Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 115 (2017) 114–126

Energy Procedia

www.elsevier.com/locate/procedia

International Conference – Alternative and Renewable Energy Quest, AREQ 2017, 1-3 February 2017, Spain

Feasibility Study for Using Piezoelectric Energy Harvesting Floor in Buildings' Interior Spaces

Adnan Mohamed Elhalwagy*[1], Mahmoud Yousef M. Ghoneem[2], Mohamed Elhadidi[3]

1 Assistant lecturer, Interior architecture Department,Faculty of Fine Arts, Helwan University, Cairo, Egypt
2 Associate Professor, Architecture Department,Faculty of Fine Arts, Helwan University, Cairo, Egypt
3 Teaching assistant,Mechanical Engineering Department-Mechatronics, Higher Technological Institute, 10th of Ramadan, Egypt

Abstract

Piezoelectric floors generate many microwatts up to many watts per step, depending on space pedestrians' frequency and piezoelectric technology. Although there are a number of earnest researches that have focused on harvesting power from piezoelectric floors tiles, the piezoelectric application is still hindered by many factors, which leads to the deprivation of the advantages of this technology. The research addresses how to get the Maximum benefits from piezoelectric energy harvesting floor in Buildings' interior spaces, according to the various weight of every usage factors, and through the integration of different kind of piezoelectric technology capabilities.

This Paper seeks to spread piezoelectric energy harvesting floor applications, through Facilitate how to conciliate and harmonize between the challenging requirement of usage factors and the application possibilities using a proposed tool. Feasibility study guide supported by various case studies that has been described as a benchmark for the future applications.

Peer-review under responsibility of the organizing committee of AREQ 2017.

Keywords: Feasibility study; Renewable energy; Energy Transformation;Piezoelectric technology; Interior space; Floor.

* Corresponding author. Tel.: +2 01002745187
E-mail address: adnanelhalwagy@hotmail.com

1876-6102
Peer-review under responsibility of the organizing committee of AREQ 2017.
10.1016/j.egypro.2017.05.012

1. Introduction

Renewable and clean energy resources have become a demanded research area due to the problems facing energy shortage and environmental concerns using fossil fuel resources. The world electricity demand will increase by almost 80% during the period of 2012-2040 in the (IEA) International Energy Agency's New Policies Scenario. [1] The IEA believes that clean energy revolution is an essential need for the world in order to break dependence on fossil fuels. Such a revolution would enhance global energy security, promote Continuance of economic growth and tackle environmental challenges such as climate change. It would break the long-standing link between economic growth and carbon dioxide (CO2) emissions. Energy harvesting technologies demand is growing as we continue to seek out greener and more efficient solutions. Like a wind generator or solar cells. Piezoelectricity is also a type of technology used for electrical energy harvesting from mechanical pressure such as walking motion.

Piezoelectric Energy harvesting floor as a sustainable clean energy is generating a usable electricity depending on people footsteps pressure, this valuable energy is wasted in spite of its available clean source (human movement). Public spaces piezoelectric floors can scavenge a reasonable amount of energy that can power electrical devices like lighting and screens. However, private offices or residential spaces are varying to use this technology due to the infeasible usage of the harvested amount of energy. Piezoelectric Energy has been applied in limited projects, opposed to the most widespread Renewable energies resources. The main factors that effect on piezoelectric technology usage are output power per step, battery storage, cost, consumption facility, number of users, distribution of high frequency walking areas and the method of utilizing this technology to get the optimal saving energy results, needing power to be used as main power or as a sensor triggering to manage the small amount of power needed to Locate users and direct a sufficient amount of power that meet their needs. This paper aims to facilitate using of piezoelectric technology by presenting the main types of this technology especially that used in harvesting energy floors, some of presented types are existing companies which have products, and other presented types are researches supported by experiments. Types' survey is followed by analytical brief. Correlation between factors has been presented as a preface for the suggested proposal and all its points are explained. Proposal was supported by using different case studies to clarify the sequence and the reliability of the proposal.

The Aim of this Paper is reaching a guide as a tool for architecture & interior architecture designers to facilitate embedding this technology in their designs as a part of the demanded low energy consumption in the buildings.

In addition,

- Utilizing piezoelectric technology as a clean energy which conserve environment and reduce CO2 emissions that produced form the fuel recourses
- Saving energy consumption and direct the surplus toward investment
- Reducing electricity bill for the consumers and reach lower price category of electricity consumption

2. Main types of piezoelectric technology that used in energy Harvesting Floor.

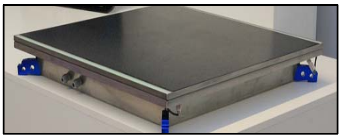
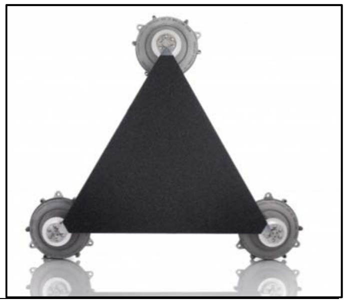
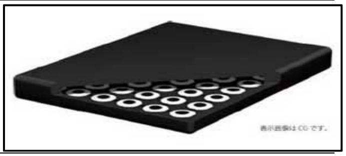
Types of piezoelectric technology were classified according to the main technical specifications in (Table 1.) and by the same order according to uses and features (Table 2.), this main types is covering the factor of available products, the basis of the feasibility study.

Table 1. Piezoelectric technology types main technical specifications, price and lifespan.

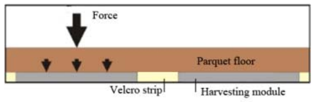
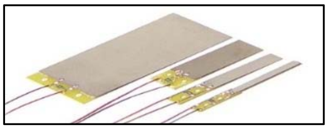
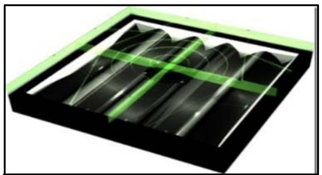
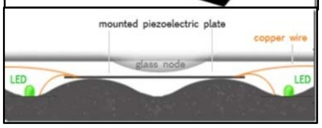
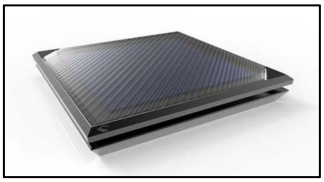
No.	Company - Technology	Product dimension	Generated energy	Price/ Egyptian pounds	Estimated lifespan by years	Ref.
1	Waynergy Floor	40 x 40 cm tile	10 W per step	4000	20	[2]
2	Sustainable Energy Floor (SEF)	75 x 75 cm tile 50 x 50 cm tile	Up to 30 watt of continuous output. Typical power output for continuous stepping by a person lies between 1 and 10W nominal output per module (average 7W)	15000	15	[3]
3	pavegen tiles	V3 Tile 50 cm each edge	5 Watts continuous power from footsteps	35000	20	[4]
4	(EAPs) Electro-Active Polymers	Sheets	1w	unknown	20	[5] [6]
5	Sound Power	50 x 50 cm tile	0.1 watt per 2 steps	unknown	20	[7][8] [9]
6	PZT ceramic (Lead zirconate titanate)	Manufacturing in a small size	8.4mW	unknown	20	[10][11] [12]
7	Parquet PVDF layers	layers	2.1mWs per pulse with loads of about 70 kg	unknown	20	[13]
8	Drum Harvesters - Piezo buzzer Piezoelectric Ceramics	vary	Around 2.463 mW	Estimated 500 /tile	20	[14]
9	POWER leap PZT	Tile 24" x 24"	0.5mW per step	The project has stopped	20	[15][16]
10	hybrid energy floor - combines human power with solar energy	75 x 75 cm tile 1 x 2 meter tile	up to 60kWh per year, per tile up to 250 kWh per year, per tile	Estimated 15000	20	[17]
11	PZT Nanofibre - nanogenerator &PZT textile nanogenerator	Sheets The volume of the material used is 0.2cm3	6mW/cm3 0.03 μW power density up to 2.4 $\mu W/cm^3$ [20]	available commercially at low cost and in a variety of designs	20	[18][19]
12	Pvdf nanofibre		4 $\mu W/cm^3$ 7.2 pW	unknown	20	
13	ZnO nanowire VINGs		5 pW 11 mW/cm^2 2.7 mW/cm^3	very economically	20	
14	BaTiO3		~7 mW/cm^3	available commercially at low cost and in a variety of designs		

Table 1. Piezoelectric technology types main technical specifications, price and lifespan.

Table 2. Piezoelectric technology types according to uses and features.

No.	Company - Technology	Uses and features	figures
1	Waynergy Floor	• Energy directly consumed or stored • Indoor/outdoor applications • Using in illumination, traffic control devices supply • high footfall areas, Public transport stations, Crosswalks, sidewalks, Security systems supply • Selling electricity to the grid	
2	Sustainable Energy Floor (SEF) [2]	• used in pavements and high footfall areas like airports, sport arenas, shopping malls, railway stations and office and apartment blocks • power street lights and signing systems • modules can be fully customized • Used in many projects like Nissan Innovation Station in 2015.	
3	pavegen tiles Floor Data Energy	• Used in various sectors including train stations, shopping centres, airports and public spaces. • can improve data-driven smart cities • Each tile is equipped with a wireless API that transmits real-time movement data analytics whilst directly producing power when and where it is needed • can power interactive messages, billboards and signage • Able to connect to a range of mobile devices and building management systems. • Footfall tracking & Identifying Footfall hotspots	
4	(EAPs) Electro-Active Polymers	• generally generated high voltages • Sensor Network Technology, sensor matrix • Pressure mapping in order to trigger a control, warning or alarm signal.	
5	Sound Power	• Power Sources for many applications. • utilized in the emergency stairs • 0.1 watt of electricity when a person steps on them is enough to illuminate 50 to 100 "Christmas-tree" LED lights wired to the tile.	
6	PZT ceramic (Lead zirconate titanate)	• Extremely brittle & Manufacturing in a small size • More expensive than PVDF (next type) • Ultra-efficient piezoelectric material that can convert up to 80 per cent of mechanical energy to electricity. • PZT is 100 times more efficient than quartz • higher piezoelectric voltage constant than PVDF • has more value of voltage conversion than PVDF	

* There is also SDF floors for the same company but the study did not mentioned it because it has special kind of movement-dance and jump-which is not included in the main point of the study(normal walking).

7	Parquet PVDF layers (polyvinylidene fluoride)	• Simple manufacturing process & inexpensive • Can be produced in a big sized foil material • Very suitable to the application of mass production technologies • Modules are characterized by a great flexibility • Very robust, resistant and has the possibility to be created in almost any geometrical size and shape • The energy yield is increasing by the multiplication of the layers • Lengthwise arrangement is more efficient • Energy yield is increasing at higher loading forces and higher thicknesses of the modules • Energy harvesters of PVDF can be used to power small electrical loads or wireless sensor system	
8	Drum Harvesters - Piezo buzzer	• Generating low power • Generate useful electrical energy which can be used to power microelectronic devices like Bluetooth, GPS modules, microcontrollers and low power sensors using ambient vibrations from various sources. • The fabrication process of these drum harvesters is cheap, easy and fast • Quite robust and as such may be embedded in a variety of structures, under floors, roads, etc.	
9	POWERleap PZT.	• As people walk across it to light up the night-time pavement • The system uses 2-inch by 1-inch PZT plates with a brass reinforcement shim covered in nickel electrodes for low current leakage • When these plates generated power induced and stimulates momentary electrical energy impulses used to light the LED's inside each tile. • Generated power can be stored in a battery as DC power	
10	hybrid energy floor (HEF)	• combines human power with solar energy • converts solar power and kinetic energy from human movement to electrical energy • designed for installation on commercial streets, public squares, parks and pavements • It uses photovoltaic panels with CIS (Copper Indium Selenide) solar technology. Main benefits of CIS solar technology are its excellent performance in shady areas and its maximum energy production with minimum power use	
11	PZT Nanofibre-nanogenerator &PZT textile nanogenerator	• light a commercial LCD and power a ZnO nanowire UV sensor for the quantitative detection of UV light • available commercially at low cost and in a variety of designs	**Common features (11-14)** • self-powering micro-/Nano systems, sensors and active sensors

12	Pvdf nanofibre self-powering	• drive a single nanowire-based UV sensor to build a self-powered system	• driving micro/Nano devices • Devices for wireless technologies & wireless data transmitters • Recent embedded electronic devices like RFID tags and remote sensors are giving stand alone and MEMS/NEMS devices a new dimension • can be integrated with other energy harvesting devices for building hybrid cells
13	ZnO nanowire VINGs & nanorods	• self-powered wireless nanodevices and systems • single nanowire can work as a nano-transducer and generate piezoelectricity • integration of multiples of these nanowires into arrays on a single substrate for improved output power • charge-generating nanodevices with piezoelectric nanorods that could be used as pressure sensors light up commercial LEDs • power a pH sensor and an UV sensor • easily synthesized in the required sizes and shapes • the most widely used material for nano-energy harvesting	
14	$BaTiO_3$	• most recent material to be reported for piezoelectric power generation	

Table 2. Piezoelectric technology types according to uses and features.

2.1. Analytical brief

Piezoelectricity types were divided to three categories as below that is affecting on types of application usage

- 1to 5 and 10 have reasonable various amount of generated power (from 0.1 W to 10 Ws)
- 6 to 9 have less various amount of generated power (from 0.5mW to 8.4mW)
- 11 to 14 have low generated power (5 pW to11 mW/cm2)

Application outline of these types has been mentioned in the Discussion and conclusion

3. Correlation between factors

To compromise between the different factors according to the budget and space specification (high pedestrian's area) the research suggests a tool for all various factors that mentioned below:

- Needed power
- Number of steps per tile
- Output power per step/tile
- LCCA[3] of new tiles
- Cost of official governmental electricity kilowatt
- distribution of high frequency walking areas

3.1. Suggested proposal as a tool for the feasibility study

The suggested proposal to facilitate feasibility study is by rearrange these factors with next steps :

- Needed power (required factor as an input)
- Number of steps per tile (required factor as an input)

---

* Life-cycle cost analysis – (all cost of the project components, installation, maintenance and dispose of an object or process according to the Lifespan)

- Feasibility of power: Feasible Number of tiles that cover the needed power (vary depending on each type output power per step and the available high frequency walking area) - (result of the formula)
- Feasibility of cost (result of the formula)

This suggested table demonstrates these steps as below (Table 3.)

Table 3. Suggested proposal to facilitate feasibility study using (Microsoft Excel).

	A	B	C	E	F
1	KW needed daily power	10000	fesible	all prices in	Egyptian pound (EGP)
2	KW price by gov. (official)	0.5	not fesible		
3	steps, per day, per tile	150000			
4	Price Fiesibility	saving percentage	92.69%	saving percentage	98.72%
5		total saved amount	EGP 33,833,333	total saved amount	EGP 36,033,333
6	Type or company	Sound Power		pavagen	
7	power gen/ watt	0.05		5	
8	unit & its equipment price	2000		35000	
9	lifespan	20		20	
10	kw price for each type daily	0.03652968		0.006392694	
11	number of tiles	Initial cost	Daily generation capacity-kwh	Initial cost/(EGP)	Daily generation capacity-kwh
12	1	2000	7.5	35000	750
13	2	4000	15	70000	1500

3.1.1. The main point of the table:

- **KWs (kilowatt) needed daily power** = given parameter
- **KW price by Gov. (official)** = given parameter
- **Steps, per day, per tile**= given parameter depending on survey, observation and simulation
- **(Type or company, power gen/ watt for each type , unit & its equipment price, lifespan)** are given information from the producer company
- **Initial cost** = unit & its equipment price * number of tiles
- **Daily generation capacity by kWh =**
  (Number of steps, per day, per tile * power generated watt for each type * number of tiles) / 1000
- **kw price for each type daily** = (Initial cost/ Lifespan by days) / Daily generation capacity by KWh
- **Feasibility of power** = number of tiles of a specific type that its Daily generation capacity-KWh covers the KWs daily needed power.
  Feasibility of power is by compare the results of (C11 daily generation capacity-kwh) with the needed power (B1) until attaining feasibility by calculate how many tiles of every type will cover the needed power
- **Price feasibility** (saving percentage) =100 - ((kw price for each type daily* KW needed daily power *Lifespan by days)/(KW price by Gov. (official)* KW needed daily power *Lifespan by days)) * 100 .
  Price feasibility is by dividing Life-cycle cost per day (e.g. B10) by the real official governmental cost of needed power to get the percentage of cost saving (e.g. C4).
  Price feasibility is varying depending on used type which can be more suited for more than budget
- **total saved amount =** (KW price by Gov. (official)* KW needed daily power *Lifespan by days)-**(** kw price for each type daily* KW needed daily power *Lifespan by days**)**

The case studies will demonstrate theses table more clearly.

4. Case studies

The case studies will apply the piezoelectric floors in two different spaces with different input factors (Needed power & Number of steps per tile). Regarding the (official) KW price by Gov. and types specifications they will be constant in both case studies. The first recommended space is a public space -the second recommended space is a private space, the variety of the kind of spaces is to figure out the feasibility of using different kinds of piezoelectric application in floors, with a clear difference of pedestrian areas and density.

4.1. Case study 1 (high pedestrian public space)

Cairo ranks the second crowded city in Africa and the 18th of the highest population cities in the world, which reach to 9,102,232 According to 2014 statistics [1] with 17,190 people per km^2 Density, Cairo population number is doubling by considering the whole population of the greater Cairo area (Adjacent and surrounding areas), who are daily use Cairo facilities. This case study investigate the most crowded spots in Cairo as a public spaces. In the first, Cairo railway Ramses station which is located in the centre of Cairo would be the spot, because it have more than 70 thousand users per day, and consider the main gateway to all country cities, but it was discovered that the adjacent spot, Ramses subway station (Elshohadaa) (Fig. 1.) has more frequency of pedestrians twice more than the first choice. Elshohadaa station is receiving daily an average 150 thousand person. The study starts by knowing the main data of the main factors like needed power for the station which is approximately 10MW daily, knowing steps number according to the number of users which is an average 150 thousand person, Analysis Densities of pedestrian disruption to Determinate the hot spots footfall areas in the station where the study can apply the experiment efficiently and that is by site observation and using –SimWalk[4]-as a guide (Fig. 2.).

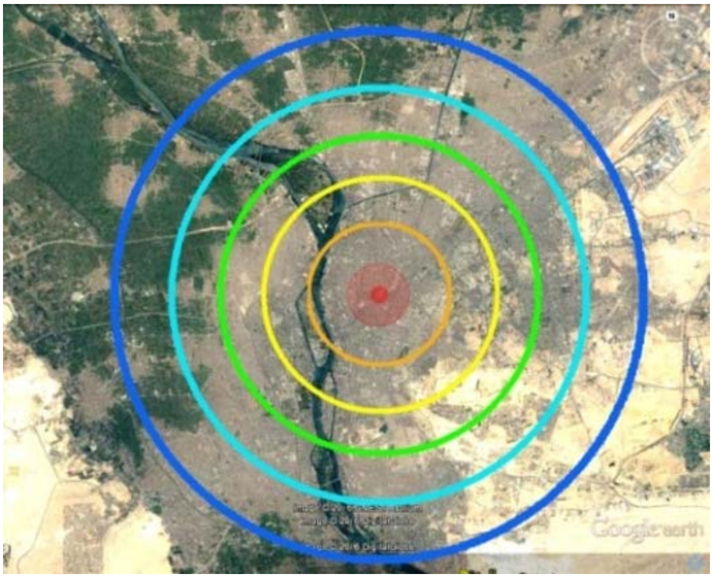


Fig. 1. Cairo map showing the central location of Elshohadaa metro station (Google earth)

* Pedestrian simulation application as one of the most specialized pedestrian Flow simulation apps, especially in the Transport projects.

Fig. 2. Analytical illustration for Elshohadaa metro station, (1) entrance & exits, (2) pedestrian density disputation

By applying the data on the proposed -feasibility study table as a tool (Table 4) the results can be shown as below:

Table 4. result of given data of case study 1

KW needed daily power	10000	fesible	all prices in Egyptian pound (EGP)					
KW price by gov. (official)	0.5	not fesible						
steps, per day, per tile	150000							
Price Fiesibility	saving percentage	92.69%	saving percentage	98.72%	saving percentage	99.48%	saving percentage	99.93%
	total saved amount	EGP 33,833,333	total saved amount	EGP 36,033,333	total saved amount	EGP 27,232,143	total saved amount	EGP 36,473,333
Type or company	Sound Power		pavagen		SEF		Waynergy	
power gen/ watt	0.05		5		7		10	
unit & its equipment price	2000		35000		15000		4000	
lifespan	20		20		15		20	
kw price for each type daily	0.03652968		0.006392694		0.002609263		0.000365297	
number of tiles	Initial cost	Daily generation capacity-kwh	Initial cost/(EGP)	Daily generation capacity-kwh	Initial cost/(EGP)	Daily generation capacity-kwh	Initial cost/(EGP)	Daily generation capacity-kwh
1	2000	7.5	35000	750	15000	1050	4000	1500
2	4000	15	70000	1500	30000	2100	8000	3000
3	6000	22.5	105000	2250	45000	3150	12000	4500
4	8000	30	140000	3000	60000	4200	16000	6000
5	10000	37.5	175000	3750	75000	5250	20000	7500
6	12000	45	210000	4500	90000	6300	24000	9000
7	14000	52.5	245000	5250	105000	7350	28000	10500
8	16000	60	280000	6000	120000	8400	32000	12000
9	18000	67.5	315000	6750	135000	9450	36000	13500
10	20000	75	350000	7500	150000	10500	40000	15000
11	22000	82.5	385000	8250	165000	11550	44000	16500
12	24000	90	420000	9000	180000	12600	48000	18000
13	26000	97.5	455000	9750	195000	13650	52000	19500
14	28000	105	490000	10500	210000	14700	56000	21000
15	30000	112.5	525000	11250	225000	15750	60000	22500
16	32000	120	560000	12000	240000	16800	64000	24000
1334	2668000	10005	46690000	1000500	20010000	1400700	5336000	2001000

It is observed from the results that have been analysed in (Table 5.) that the feasibility of power needs can be covered by:

option	Number of tiles	Company	Initial cost- EGP	saving percentage	total saved amount
1	1334	sound power	2668000	92.69%	33,833,333
2	14	pavagen	490000	98.72%	36,033,333
3	10	SEF	150000	99.48%	27,232,143
4	7	Waynergy	28000	99.93%	36,473,333

Table 5. Output results of case study one

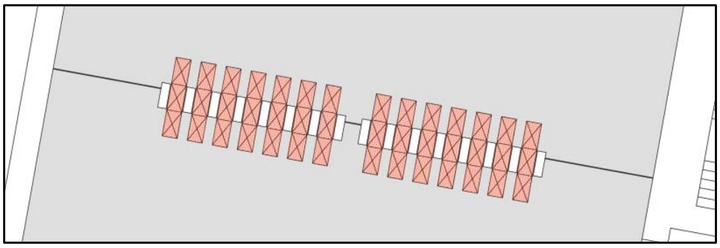


Fig. 3. Proposed tiles location between turnstiles

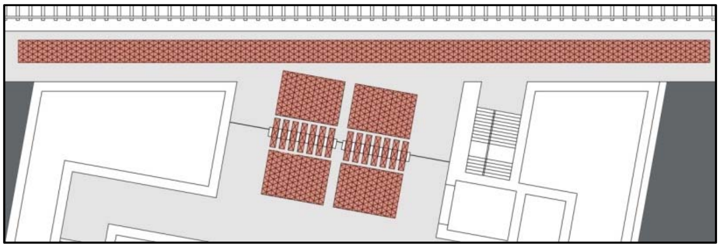


Fig. 4. Proposed tiles location to generate extra power

Also feasibility of cost has been achieved in the four types (green colour), but it has been shown that depending on the space distribution of the high pedestrians spots analysis (Fig.2.), the 16 metro ticket gates (turnstiles) have the peak number of pedestrians, the closest matching number of tiles that has resulted from the table and matches with ticket gates number belongs to pavagen solution that covers the needs with 14 unites, which is more suitable with the high pedestrians spots distribution. Other solutions are less efficient according to the high pedestrians' distribution areas of this space that don't match with other solutions tiles number. But other spaces might by fitted more with other types.

Since the needs of power were covered with a small area of tiles compared with the high pedestrian area of this space, the extra number of tiles is feasible also but it is more than needed power. If we have extra high pedestrian areas more than needed area like this case, we can install more tiles just to generate extra power and export it to any power supplier as an investment to keep the feasibility of cost. Otherwise, it will be extra useless cost. It is possible to exploit this area as a "crowd farm" (which is a conceived project by MIT students Tad Juscyzk and James Graham aimed to convert the energy of human movement in urban settings to energy suitable for consumer use) [21]. Elshohadaa station area which is about 5000m^2 on both metro directions has nearly 25% high pedestrians footfall area, If we use this tiles to cover this areas which are around 1250 m^2 with 5000 tiles, this will generate daily around 3.741 GW and will save more than 1.5 million EGP (extra energy) from only one station out of 75 stations (Metro company pays 10 million monthly for the electricity bill).

Of course other station will be less pedestrian but they will be rewarding and we can use different types of tiles depending on different pedestrian's frequency for the same space to make balance between tiles efficiency and various areas pedestrians' distribution to get the maximum benefits.

4.2. Case study 2 (low pedestrian private space)

The second recommended space is a private residential apartment with 5 users -family (Fig. 5.)The study starts by knowing the main data like needed power for the apartment which is approximately 10 kw daily, knowing the number of steps according to users number which is an average 150 steps per tile daily for all users, (we have 5 persons; everyone is passing through the apartment corridors with an average 25 times daily in variable rates) according to survey and observation, Analysis Density of pedestrian to Determinate the hot spot areas where the study can apply the experiment efficiently, and that is by site observation and using –SimWalk-as a guide(Fig. 6).

Fig. 5. Apartment lay out with furniture

Fig. 6. Analytical illustration of pedestrian density disputation

The apartment area is 150 m ^{2} It is found that the highest pedestrian's areas are in the main corridors and in front of doors, then sub corridors. The highest pedestrian's areas are about 15% of total area because furniture Occupy large area, by applying the data on the feasibility study proposed table as a tool (Table 4.) the results can be shown as below:

KW needed daily power	10	fesible	all prices in Egyptian pound (EGP)					
KW price by gov. (official)	0.5	not fesible						
steps, per day, per tile	125							
Price Fiesibility	saving percentage	-8667.12%	saving percentage	-1434.25%	saving percentage	-526.22%	saving percentage	12.33%
	total saved amount	EGP 3,163,500-	total saved amount	EGP 523,500-	total saved amount	EGP 144,054-	total saved amount	EGP 4,500
Type or company	Sound Power		pavagen		SEF		Waynergy	
power gen/ watt	0.05		5		7		10	
unit & its equipment price	2000		35000		15000		4000	
lifespan	20		20		15		20	
kw price for each type daily	43.83561644		7.671232877		3.13111546		0.438356164	
number of tiles	Initial cost	Daily generation capacity-kwh	Initial cost/(EGP)	Daily generation capacity-kwh	Initial cost/(EGP)	Daily generation capacity-kwh	Initial cost/(EGP)	Daily generation capacity-kwh
1	2000	0.00625	35000	0.625	15000	0.875	4000	1.25
2	4000	0.0125	70000	1.25	30000	1.75	8000	2.5
3	6000	0.01875	105000	1.875	45000	2.625	12000	3.75
4	8000	0.025	140000	2.5	60000	3.5	16000	5
5	10000	0.03125	175000	3.125	75000	4.375	20000	6.25
6	12000	0.0375	210000	3.75	90000	5.25	24000	7.5
7	14000	0.04375	245000	4.375	105000	6.125	28000	8.75
8	16000	0.05	280000	5	120000	7	32000	10
9	18000	0.05625	315000	5.625	135000	7.875	36000	11.25
10	20000	0.0625	350000	6.25	150000	8.75	40000	12.5
11	22000	0.06875	385000	6.875	165000	9.625	44000	13.75
12	24000	0.075	420000	7.5	180000	10.5	48000	15
13	26000	0.08125	455000	8.125	195000	11.375	52000	16.25
14	28000	0.0875	490000	8.75	210000	12.25	56000	17.5
15	30000	0.09375	525000	9.375	225000	13.125	60000	18.75
16	32000	0.1	560000	10	240000	14	64000	20
1040	2080000	6.5	36400000	650	15600000	910	4160000	1300
1041	2082000	6.50625	36435000	650.625	15615000	910.875	4164000	1301.25
1600	3200000	10	56000000	1000	24000000	1400	6400000	2000
1601	3202000	10.00[illegible]	[illegible]	[illegible]	[illegible]	1400.875	6404000	2001.25

Table 6. Result of given data of case study 2

It is observed from the results (Table 7) that the feasibility of power needs can be covered by:

option	Number of tiles	Company	Initial cost- EGP	saving percentage	Total saved number
1	1600	sound power	3200000	-8667.12%	3,163,500 -
2	16	pavagen	560000	-1434.25%	523,500-
3	12	SEF	180000	-526.22%	144,054-
4	8	Waynergy	32000	12.33%	4,500

Table 7. Output result of case study one

Option 1 is Feasible as a power but it cannot be a solution due to the fact that 1600 tiles wouldn't be suited with the small high pedestrian area in this apartment regardless it has infeasibility cost. Feasibility of cost has been achieved by only option 4 (Fig.7.) with very low saving percentage. The restriction of this case study is the low pedestrian numbers. In both case studies, Investment in energy harvesting floor tiles has to be after achieving both power and cost feasibility depending on the space data like high pedestrian's areas distribution and steps numbers, that is by increasing the number of tiles, but it needs other calculation.

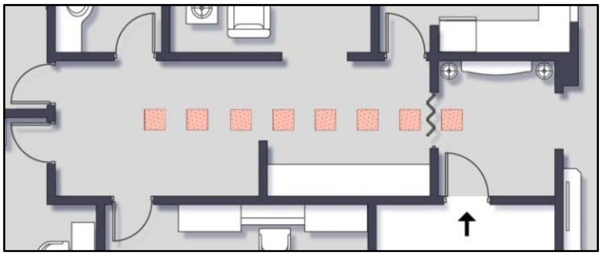


Fig.7. Proposed tile location in the main entrance, separated to cover more space.

5. Discussion and conclusion

Low pedestrian Spaces like apartment case can use harvesting floor tiles in a different way to generate and save energy. Firstly, Using high generated power tiles as that one used in the study as a power source generators, that can be used to operate LED lighting systems, since LEDs use far less energy than more conventional (fluorescent and incandescent) bulbs. But other types that harvesting very low power; Nano or micro watts, can be used as a trigger for a self-powered sensors that tracking the users and control all equipment depending on their movement.

Wireless sensor networks came about as a result of a shift from wired to wireless links for communication in sensor networks. This coupled with low power, low data rate and low cost make WSN (Wireless sensor networks) an attractive solution for many monitoring and data gathering applications. [22]

The output electrical energy is enough for driving wireless data transmitting device like (Wi-Fi, li-fi, Z-Wave, RF, 3G). Piezo sensors produce electricity when pressure is applied on them. These sensors are then connected in series and parallel combination and placed in a tile like structure; this tile can be used in any place wherever pressure is applied. The harvested power can be stored in a battery and used for AC or DC loads and also voltage generated by a single tile can be displayed on display devices like LCD located at a different location using zigbee technology[5] for smart analysis [23]. Moreover, built environment Monitoring of the internal environmental conditions and adaptation of heating, lighting etc. in response to human occupancy and activity is a major potential application for sensor networks, whether based on wireless communications or on wired connections to monitor power consumption with the aim of detecting locations or devices that are consuming a lot of electrical power and drive a wireless transmitter module to detect users current position [24] , Finally ,the most common uses of various piezoelectric floors is sensors transducer, frequency controlling , devices high voltage and power sources. [25]

Feasibility study Proposed tool can evaluate other given prices and factors data in the same way, as you can change the input data in the case its change, or if there is more accurate data. Piezoelectric for Sensors application and calculation will be covered more specifically in a future study.

* ZigBee is an open global standard for wireless technology designed to use low-power digital radio signals for personal area networks

References

[1] Scenario, N. P., M. East, and P. Cedex. "World energy outlook 2014 factsheet." Paris: International Energy Agency (2015).
[2] Rodrigues, João André da Costa Coimbra. Waynergy: The way for energy harvesting: Business model design. Diss. NSBE-UNL, 2011. http://utenportugal.org/wp-content/uploads/Waynergy-The-way-for-energy-harvesting.pdf, Accessed September 2016
[3] http://www.energy-floors.com/sustainable-energy-floor/, Accessed September 2016
[4] http://www.pavegen.com/ Accessed September 2016
[5] Farouk Balouchi. "Footfall Energy Harvesting Conversion Mechanisms." Ph.D. Thesis, University of Hull, 2013.
[6] Pintér, Ákos. "A Novel Floor Sensor Network Technology Based on Dielectric Electro-Active Polymers." Periodica Polytechnica. Engineering. Mechanical Engineering 59.3 (2015): 137.
[7] Ryall, Julian. "Japan harnesses energy from footsteps." *The Telegraph* 12 (2008).
[8]http://www.soundpower.co.jp/work/vibration.html#ttl_N7 Accessed September 2016
[9] BI Farahat." Piezoelectric materials "Potentials and Constrains "Upgrading Designs and Techniques" http://www.bau.edu.lb/Library/Files/Architecture/Publications/Piezoelectric%20materials.pdf, Accessed September 2016.
[10] Starner, Thad, and Joseph A. Paradiso. "Human generated power for mobile electronics." Low power electronics design 45 (2004): 1-35.
[11] E. Bischur, N. Schwesinger "Energy harvesting from floor using organic piezoelectric modules", 2012 Power Engineering and Automation Conference
[12] Ariel Schwartz ."Electricity Generating Dance Floors and Other Miracles of Piezoelectricity ", articles, 2011. https://www.good.is/articles/electricty-generating-dance-floors-and-other-miracles-of-piezoelectricity, Accessed September 2016
[13] Bischur, E., and N. Schwesinger. "Piezoelectric energy harvester under parquet floor." *SPIE Smart Structures and Materials+ Nondestructive Evaluation and Health Monitoring*. International Society for Optics and Photonics, 2011.
[14] Mishra, Ritendra, et al. "Vibration Energy Harvesting Using Drum Harvesters."*International Journal of Applied Engineering Research* 10.14 (2015): 34995-35001.
[15] Farouk Balouchi. "Footfall Energy Harvesting Conversion Mechanisms." P.hd Thesis , University of Hull, 2013.
[16] http://www.mascontext.com/tag/powerleap/ , Accessed September 2016.
[17] http://www.energy-floors.com/products/sef_solar/, Accessed September 2016.
[18] Dakua, Indrani, and Nitin Afzulpurkar. "Piezoelectric energy generation and harvesting at the nano-scale: materials and devices." *Nanomaterials and Nanotechnology* 3.Godište 2013 (2013): 3-21.
[19] Wang, Zhao, et al. "Piezoelectric nanowires in energy harvesting applications."*Advances in Materials Science and Engineering* 2015 (2015).
[20] Z. Zhou, H. Tang, and H. A. Sodano, "Scalable synthesis of morphotropic phase boundary lead zirconium titanate nanowires for energy harvesting," Advanced Materials, vol. 26, pp. 7547–7554, 2014
[21] http://news.mit.edu/2007/crowdfarm-0725, Accessed September 2016.
[22] Farouk Balouchi. "Footfall Energy Harvesting Conversion Mechanisms." P.hd Thesis , University of Hull, 2013.
[23] Sowmyashree, M. S., et al. "Power Generation System by using Piezo Sensors for Multiple Applications."
[24] Wu, Tsung-Tsi, et al. "Analysis of high efficiency piezoelectric floor on intelligent buildings." *SICE Annual Conference 2010, Proceedings of*. IEEE, 2010.
[25] Wang, Zhao, et al. "Piezoelectric nanowires in energy harvesting applications."*Advances in Materials Science and Engineering* 2015 (2015).