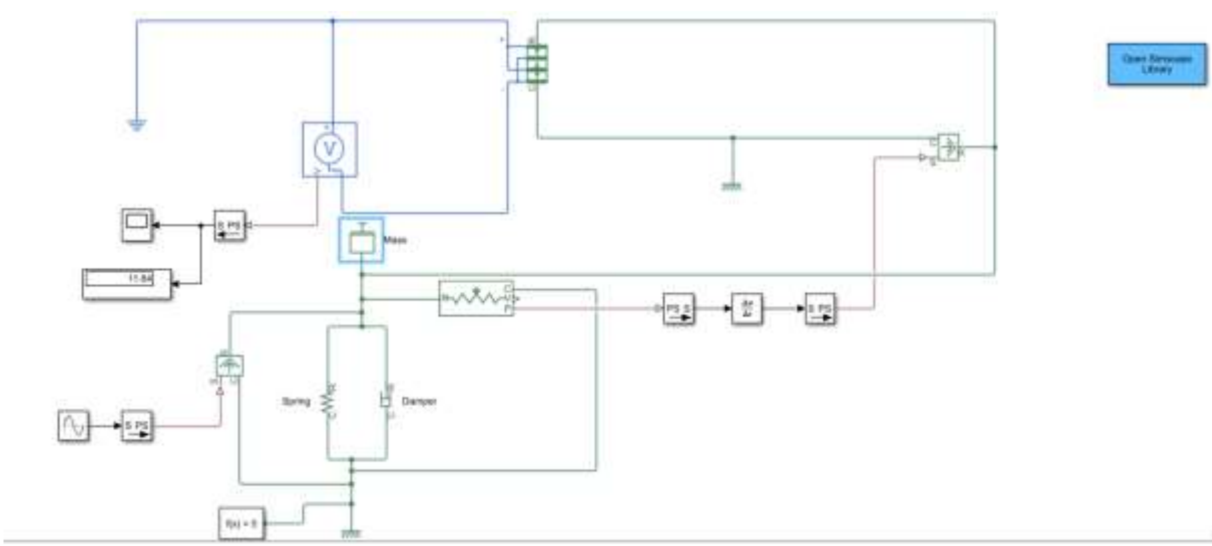


Figure 4: Simulink electro-mechanical model of the piezoelectric transducer

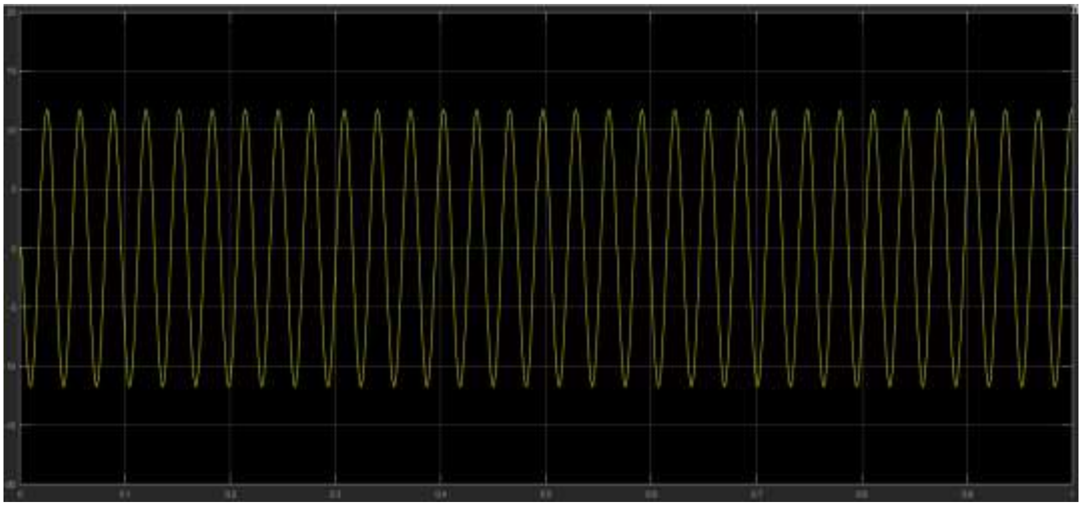


Figure 5: Output voltage waveform of piezoelectric transducer

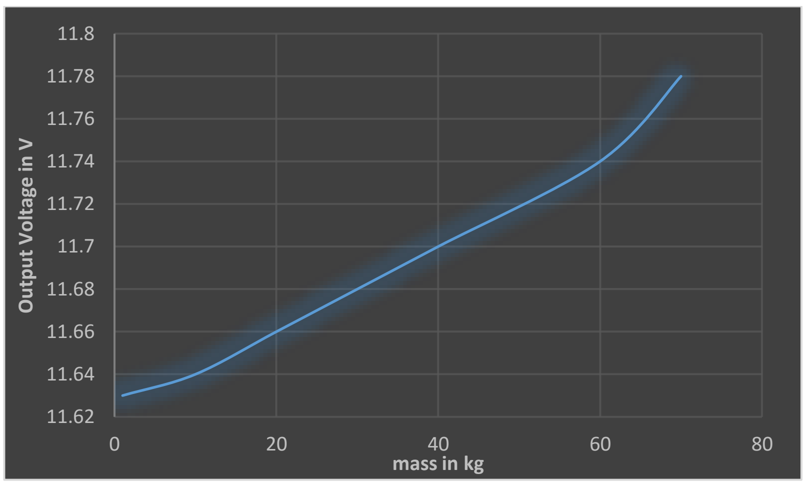


Figure 6: Varying the output voltage of piezoelectric transducer for different weights

2.2. Solar PV floortile

a. Solar PV tile technology

The technology of the PV floor tile is based on the photovoltaic effect. The photovoltaic effect is observed when sunlight hits the surface of solar panels, the photons from the sun are absorbed by the semiconducting material of the panels and then excite the electrons of the panel material thus producing electric potential when separating the charges. This effect is elaborated in illustrations presented in Figure (7)[31].This technology have been widely applied and implemented to produce electrical energy from the renewable solar energy. It was just mostly implemented by either installing panels at roofs of buildings or by using the panels as a building material known as "building integrated photovoltaic" BIPV[1, 8]. The current research investigates integrating this technology in the form of floor tiles.

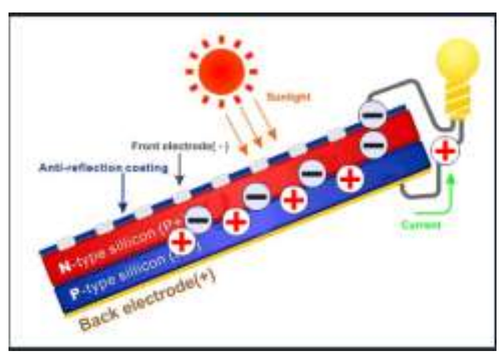


Figure 7: Photovoltaic Effect, [31]

b. Onyx Solar tile

This tile is composed of PV solar cells, thus when installed in an open area floor it captures solar energy and converts it into electrical energy. Onyx Solar®[9] is a company that is successfully manufacturing these tiles using amorphous Silicon and crystalline Silicon. Figure (8) shows different shapes of the Onyx non slip PV floor.

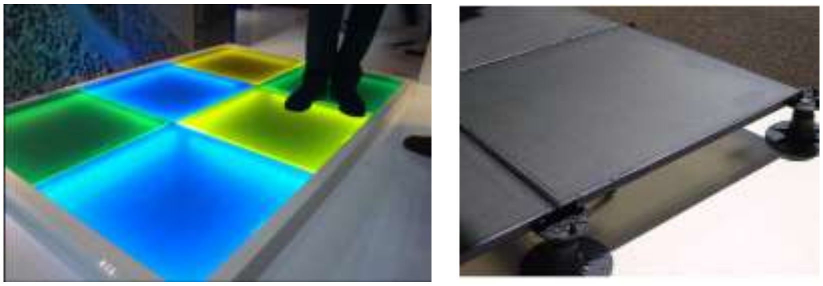


Figure 8: Onyx Solar non slip PV tiles [32, 33]

c. PV model built in Simulink

A PV array is simulated in Matlab® Simulink® environment and the simulation model is illustrated in Figure (5). As the case study adopted in this research is concerned with the International Cairo Stadium located in Nasr City district in Cairo, the solar irradiance and the temperature values used in the simulation were varied around the values of those of the Nasr City location. The values obtained for Nasr City location with Latitude 30.05 and Longitude 31.33 from radiation database: PVGIS-SARA[34]are a direct irradiance maximum value of 934.5 W/m^2 , a minimum value of 0 W/m^2 and an average value of 183.7 W/m^2. The temperature values obtained for this location are a maximum value of 42.68 ^{o}C, a minimum value of 7.18 ^{o}C, and an average value of 22.9 ^{o}C. The model depicted in Figure(9) was used to plot the V-I curve and the V-P curve for the PV array simulated. The VI curve was plotted by varying the irradiance values at constant ambient temperature of 25 ^{o}C as shown in Figure (10). The V-P curve was plotted by varying the temperature at constant irradiance value of 1000 W/m^2 as presented in Figure (11).

It is observed from Figure (10) that the output power of the PV array simulated reaches 200W at the maximum temperature recorded for the area of interest at 42.68 ^{o}C average value, whereas the output power increases at the average temperature value of 22.9 ^{o}C. It is also noted from Figure (11) that the current value is more than 5.5 A for the maximum irradiance value for the area under study which is 934.5 W/m^2, the current decreases to less than 1.5 A for the average irradiance value of 183.7 W/m^2.

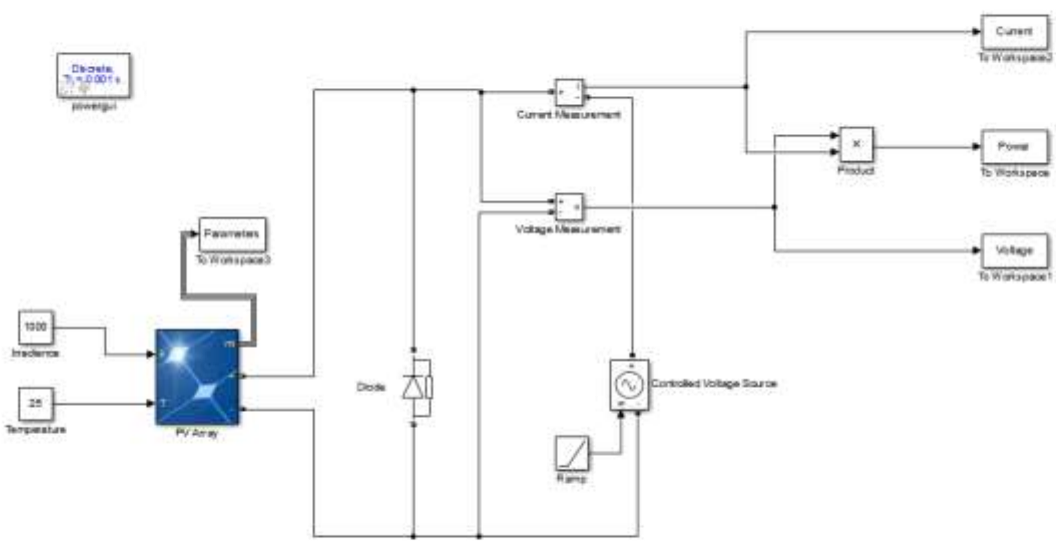


Figure 9: PV array simulation model

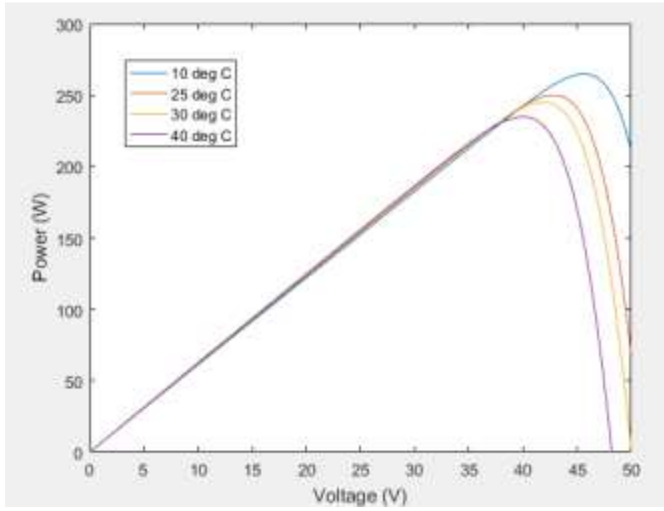


Figure 10: V-P curve of the simulated PV array

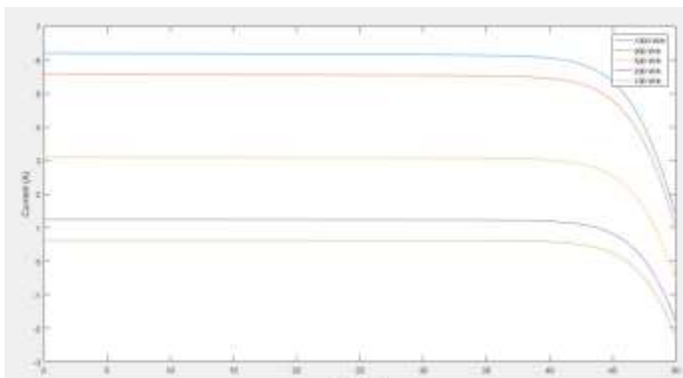


Figure 11: V-I curve of the simulated PV array

2.3. Hybrid PV-Piezofloor tile

As the main aim of this paper is to implement a floor tile that produces electrical energy from alternative dual renewable resources, a hybrid floor tile from the two resources; piezo and solar PV, described in the previous sections is proposed.

a. PV-Piezo tile technology

This hybrid tile will capture energy during the day from the sun via the PV panels, and from the kinetic energy of footsteps all day long according to the availability of motion over the tiles. The block diagram shown in Figure (12) illustrates the 2 technologies incorporated in the hybrid floor tile. It is shown that the 2 technologies elements are connected to voltage regulators, rectifiers/converters before their generated energy is to be utilized by loads, stored in batteries, or injected to the grid. When the generated power is fulfilling the load and there is excess power, it is either injected to the grid or stored in storage systems.A cross section view of the hybrid floor tile proposed in[32] showing its internal components and a top view of the tile showing the solar cell glass cover are depicted in Figure(13).

The calculations in this research are based on the design of the hybrid PV-Piezo floor tile proposed in[9, 32]. This floor tile is designed with specific characteristics some of these characteristics are shown here under. There are several sizes available of this tile. A module of an approximate weight of 15 kg provides a max output power of 20 W. A module can produce from 1 to 10 W from continuous footsteps motion using piezo element within the tile module, and about 25Wp from PV glass cover of the module. The temperature for module operation ranges from -40 to +50 ^{oC}, [9, 32].

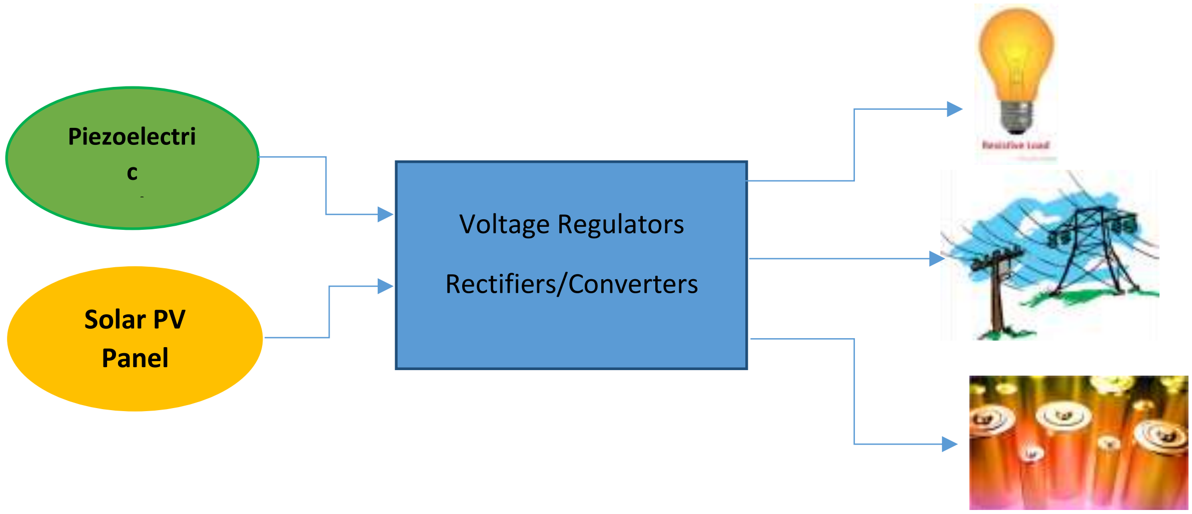
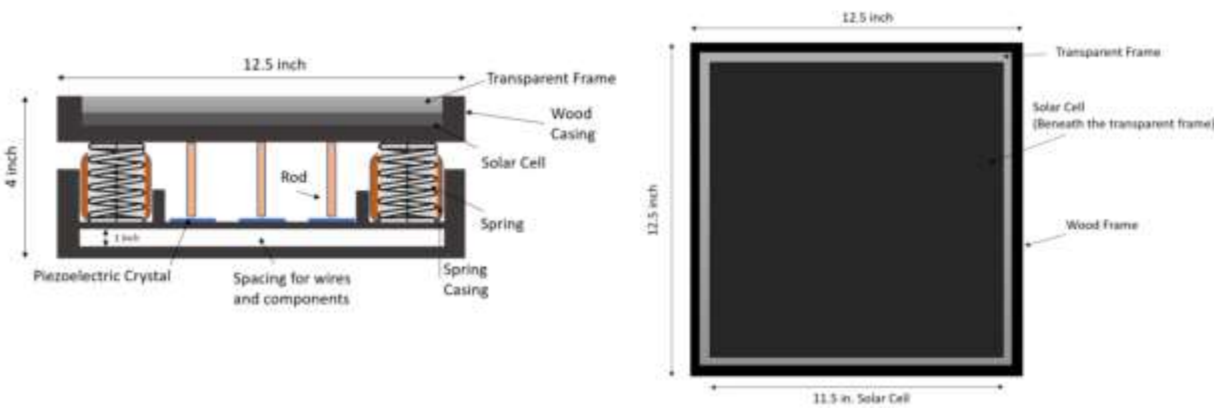


Figure 12: Hybrid tile system block diagram



(a) (b)

Figure 13: Hybrid PV-Piezo floor tile (a) cross section view of internal components (b) top view of the hybrid tile[32]

b. Energy Floors

Figure (14) shows some examples of the Energy Floors company installations of the PV floor tiles and the piezoelectric floor tiles. The Dancer tile produces energy from solar PV glass cover during the day and The Walker & The Gamer tiles produce energy from the piezoelectric at any time of the day according to the foot traffic[10].As these two concepts are being commercialized, it inspired the authors in[32] and in this research work to merge both technologies to increase productivity and efficiency of the tile.

Figure 14: Energy Floors tiles installations, [10]

3. Case study description

3.1. Stadium dimensions and installation requirements

The International Cairo Stadium is designed based on international standards. Its main stadium shown in Figure 15 has an area field of 68m by 105m, surrounded by an athletic track of a total area of 10,000m^2. To avoid the complexity of installation in rounded corners of the track, the area of concern in this research is the straight area of the track. The straight area on each side of the field has a length of 84.39m and its width is formed of 8 lanes each of 1.22m thus a total width of 9.76m, this is depicted in Figure 16[35-37].

Thus, the total area under study is “84.39m by 9.76m by 2” (for both sides) which is equal to a total area of 1647.29 m^2. The hybrid tile modules for this study will be designed to cover an area of 1600 m^2.

Figure 15: Main stadium in International Cairo Stadium, [35]

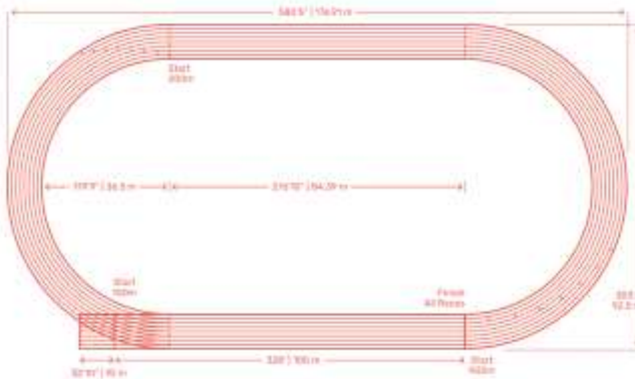


Figure 16: A 400 meters athletics track dimensions, [37]

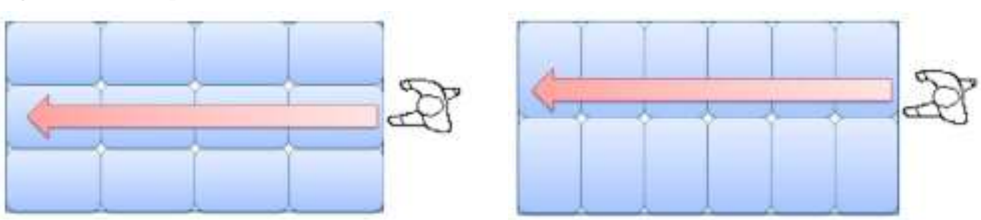
3.2. Design and orientation for hybrid tile installation

The orientation and design of the tiles impacts the amount of energy generated. The number of tiles along a path or a corridor varies according to the tiles deployment orientation/design. The optimum design is the one that captures the maximum number of footsteps. A formula shown in equation (1) is proposed in [11] to represent the relation between the length of the path/corridor and the number/size of tiles to be installed in this corridor.

$$n = \frac{L_l}{L_t} \tag{1}$$

Where; L_l is the length of the corridor/path and L_t is thelength of the tile side coinciding the corridor/path.

This is illustrated using an example depicted in Figure 17 where a corridor is covered with 12 tiles, that are installed using 2 different orientations; lengthwise and widthwise orientations. It is shown how in tiles orientation (a) only 4 tiles are stepped over, whereas; in orientation (b) 6 tiles are activated, which means more power generated from orientation (b). Thus, the orientation of the tiles is a variable that affects the amount of energy generated when stepping over the tiles. Hence, the length of the path and the sides of the tiles are to be measured in real case studies and used to optimize the number *n* of tiles to be deployed to maximize the generated power, [11].



(a) (b)

Figure 17: PV-Piezotile deployment (a) Lengthwise orientation(b) Width wiseorientation, [11]

3.3. Hybrid tile output power and cost

In this section a discussion of the cost and output power of the required floor tile is presented.

The information for the hybrid tiles (the cost and the output power) used in this proposed project will be obtained from 2 companies:

1. Pavegen: for the piezoelectric part required for the hybrid floor tile.
2. Onyx Solar: for the PV glass cover component of the hybrid floor tile.

These 2 companies were chosen as they are the ones which announced both theoutput power and costs information explicitly. Moreover; they provide the least cost when compared to other competitors.

3.3.1.Output power and cost for the piezoelectric system

One Pavegenpiezoelectric system tile of dimensions (***0.6m x 0.45m***) produces***7 Watts*** from one step and it costs about ***$76***[38, 39].

Thus, the total installation cost of and the total power produced by the piezoelectric system for the tiles of the proposed track are calculated as follows:

$$\text{Total cost} = C_{piezo} = 1600\text{m}^2 \text{ x} \frac{\$76}{(0.6\text{m x } 0.45\text{m})} = \$450{,}370.37.$$

Power produced = W_{piezo}

$$= 1600 \text{ m}^2 \text{ x} \frac{7 \text{ W}}{(0.6\text{m x } 0.45\text{m})}$$

= 41,481.48 W = 41.48 kW.

This calculation done is based on a simple assumption which is 1 step on each foot of the Pavegen piezoelectric system. In other words, these kilowatts are obtained when each foot of the Pavegen piezoelectric system experience 1 step. This apparently depends on the population using the track, an increase or decrease would change the number of kilowatts generated.

3.3.2. Output power and cost for the PV system

Onyx Solar glass PV floor tiles produce40 Wp/m^2[40]with a total cost of $ 4.9 per square feet[41].

Thus the total installation cost of the PV system for the tiles of the proposed track is calculated as follows:

Total area = 1600m^2 x 10.7639 = 17,222.26 ft^2

Then, total installation cost = C_{PV}

= 17,222.26 ft^2 x $4.9 = $84,388.976.

Moreover, the track will produce a power of:

Power produced = W_{PV}

= 1600 m^2 x 40 Wp =64000 Wp = 64 kWp.

This generation is certainly obtained during the day time.

3.3.3.Total output power and cost of the hybrid tile

The total cost of the PV-Piezo hybrid energy floor proposed to be installed in the straight area of the athletics track in International Cairo Stadium is simply obtained by summing up the values got from the 2 previous subsections.

Thus, the total output power of the hybrid PV-Piezo floor deployed over 1600 m^2 of the track is

$W_{PV\text{-}Piezo} = W_{piezo} + W_{PV}$ = 41.48 kW + 64 kWp = 105.48 kW

and the total cost required for the installation is

$C_{PV\text{-}Piezo} = C_{piezo} + C_{PV}$

= $450,370.37 + $84,388.976 = $ 534,759.346

Figure 18 depicts the costs in dollars and the output power in kW for different technologies of the tile floors.

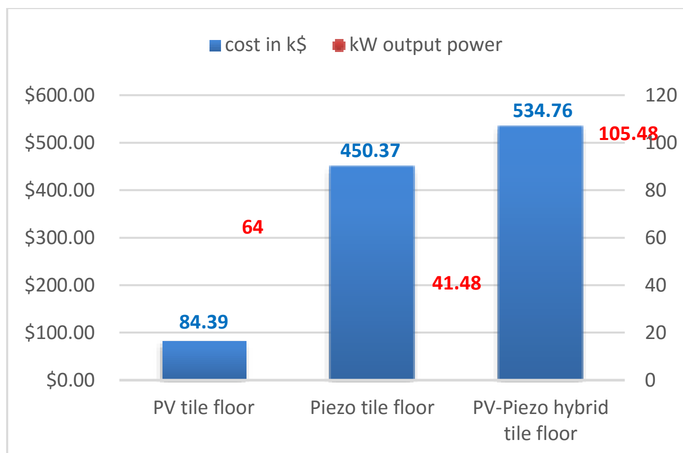


Figure 18: Output power and costs for the three tile floor technologies

4. Benefits of PV-Piezohybrid floor deployment

The advantages and benefits of the proposed PV-Piezo hybrid floor deployment will be investigated from 2 aspects: economic wise and environmental wise.

4.1. Hybrid floor cost and payback period

The two renewable energy resources integrated in the proposed floor tile are almost for free resources when it comes to running costs. Thus, the payback period through which the capital investment will be recovered will be calculated based on having a main cost which is the high capital cost obtained in section 3, whereas; the running cost is almost zero.

The electricity cost in Egypt is \$0.074 /kWh (1.162 L.E./kWh)[42]. This implies that gain from the hybrid floor installed is(105.48 kWx 24x \$ 0.074) x30 = 5,620 \$/month. Thus, the payback period for the 1600m^2 of the PV-Piezo hybrid floor installed is \$534,759.346 / \$5,620 = 8 years.

4.2. Hybrid floor environmental impact

In this section the amount of pollutants and emissions from the proposed installations of the hybrid floor is calculated and compared to that of other energy resources. The focus will be on the emissions of CO_2 gas. Figure 19 presents the amount of CO_2 emissions from several energy resources. The most commonly used resources in our country are oil and natural gas[43], thus; they will be compared to the proposed hybrid floor in terms of the amount and cost of CO_2 emissions. The CO_2 emissions; from a natural gas plant, is 443gmofCO_2/kWh and from an oil plant is 778 gm of CO_2/kWh. It is worth noting at the beginning that one ton of CO_2 would cost around \$3,500 to be removed after being emitted from power plants, [8 , 44].

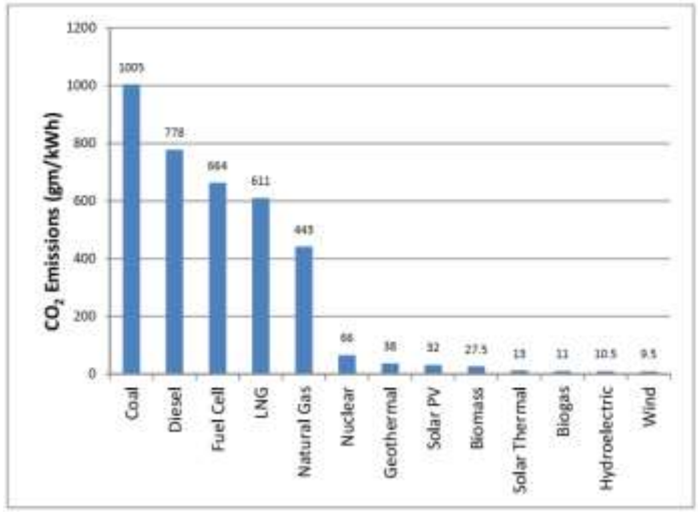


Figure 19: CO_2 emissions in gm/kWh for different energy resources, [8, 44]

The total energy produced from the proposed system in the first year is 924,004.8 kWh. Assuming a degradation rate of 1% in generation annually, during a life of 30 years this system will generate 27,325,402.68 kWh. Table (1) presents the costs of the CO_2 emissions produced from the proposed hybrid floor compared to those produced from natural gas and oil power plants. It is apparent from the numbers obtained that the hybrid floor proposed saves more than 43 million dollars for CO_2 emissions when compared to natural gas as an energy resource, and it saves more than 79 million dollars when compared to oil as an energy resource.

Table (1) Comparison of CO_2 emissions cost

Energy resource	Emissions of CO_2	Co_2 removal cost
Hybrid floor	32 gm x 27,325,402.68 kWh = 874,412,885.76 gm = 963.875 tons	963.875 tons x \$3,500 = \$3,373,562.5
Natural Gas	443 gm x 27,325,402.68 kWh = 12,105,153,387.24 gm = 13,343.647 tons	13,343.647 tons x\$3,500 = \$46,702,764.5
Oil	778 gm x 27,325,402.68 kWh = 21,259,163,285.04 gm = 23,434.216 tons	23,434.216 tons x \$3,500 = \$82,019,756

5. Conclusion

The deployment of a PV-Piezo hybrid floor tile in the International Cairo Stadium of Egypt was investigated in this paper. This dual-resource tile generates electricity from solar energy and human footsteps. The surface of the tile is formed of solar PV panel that converts sunlight into electricity during daytime. Moreover, a piezoelectric device is installed within the tile to convert mechanical energy from footsteps into electrical energy at any time according to foot traffic in the place. The research studied the economic and the environmental aspects for the implementation of this hybrid tile over a 1600m^2 of the athletics track in International Cairo Stadium of Egypt. The results showed that it is a worthwhile technology to be deployed, as the gain from the 1600m^2 of the PV-Piezo hybrid floor installed is 5,620 \$/month with a payback period of 8 years. Moreover, for a 30 years lifetime hybrid floor system with an Annual degradation rate of 1% in generation, the system generated 27,325,402.68 kWh. Calculating the CO_2 emissions cost for this hybrid floor proposed, it was found that it saves more than 43 million dollars for CO_2 emissions when compared to natural gas as an energy resource, and it saves more than 79 million dollars when compared to oil as an energy resource.

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