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Viability of piezoelectric materials in India: A sustainable alternative for harvesting energy

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Abstract: Humanity faces an unprecedented challenge: the need for abundant sources of energy to power our modern economy. This need is compounded by the fact that our primary sources of energy—fossil fuels—are finite and are being depleted at an alarming rate. In order to maintain our current standard of living, we must find ways to harvest energy from renewable sources instead. But our current energy paradigm is far from being sustainable: not only are our primary sources of energy polluting and detrimental to the environment, they are also becoming harder and harder to extract, requiring us to go to ever more dangerous lengths to obtain them.

In this research we will learn about the concept of piezoelectric and how can we apply them in architecture for a sustainable green building environment. The research is carried out through literature studies and case examples were piezo technologies has been used and further case development to prove the viability of piezoelectric technology in Indian respect taking a case of a railway station of Delhi, India. Furthermore, conclusions and recommendations have been derived from all the research work as to how efficient and feasible this energy harvesting technique is in today's world.

***IndexTerms* – Piezoelectricity, Piezoelectric, piezo, tiles, energy, energy harvesting, resources**

I. Introduction

Energy accounts for 52 percent of commercial and industrial respondents in India. With the country's annual increase in electricity demand, it's past time to consider alternative energy sources. (Anand & singh , January 15, 2021). Energy is required to power our homes, businesses and economy. We are fortunate to live in a country with abundant energy resources, and for most of our nation's history, we have been able to take our energy supply for granted.

Today, however, we find ourselves in a unique situation where our energy demand is outstripping our ability to supply the needs of the country through traditional energy sources. In other words, we are facing an energy deficit. The world's reliance on fossil fuels has caused a lot of environmental damage over the years. The majority of our energy still comes from fossil fuels, but the world needs to get away from that in order to reduce its carbon emissions and tackle climate change. We have been relying on renewable energy resources such as wind, water and solar power to generate the energy we need, but the amount of energy we need has been increasing, and we have not been able to generate enough renewable energy to keep up with that.

Although, there are these renewable energy resources but exploiting them constantly eventually do harm to the natural environment.

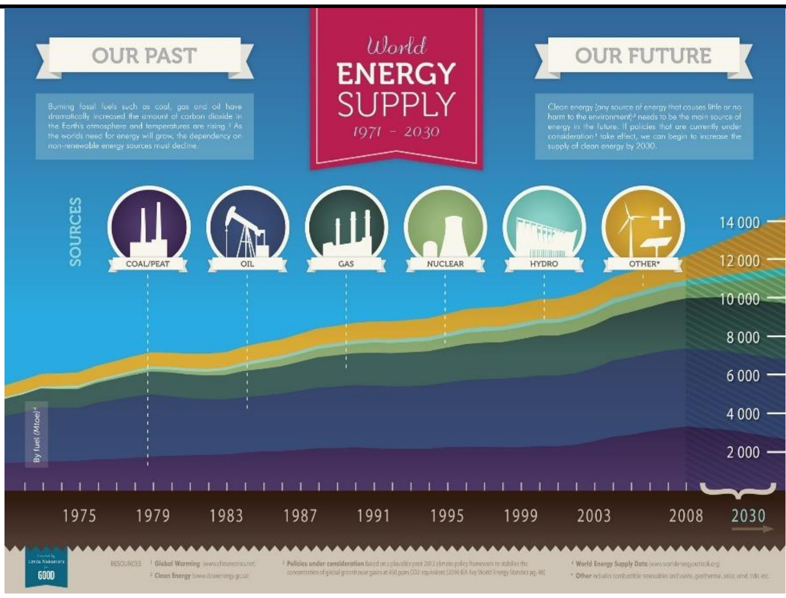


Figure 1:Current scenario of energy supply

This has led us to a situation where we are facing a lot of energy shortages, and the only way to solve that is by generating energy on the spot, regardless of whether it is renewable or not.

But our current energy paradigm is far from being sustainable: not only are our primary sources of energy polluting and detrimental to the environment, they are also becoming harder and harder to extract, requiring us to go to ever more dangerous lengths to obtain them.

Energy consumption has always evolved at an exponential rate, and there has always been a growing demand for energy in some form or another. For this reason, the Indian electricity sector has already taken a number of steps to promote renewable energy sources such as solar, wind, and hydropower through laws and plans that benefit all stakeholders. However, there is still a need for many more ways to create electricity. (Anand & singh , January 15, 2021).

The global energy consumption is steadily increasing due to industrialization and population growth. A large fraction of this energy is generated using fossil fuels (coal, oil, uranium etc). It is well accepted that we have to find alternative sources of energy as fossil fuels are depleting very fast and moreover, they are creating environmental problems such as global warming, carbon dioxide emissions and damage to ozone layer. The sun is the world's most plentiful renewable energy source, and the solar energy received by the earth in an hour exceeds the power consumed in a year. As a result, photovoltaic (solar) materials are one of the most important sources of alternative energy. This research will cover the principles of photovoltaic materials. The chapter will also offer a historical overview of photovoltaic energy harvesters, as well as their efficiency in comparison to piezoelectric materials. (Vatansever, Siores, & Shah, 2012)

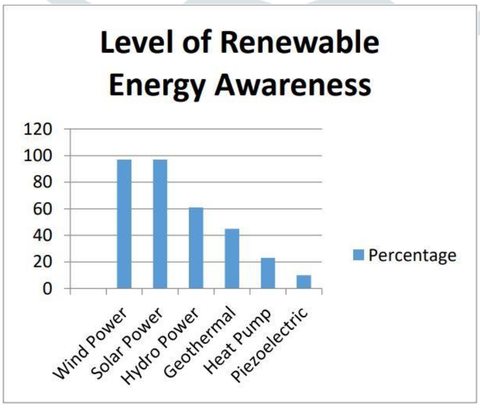


Figure 2: Piezoelectric devices consumption level

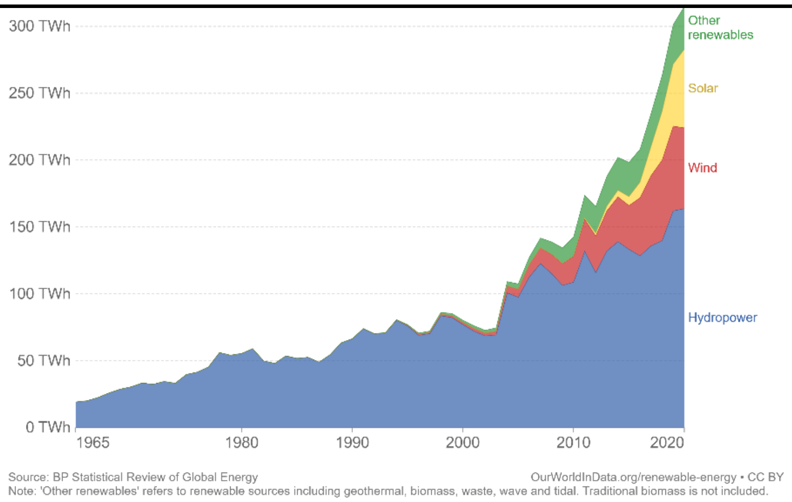


Figure 3: Renewable energy generation in India

Aim

The aim of the study is to analyse the viability and workability of piezoelectric materials as an energy harvesting alternative in India by taking a case of a railway station as an example.

Objectives

To evaluate and quantify the longevity and endurance of piezoelectric materials through inferences from studies and case studies.

Analyzing the reliability and usability of the materials.

The initial cost that will be involved in installing them.

The amount of energy that can be harvested from these materials.

How and where can they be installed and used.

Feasibility of these materials in large scale projects.

Analyzing a railway station in New Delhi as an example to test and compare the workability of these tiles.

Need and Significance

As discussed above that advancement in technologies have led to the innovative reviews for energy harvesting, thus bringing in the concept of piezoelectric materials. And in today's world when there is already a scarcity of natural resources through which we harness energy, such alternative resources are the need of the time.

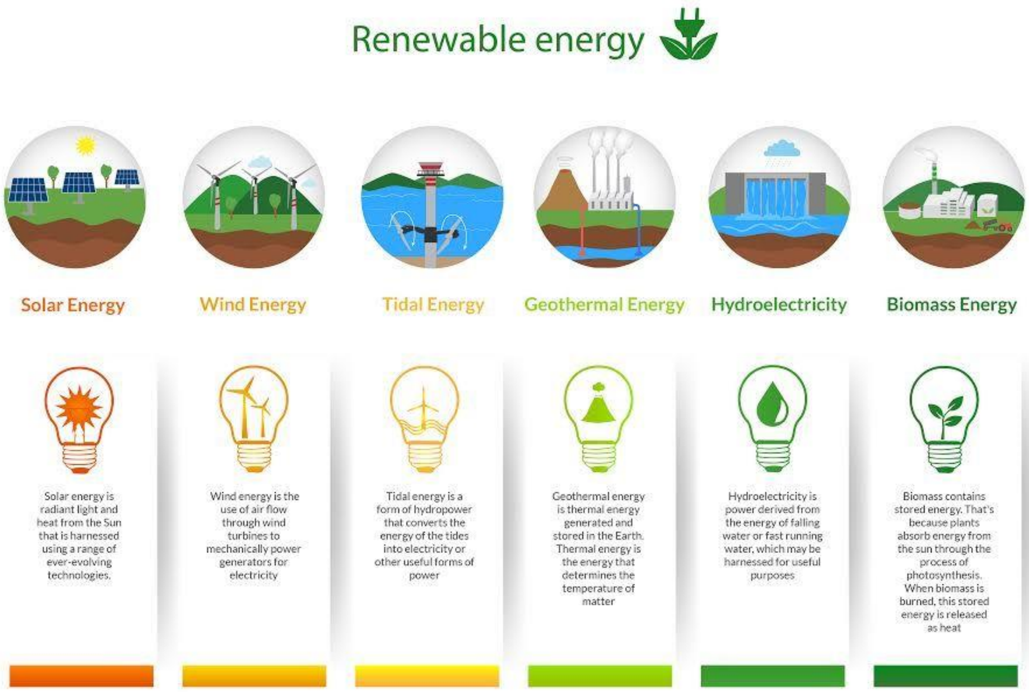


Figure 2:Most common energy harvesting resources

Scope

The scope of the study is to understand the use of piezoelectric technology for harvesting energy and to analyze its viability in Indian context.

The research would investigate how capable these materials are in generating energy and also the amount of energy that can be harvested through them.

To analyze a railway station for application of piezoelectric materials and compare them on the basis of their workability there.

Analyzing the architectural feasibility and sustainability of these tiles in the selected campus.

The study encompasses the applications and costs that will be incurred initially.

Limitations

The study is limited to energy harvesting through piezoelectric materials.

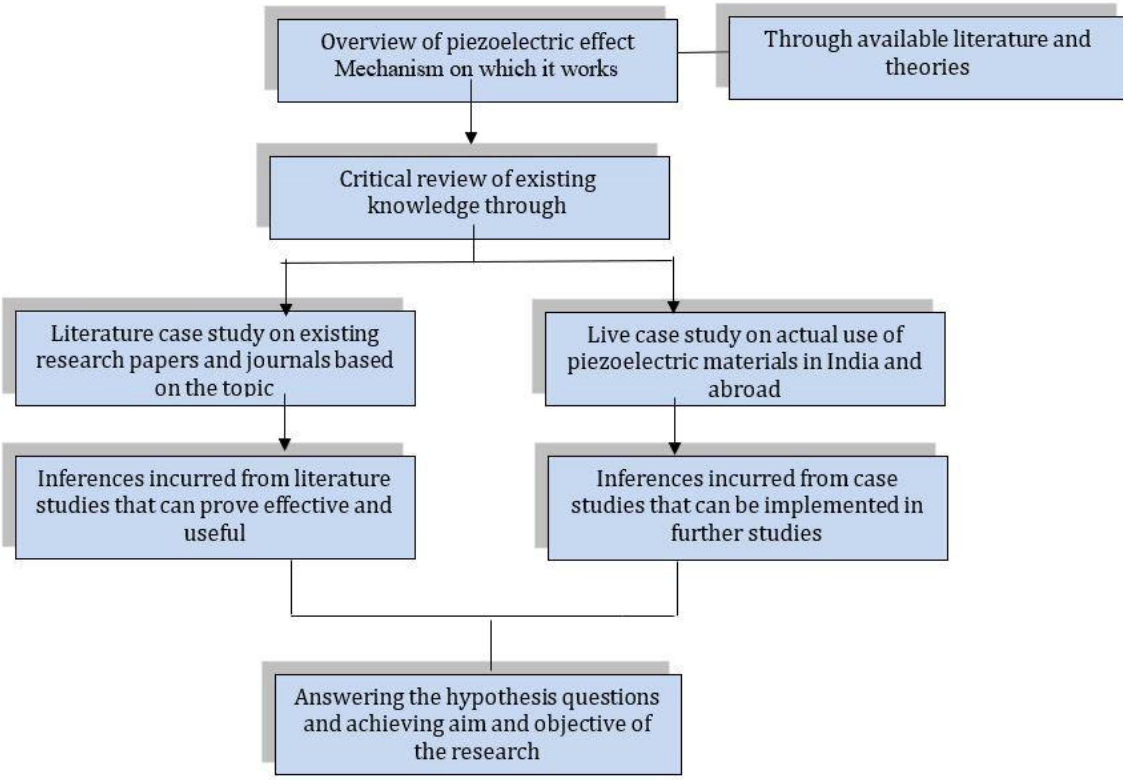
The study will not include the overall life cycle cost analysis of these materials.

Research work will be specific to Indian context only.

The study excludes all kinds of mathematical and physical equations involved in the working of these materials.

The study is purely based on theoretical data that will be collected from research papers, journals , books etc.

Methodology



II. LITERATURE STUDY

Researchers have been exploring alternative energy systems that can capture energies present in the ambient environment in response to the global energy crisis and environmental pollutions caused mostly by rising consumption of non-renewable energy sources. Mechanical energy is the most common form of ambient energy that can be absorbed and turned into usable electricity.

Due to its high electromechanical coupling rate and piezoelectric coefficient, piezoelectric transduction is the most frequent mechanical energy harvesting process when compared to electrostatic, electromagnetic, and triboelectric transductions. Consequently, piezoelectric energy harvesting is of great interest to the scientific community. (Koç & Sezer, November 2020).

Piezoelectric and pyroelectric technologies have been investigated as part of the search for alternate energy sources. The application of these technologies to pavements and city roadways could result in a significant energy source. Shifting from traditional fossil fuels to energy created by integrated piezo- and pyro-electric pavements is a clean, green, and sustainable energy harvesting approach that will not only cut carbon emissions but also enable future generations to adopt a more viable and stable source of energy. (Shukla & Ansari, Feb-2018).

The fact that piezoelectricity is based on a concept and that it falls under the category of renewable energy has yielded the predicted outcomes. Renewable energy can be used in a variety of ways a variety of strategies for reclaiming energy lost in the environment. However, they are insufficient to entirely solve the problem to rely on to compensate for increased consumption. These techniques are unable to harvest the mechanically exerted ambient energy. Piezo electric's property to emit zero carbon emissions and to cleanly convert mechanical to electrical energy is the main reason of their popularity. The method drew the interest of many people who wanted to combine piezoelectricity with other renewable energy sources to expand its potential possibilities. (Kumar, popat, Anand, & Raj, September,2017)

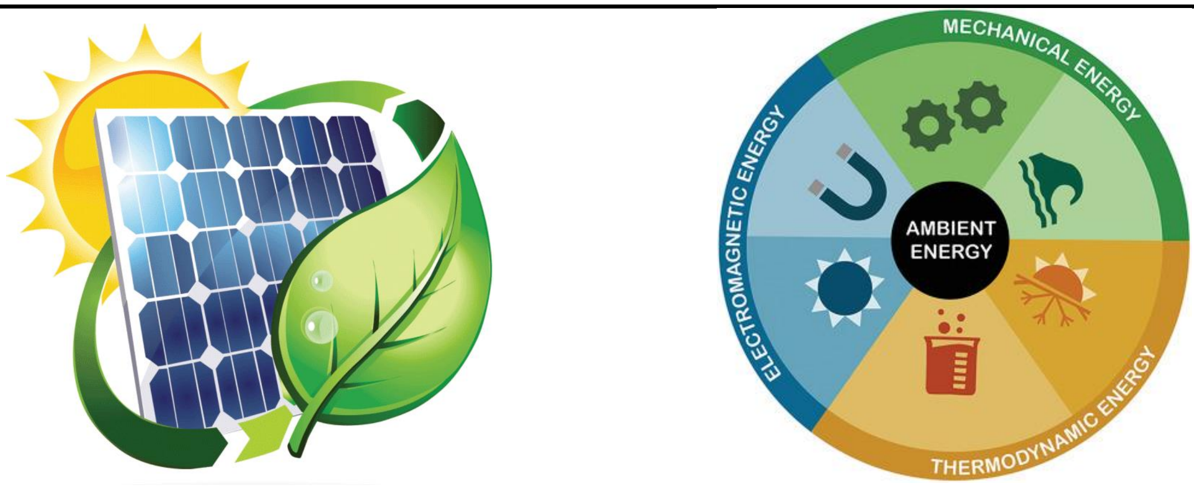


Figure 3:Natural and ambient energy sources

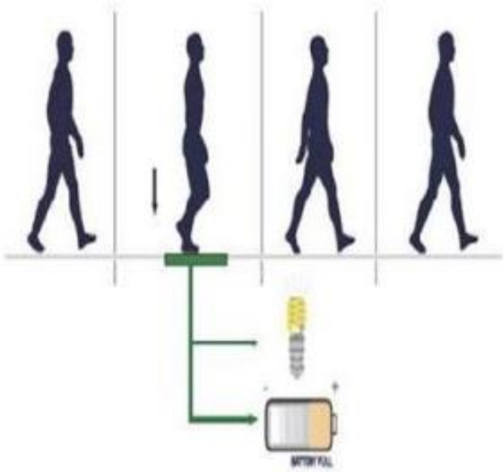


Figure 4:Generating energy through walking(body motion)i.e,piezoelectrics

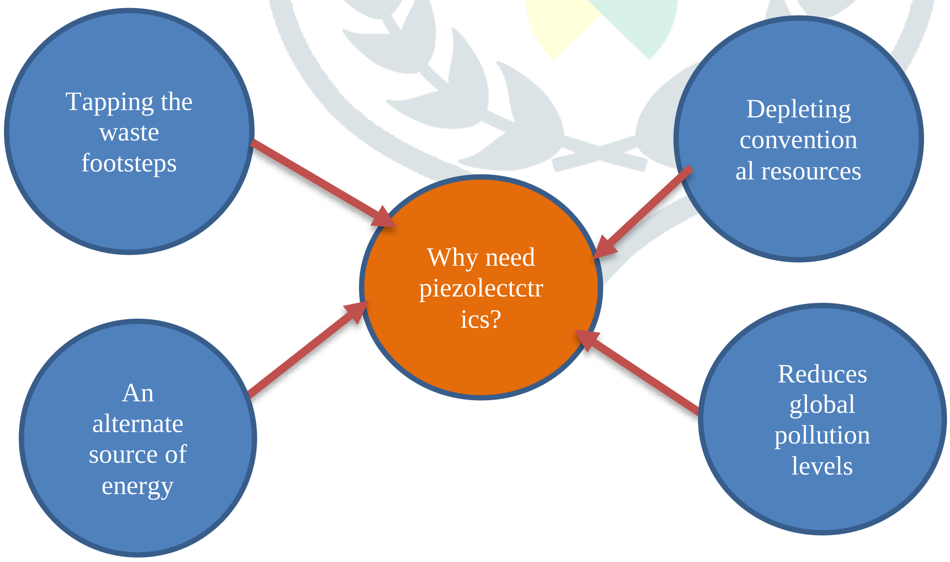


Figure 5: Need of piezoelectric technology for energy harvesting

Because the piezoelectric effect is solely based on the intrinsic polarisation of the material, it does not require a separate voltage source, magnetic field, or contact with another material, unlike electrostatic, electromagnetic, and triboelectric energy harvesting, it is a very convenient mechanism for capturing ambient mechanical energy and converting it into electric power.

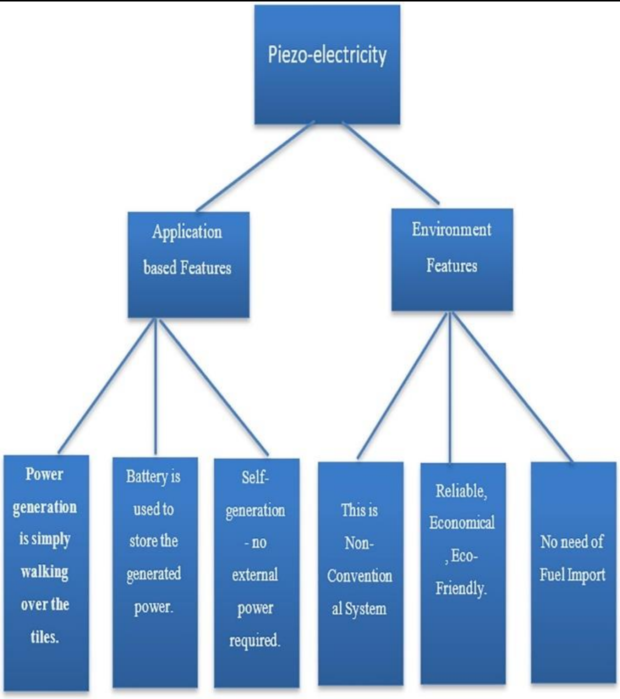


Figure 6:Piezoelectricity properties layout.

Piezoelectricity

Piezoelectricity can be considered a sustainable energy source as it does not use fossil fuels. It is important to consider that clean energy means to produce or consume energy without generating or generating in minimal quantities, waste and greenhouse gas and global warming. (Tavares, Pinto, & Reis Nascimento)

First let us learn about piezoelectricity and piezoelectric effect. The ability of a substance (particular ceramics and crystals) to generate an electrical charge when pressure is applied is known as piezoelectricity (squeezed or stressed). Piezoelectricity is the generation of an electric current when a piezoelectric material is deformed. The first observation of the piezoelectric effect was in 1831 when Pierre Curie and Bernard Cazin observed that crystal surfaces generate a small electric current when they are mechanically strained. In 1880, the Curie brothers (Pierre and Jacques Curie) discovered that single crystal quartz has a direct piezoelectric action. Quartz generated electrical charge/voltage from quartz as well as other minerals under pressure. Because the root of the term "piezo" in Greek meant "pressure," the original meaning of piezoelectricity implied "pressure electricity." Materials that exhibit this effect have a geometrical strain that is proportional to the applied electric field. Gabriel Lippmann discovered the opposite piezoelectric effect in 1881.One of the most essential aspects of the Curie brothers' work was that they not only chose specific materials that they believed would demonstrate the piezoelectric phenomena, but they also realised that the piezoelectric phenomenon could be observed in any material. Recognizing the link between the two phenomena aided Pierre Curie in formulating ground-breaking views regarding the fundamental significance of symmetry in physics principles. Meanwhile, the Curie brothers put their discoveries to practical use by inventing the piezoelectric quartz electrometer, which could measure tiny electric currents; 20 years later, this aided Pierre's wife, Marie Curie. (Uchino, December 2017)

Piezoelectricity has been utilized in a variety of applications, including sensors, actuators, and ultrasound imaging. Piezoelectric materials are found in a wide range of natural and synthetic materials, and can be engineered to exhibit piezoelectric properties in the absence of deformation.One of the distinctive feature of this is the The direct piezoelectric effect (the creation of electricity when stress is applied) is reversible, which means that materials that show the direct piezoelectric effect (the electricity generation when force is exerted) can also display the reverse piezoelectric effect (the production of stress when an electric field is induced).

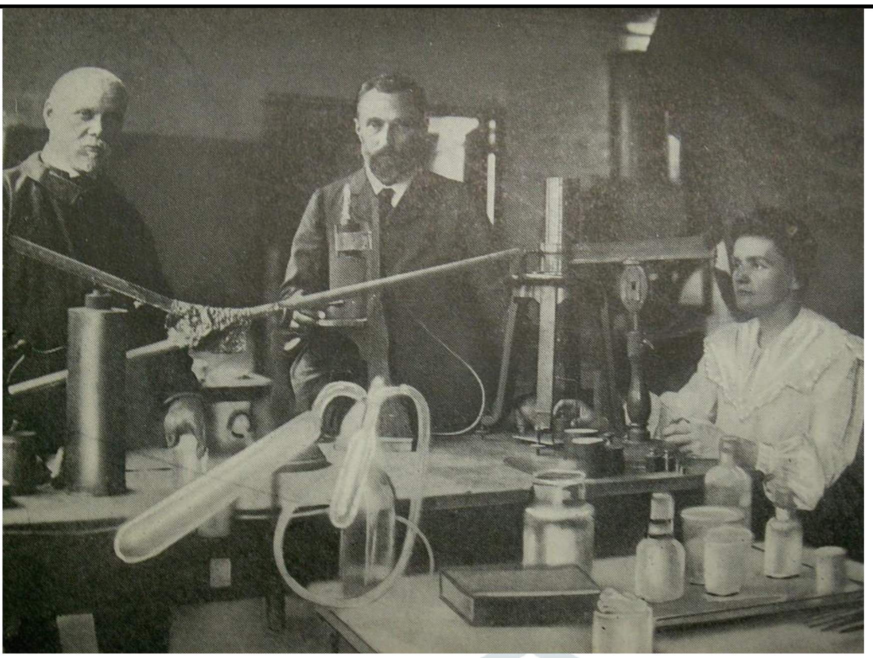


Figure 7:Pierre Curie and Jacques Curie: discoverers of piezo effect

Within the next few decades, piezoelectricity remained a laboratory curiosity, with additional research being done to uncover the piezoelectric effect's enormous potential. The launch of the first practical implementation for piezoelectric devices, the sonar device, coincided with the outbreak of World War I. This early application of piezoelectricity in sonar sparked a global interest in piezoelectric devices. New piezoelectric materials and applications for those materials were studied and developed throughout the next few decades. (https://www.nanomotion.com/nanomotion-technology/piezoelectric-effect/, 2018)

During WWII, scientists in the United States, Russia, and Japan found a new class of man-made materials known as ferroelectrics, which had piezoelectric coefficients several times greater than natural piezoelectric materials. (https://www.nanomotion.com/nanomotion-technology/piezoelectric-effect/, 2018).

Mechanism of Piezoelectricity

Between two metal plates a piezoelectric crystal is placed. At the moment, the material is perfectly balanced and does not conduct electricity. During this process, the metal plates apply mechanical pressure to the material, forcing the electric charges within the crystal out of balance. Positive and negative charges accumulate on opposite sides of the crystal face. The charges are collected by the metal plate, which can then be used to generate voltage and convey electrical current through a circuit. A voltage potential exists across the material. The piezo crystal is sandwiched between two metal surfaces. The charges are collected on the metal plates, which results in voltage (lightning bolt symbol), i.e. piezoelectricity. Because it generates electricity, the piezoelectric effect behaves like a small battery in this way. The direct piezoelectric effect is what we're talking about here. Microphones, pressure sensors, hydrophones, and a variety of other sensing devices all utilise the direct piezoelectric effect. (Yang, Sept. 17, 2016)

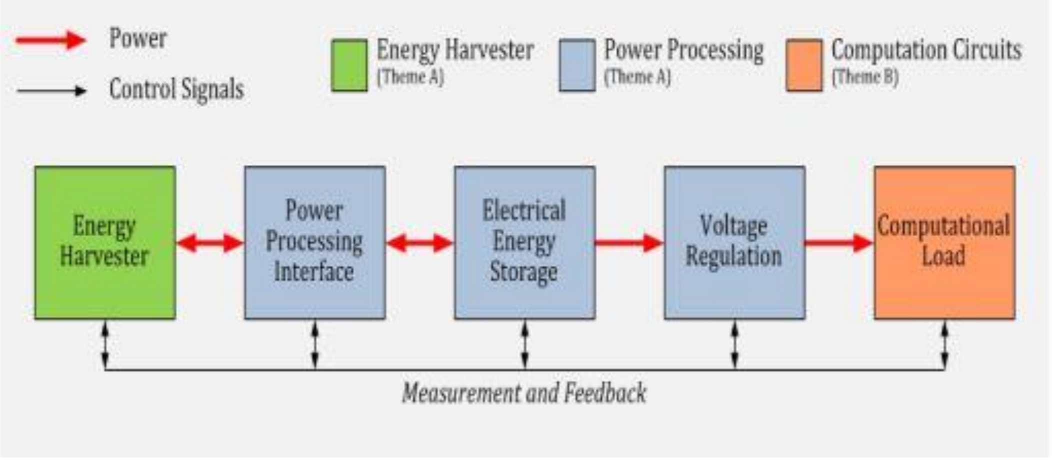


Figure 8:Process of Generation of Electricity using piezoelectric

The inverse piezoelectric effect describes how the piezoelectric effect can be reversed. When a piezoelectric crystal is exposed to electrical voltage, it shrinks or expands. Inverse piezoelectricity can be used to aid in the development of acoustic sound wave generators and producers. Speakers (often found in handheld devices) and buzzers are examples of piezo - electric acoustic devices. (Yang, Sept. 17, 2016)

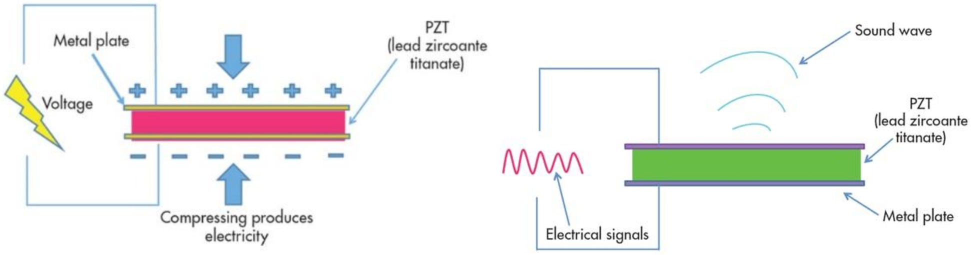


Figure 9:Mechanism of Direct and inverse piezoelectric effect

Piezoelectric Materials

Piezoelectric materials have been used throughout history for a variety of purposes. Today, they are most commonly utilized in devices that require a small amount of electricity, such as watches and radios. Piezoelectric materials can be found in a wide range of products, including cameras, microphones, car dashboards, and even power tools. They are found in everything from shoes and baseball bats to fishing lures and flashlights.

Piezoelectric materials are a class of materials that can generate small amounts of electricity when they're squeezed or otherwise deformed. Since their discovery in the 19th century, piezoelectric materials have been used in a wide variety of applications, including as sensors in machines, as components in batteries and to generate electricity from vibrations and other energy sources. In recent years, engineers have begun to explore the use of piezoelectric materials for energy harvesting, or the process of generating electricity from a variety of sources, including the human body, the environment and kinetic movements. The most common way to harvest energy is through the use of devices such as solar panels and wind turbines, which convert environmental energy into electrical energy.

When piezoelectric materials are subjected to mechanical strain, it causes an asymmetric shift of charges or ions. (https://www.nanomotion.com/nanomotion-technology/piezoelectric-effect/, 2018) When a piezoelectric material is subjected to mechanical stress, the positive and negative charge centers change in the material, resulting in an external electrical field. An outside electrical field compresses or stretches the piezoelectric material when it is reversed. Piezoelectric materials are ferroelectric materials with a molecular structure that allows for a local charge separation, also known as an electric dipole. Because the electric dipoles in artificial piezoelectric materials are randomly orientated, the material lacks the piezoelectric action. When an intense electric field is produced, however, the electric dipoles realign themselves. (Vatansever, Siores, & Shah, 2012). Quartz, barium titanate, and topaz are examples of crystalline materials. Tourmaline, Rochelle salt (sodium potassium tartrate tetrahydrate [(NaKC4H4O6H4O)], and natural organic compounds such as Cane sugar has piezoelectricity, which means it generates electricity when it is squeezed the influence of applied press. The asymmetric shift of charges is how it's explained when piezoelectric materials are subjected to mechanical strain, or ions of piezoelectric materials Quartz, barium titanate, and topaz are examples of crystalline materials. Tourmaline, Rochelle salt (sodium potassium tartrate tetrahydrate [(NaKC4H4O64H2O)], and natural organics.

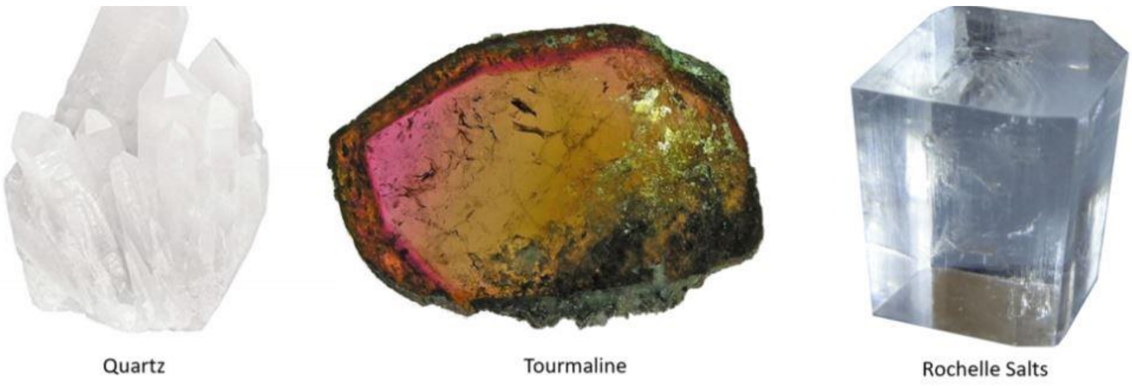


Figure 10:Naturally occuring piezoelectric materials

With rising global warming levels there has been a sudden realization of the depleting energy resources, mostly the renewable ones. Even though the world is rapidly advancing in technology, there are still many things we cannot do with our current energy infrastructure. We are currently relying on fossil fuels, which are limited, and result in many negative consequences for the environment. Renewable energy such as solar and wind is great, but it is not constant, causing our energy needs to fluctuate.

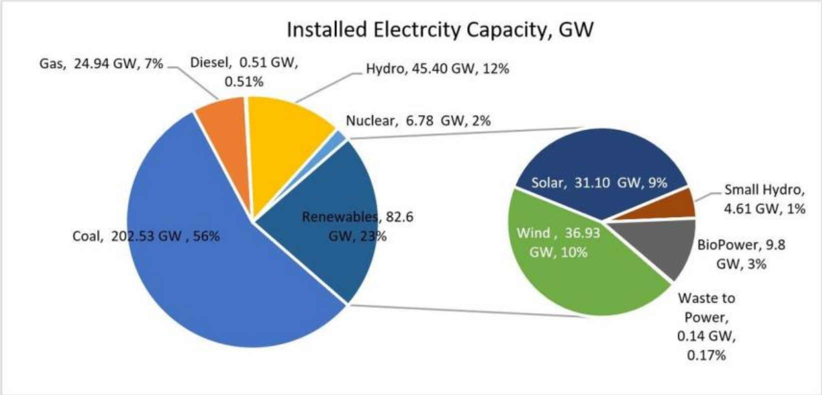


Figure 11:Installed energy capacity

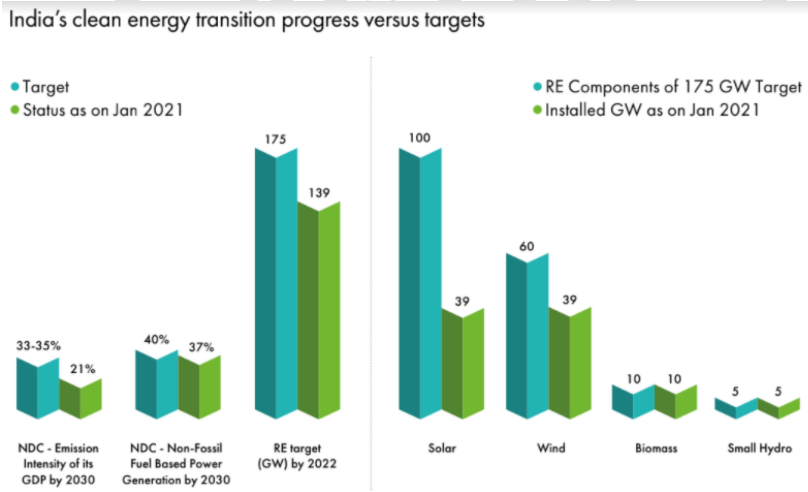


Figure 12: india's clean energy progress vs target

This is where energy harvesting comes in. Electricity and other forms of energy are vital to modern life, but the amount of resources required to generate and transport energy are finite. This has led to the development of energy harvesting, which is the collection of energy from non-renewable and renewable sources, such as ambient heat, kinetic energy, and human motion, into a usable form. By harnessing the energy around us, we can reduce the amount of energy we need to extract from the environment, while also helping to preserve it.

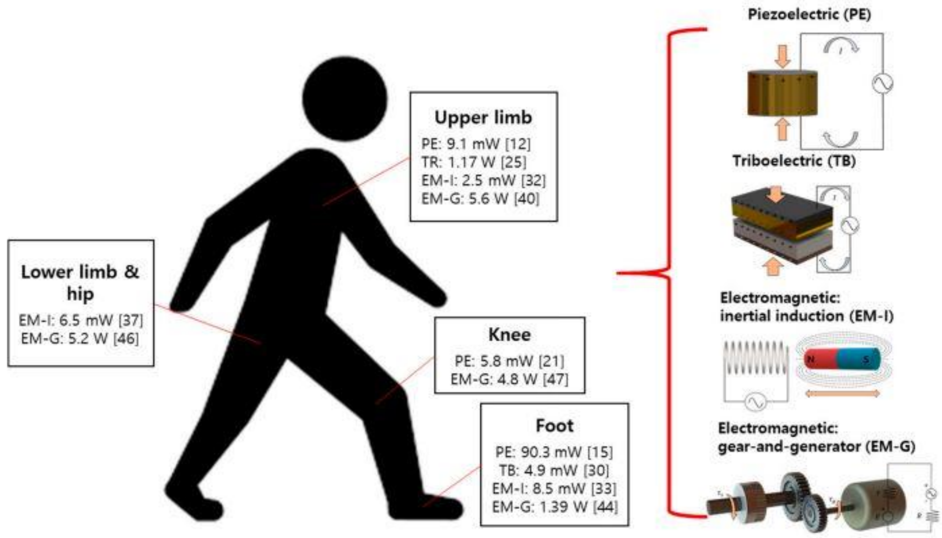


Figure 13: Vibrational energy generation techniques through human motional energy

Energy Harvesting has been the subject of numerous studies involving piezoelectric materials. With recent advancements in low-power electronic devices, such as microelectronics and wireless sensing, the global relevance of "piezoelectric" energy harvesting has grown in prominence over the last decade. In general, piezoelectric energy harvesting relies on three main mechanisms: piezoelectric devices, electronic power interfaces, and electrical energy storage. Increased harvesting power is the main concern with vibration-based PEHS. This is usually accomplished by creating novel materials with better electrical conversion potential and new topologies that can capture energy more effectively. (Sarker, Sabariah , Faizul, & Sabri,, 22 September 2019)

III. Applications of Energy Harvesting via Piezoelectric Materials in Architecture as a Sustainable Alternative

The application of energy harvesting piezoelectric materials in architecture is becoming more common, particularly in the design of buildings that are more energy efficient and sustainable. Since with the rising concern of global warming because of pollution and population and huge environmental degradation day by day, there has been a great development in the green building sector. Architects and sustainable planners have become more aware and concerned about how through their buildings they can make the carbon impact lesser into the environment. Thus, the knowledge of piezoelectric effect has proven a boon in the construction industry also since the past few years of its introduction in the field.

Zhang et al developed a mechanism for harvesting the mechanical energy of the foot by combining a stiff spring and an energy generator. The harvester was placed near the heel of a shoe, such that when the person's foot stepped on it, it compressed a pedal and bent a piezoelectric beam, generating electrical energy. The stiffness spring had already accumulated elastic potential energy when the foot lifted off the ground, which was transferred to kinetic energy, bending the piezoelectric beam once more. Per step, a 60-kg person might get 235.2 mJ. (Covaci & Gontean, 21 June 2020).This was one of the experiments which did not prove out to be that popular as it required mass involvement and also awareness about these shoes .

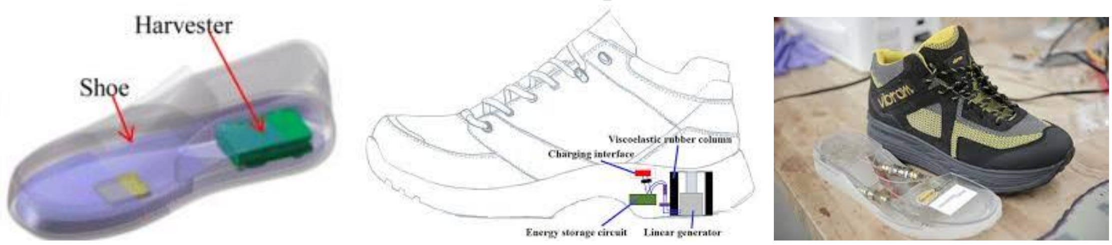


Figure 14:mechanism for harvesting the mechanical energy of the foot by combining a stiff spring and an energy generator.

Table 1: Table showing power generation through different body movements

Joint/Motion	Work (J/step)	Power (W)	Max Moment (Nm)	Negative Work (%)
Foot strike	1–5	2–20	-	50
Ankle	33.4	66.8	140	28.3
Knee	18.2	36.4	40	92
Hip	18.96	38	40–80	19
Elbow	1.07	2.1	1.2	37
Center of gravity (*COG*) *	10	20	-	-

* With 20 kg payload [9].

After giving more thought to the process technicians and experts came up with the idea of piezoelectric tiles. A study comparing vibrational energy harvesting in sidewalks vs. stairways was presented. Because of the inherent increased pedestrian activity involved in travelling the stairs, the authors found that piezoelectric tiling placed in a stairwell function better than those placed in walkways. In order to improve the amount of harvested electricity, they also suggested that the flooring design take into account the naturally unpredictable aspects of foot activity.

After much modifications this concept of piezoelectric tiles was worldwide accepted and tried to be in par with the emerging energy demands

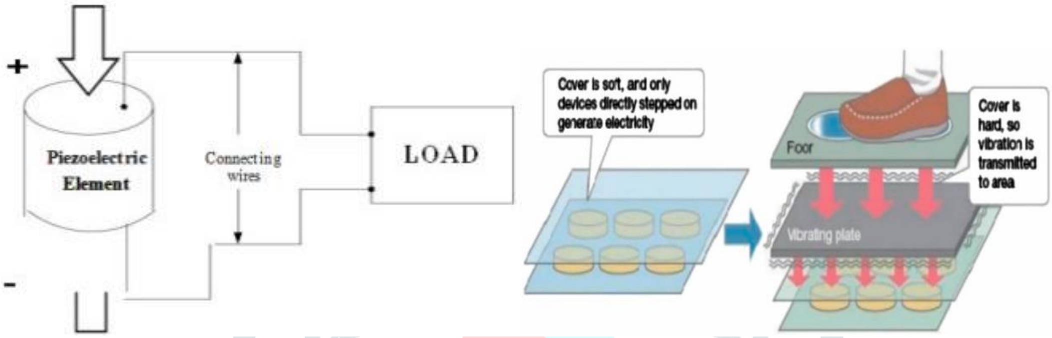


Figure 15: Mechanism on which piezoelectricity works

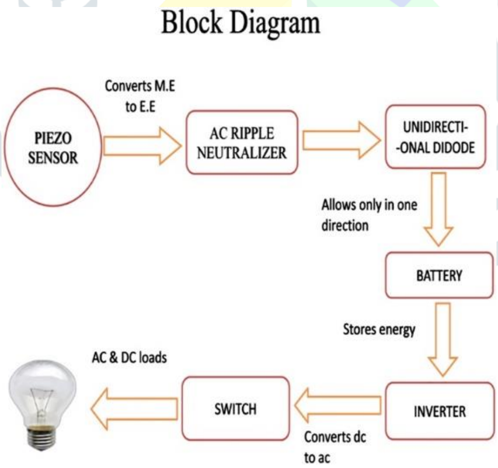


Figure 16: Diagram showing the working of piezoelectric effect

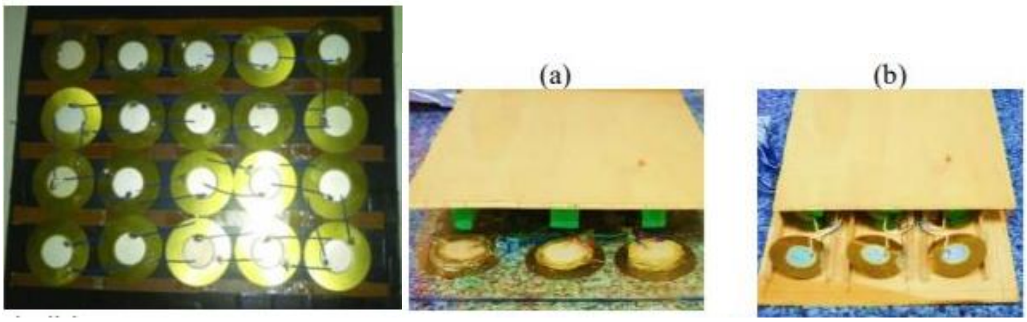


Figure 17:Piezoelectric disks arrangements on power generation tile and

Piezoelectric tiles (a) Tile 1 (b) Tile 2

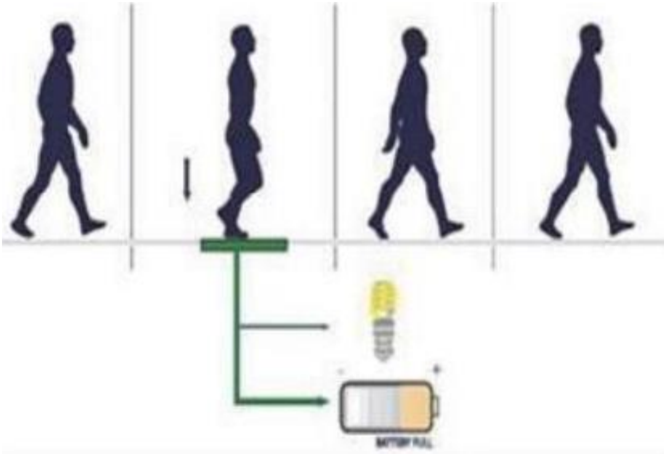


Figure 18: Illustration showing how energy is generated through piezo tiles

The following are the steps for transforming pressure into electric power:

Step 1: Use a piezoelectric ceramic tile to convert pressure to electricity.

Step 2: Foot pressure is used to apply pressure to ceramic tiles that contain piezoelectric elements.

Step 3: Circuit for an AC-DC tension rectifier

Step 4: Buck-Boost or DC-DC voltage enhancer with a schematic Joule Thief circuit. (Shanmugam, Selvaraj, Kasirajan, Sivakumar, & Kandasamy, september 2020)

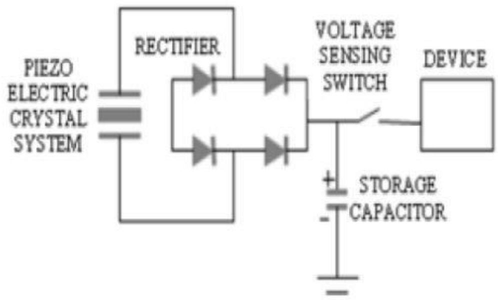


Figure 19: Basic piezo electric circuit diagram

The pressure exerted by the foot hitting the ceramic tile is one of the vibrating sources utilized as a modulator for producing electricity utilizing piezoelectric materials implanted in tile. The piezoelectric material generates ac voltage. To convert voltage from AC to DC, an AC-DC voltage converter circuit is employed. To increase DC voltage, the voltage regulator circuits and the Joule Thief Method are utilized. (Shanmugam, Selvaraj, Kasirajan, Sivakumar, & Kandasamy, september 2020)

IV. CASE DEVELOPMENT

While "Green Railways" is still an emerging initiative in India by the Indian government where a few Indian railways stations haveen powered totally by the solar energy, other energy harvesting concepts like piezoelectricity may very early pave their way to the Indian sector. As we all know despite of being the most popular and most used renewable energy resource , Solar energy still has its own limitations ; be it the climatic limitations or spatial limitations. But, due to the less popularity and being an extremely new concept piezoelectric energy can be used in combination with solar energy as a hybrid energy generation source to enhance the energy generation capacity and also using the available resources to the maximum.

In this research, the learnings from the literature and case studies have led us to propose a hybrid arrangement of energy harvesting through both solar and piezoelectric devices to help producing better and larger amount of energy. To generate electricity, a combination of piezoelectric devices and solar panels on a platform were used. The case of Delhi railway station was considered. A railway station being a place of highest footfall in terms of people per hour could be the best way to check the feasibility of these tiles. A system prototype that generates electricity from a solar panel and when people step on tiles set on the pavement have been proposed in this paper parallelly . Making use of both energy sources will allow us to get the benefits of both.

Case Development Study of New Delhi Railway Station

PROJECT NAME: Research on energy generation by piezoelectric materials at new delhi railway station
RESEARCHER: Research Scholar, Department of Electrical Engineering, AIET, Faridkot
YEAR: 2006
LOCATION: NEW DELHI, INDIA
TYPE OF PROJECT: RESEARCH PROJECT
Nowadays, energy and power are two of the most essential requirements in the modern world. Because the need for energy is growing by the day, the most effective way to address these issues is to use renewable energy sources. In our research, we applied the technique of energy production through footsteps as a renewable energy source that we can receive by stepping on certain arrangements such as walkways, stairs, and plate shapes, and similar systems may be used elsewhere, particularly in densely inhabited places. The piezoelectric sensor serves as the foundation for our project's 'footstep energy generation system. So, to put this foot step power generation system into action, researchers have designed a piezo electric tile footpath at the New Delhi railway station. It is capable of generating electrical energy by mechanical reaction (force). This type of technology can be employed as an alternate source of electric power. An analysis of the economic, environmental, and social implications of installing energy-harvesting Pavegen piezoelectric floor tiles in a railway station has been conducted. The kinetic energy of a footstep is used to strain a piezoelectric material in the Pavegen floor tiles. This strain generates a voltage, which can be used to generate green energy when integrated into a circuit. (Singh, Sandhu, & Singh, December 2016)

Piezo Power Plant Cost Analysis at Delhi Railway Station

This study looks into the financial, environmental, and social implications of building a 1Km walkway at the New Delhi Railway Station utilising energy-harvesting Pavegen piezoelectric floor tiles. The kinetic energy of a footstep is used to strain a piezoelectric material in the Pavegen floor tiles. This strain generates a voltage, which can be used to generate green electricity when integrated into a circuit. This power can be stored in batteries and utilised to power a variety of devices. (Singh, Sandhu, & Singh, December 2016)

Table 2:Specifications of Piezoelectric Tile

Parameter	**Value**
Tile Size	1.6m * 0.45m
Tile Lifespan	5 years
Tile Cost	$7.6
Energy Generation	7W at 12V DC (average human foot step)
Recyclable	100%

Distance covered by Pedestrians

The main railway station in Delhi is the New Delhi Railway Station (station code NDLS), which is located between Ajmeri Gate and Paharganj. In terms of both train and passenger traffic, it is the busiest railway station in the country. It has 16 platforms and accommodates approximately 400 trains and 500,000 people every day. The New Delhi railway station, along with the Kanpur Central Railway Station, has the world's largest route interlocking system, with a total of 48. In central Delhi, the station is around two kilometres north of Connaught Place. (WIKIPEDIA, n.d.)

Table 3:Distance covered by Pedestrians

Parameter	**Value**
Daily Pedestrian	5 Lakh (per day)
Walk of 1 Pedestrian (from Parking to Platform)	1KM
Distance covered by 5Lakh Pedestrians	5 Lakh Kilometers

Total footsteps

About 2.2 to 2.5 feet is the average step length for adults.

Table 4:Calculation of Total Foot Steps

1foot step	2.5 feet
1Km	3289.84 feet
5 Lakh Km	1640420000 feet = 656,168,000 foot steps / day

Table 5:Annual Energy Generated

Parameter	Value
1 foot step is kept for	.6 seconds
1 foot step production	7 W (for .6 seconds)
Energy	4.2 Joules per foot step
1foot step	4.2 Joules
656,168,000 footsteps / day	2.76 Giga Joules / day
Annual Energy Generation	2.76 * 365 = 1005.90 GJ

No. of Piezo floor tiles required

Estimated piezo module numbers for the power plant are derived from the total area coverage and the area covered by each floor tile.

Number of Piezo modules required = (Total Area Coverage) / (Area covered by Single Tile)

Table 6:Number of piezo floor tiles required

Area Coverage	1Km * 5 Meters = 5000 m^2
Tile Size	1.6m * 0.45m
Area Covered By 1 Tile	.72 m2
Number Of Tiles Required	6950 Tiles

Piezo Floor tile costs

The price of piezo floor tiles may vary depending on transportation costs, how many tiles are required, government subsidies, labor costs, and connection costs. (Singh, Sandhu, & Singh, December 2016)

Table 7:Installation Costs of Piezo Model

Cost Of 1 Tile	$7.6
Cost Of 6950 Tiles	$ 52,820 = Rs. 34,86,120

Operation and Maintenance

The cost of operation and maintenance can be calculated as a fixed amount per year or as a percentage of the turbine's purchase price. This might also include a 1-percent-of-capital-costs servicing contract with the piezo tile producer. (Singh, Sandhu, & Singh, December 2016)

Table 8:Analysis of Piezo Plant Cost

Capital Costs (Rs)	34,86,120
Operation & Maintenance Expenses (Rs.Lacs per annum)	1% of capital cost in 1st year with an escalation of 5.72% for each year thereafter
Plant Life (years)	5
Depreciation (%)	7% per annum
Interest on Debt (%) per annum	12.75
Annual Production (units)	2,79,419

Equivalent annual cost

The annual cost of owning an object for the duration of its useful life. Firms often use equivalent yearly cost to make capital budgeting decisions. The annual equivalent cost is determined as follows:

ASSET PRICE X DISCOUNT RATE/1-(1+DISCOUNT RATE)
where
Asset Price = Capital Cost of the Component
Discount Rate = The Rate at which bank provides the loan
Number of Periods = Lifetime of Component.
Annualized Cost of the Component = Equivalent Annual Cost + Maintenance Cost

Table 9: Annualized capital cost

Plant Type	**Annualized Cost (Capital Cost + Maintenance Cost In Rs.)**
Annualized Capital Cost	9,87,734
Maintenance Cost	34,861

Electricity cost computation

COE(Cost of electricity) = ACS / AEO
=10,22, 595 / 2,79,419
= 3.66 Rs/ unit
Where:
AEO = Annual Energy Output (Sum of energy produced by system over a day * 365 days)
ACS = Total Annualized Cost
COE = Cost of Electricity (Rs./KWh)

Table 10:Computation of cost of per unit

	PIEZO MODEL	EXISTING MODEL(GRID)
COST PER UNIT (in Rs.)	3.66	8.40
Units Consumed	279419	279419
Bill	1022673.54	2347119.60

The investigation revealed that installing Piezoelectric tiles would result in significant cost savings and would promote environmental awareness by promoting sustainability and green energy generation, with the amount of electricity harvested over the tiles' 5-year lifespan covering the costs of initial purchase, transportation, installation, maintenance, and disposal.

Conclusion

Mechanical strain energy can be converted into electrical charge in piezoelectric materials. Today, piezoelectric materials are not a viable option for large-scale energy generation. The cost of installing the tiles greatly outweighs any potential profit from electricity generating. One potential application is to link one of these tiles directly to a low-power device. The amount of energy created is proportional to the number of pedestrians going by and the number of piezoelectric devices on the route. It seems to have a lot of potential for future energy/power solutions that are more sustainable.

The concept has been successfully tested and has proven to be the most cost-effective and accessible energy alternative for the general public. This can be utilised for a variety of applications in urban settings that require greater electricity. India is a developing country with a large population, making energy management a major concern. We may drive loads according to the force through this project.

It is obvious that the piezoelectric approach will provide our energy needs at a much lower cost than current costs. Because we have exploited renewable energy sources, prices will remain constant (stable) for a long time. Furthermore, the government is taking steps to provide incentives for renewable energy generation plants, which will down capital and production costs even more. The suggested framework is environmentally beneficial because it produces no hazardous emissions or carbon footprints. The tiles can be recycled, which lowers the cost of production even further.

V. CONCLUSION & RECOMMENDATIONS

To address the challenges connected with the usage of non-renewable energy sources, the quest for clean sources of energy is becoming increasingly important. There have been several developments in the field of energy-efficient construction materials. The use of piezoelectric applications in energy conversion from mechanical to electric energy is a promising subject of research. However, due to variables such as economic efficiency and service life, its use is currently limited in order to offset its high capital cost. (Anton & Sodano)

This is focused on transforming mechanical power to clean power production, which is especially critical to public projects with high population density and occupation patterns. As a consequence of the extensive assessment of literature for the application of piezoelectric flooring tiles, referencing research papers and worldwide case study projects, two main varieties were shortlisted all throughout review phase: waynergy and SEF.

The literature review was stripped of parameter integration for the right selection of piezoelectric tiles. Its successful implementation in the construction business was determined by this. These were broken down into elements such as project kind and location, as well as correct piezoelectric tile product selection. In the case study, this idea was put to the test. As a result, the use of piezoelectricity was examined in a Railway Station in a major Indian city, with an estimated daily passenger count of about. The railway line and station, as well as the tile installation location, were chosen based on the highest passenger density class that gave the most step-footage. Furthermore, the number and type of piezoelectric tiles were chosen based on the energy consumption of the current project. In terms of electricity generation capacity, initial capital cost, lifespan, and estimated savings, the study compared the two nominated types of tiles. Energy consumption and carbon emissions were also reduced as a result of the study.

. Because this research is still under progress, additional future research on the usage of piezoelectricity in various building applications will bolster the conclusions of this study.

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