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Advances in the design of an alternative power generation device using piezoelectric

Avances del diseño de un dispositivo de generación de energía alternativa por medio de piezoeléctricos

MUNGUÍA-NAHUÁCATL, Karen Jazmín†* & FRANCO-MARTÍNEZ, David

Programa de Maestría y Doctorado en Arquitectura, Facultad de Estudios Superiores Aragón, UNAM
Centro Tecnológico, Facultad de Estudios Superiores Aragón, UNAM

ID 1st Author: *Karen Jazmín, Munguía-Nahuácatl* / **ORC ID**: 0000-0003-2200-3918, **CVU CONACYT ID**: 1104844

ID 1st Co-author: Da*vid, Franco-Martínez* / **ORC ID**: 0000-0002-0464-8504, **CVU CONACYT ID**: 69978

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Abstract

This article will give the progress of the project of design of a device of alternative energy generation using piezoelectric, applied in the improvement of the lighting of an urban dwelling. Giving the background of the piezoelectric effect, a diagnosis of the conditions of the housing unit in terms of the energy demand for lighting, its vehicular capacity and road conditions, as well as the proposed solution to the demand for electrical energy, indicating the necessary electronic components in the first proposal and ending with the initial design and technical analysis, to conclude with the results of the research project. It is also important to consider that within the 13 modules that are required to form the speed reducer when a vehicle passes it will not pass through the 13 modules, but only a few, so the energy generated will also have variations in the results; unless a way is sought that when the vehicle passes over the reducer, all modules are pressed at the same time.

Piezoelectric, Energy harvesting, Alternative energy

Resumen

En el presente artículo se darán los avances del proyecto de diseño de un de un dispositivo de generación de energía alternativa por medio de piezoeléctricos, aplicado en el mejoramiento del alumbrado de una vivienda urbana. Dando los antecedentes del efecto piezoeléctrico, un diagnóstico de las condiciones de la unidad habitacional en cuanto la demanda de energía por alumbrado, su aforo vehicular y condiciones viales, así como la propuesta de solución a la demanda de energía eléctrica, señalando los componentes electrónicos necesarios en ta primera propuesta y terminando con el diseño y análisis técnico inicial, para concluir con los resultados del proyecto de investigación. También es importante considerar que dentro de los 13 módulos que se requieren para formar el reductor de velocidad, cuando pase un vehículo no pasara por los 13 módulos, sino solamente por unos cuantos, por lo que la energía generada también tendrá variaciones en los resultados; a menos que se busque la manera de que cuando el vehículo pase sobre el reductor, todos los módulos sean presionados al mismo tiempo.

Piezoeléctrico, Cosecha de energía, Energía alternativa

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*Correspondence to Author (e-mail: jrodriguez@itcj.edu.mx)
† Researcher contributing as first author.

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Introduction

The growth and concentration of the population in the city have led to the development of the expansion of urban housing, so in the main cities housing complexes have been built, where the lack of public lighting has caused various problems such as the deterioration of common areas, the vulnerability of passers-by to criminal acts, inappropriate use of the collective areas for which they were designed and their progressive appropriation of illegal trade (SEDATU, 2014).

Such is the case in the housing unit: Arcos de Aragón, located in the Gustavo A. Madero mayor's office, Mexico City; since due to the lack of lighting in different areas of common use has been limited to their use of them and insecurity has been affected.

This article will give the progress of the project of design of a device for alternative energy generation using piezoelectrics. Giving the background of the piezoelectric effect, a diagnosis of the conditions of the housing unit in terms of the energy demand for lighting, its vehicular capacity and road conditions, as well as the proposed solution to the demand for electrical energy, indicating the necessary electronic components in the first proposal and ending with the initial design and technical analysis, to conclude with the results of the research project.

1. Background

The piezoelectric effect was discovered in 1880 by the Curie brothers and was first used by Paul Langevin in the manufacture of sonars during World War I using quartz crystals coupled to metal masses to generate ultrasound in the tens of kHz belt. (Venet Zambrano & Alves Pereira, 2004).

These materials have the peculiarity of generating electrical charge when external pressure is applied on them, which works under the piezoelectric effect. Piezoelectricity consists of the presence of an additional electric charge, due to the application of this force.

This principle is based on the change of polarization of the material due to the deformation generated by a force applied on the crystals.

The functioning of these crystals depends on the individual molecules that compose them, normally, when the crystal is not under any type of external stress, the charges are uniformly dispersed in the molecules through the crystal. But when quartz is stretched or squeezed, the order of the atoms changes slightly. This change causes negative charges to accumulate on one side and positive charges to accumulate on the opposite side.

2. Initial proposal

The initial proposal contemplates the housing unit: Arcos de Aragón, and aims to propose a system to generate electricity, taking advantage of the vehicular traffic of the housing unit, harvesting the energy through piezoelectric devices whose operation is based on exerting pressure on them and have the advantage that they do not produce polluting emissions. The energy generated will be stored in batteries and distributed in the lighting of the outdoor areas of the housing unit, that is, in the spaces of transit and common use such as recreational centers and parking.

2.1. Site information

The Arcos de Aragón housing unit is located on the San Juan de Aragón road and Av. Rio de Guadalupe and as a reference, it is located between Av. Eduardo Molina and Av. Gran Canal, in the Gustavo A. Madero delegation, this unit is divided into 3 sections that have independent accesses and exits from each other, but are part of the same unit. (See Figure 1).

Figure 1 Location and distribution of the sections of the Arcos de Aragón housing unit
Source: Elaboration with capture of Google maps 2022

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Different sections are made up of a set of Rinconadas with 9 towers of buildings (FIGURE 2) each, in the center of each Rinconada there are 34 parking drawers, and there are others outside, Rinconada is along the entire housing unit that is for use by the owners.

Figura 2 Distribución de las secciones de la unidad habitacional Arcos de Aragón
Source: Elaboration with capture of Google maps 2022

Sections 1 and 2 share a parking lot that is located between the 2 sections, and 3 recreation areas, the first located at the access on Av. Eduardo Molina has a multipurpose court and a children's play area, this area does not have much lighting, the second is followed by parking between both sections and has 3 multipurpose courts, an area of exercise equipment and children's games, despite having a luminaire in this area, it has been observed that not enough maintenance has been given and the luminaire system does not work completely, and the third is at the bottom of section 2 which is a pet park where there is no luminaire. Because section 1 has a larger surface area and habitability, the study will be carried out only in this area.

2.2. Characteristics of energy demand

On the other hand, the electrical service of the Arcos de Aragón housing unit is divided into domestic and collective, which is for domestic use refers to the consumption of the department of each owner, and collective use includes the lighting of the parking lot in each Rinconada the use of water pumps that is an independent expense of the maintenance of the facilities and services of the entire unit (common areas, gardening, parking lighting, surveillance, etc.)

Will be important to capture the distribution of the currently active luminaires in the housing unit, as well as those in poor condition and those not in operation.

In each Rinconada are distributed 4 luminaires around each Rinconada, these luminaires are incandescent lamps, and it is observed that some of them are not in operation; due to this, the inhabitants of the unit have been forced to place lamps whose consumption runs through their homes to illuminate these areas. These types of luminaires are also found in recreation areas that are in the same situation.

In the parking lot there are halogen pendant luminaires placed on the roofed levels of the parking lot, and on the upper-level luminaires with incandescent lamps.

Finally, on the main roads of circulation, there are 2 types of luminaires; incandescent lamps that are in poor condition and some are not in operation, and luminaires with solar panels and LED lamps that in the same way are not all in operation.

Kind of luminary	quantity	Operation		Efficiency		Useful life	Time on
		Yes	No	lm	W	(hours)	(minutes)
LED with solar panels	22	18	4	80	100	50,000 a 100,000	Instant
Luminary VSAP	51	37	14	45	150	24,000	3-5
Combined	4	3	1				

Table 1 Capacity of existing luminaires in section 1 of the Housing Unit
Source: Own Authorship 2022

2.1. Vehicle capacity

The objective of making a vehicular capacity, is to know the number of vehicles that transit within the housing unit, will be carried out using a vehicular capacity, in the access and exit of the unit, and the movement of the vehicles, that is, the route they make within the unit to the main parking lot and the other Rinconada.

Data collection by direct observation

This observation was made at different times and seasons, it was observed that vehicular traffic is continuous and constant, and varied according to the types of vehicles, since not only the vehicles of the owner's transit, given that it is a complex with an area of almost 10 hectares.

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It has been observed that the circulation made by the vehicles of the owners of the unit is multiple, since some have a parking drawer in the main parking lot, away from their home, so when they make purchases or make family trips, they first make a stop to the parking lot of the Rinconada, either to load and/or unload for convenience to the proximity of their home, and finally make another move to exit the unit or take your vehicle to the designated parking drawer (as the case may be).

Regarding other vehicles that enter the housing unit, it has been observed with medium frequency those that provide maintenance services (telephone-internet, electricity, gas, construction, etc.) these vehicles go directly to the place that is requested and are removed from the unit. Mobility and parcel service vehicles have also been observed with a high frequency and at very varied times during the day. Finally, heavy-duty vehicles are considered, such as removals and delivery of low-frequency furniture stores, as well as some suppliers of groceries with a very low frequency.

La vialidad principal de la unidad habitacional cuenta con 2 sentidos de circulación con un carril cada uno delimitado con señalamiento horizontal y vertical, el cual se refiere a la pintura en el piso para delimitar los carriles de circulación y el control de la circulación con señalamientos de cruce peatonal, alto, límite de velocidad y reductores de velocidad y así evitar accidentes entre conductores y peatones.

In the main parking lot, there is a ramp for access and delimited direction of circulation with horizontal signaling to know the direction of circulation and avoid conflicts, as well as vertical signaling which are mostly restrictive signs of the speed limit and high, and preventive pedestrian crossing.

Data collection

To obtain accurate data on the vehicles transiting in the housing unit, a continuous accounting of vehicles was carried out during a typical day. For this case, these capacity points were in the accesses of section 1, accounting for the access and exit of the vehicles in a period from 6:00 a.m. to 24:00 p.m. at intervals of 15 min, taking into account the type of vehicle registering it in a log.

Likewise, directional flow sampling was carried out, to detect the movements made by the vehicles once they enter the housing unit and made them go to their Rinconada.

The points that were considered were the accesses to each Rinconada and the main parking lot, counting in the same way the number and type of vehicle. Below is an outline of how such capacity will be carried out. (Figure 3)

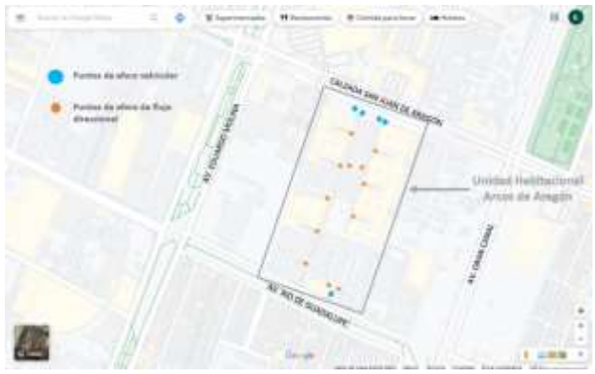

Figure 3 Scheme of vehicular and directional flow gauging stations in the Arcos de Aragón housing unit
Source: Own Authorship 2022

The results obtained are shown in the following board, extract from the log where the capacity was recorded, which shows the number of total vehicles entering and leaving; the type of directional flow movement was considered for entry vehicles concerning Figure 3, but without accounting for the movements of motorcycles.

Table 2 Result of vehicular capacity including directional flows of entry vehicles
Source Own Authorship 2022

3. Alternative selection

What is intended is to satisfy the energy demand of the exterior lighting of the housing unit, so the electronic devices within the initial energy harvesting device are considered to use piezoelectrics to meet that objective.

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3.1. Types of piezoelectric materials

These devices come from natural materials such as quartz, tourmaline and Rochelle salt, these materials are very small, so materials with improved properties have been developed such as polycrystalline ferroelectric materials such as Barium Titanate (TiBaO3) and Lead Zichromate Titanate (PTZ), the latter are available in many variations and are the most used today. The crystal structure of this element is cubic centered on the faces before polarization and after polarization exhibits tetragonal symmetry below the Curie temperature, which is the one where the crystal structure changes from piezoelectric to non-piezoelectric shape. (Cúpich & Elizondo, 2000, p.2)

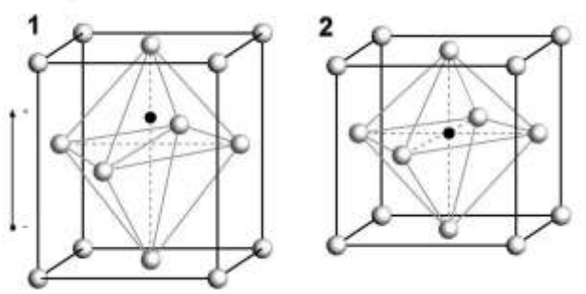

Figure 4 Structure of a piezoelectric ceramic type PTZ, below and above the Temperature of Curie
Source: *Cúpich & Elizondo, 2000*

3.2 Required electronic components

For the operation of the system that will be elaborated in the research work, it is important to know the necessary electronic components to be used, which protect and distribute the energy generated correctly.

First it must be identified that a piezoelectric material according to its properties, produces a current when external pressure is applied to them, transforming mechanical energy into electrical energy; that happens by changing the order of the atoms of these materials, and the negative charges accumulate on one side and the positive ones accumulate on the opposite side, if one end of the crystal is connected to the other, the potential difference is used to produce an electric current. To convert this mechanical energy to electrical energy by piezoelectric devices and to be able to store it, an electronic system is required; which is a set of interrelated circuits that interact with each other to obtain a result, which is made up of 3 stages:

a) Inputs
b) Signal processing circuits
c) Outputs

Inputs can be sensors or transducers that take a physical signal and convert it into a current or voltage signal.

Signal processing circuits consist of electronic parts connected to manipulate, interpret, and transform voltage and current signals coming from transducers.

Outputs can be actuators or other devices such as transducers that convert current or voltage signals into physically useful signals.

The different electronic components that make up an electronic circuit are classified according to the following board.

Information type	Regime type	Signal type	Configuration
-Analog -Digital -Mixed	-Recurring -Transient -Permanent	-Direct current -Alternating current -Mixed	-Series -Parallel -Mixed

Table 3 Classification of components within an electronic circuit
Source: Own authorship 2022.

Regarding the research topic, and the objective to be achieved, the following scheme is considered:

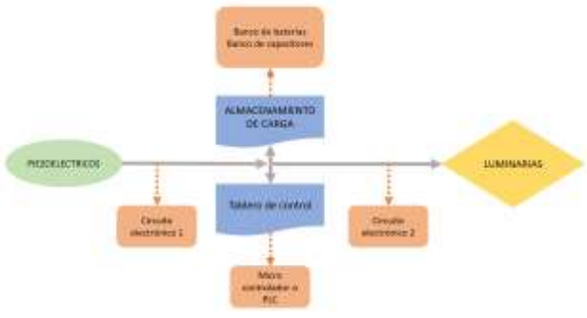

Figure 5 Electronic circuit operating scheme
Source: Own Authorship 2022

For the above, in the first step of the piezoelectrics to the first circuit, the following components are considered:

– Components: Cables.
– Analog devices: diode, Zener diode, transistor, inductor, op-amp.
– Power devices: Fuse.

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– TRIAC, transformer, varistor.
– Transducers: piezoelectric transducer

For cargo storage and control board will be required:

Components:
– Cables
– Switch
– Battery
– Speaker

Analog devices:
– Diode
– Zener diode
– Potentiometer
– Relay
– Resistor
– Transistor

Digital devices
– Memories
– Microcontrollers
– Logic gates

Power devices
– TRIAC
– Varistor

Transducers
– Photoelectric transducer
– Thermoelectric

Power supplies (UPS)
– Interactive line

Control system
– Electronic

Measuring equipment
– Galvanometer
– Ammeter
– Ohmmeter
– Voltmeter
– Oscilloscope

4. Design and technical analysis

According to the background mentioned above and the current conditions of the study site, in this section, the first proposal of the prototype and the solution to the energy demand of the housing unit with the chosen energy harvesting materials is made.

4.1. Initial prototype

The proposal is made with devices for traffic control and road safety, in recent years these prefabricated devices of recycled tire rubber have been occupied, these are placed on the rolling surface, by modules that facilitate and speed up the installation of them. They have yellow reflective tapes to increase visibility even in places with low lighting. They also have a superficial pattern, which ensures a correct grip of the tires of the vehicles avoiding any skidding. (Figure 6).

Figure 6 Electronic circuit operating scheme
Source: https://gnrmexico.com.mx/reductor-de-velocidad-safety-rider-v/

As said above, it is important to consider the use of these prefabricated elements that help with the implementation of what is intended to be developed in the present research, adapting these reducers with piezoelectric devices.

Below, 2 possible solutions with different numbers of piezoelectrics are shown, which is not yet a definitive model, since the electricity consumption of the exterior lighting of the housing unit and the existing vehicular flow has yet to be considered. (Figures 6 and 7).

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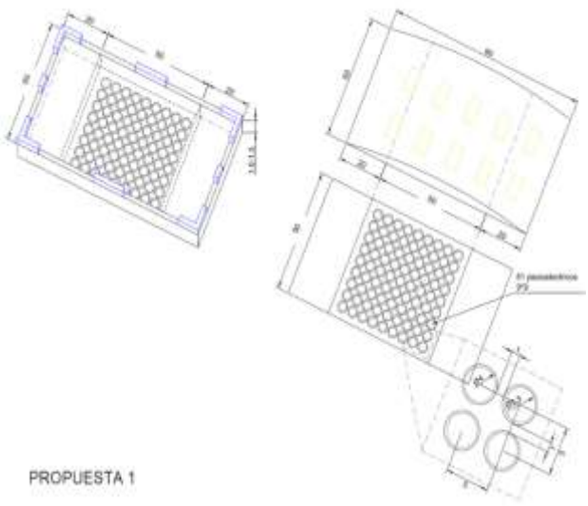

Figure 7 Electronic circuit operating scheme
Source: *Elaboration using AutoCAD 2022 software*

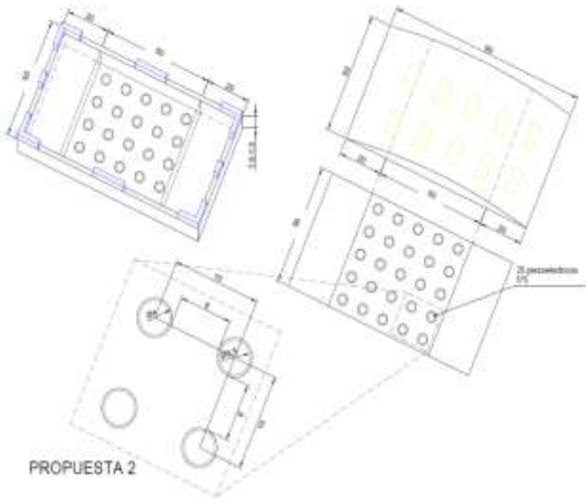

Figure 8 Electronic circuit operating scheme. Source: *Elaboration using AutoCAD 2022 software*

The previous arrangement considers one of the modules for a speed reducer; in a road stream of (x) linear meters so the number of modules will be variable, according to the road stream of the access and exit of the housing unit which is 6.50m wide and according to the measurements of the modules that is 0.50m wide, for this case 13 modules are needed to form a speed reducer, which is connected for energy storage and therefore a total of 1,053 piezoelectrics would be projected in proposal 1 and 325 piezoelectrics in proposal 2.

4.2. Amount of energy generated.

To obtain the power of the system will be obtained by the following formula:

$$Power\ (Watts)=I*V \quad (1)$$

Considering a series arrangement of 4 parallel-connected piezoelectrics of 35 mm in diameter; was generated by manually pressing a voltage of 1.8 V, as measured with a multimeter.

Therefore, we can calculate the power for the arrangement of 4 piezoelectric devices connected in parallel:

$$Power\ (Watts)=0.02\ A*1.8\ V$$

$$\boldsymbol{Power\ (Watts)=0.036\ Watts}$$

To check or make a comparison of what was obtained, a technical sheet of a stainless steel piezoelectric device of 20 mm in diameter is presented below.

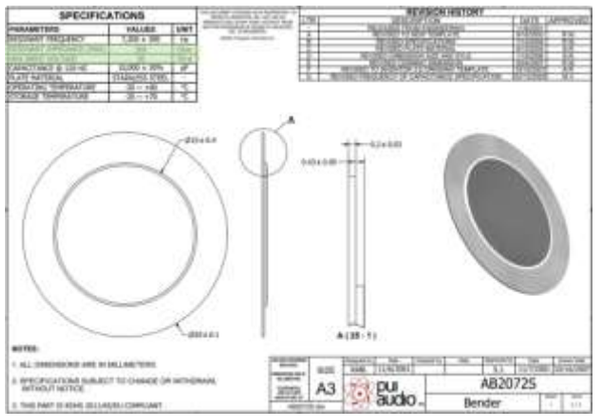

Figure 7 Technical data sheet of stainless steel piezoelectric device
Source:
https://www.digikey.com.mx/es/products/detail/pui-audio-inc/AB2072S/1464747

With the data you have of the resistance and the maximum input voltage, you can get the power that a device would generate. It is worth mentioning that these data are specifications of the device and are the maximum of operation, so the results obtained are with a significant clearance.

According to Ohm's law, we can obtain the current as follows:

$$A=V/\Omega \quad (2)$$

So to get the power:

$$Power\ (Watts)=0.1\ A*30\ V$$

$$\boldsymbol{Power\ (Watts)=3\ Watts}$$

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Considering that the specifications are with maximum and optimal values, the experiment with four piezoelectric devices is acceptable.

For the projection of the system, the number of vehicles that travel in the housing unit will be considered, and the 13 modules would be placed along the road stream.

Considering that the specifications are with maximum and optimal values, the experiment with four piezoelectric devices is acceptable.

For the projection of the system, the number of vehicles that travel in the housing unit will be considered, and the 13 modules would be placed along the road stream. Therefore, in the following board, the projection of what was obtained with the experiment will be made, and the number of piezoelectrics of proposals 1 and 2, are mentioned above. (Board 4).

# Piezo	V	A	W	Modules	Cars in	Total W
4	1.8	0.02	0.036	13	1251	585.47
25	11.25	0.02	0.225	13	1251	3,659.18
81	36.45	0.02	0.729	13	1251	11,855.73
100	45	0.02	0.9	13	1251	14,636.70
150	67.5	0.02	1.35	13	1251	21,955.05

Table 4 Estimation of power obtained from different numbers of piezoelectrics from both proposals 1 and 2
Source: Own Authorship 2022

5. Proposal of luminaires

Considering an outdoor luminaire that has a power of 25 W up to 100 W with an average life of 75,000 hrs, the projection of how many piezoelectric devices would be needed to operate this luminaire was made. (Figure 8).

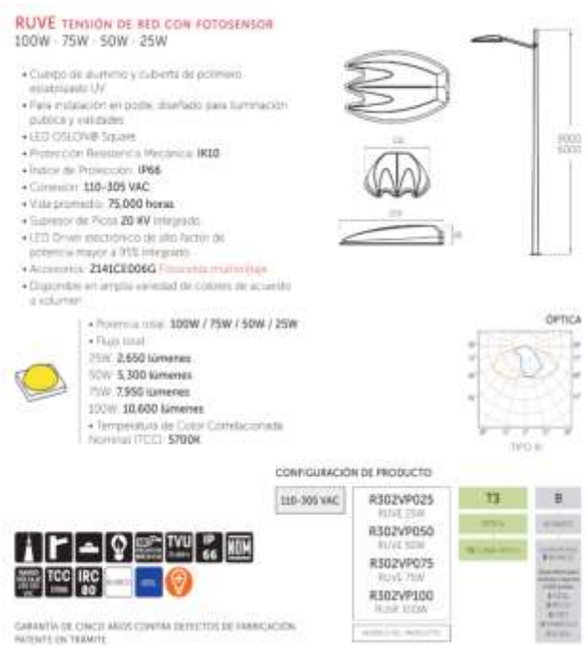

Figure 8 Technical sheet of luminaire for outdoor lighting, LED technology
Source: Zaraus lighting catalog 2020-2021

Now, to know the energy consumption of the luminaires, according to the technical sheet they have 25 W, 50 W, 75 W and 100 W, since the total power was considered according to the daily vehicular flow, therefore, the results obtained reflect the hours a day that the luminaires would be on in the day. Board 5.

Number lamps					
Number piezo	W	25	50	75	100
4	585.47	23	12	8	6
25	3659.18	146	73	49	37
81	11855.73	474	237	158	119
100	14636.70	585	293	195	146
125	18295.88	732	366	244	183
150	21955.05	878	439	293	220

Table 5 Estimation of the number of lamps of different numbers of piezoelectrics
Source: Own Authorship 2022

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Conclusions

According to the results that were obtained, it seems that the system is optimal and viable to implement, however, many other factors remain to be considered, such as the other components that will make up the system, the storage battery and the distance at which the luminaire will be placed from the speed reducer, these elements could make that amount of power affected and be lower.

It is also important to consider that within the 13 modules that are required to form the speed reducer, when a vehicle passes it will not pass through the 13 modules, but only a few, so the energy generated will also have variations in the results; unless a way is sought that when the vehicle passes over the reducer, all modules are pressed at the same time.

Regarding the materials for the harvesting of energy, it is important to address, that the importance of the study of them, in recent years is very beneficial, since one of the main challenges of the planet today is to find new sources of energy that do not affect the environment, and reduce the greatest amount of polluting gases, as well as the exploitation of natural resources.

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