Characterization of Energy Efficiency in Lighting Systems Using Solar Panels by Light Self-Regulation Applied to Higher Education Centers

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Abstract

The purpose of this document is to provide environments with optimal lighting levels, obtain efficient energy savings and avoid discontent regarding the sensation of light intensity. The use of energy that keeps light energy emission costs linear and how to optimize it in high-demand areas such as higher education centers has become one of the most questioned puzzles in recent years. This is followed by the poor regulation of lighting present inside the classrooms, which means that the students present in the various houses of study (whether they have natural lighting during the day) are affected by the opaque visibility generated by the contrasts of light in the different parts of a room. The application of new technologies such as the management of buildings with photovoltaic panels together with automated sensors for the regulation of light intensity has become one of the most viable and successful solutions in terms of improving the comfort of students and reducing budgeted costs.

Keywords
Photovoltaic panels, Light intensity sensor, Smart lighting, Arduino microcontroller.

1. Introduction
The energy requirement in the 21st century is the most relevant concern among researchers working on an energy efficient system (Bhakre 2022)
Over time, the problem of light regulation has been presented in various study centers, which deal with this inconvenience every day, mistakenly making it typical of the academic environment. This directly negatively affects the student performance of university students, that is why we propose through this article not only a self-sustaining solution but also reduce costs using lighting technology that can improve efficiency between 50 - 90% over existing lighting. (CENTRICA 2017)
The rapid growth of inhabitants, technological development, and industrialization have resulted in an increase in the demand for energy in recent years. This demand causes a high increase in electricity production since it is a favorite form of energy use. Cumulatively, total global electricity demand is anticipated to grow by approximately 30% in 2040 compared to 2015 (Elkadeem 2012). The scarcity of fossil fuels and low storage capacity force us to look for more viable, reliable, and clean energy options for the climate. Among renewable energy sources, solar energy is considered the most fascinating energy source capable of balancing this difference between electricity demand and generation (Pachauri 2021).
Although the global installed capacity of solar energy has increased considerably as solar panel prices have steadily decreased over the last decade, the use of solar systems in buildings remains a minority (Hyvönen 2022). Then the maximum use of solar energy through solar panels would be an effective way to solve the dilemma of environmental degradation that has been gradually introduced in all aspects of society (Deng Q 2022). Thus, it will begin by capturing sunlight through the solar panels integrated in the building, transferring the energy to a source that will allow us to quantify it and store it for later distribution, regulated in the electrical circuit installed in said building. Simultaneously, we will obtain records of light intensity from sunlight and detect areas with less light input; in these cases, we will

incorporate an electric light that equalizes light levels throughout the environment, guaranteeing lighting uniformity. In the whole environment. There are mechanisms that help us automate the regulation of light captured by solar panels, changing them into controlled signals directed to the bulbs.
Among the most prominent, we find the "Arduino platform" which will receive signals from an LDR sensor with an input and output interface. Arduino behaves like a small computer with the ability to work with a complete operating system. It is generally used as a controller when a processing capacity greater than that of a conventional controller is required, or as a local server, since its structure has connectors compatible with standard Ethernet cables and communication through different protocols. (La Cruz J 2018).
In large buildings, thousands of sensors produce gigabytes of information, which tends to grow as new technologies and stakeholder demands emerge (Pachauri 2021). The Arduino microcontroller has two interfaces. The input interface works as a connection between the board and different types of peripherals. The information collected by this first device will be transferred to the microcontroller, which will oversee the processing of this data. While the output interface is responsible for carrying the information that has been processed in the Arduino to other peripherals, in this case it will be the light bulbs. (Arduino.cc 2022)
In this way, it is possible to automate lighting through a sustainable and economical solution, reducing the electrical expenses of higher education institutions, which vary depending on the private costs to be paid and the measurements they receive. In addition, expenses for electricity consumption in universities usually have different values depending on the number of students admitted and the frequency of their use, among other parameters.
Thanks to a compilation of data from universities around the world, it is found that good management of energy efficiency has reduced consumption expenses in different universities. One of the cases is that of the Autonomous University of Barcelona, where the activities of the third quarter of 2021 have made it possible to reduce electricity consumption by 6%, and this, in turn, has contributed a large part of the accumulated savings of 473,179.27 euros (UAB 2021), as shown in Figure 1.

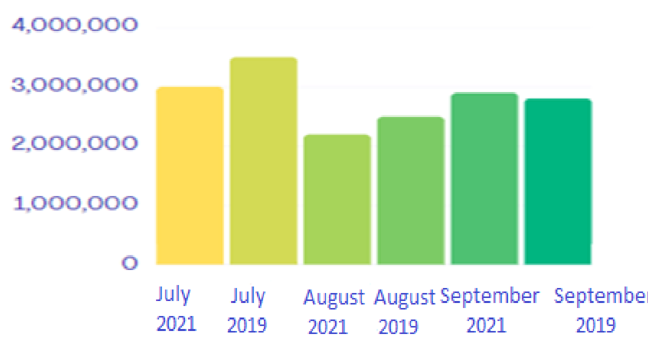


Figure 1. Comparison of electricity consumption between 2019 and 2021 through energy efficiency (UAB 2021).

The luminaire incurs electrical losses in the drivers and control systems, as well as optical losses (luminous flux) (Sarkar A 2018). It is necessary to point out that the operation of the lighting systems belonging to the building will work in harmony with sunlight during the day, fulfilling the function of lighting regulation by the microcontroller and the sensor.
There are different types of natural lighting systems: lateral, ceiling, or combined. The choice between them depends on the climate, the architectural environment, or the use of the building, among other factors. The most frequent natural lighting systems are the sides, such as windows. However, it is difficult to achieve good daylighting conditions in large and deep spaces, such as classrooms and offices, when only lateral systems are used. (Deng Q 2022). That is why it is important to find a solution to all this inconvenience for students.
Artificial light systems cannot work in a unique way in closed environments throughout the day, as it causes inconveniences in people's daily rhythms. It is known that the lack of natural light alters the light rhythms of people, negatively affects their sense of orientation and time, and can cause claustrophobia, anxiety, and depression (Fernández-Ahumada L 2022).
Mood directly affects feelings of health and well-being. Mood and perceived ability jointly influence motivation to perform the task and thus performance (Castilla N. 2015).

It is for this reason that it works to complement natural lighting, and it is essential that in all classrooms there be some system that allows the latter to enter, at least during the day. In addition, the lack of natural daylight can cause seasonal affective disorder, with symptoms such as depression, insomnia, and irritability.
One cause of this condition is that we spend most of our time in space without a view. Such spaces may consist of spaces without windows, or they may be spaces with windows but poorly designed for daylight access (Castilla N. 2015).

1.1 Objectives
The objective of the article is to modulate lighting in higher education centers by capturing sunlight through solar panels, processing this information with the use of Arduino microcontrollers, thus reducing energy consumption while providing optimal Luminous intensity.

2. Literature Review
Existing studies have revealed that the environmental quality of classrooms has a significant impact on student well-being and performance. Among all the environmental factors, light is believed to play one of the most important roles. One study showed that light contributed 21% to the increase in student progress, marking the highest portion compared to six other environmental factors.
Most of the studies on lighting control systems focused on energy savings and achieved considerable results. As summarized in a review on lighting control, energy savings ranged from 35% to 68% in the classroom and office environment. (Sun B., Zhang Q. 2020).
There are many articles related to the application of the Arduino microcontroller, giving it different applications, and in this way, information is obtained.
The evolution of final energy consumption has followed a trend towards stabilization and contraction of demand as of 2004, consequently, as has been mentioned, of the improvement in efficiency (Gavilan A. 1995).
Automatic control systems in the field of science and technology have recently developed very rapidly. Therefore, the Arduino and the LDR sensor can be part of an efficient and cost-saving system.
The automatic shade control system works during the day and at night. The operating principle of this tool is that during the day the lighting system is put into practice, and at night savings are generated.
In addition, natural lighting improves the well-being of the occupants, and this is not to be ignored by businesses since lighting in leisure centers, for example, can represent up to 20% of total energy costs. (Sun B. and Zhang Q. 2020).
These lighting conditions can affect human performance through three systems: the visual system, the circadian system, and the perceptual system.
Through these three systems, light has visual, biological, physiological, and psychological effects on the human being. Visual comfort has an indirect effect on mood and, through mood, an effect on feelings of health and well-being (Castilla N. 2015).

3. Methods
The generation of solar energy depends directly on the time of day, the cloudiness, and the time of year. This means that the generation of energy by solar panels does not satisfy the energy demand of most buildings, which limits its use (Sun B. and Zhang Q. 2020).
The light intensity in real time will be recorded by the LDR sensor. However, LDR limitations (such as light intensity saturation and ineffectiveness in low visibility conditions) can deteriorate solar tracking performance.
LDR saturation occurs when light exposure to LDR reaches a certain saturation level. Consequently, the saturated LDRs return to the tracking algorithm with almost constant voltage values, tracking the algorithm. (Jamroen C. 2021), as shown in Figures 2 and 3. According to the inverse law of cosine, it develops now that the light beam infers perpendicularly on the surface. If the plane of the surface forms an angle with respect to the beam of light, it is considered, and the relationship will be: (Álvarez T. 2015).

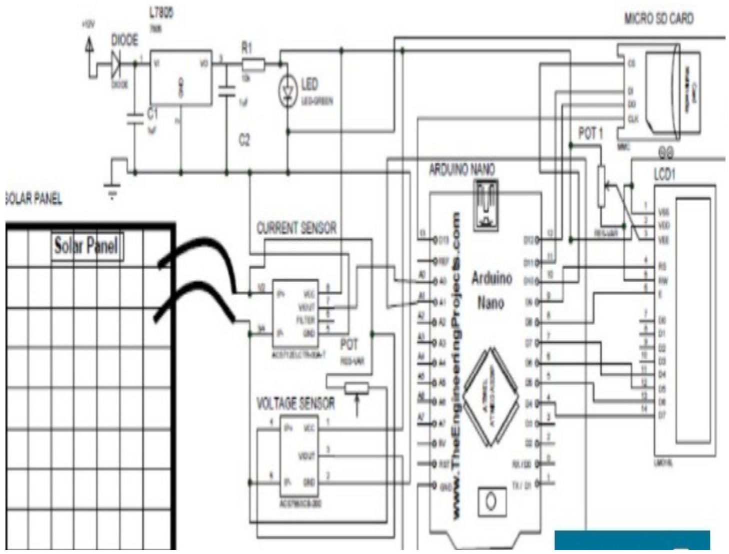


Figure 2. Sequence of energy processing (Pachauri R. K. 2021)

$$E = I/d^2 \tag{1}$$

Where:E:
Illumination level (Lux)
I: Luminous intensity (Cd)
d: Distance (m)
Ɵ: Angle formed by the working plane with the plane perpendicular to the direction of the light flow.

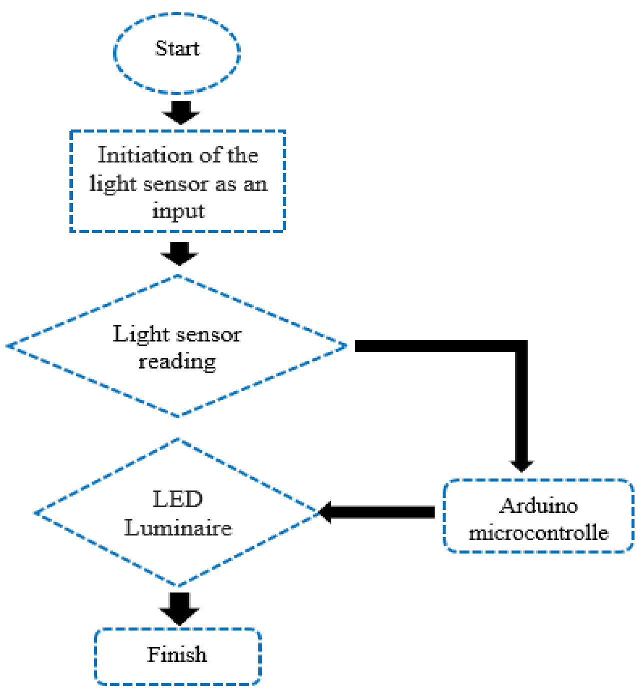


Figura 3. Processing sequence of data collected by the sensor

The light readings taken by the sensor, which functioned as a peripheral, were sent to the microcontroller. The model is the Arduino UNO edition, a version of the AVR® MCU (which includes Microchip/Atmel ATmega328 8-bit microcontroller running at 16 MHz). It processed them and sent coded information to the bulbs. The results that were anticipated have been achieved: during the day, the lights provide little illumination. This implies that autoregulation also worked at night. (UAB 2021) The self-regulation process developed in the system allows us to measure both external natural light and internal light and thus, with the energy stored as a reserve, achieve optimal luminosity in the classrooms.
The term "energy efficiency" refers to the set of actions that have made it possible to use energy optimally, which, using the Arduino microcontroller, allows reducing the use of electrical energy, producing the same amount of lighting. Consequently, the quality of stay in the place for the students of the higher education center was improved, obtaining better comforts for the students in the development of their learning, reducing costs and the production of greenhouse gasses.

Load analysis of a building:

The first thing that is done is to see the amount of installed load that the building presents. To find out the current in KVA (Bustamante C., 2013), the following formula is used:

$$I = \frac{KW * 1000}{1.732 * E * FP} \tag{2}$$

Where:
W=Watts
E= Voltage in Volts
PF=Power Factor

$$KVA = \frac{I * E * 1.732}{1000} \tag{3}$$

Where:
I=Amperes
E=Voltage in Volts

As we have said, luminous intensity is a determining factor in the academic environment. Due to this, we must know the correct level of luminous flux necessary, the number of luminaries and the height that must be found. To answer these questions, we will use the Lumens Method.
This method will allow us to know the average level of illuminance in a facility, which in our case, will be the classrooms of the higher education center. First, we will calculate the total luminous flux necessary and the number of luminaries necessary in said environment. (Castilla N. 1995), as shown in Table 1.

$$\Phi_T = \frac{E_m \cdot S}{C_u \cdot C_m} \tag{4}$$

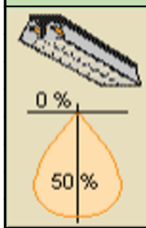
Where:
Em = average lighting level (in LUX)
ΦT = luminous flux that a certain room or area needs (in LUMENS)
S = surface to be illuminated (in m2)
Cu = Coefficient of use.
It is the ratio between the luminous flux received by a body and the flux emitted by the light source, Cm = Maintenance coefficient. It indicates the level of conservation of a luminaire. The coefficient of utilization is calculated by finding the value of *global k*, as follows:

$$K = \frac{(axb)}{h(a+b)} \tag{5}$$

Where:

a, b = dimensions of the study room
h = height of the luminaire with respect to the work plane. Then this value of global k intersects with the reflectance values of the ceiling and the walls in Table N°4. (Lopera J. 2009)

Table 1. Utilization coefficients for pairs of lamps T-12 for later models.

Type of lighting fixture	Local index k	Utilization factor (η)											
		Ceiling reflection factor											
		0.8			0.7			0.5			0.3		0
		Reflection factor of the walls											
		0.5	0.3	0.1	0.5	0.3	0.1	0.5	0.3	0.1	0.3	0.1	0
	0.6	.27	.24	.21	.27	.23	.21	.27	.23	.21	.23	.21	.20
	0.8	.33	.29	.26	.32	.29	.26	.32	.29	.26	.28	.26	.25
	1.0	.36	.33	.30	.36	.33	.30	.35	.33	.30	.32	.30	.29
	1.25	.40	.36	.34	.39	.36	.34	.38	.36	.34	.36	.34	.33
	1.5	.42	.39	.37	.42	.39	.37	.42	.39	.36	.38	.36	.35
	2.0	.45	.42	.40	.44	.42	.40	.44	.42	.40	.41	.40	.39
	2.5	.47	.44	.43	.46	.44	.42	.46	.44	.42	.43	.42	.41
	3.0	.48	.46	.44	.47	.46	.44	.47	.45	.44	.44	.43	.42
$D_{max} = 0.8H_m$	4.0	.50	.48	.46	.49	.48	.46	.49	.47	.46	.46	.45	.44
f_m .65 .70 .75	5.0	.50	.49	.48	.50	.49	.48	.50	.48	.47	.47	.46	.45

The maintenance coefficient will depend on two evaluations: the cleanliness of the classroom (Table N°3) and the type of space where the luminaire is located. (Table N° 2) (Castilla N., 1995)

Table 2. Maintenance coefficient depends on the work environment.

THE WORKING ENVIRONMENT	Fm
Aceria or Fundations	0.65
Welding or machining industries	0.70
Industrial offices or rooms	0.75
Operations courtyards or public locations	0.80
Offices, comercial or computer offices	0.85

Table 3. Maintenance coefficient with respect to the cleanliness of the environment. (Castilla N. 1995)

Rooms	Coefficient of Maintenance
Cleanly	0.8
Dirty	0.6

To calculate the number of luminaries we will use the following formula:

$$NL = \frac{\phi T}{n.\phi L} \tag{6}$$

Where:
NL = Number of luminaries
TΦ = Total luminous flux necessary in the environment
LΦ = Luminous flux of a lamp (obtained from table)
n = Number of lamps that the luminaire has.

Given the formulas, we must consider some necessary input data, such as:
Height of the work plane. (h')
Medium lighting level. (um)
Selection of the type of lamp. Selection of the type of luminaire (obtained from the table) and the suspension height.
Since the environment to be studied is a classroom, the dimensions will be the standard ones of a=12m, b=6m, H=4m.
The other point to consider is the work plane that is used for the Lumens Method in an academic environment. It is located at a height of 85 cm.
Next, we must determine the Utilization Coefficient (Cu) using data provided by the manufacturer of the luminaire based on reflection coefficients and the local k index. Then we must establish the maintenance coefficient (Cm) according to the type of environment and thus find the number of luminaries obtained with the formula previously shown and the verification and verification of results.
For the generation of energy through solar panels (Epv), (Aguirre A. 2012) the following formula will be used:

$$E_{PV} = WMP \; x \; h.p. \; x \; \frac{30}{1000} \quad (7)$$

Where:
WMP = Maximum power generated by the solar panel.
h.p.= Number of peak hours.
The unit of energy generated by a panel (Epv) will be kW/h per month.

4. Data Collection

A compilation and review of the related literature has been carried out. Analysis of the process of the minimum lighting levels in different types of work environments, in this case the most feasible for our research, are presented in Table Nª4.
For college students to have good academic performance, they must have efficient lighting. That is why an intelligent lighting system was developed in the halls.

Table 4. Minimum lighting levels in work environments (García. M. 2007)

WORK SPACE	INTENSITY	CUD_L	R_a
Class of class	300	19	80
Che teachers room	300	19	80
The Reading room	500	19	80
Boards	500	19	80
Teaching workshop	500	19	80
Computing practices laboratories	500	19	80

For the analysis of solar panels and the energy they produce, a compilation of the minimum and maximum values of the solar panel powers of manufacturers worldwide was made. From these power ranges, average values have been obtained for each one. (Aguirre A. 2012), as shown in Figure 4.

Solar panel manufacturers	Minimum	Maximum	Average
Amerisolar	240	330	285
Axitec	250	350	287
Solar canadiense	225	350	292
CentroSolar	250	320	278
ET Solar	255	340	296
Brillo Verde	230	300	266
Hanwha Q CELLS	285	390	324
Hyundai	265	375	346
Kyocera	260	330	295
LG	315	375	346
REC Solar	275	380	236
Silfab	290	380	329
Poder del sol	320	435	353
Trina Solar Energy	260	370	320

Figure 4. List of manufacturers of solar panels worldwide. (Aguirre A. 2012)

In addition, the World Bank published an atlas that indicates the power in kWh produced by solar panels per unit area, depending on the area in which they are located, and the amount of radiation received by said area. (Bermudez K. 2021), as shown in Figure 5.

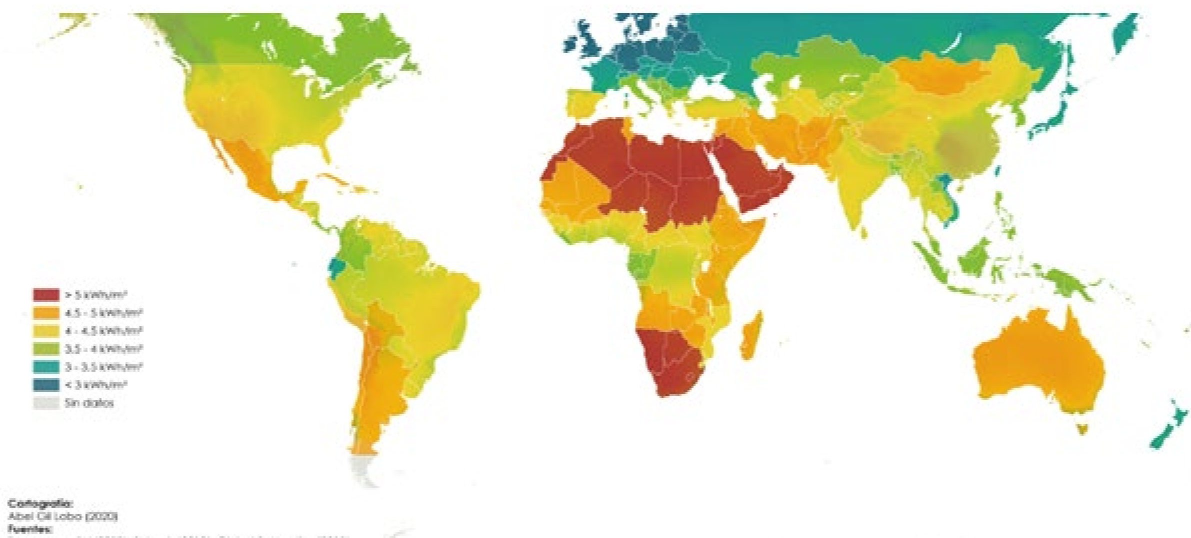


Figure 5. Map of solar energy potential by country (Bermudez K. 2021).

5. Results and Discussion

Solar panels capture enough solar energy to be transformed and self-regulated, so that they can supply, to a certain degree, the higher education center. Likewise, energy reserves are stored in a load tank. The previously stored energy is directed to systems using light sensors, whose operation is linked to and followed by the system code of the Arduino microprocessor. This idea arose to meet the needs of systems that automate the control and development of luminaires that work in a complementary way to natural light during the day; and at night based on this same intensity of sunlight.

5.1 Numerical Results

Number of Lights Required

The minimum required lighting value per room is regulated differently in each country. Taking the "PROJECT REGULATION OF LIGHTING CONDITIONS IN WORK ENVIRONMENTS" of the region, the lumen value required in minimum average (Em) for study areas is 300 lux. (Table 5)

The estimated area for the room where the academic activities will be carried out is the standards: 6.00m x 12.00m, giving 72 m2 of area for which light should be projected. The values of the utilization (Cu) and maintenance (Cm) factors are governed by a global value of k. Knowing that the value of his 3.15 m., the global k turns out to be 1.27. With Table N° 1, we analyze the values of Cu. Regardless of the colors of the walls and ceilings, taking average values, the reflectance factors of both respectively are 50% and 30%, thus obtaining a value of Cu equal to 0.7203.

With Table N°3 we obtain that the Cm is, in the first instance, 0.80; and later, seeing that the space where the luminaire is located is a study room, which can be considered as an office, the Cm is 0.75, according to Table N°2. In the most favorable case, Cm equals 0.80.

According to Formula N°4, the value of the luminous flux in the analyzed classroom is: ϕT =37500 lumens. A T8 luminaire can produce ϕL=2000 lumens. Since we locate two T8 tubes per lamp, the value of n will be 2. And thus, the number of lamps will be approximately N.L. = 10, which, in a uniform distribution throughout the room, can be located as 2 rows of 5 lamps, each one distanced from the other, 2 meters between axes.

Load analysis in a higher education building

The following table presents a summary of the power consumed by LED lamps in a higher education building. Among different types of luminaires, the most optimal for energy efficiency and visual comfort was chosen, the T8 9W LED as shown in Figure 6.

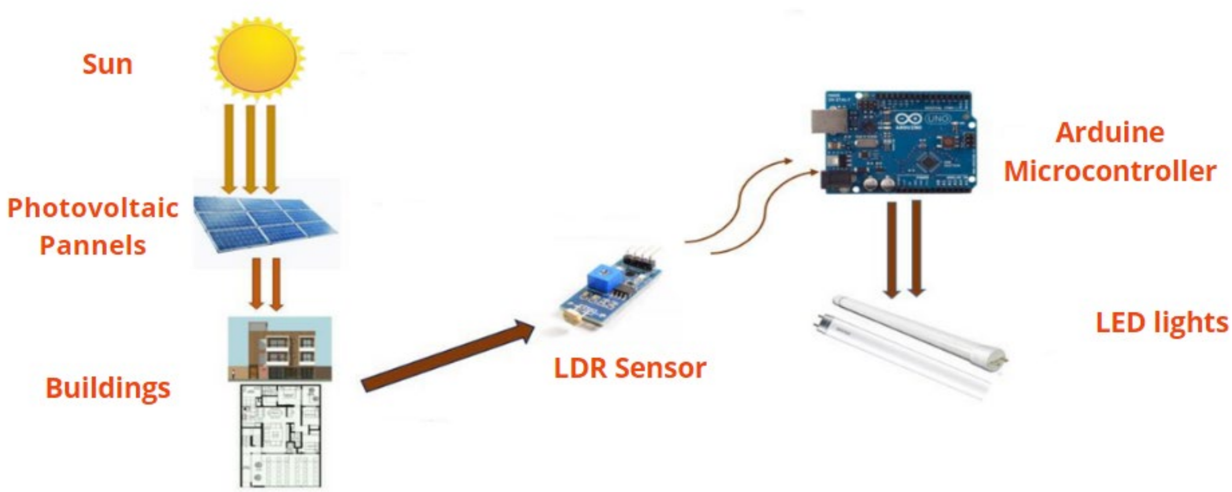


Figure 6. Energy cost reduction system.

TUBE (Castro M. and Posigua N 2015) For all the cases considered, the design of the lighting system implies the installation of 9 luminaries, considering an average 5-story building and, in turn, considering an area of two blocks, the number of classrooms will be 10. (Pineda V. 2008) The total number of luminaries was calculated based on the number of luminaries, classrooms, and floors, resulting in 450 lamps, as shown in Table 5.

Table 5. Total power in a higher education building

Emitter of light	Powered	Quantity	Powered
LED T8 9W	9	500	4500

Given that each lamp has a voltage of 220 V (Fernández-Ahumada L, 2022).

$$I = \frac{4500}{220} = 20.45A$$

With the value of I calculated, now substituting in equation (3)

$$KWA = 5.84(0.8) = 4.68\ KW$$

Energy generated by solar panels

The energy provided by a solar panel depends mainly on the power that the same panel can produce. For this model, we assume an average of the values collected from different suppliers of photovoltaic panels for a model of 60 cells (Fig. 4), giving a maximum average power (WMP) of 300 W. Each cell has a dimension of 156 mm x 156 mm, in a location of 6 rows and 10 columns, we find an area of 1.50 m2. (Aguirre A. 2012)

According to the World Bank (Bermudez K., 2021), in an arbitrary region where the radiation values are the standards for obtaining photovoltaic energy, an energy value of 3.5 kWh/m2 per day is attributed. This parameter of kWh/m2 per day, for design terms, is assumed equal to the number of peak hours per zone. Taking the area of the panel and the value of the energy it produces per unit area in an average radiation zone, according to Formula No. 7, the value of the energy produced by the panel will be 31.5 kW/h per month.

5.2 Graphical Results

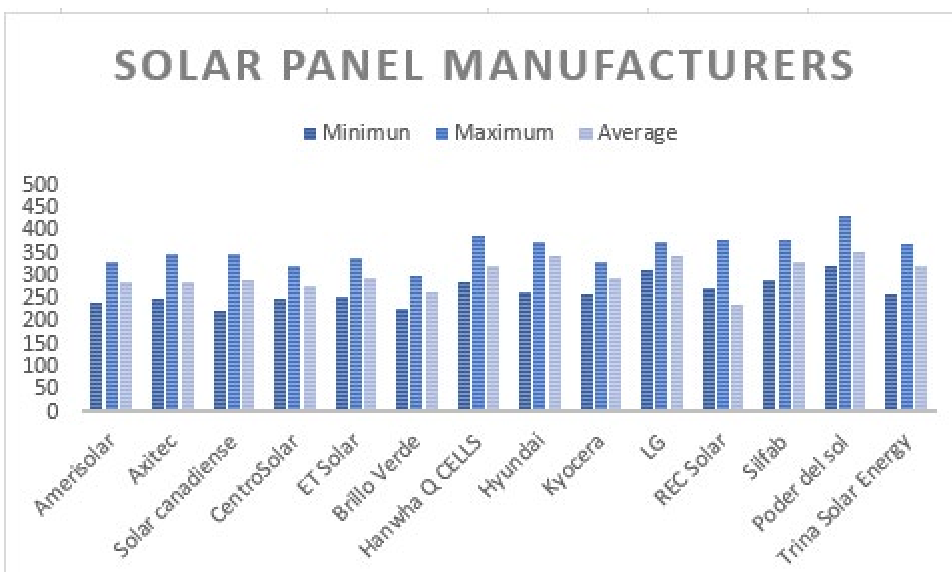


Figure 7. Adapted. Solar panel worldwide manufactures (Aguirre A. 2012)

5.3 Proposed Improvements

We propose using recessed LED panels since they have excellent light distribution, provide not only uniform and efficient lighting, but also reduce visual fatigue, due to their ultra-thin opal diffuser (Castro M. 2015).

We propose the use of T5 LED tubes since they give us an increase in efficiency; they require less energy for their use; they last around 30,000 hours longer compared to fluorescent bulbs, and they do not have mercury like these.

5.4 Validation

With the solar panels, we supply the necessary quantity to the luminaires to be able to regulate a system that mainly does not depend on a single lighting mode, likewise, the sensors, being in an environment with previously parameterized low lighting, send information to be able to self-regulate through the Arduino controllers.

6. Conclusion

In higher education centers it is important to consider the potential for savings with respect to energy consumption, which is emphasized for proper energy management. As seen in Table No. 6, for a certain number of luminaires in each classroom, it is considered 9, therefore, according to formulas No. 2 and 3, a favorable result of 4.68KW was obtained, which can be compared with the amount of power of a building of an education center resulting in 6.47 KW, it can be concluded that there was a saving of 1.79KW thus demonstrating an efficient energy saving.

After having carried out the analysis of the systematization of the automated electrical circuits through an Arduino microcontroller device, it can be concluded that there is an efficient saving in the building. During the day there is less demand for energy which implies a reduction in costs. The Arduino microcontroller system had an efficient optimization in the control of energy use. With the use of solar panels, an energy use of 31.5 kW/h per month is obtained, which contributes to considerable savings in consumption expenses that arrive by receipt at the end of the month.

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