THE IMPORTANCE OF ENERGY RECOVERY TECHNOLOGIES FOR THE IMPLEMENTATION OF SMART SOCIETY AND SMART CITY CONCEPTS

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Abstract: *An intelligently developed society is defined by a concept that integrates information technology in all its fields in which man is the direct beneficiary of this environmentally friendly process. Man is both the main actor and the direct beneficiary of the products and services of the intelligent society. This detail must be the determining factor for the development of any society from a classical to a smart one and here comes the concept of Human Informational Field (HIF) accompanies the human being in his interactions. But smart society is about connecting between people, systems, about sharing information and so we get to the Internet of things, or IoT a system of interrelated computing devices, mechanical and digital machines, objects, animals or people. The internet of things helps people live and work smarter, as well as gain complete control over their lives. Because IoT is a sensor network of billions of smart devices the problem of energy supply appears. Energy recovery or harvesting systems is a possible solution that could enable IoT nodes to scavenge self-sustaining energy from environmental sources. In this article we will review these systems and emphasize their importance in the development of smart society or smart city.*

1. INTRODUCTION

The concept of Smart City has more and more global followers becoming a "must have" of the big cities.It is a growing concept, and research is focused on creating an urban infrastructure that allows the implementation of SMART technologies and, on programs that can change invalid refractory mentalities to technological evolution. Because energy has an extremely important role for the creation of the SMART City infrastructure Energy deserves special attention.A smart city will optimize energy resources and technological innovations in the field are no longer a purpose but a means of maximizing services for its citizens. Here comes the Internet of Things (IoT).

The energy supply of the Internet of Things (IoT) networks to ensure uninterruptible optimization of smart cities is a big problem that among other challenges has continued to focus efforts towards energy harvesting.During the pandemic pandemic, the imposed jams that almost paralyzed everyday activities in many corners of the world, the option of remote human interaction became imperative to impose distance. So the world has become aware of the importance of IoT devices, being intelligent components of the intelligent city. Energy harvesting is a sustainable solution that could allow iot nodes to capture self-sustained energy from ambient sources. In this article, we will analyze a part of the sources available in the city where the energy could be harvested, according to the literature. These energy sources can be specific to the application, so, if there are many free sources in the city, energy should be collected in close proximity to the need for different IoT devices or wireless sensor networks (WSNs) for city automation intelligent.In the intelligent city, there is web technology through which objects are connected to the Internet and become "intelligent" by allowing them to interact with them or the human factor [5].The Internet of Things (IoT) is simply a network interconnected by objects or people who relate to them through the cloud. IoT transmits data to physical devices that are connected to the Internet via sensors. thus allowing the interactions mentioned above, however, the intelligent city data is made available by IoT for autonomous planning and decision-making on the needs of such a city, with the clear purpose of improving the living standards of the inhabitants. This is illustrated in *figure 1*.

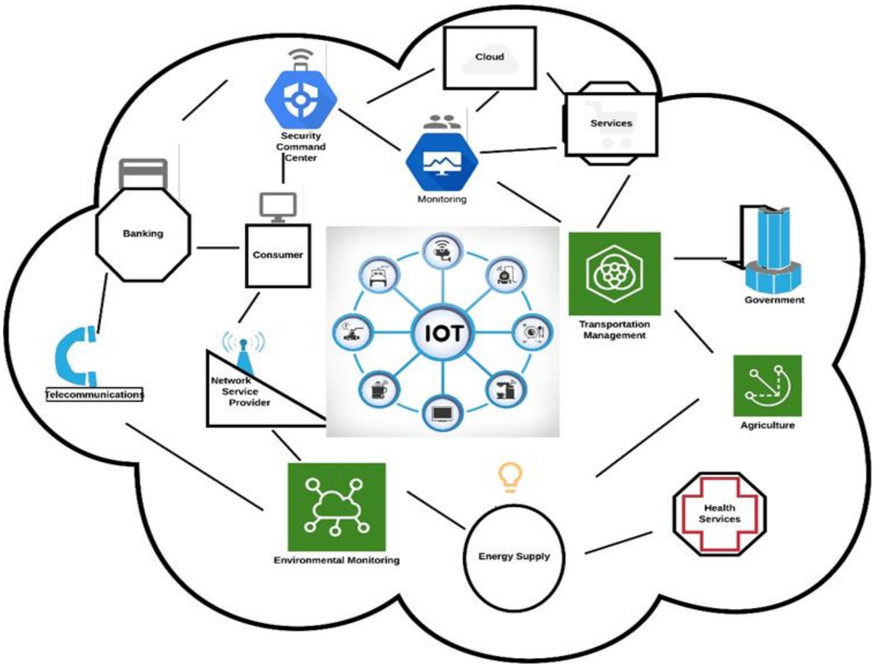

Fig. 1. The Internet of Things

2. IOT AND HARVESTING ENERGY – THE MOST IMPORTANT SOURCES

IoT technologies are now accessible to people of different categories. The Pandemy of Covid-19 and the blocking of activities accelerated the research and development of the Internet of Thing concept [9] .IoT and web technology have become indispensable for people to continue to live almost normally during this global pandemic [10]. I insist on the idea that IoT power supply is a very important requirement to ensure that connected devices are constantly working. Therefore, the problem in achieving the intelligent city and its sustainability is how iot nodes and / or connected devices could be fed to continue to provide intelligent city planners uninterruptible data.Researchers have made efforts to conduct studies focusing on the management and maintenance of energy supply at the first WSNs and currently at iot nodes [1]. Recent international research projects are focused on applying energy management systems to reduce the energy consumption of smart buildings. In 2002, the EU Parlament adopted directives on implementation methods for improving the energy efficiency of buildings, and later, scientists predicted that smart buildings will have over 500 intelligent devices connected in 2022 [11]. So it is essential to pay attention to the growing energy needs of Internet of Things.The challenge is to discover ambient energy sources that are available in a city and conversion mechanisms that can be used, and this will, instead, omnipresent and self-sustainable, with long-term energy sources . It is to limit the use of classical batteries because replacement of waste batteries is a major difficulty when IoT devices are implemented in inaccessible or toxic environments, and the maintenance cost decreases. Energy harvest techniques have many unique advantages and features for the future reported on IoT and wireless communications technology, with the emergence of 5G technology in 2020 and the future 6G. These advantages that can not be offered by existing batteries or network communications are: self-sustainable capacity, omnipresent energy, carbon footprint reduction and battery replacement and / or no links to electrical networks and are easy to use. deployed in toxic and / or hostile and inaccessible environments.Areas of application of energy harvesting techniques are; Internet of Medical Things (IomT), Internet of Mobile Things (IomobT), Internet of Remote Things (IorT) [13] and Internet of Environmental Things (IoenvT).The benefits of harvesting energy have been reported in the literature at different times [2]. So,we have revised and classified various energy harvesting methods that are available by analyzing the recent studies by different researchers. We have taken into account aspects such as the various transduction mechanisms that have been adopted to convert the energy and output power that can be achieved.

We have made the summary that is presented in Table 1 following the revision. The table indicates the type of harvesting machine model, the power density that can be obtained and the sources of information.

Table 1. Current energy harvesters' technologies' characteristics summarized.

Harvester	Physical/Chemical Operation Mode	Power Density	Efficiency (%)	Mature/ Emerging	References
Photovoltaic	Photovoltaic effect	Outdoors: 15 mW/cm^2 Indoors: 10–100 μW/cm^2	Until 40	Mature	[17]
Piezoelectric	Piezoelectric effect	330 μW/cm^3 shoes insert	Until 30	Mature	[18]
Electromagnetic	Faraday's law	Human: 4 μW/cm^3 @ kHz Industrial: 306 μW/cm^3 @ kHz	Until 67	Mature	[18]
Electrostatic	Vibration-dependent capacitors	50 μW/cm^3 to 100 μW/cm^3	9.5–23.6	Emerging	[17]
Pyroelectric	Olsen cycle	3.5 μW/cm^3 at the temperature rate of 85 °C/s @ 0.11 Hz	1–3.5	Emerging	[14]
Thermoelectric	Seebeck effect	Human: 100 μW/cm^3 Industrial: 100 mW/cm^3	10–15	Mature	[15]
Magnetic	Ampere, Maxwell, and Faraday laws	1.8 mW/cm^3 with 400 A at 4 cm from conductor	0.1325	Emerging	[18]
RF	Ubiquitous radio transmitters	GSM: 0.1 μW/cm^2 WiFi: 0.01 μW/cm^2	50–70	Mature	[15]
Wind and water	Faraday's law	1.16 mW/cm^3 at the speed of 5 m/s 4.91 μW/cm^3 at the speed of 3 L/s	0.61–17.6 1.7–29.5	Emerging in small scale	[18]
Acoustic	Helmotz effect	1.436 mW/cm^2 at 123 dB	0.012	Emerging	[19]

In this short review, we will presented different sources from which energy could be harvested in a city.Potential sources for EH are grouped across different categories, depending on the type of mechanism used.We review the most important sources.

2.1. Photovoltaic Harvester's Technology and Devices

Photovoltaic harvesters [12] generate electrical power, converting sunlight or artificial light into electricity using the photovoltaic principle. The solar panel is a modular device, which is composed of n cell in parallel and in series. Thus, harvested energy is proportional to the surface area of the module and can be scaled to the desired size of power generation. The amount of energy that they gather depends on weather conditions and light/dark periods. Besides, efficiency limits photovoltaic harvesters' electric energy generation. The materials that compose the cell determine their efficiency. Current photovoltaic cells are classified into four categories based on their composition: multi-junction, crystalline silicon, thin-films and emerging. A comparison between different solar cell technologies is shown in *figure 2* [14].

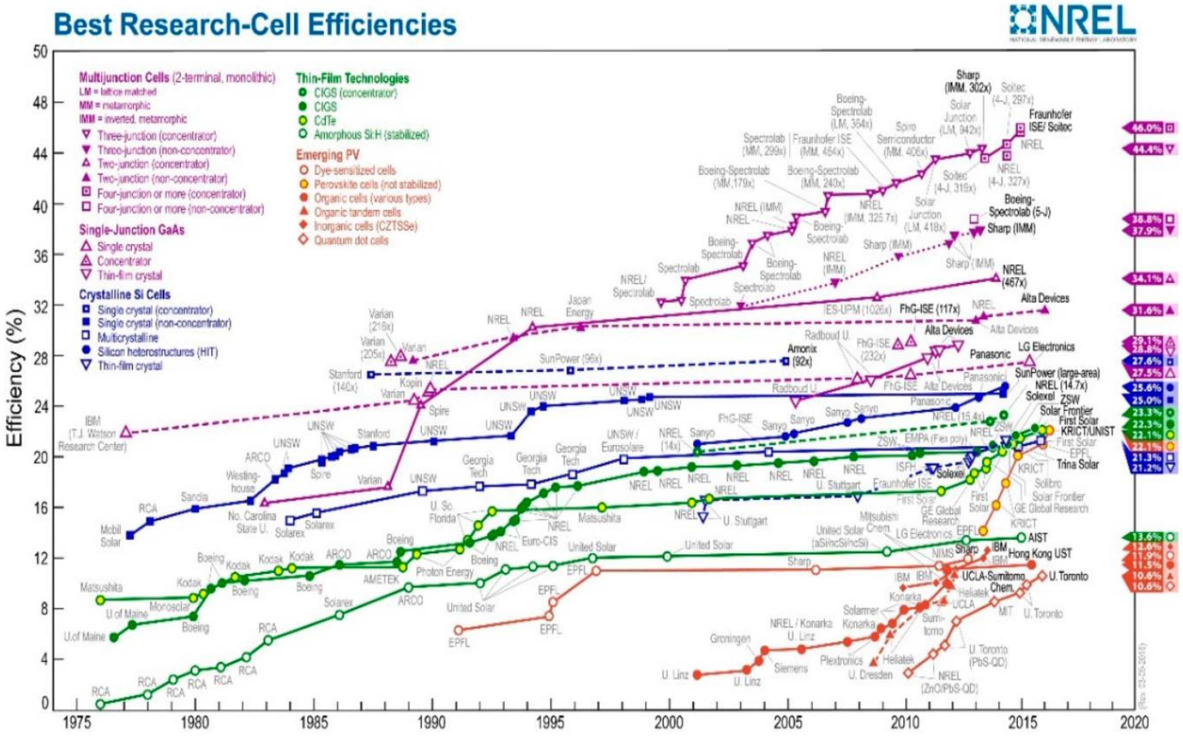

Fig. 2. Cell efficiencies research state

Photovoltaic cells designed for energy harvesting activities are suitable for both outdoor and indoor environments. Indoors light intensity is often much lower than outdoors. The sun generates power intensity far higher than that produced by artificial light sources such as an incandescent light bulb, fluorescent tube, or halogen lamp. Thus, it must be born in mind solar cell spectral properties to achieve the maximum feasible power, since spectral characteristics determine the operation range of each light type. Consequently, a photovoltaic cell would be more efficient on a given wavelength range, depending on the material which it is made of. *Figure 3* shows the spectral operation range of different type of lights [15].

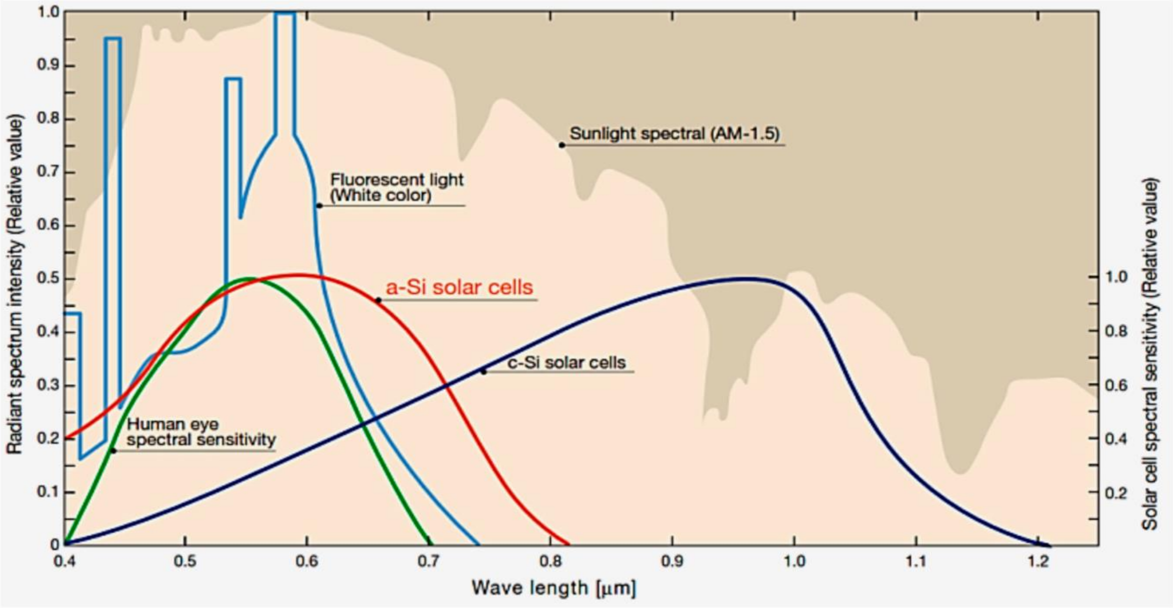

Fig. 3. Comparison of relative radiant spectra of sunlight vs. artificial light from incandescent bulbs and fluorescent lamps.

2.2 Kinetic Harvester's Technology and Devices

Kinetic devices convert mechanical energy into electrical energy through electromechanical transducers. The most common transduction mechanisms are piezoelectric and electromagnetic conversion. Kinetic energy harvesters have a resonance frequency that usually ranges from tens to hundreds of Hertz. In these conditions, they provide energy that ranges from tens to hundreds of microwatts.

Table 2. Comparison of various vibrational-harvesting technologies.

	Piezoelectric Devices	**Electromagnetic Devices**	**Electrostatic Devices**
Advantages	-high output voltages -high capacitances -no need to control	-high output currents -long lifetime -robustness	-high output voltages -low-cost systems -coupling coefficient easily adjustable high coupling coefficients -e reduction increases capacitances
Disadvantages	-expensive materials -coupling coefficient linked to material properties	-low output voltages -expensive material -low efficiency in low frequencies and small sizes	-low capacitances -high impact of parasitic capacitances -no direct mechanical-to-electrical conversion for electret-free converters

2.3. Piezoelectric Transduction

Piezoelectric harvesters [2] generate energy by bending mechanical elements, i.e., beams or membranes. The resultant mechanical vibrations oscillate at resonance frequencies which can range from tens to hundreds of Hertz.

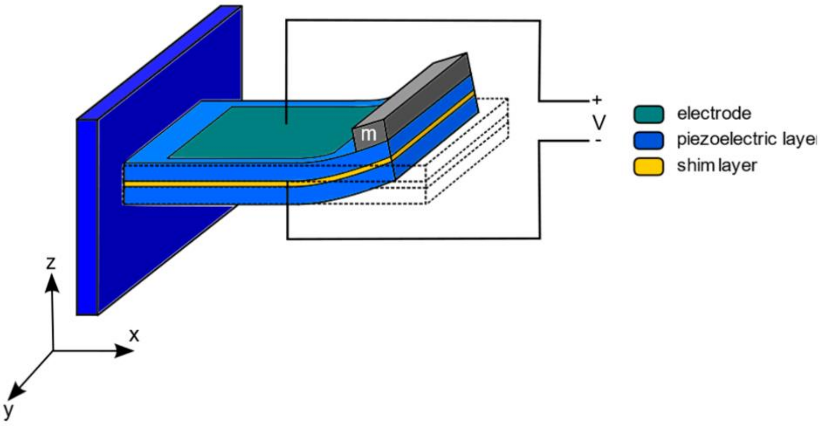

Fig. 4. Piezoelectric kinetic harvester

2.4. RF Harvester's Technology and Devices

Radio frequency (RF) harvesters [13] obtain energy from RF and wireless microwave power. The background RF radiation emitted by broadcast transmitters, cell phone towers, Wi-Fi nets or low power wireless networks, could eventually be used as energy harvesting sources. In this context, radio frequency waves include frequencies from 3 kHz to 300 GHz. The harvested power depends on the incident power density, the distance between the transmitter and receiver, the power conversion efficiency and the harvester antenna size. Thus, the intercepted power is directly proportional to the size of the antenna aperture. A coil and a separator compose an RF harvester, *fig. 5*.

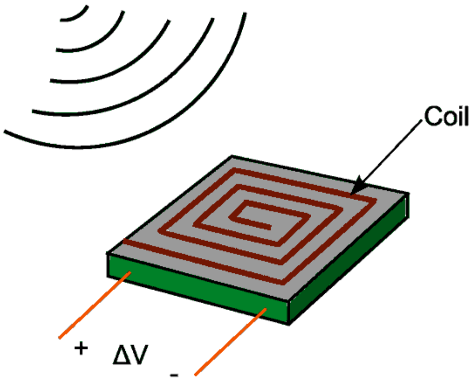

Fig. 5. RF harvester.

Table 3. RF energy harvesting experimental data

Source	**Source Power (W)**	**Frequency (MHz)**	**Distance (m)**	**Power Harvested Rate (µW)**
Isotropic RF trans.	4	902–928	15	5.5
Isotropic RF trans.	1.78	868	25	2.3
Isotropic RF trans.	1.78	868	27	2
TX91501 power trans.	3	915	5	189
TX91501 power trans.	3	915	11	1
KING-TV tower	960,000	674–680	4100	60

3. CONCLUSION

There are plenty of ambient energy sources in the urban environment that could be exploited to generate sustainable energy for IoT and WSN, especially IoT devices for the development of smart city

Ambient energy can be harvested directly from the system, as it is available in almost any place where there are vibrations, solar light, heat, wind, radio frequency, water, and many other natural sources. This will provide optimal benefits of EH systems in the intelligent city. Energy harvest systems have been presented as an avant-garde solution for ecological communications. The energy harvest capacity facilitates the development of smart cities through omnipresent interconnectivity of Internet of Things as long-lasting energy sources.

The use of renewable energy sources is one of the most urgent ways to solve the energy and environmental problems of large cities. These problems significantly affect the life of the population and require an immediate solution.

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