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A Review of Energy Scavenging Methods & their Application in Built Space

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***Abstract*—** **Global energy demand has been gradually increasing. As per IEA's (International Energy agency) Global Energy & CO2 Status Report 2017, the energy demand has increased from 0.9% in 2016 to 2.1 % in 2017. The demand is expected to increase by 80% from 2012-2040. Energy shortage and environmental concerns due to the exploitation of non-renewable sources of energy has led the world to look up to alternate technologies to harvest energy. Currently, renewable sources of energy like wind, solar and hydropower sectors contribute to 24% of global electricity demand and is expected to rise to 31% by 2040. Prevalence of building automation, the need for wireless sensors which are autonomous has increased. Energy Scavenging is one such system which reduces the load on the primary energy system by reclaiming energy from the unused portion of energy which otherwise is lost in form of heat and sound, also eliminates the wiring network and maintenance required in case of monitoring sensors. In this paper, current energy scavenging technologies are reviewed. The core objective of this paper is to focus on aspects concerning technology, planning and applicability of various scavenging methods, using set parameters like technology readiness, ease of installation, energy conversion efficiency and power output, in typical built forms and conclude with certain considerations to be made while application.**

Keywords- Energy, Harvesting, Scavenging, Renewable, Technology.

I. INTRODUCTION

Energy is sturdily associated to almost every conceivable facet of growth or development. Based on World Bank Development Indicators fortune, well-being, nourishment, water, education, physical infrastructure, and life expectancy, are sturdily and considerably related to the consumption of energy per capita [12]. Thus the global energy demand has been gradually increasing in both developed and developing countries resulting in the need for new and efficient ways of energy harvesting. Climate change and related issues have led us to look towards new sources of energy. One step taken to meet the energy demand without compromising the environment is adopting renewable energy sources. Significant amount of developments have been observed in various renewables over the past decade specifically in wind, solar and hydropower. However, increasing energy demand requires other interventions to support primary energy supply systems.

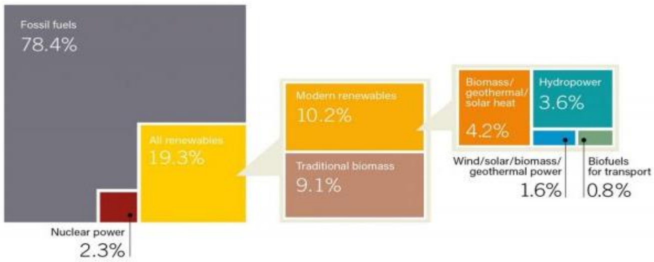

Figure 1. Renewable Energy Share, 2015 (Renewables 2017, Global Status Report)

Energy harvesting and scavenging are often interchangeably used. Nevertheless, there is a slight distinction between them. Harvesting is where energy is produced from primary resources creating specific conditions and is typically large in scale. For instance, thermal power production where coal is burnt to generate heat. This heat is used to boil water for making steam. The steam is used to run the turbines which are connected to the generators to produce electricity. Scavenging is gathering of energy from the ambient conditions in the environment which unless goes unused and is typically smaller in scale [15][17]. For instance, solar power production where light energy from the sun is used to generate electricity using photovoltaic panels.

The building & construction sector is the largest energy-consuming sector, accrediting for over 36% of final global energy consumption and 55% of global electricity demand (International Energy Agency, 2013). Of this 90% is used for the operation of the building. The buildings sector, which comprises of the residential and service sub-sectors, uses a wide array of technologies. These technologies are majorly used in the building envelope and its insulation, in HVAC (Heating ventilation and air conditioning) systems, in lighting, in numerous appliances and consumer products, and in business equipment. The durability of buildings and associated equipment presents both challenges and opportunities for this sector to apply wide range of technologies to meet the energy demand.

In the following sections of the paper, various energy scavenging methods will be reviewed and their applicability in buildings will be studied based on set parameters.

II. REVIEW OF ENERGY SCAVENGING SOURCES AND METHODS

Sources of energy are all around us. Potential energy sources which can be scavenged can be classified into the following:

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Table I. Energy Scavenging Sources [17]

S. No.	Sources	Example
1.	Natural Energy	Wind, Hydro power, tidal potential and solar energy
2.	Mechanical Energy	Mechanical vibrations, mechanical stress, strain from high-pressure motors, waste rotations of mchines
3.	Thermal Energy	Heat energy emitted from furnaces, heating sources and frictional losses
4.	Light energy	Various light emitting sources (indoors and outdoors)
5.	Electromagnetic Energy	Inductors, coils, transformers
6.	Human Energy	Physical movement and Metabolic heat
7.	Acoustic Energy	Vibrations from extremely high noise levels

Energy scavenging methods and their output potential vary based on their sources.

A. *Natural Energy Scavenging*

Wind energy scavenging where wind movement is used to rotate the blades of a windmill which in turn is connected to turbine/generator that generates electrical energy. Initially, windmill's kinetic motion was used for grinding and pumping water.

Hydropower/water's mechanical energy drives the wheel of the turbine which in turn drives an alternator. The latter transforms mechanical energy into electrical energy.

Solar energy scavenging, where solar radiation is used to generate heat and electrical energy using photovoltaic panels. The photovoltaic panels are made of a semiconductor material that hosts the electrons which are excited by solar rays (photons) to produce electricity.

B. *Mechanical Energy Scavenging*

Piezoelectric energy scavenging is where the material property of certain materials let them generate electrical energy when subjected to pressure or strain [10]. Greater strain corresponds to a greater potential difference resulting in higher energy outputs. The voltage generated varies with respect to time and applied strain, effectively producing an irregular AC signal on the average. Piezoelectric tiles are commercially available in some countries and have been implemented in many public buildings which attract higher footfall. Sustainable dance club, on such manufacturer, with the use of sustainable energy floor tiles (piezoelectric tiles), have registered cases where over 30% of the energy requirement of the dance club has been met. These tiles have a conversion efficiency of up to 50% i.e. they can convert 50% of the potential energy capable of scavenging when subjected to certain force. Relatively higher voltage and power density levels than that of the electromagnetic system.

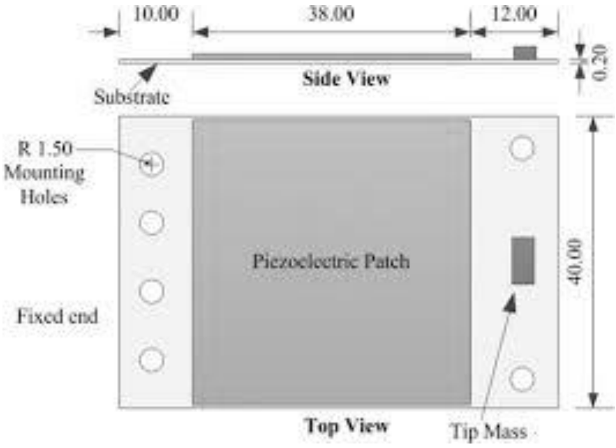

Figure 2. A Typical Piezoelectric tile [7].

Electromechanical energy scavenging can be further classified into two:

Electromagnetic, where a magnetic field is used to convert mechanical energy into electrical energy. This is based on simple principle of Faraday's Law. The voltage that is induced is minor and must be amplified to be used as a workable source of energy using a transformer, increasing the magnetic field or increasing the number of turns in the coil that is attached to the oscillating mass [17].

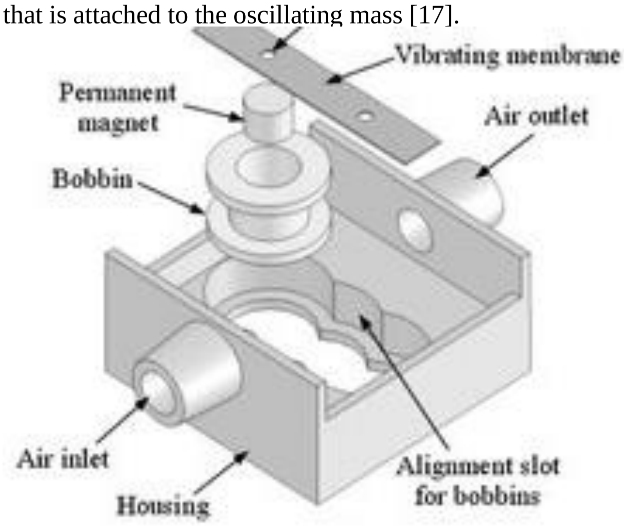

Figure 3. Exploded view of the Windbelt-based energy scavenger [11].

Electrostatic, where initially charged variable capacitors will detach its plates by vibrations thereby transforming mechanical energy into electrical energy. This generated energy can be then used to charge a battery, generating the required voltage source. Higher and more practical output voltage levels are generated than that of the electromagnetic method, with moderate power density [17].

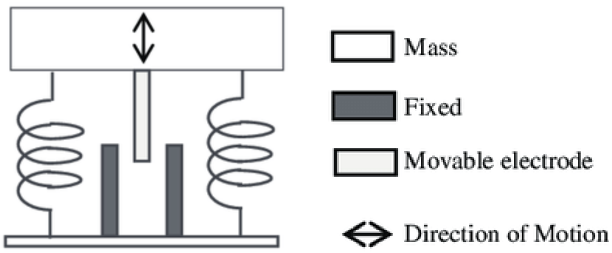

Figure 4. Electrostatic energy-harvesting process: in-plane overlap [2]

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C. Thermal Energy Scavenging

The thermoelectric method which uses thermoelectric effect/ Seebeck effect using thermopiles to generate electricity, in which temperature difference between two dissimilar electrical conductors or semiconductors in this case thermopiles induces a voltage difference between the two substances. The temperature variations due to natural origins can provide a means, other than temperature differences occurring in mechanical systems, by which energy can be scavenged from the environment with high-temperature differences. A thermoelectric microdevice, which is adept of altering 15 _W/cm^3 from 10°C temperature gradients have been demonstrated by Stordeur and Stark. The thermoelectric generator (TEG) designed and introduced by Pacific Northwest National Laboratory in 2007 can scavenge energy from minute temperature differential of 2°C to produce few microwatts to hundreds of milliwatts. TEG developed by Applied Digital Solutions Corporation is adept of producing 40mw of power from 5°C temperature differential using a device that is 0.5 cm^2 in area and a few millimeters thick. This device has an output voltage of about 1V [17]. These can cater to a wide range of applications like security surveillance, automotive performance monitoring, and many other low-power applications.

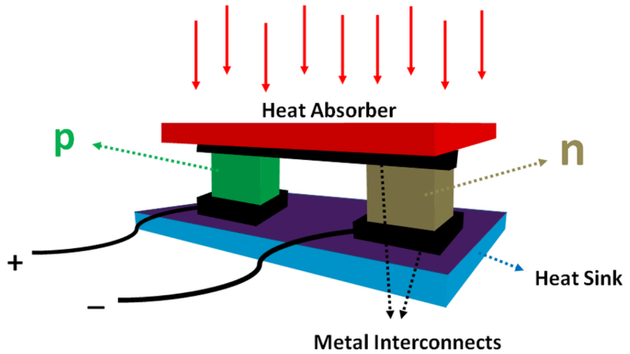

Figure 5. Thermoelectric generator structure [13].

Pyroelectric energy scavenging where the material property of certain materials let them generate an electric potential when heated/cooled (temperature change). When pyroelectric materials undergo temperature change, the positive and negative charges move to opposite ends through migration and thus, an electrical potential is established. Pyroelectric energy harvesting applications require inputs with respect to time inconsistencies which results in lower power outputs in energy-scavenging applications. The major advantage that pyroelectric energy scavenging has over thermoelectric energy scavenging is the material stability is over 1200 °C. This factor allows this energy scavenging method's applicability even from high-temperature sources with increasing thermodynamic efficiency [17].

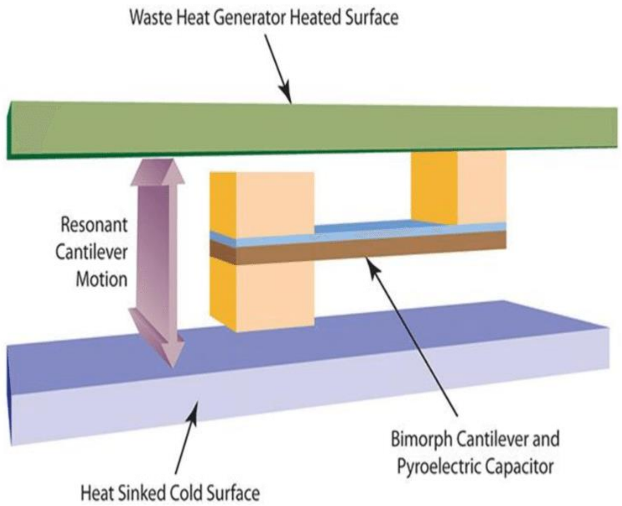

Figure 6. MEMS pyroelectric generator [1].

D. Light Energy Scavenging

The photovoltaic effect is used to generate electrical energy. Several research efforts have been conducted so far have demonstrated that photovoltaic cells can generate adequate power to uphold a microsystem. This method offers relatively higher power output levels when compared with the other energy-scavenging methods. Nevertheless, its power output is sturdily reliant on varying light intensity and thermal conditions.

E. Human Energy Scavenging

Active methods which need an extra effort like winding up generators, squeezing, pushing, pumping etc. For instance energy harvesting generator driven mechanically by push of the button. The energy harvester system has an integrated mechanism for movement conversion where linear movement of the button is converted into rotation with a rotational speed of 1000 rpm. An electromagnetically part of harvester consists of in FR-4 embedded multilayer planar coils and of multipole NdFeB hard magnets. The miniaturized energy harvester generates a maximum open circuit output voltage of about 500 mV with duration of about 2 s and a maximum short circuit output current higher than 40 mA.

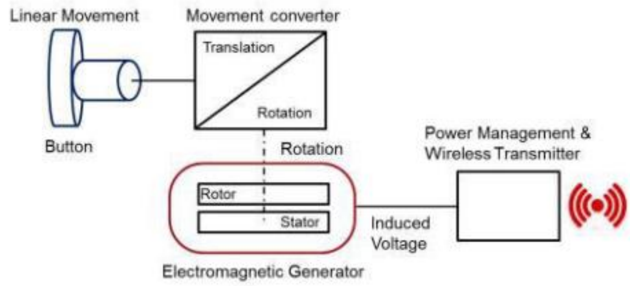

Figure 7. Schematic of Energy scavenging by linear movement - pushing [4].

Passive methods which do not need an extra effort like powering wearable electronics, piezoelectric store etc. For instance, by installing piezoelectric crystals in shoes at the rear end near heel. With each step piezoelectric crystal would undergo compression which in turn will generate enough energy to power cell phones, mp3 players etc. Though more experimentations on such wearable's are going on, and main hurdle is electricity output generated is very less; thus attempts are made to increase power output of such shoes so

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that one's daily movements will be able to generate electricity enough to charge up small electronic gadgets.

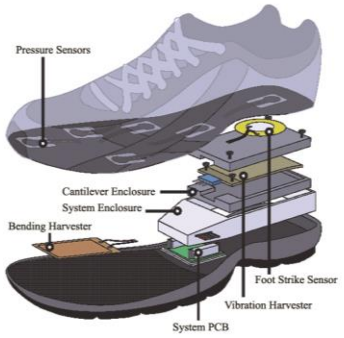

Figure 8. Exploded view of shoe with attached piezoelectric crystal [14].

F. *Acoustic Energy Scavenging*

Noise is a regenerative energy resource that can be harvested to generate electricity. Using noise barriers to simultaneously reduce noise and generate electricity is an ideal solution. Acoustic energy harvesting system scheme mainly consists of four components: a noise collection input module, a sound pressure amplification module, an electricity generator module and a power storage module. The sound pressure is amplified in a Helmholtz resonator, and a Polyvinylidene Fluoride (PVDF) film in the electricity generator module can convert acoustic energy into electric energy. The power storage module stores the electric energy in super-capacitors that power small electronic devices, such as the monitors along the railway. Based on the experiments, one unit of the system can produce an instantaneous maximum output voltage of 74.6 mV at 110 dB (SPL), Piezoceramics are also used to convert vibrations resulted from extremely high noise levels into energy.

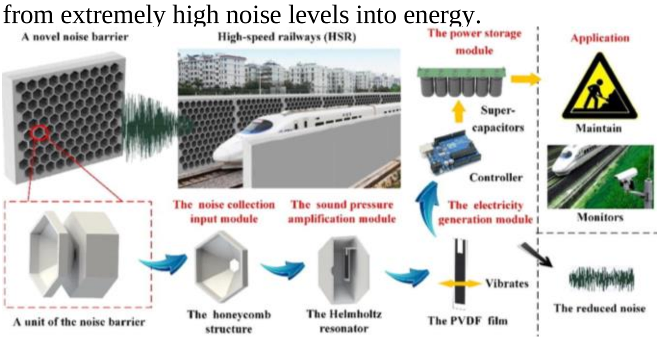

Figure 9. Acoustic Energy Scavenging System [16].

III. APPLICATION IN BUILT SPACE

The application of energy scavenging methods in a built form depends on many factors both with respect to the building and the technology itself. Considering the built form to be constant and supportive of all means of energy scavenging the scavenging method is analyzed.

The application of energy scavenging methods in the built spaces can be as follows:

- Windmills are more suited to high rise buildings due to the available potential.
- Scavenging through PV panels are universally applicable for all the built forms provided the sky commonly is clear. The placement of the panels should be such that no shadow is cast on them as it would reduce their efficiency.
- Piezoelectric flooring can be adapted in commercial buildings or spaces that experience heavy footfall to scavenge the energy caused by movement and utilize it to power lighting devices and information screens.
- Electromechanical (Electromagnetic and electrostatic methods) and Thermal (Thermoelectric and Pyroelectric methods) can be adapted to power wireless sensors in buildings that depend on automation using sensors. This reduces the requirement of wiring and maintenance.
- Human energy scavenging methods (Active and Passive) can be adopted where there is an intense physical activity for instance in fitness or dance clubs, transit stations etc.

Based on set parameters like technology readiness which deals with commercial availability of the technology, ease of installation which deals with complexity and skill attached to the installation of certain technology, energy conversion efficiency and power output each method is assigned a score from 1 to 10 for comparison. The scores assigned to each method are considering the best practices adaption for each method.

For instance, the energy conversion efficiency of windmills, as proved by Fredrick W. Lanchester, is about 59.3% [3] i.e. a windmill is able to convert 59.3% of kinetic energy due to motion of wind into electrical energy thus a score of 5.93. Similarly, hydropower turbines have an efficiency of around 80% thus a score of 8 is awarded.

Table II. Comparative Scores of Energy Scavenging Methods

Method	**Parameters**			
	Technology readiness	***Ease of installation***	***Energy conversion efficiency***	***Power Output***
Windmills	10	9	5.93	9
Hydropower turbines	10	7	8.75	9
PV Panels	10	10	3.3	9
Piezoelectric	6	6	5	4
Electromagnetic	4	7	3	1
Electrostatic	4	7	4	2
Thermopiles	3	6	4	2
Pyroelectric	3	6	4	1

IV. CONCLUSION

This paper shall act as a tool for reference to integrate renewable energy strategies in designing sustainable built spaces. Further study should be carried out with respect to the cost involved in application and feasibility as it shall vary from place to place and from one built space to another.

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