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Rural residential Illumination through the use of solar energy and LED bulbs

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ABSTRACT

Nowadays, LED bulbs are an efficient lighting source, with low energy consumption and with a luminous power equivalent to the existing tungsten filament bulbs. The above, plus its operation with DC voltage, becomes an important advantage in systems that use these bulbs and solar panels as energy supply devices. The present paper presents the design, implementation and analysis of a residential illumination system in an isolated rural zone; this system its composed by solar panels as energy acquisition device, LED bulbs as illumination devices and a rack of batteries as energy storage device, which are in charge of the nightly energy supply.

Keywords: Solar energy, LED bulb, Charge storage, photovoltaic panel.

1. INTRODUCTION

Over the last years, the use of LED bulbs has been increasing, given the evident advantages compared against conventional bulbs. LED bulbs can generate near 85 lumens per watt, which is about a sixth of the energy consumed by a 60 Watt conventional bulb producing the same amount of illumination (Stevenson, 2012). Additionally the lifespan of LED bulbs is much longer.

Following these facts, several researches on the use of these bulbs within everyday activities have been conducted, for example (Kim et all, 2012) presents the design of an ac-dc converter, which derives the energy required to operate these bulbs from the domiciliary electric grid. Also, (Kasuga et all, 2012), presents a study on the generation of electromagnetic noise produced by the ac-dc conversion system and its effects over the environment.

Given that, solar panels delivers energy in direct form DC, the need of a converter in LED illumination systems is not required, besides all the problems inherent to those converters are avoided. These kind of solar panel-LED bulb systems have been gaining attention between researchers, for example at (Ali el all, 2012) and in (Nunoo el all, 2010) systems based in solar panels and LED bulbs are used to illuminate several streets.

However, no researches have been made in order to apply these system in rural areas and this was the primary motivation for the development of this work, which presents a system composed by solar panels, LED bulbs and a rack of batteries, implemented in order to provide illumination to a two ambient rural house.

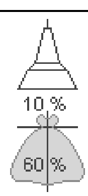
This paper its composed by 4 sections; Section 2 presents the illumination system design, Section 3 describes the implementation of the photovoltaic system, Section 4 presents an analysis of the results obtained from the implementation of the whole system and in section 5 the achieved conclusions are socialized.

2. Illumination system design

In order to calculate the luminous flux inside a chosen area (indoor lighting), the international illumination committee (CIE) establish a series of parameters that must be used to create an accurate estimation of this flux. So, the total luminous flux necessary to illuminate a determined environment is given by equation 1 (Rea, 2000).

$$\Phi T = \frac{E * S}{\eta * fc} \quad (1)$$

Where *E* corresponds to the required average illumination, *S* corresponds to the area that should be illuminated given in square meters, *fc* corresponds to a conservation factor of the place and *n* corresponds to the use factor. The required average illumination *E* its referenced at CIE tables, which are specified in ISO 8995 standard, likewise tabulating the conservation factor. To determine the use factor it is necessary to know the local index *k* which depends on the illumination type and on the lighting area; once determined this factor is obtained using table at Figure 1.

Tipo de aparato de alumbrado	Índice del local k	Factor de utilización (η)											
		Factor de reflexión del techo											
		0.8			0.7			0.5			0.3		0
		Factor de reflexión de las paredes											
		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	.39	.35	.32	.38	.34	.32	.38	.34	.31	.33	.31	.30
	0.8	.48	.43	.40	.47	.42	.40	.46	.42	.39	.41	.38	.37
	1.0	.53	.49	.46	.52	.48	.45	.51	.47	.45	.46	.44	.41
	1.25	.58	.54	.51	.57	.53	.50	.55	.51	.49	.50	.48	.45
	1.5	.62	.58	.54	.61	.57	.54	.58	.55	.52	.53	.51	.48
	2.0	.66	.62	.59	.64	.61	.58	.61	.59	.57	.56	.55	.52
	2.5	.68	.65	.63	.67	.64	.62	.64	.61	.60	.59	.57	.54
	3.0	.70	.67	.65	.69	.66	.64	.65	.63	.61	.60	.59	.56
$D_{max} = 1.0 H_m$	4.0	.72	.70	.68	.70	.69	.67	.67	.66	.64	.63	.61	.58
f_m .70 .75 .80	5.0	.73	.71	.70	.71	.70	.68	.68	.67	.66	.64	.63	.59

H_m: altura luminaria-plano de trabajo

Figure 1: Factor de utilización. Tomado de http://edison.upc.edu/curs/llum/iluminacion-interiores/ejercicios.html

Characteristics of the desired illumination system are aimed to provide nightly illumination to a two-zone, small-size rural house, with dimensions presented at figure 2 and which height is 2 meters. Such measurements along with the lumen method (Chapa, 2004) allow to estimate the average value of luminance; for those measurements a semi-indirect and an indirect illumination local index *k* are established as shown in equation2:

$$k = \frac{3 * a * b}{2 * h * (a + b)} \quad (2)$$

Where *a* corresponds to the area width, *b* to the length and *h* to the illumination source height.

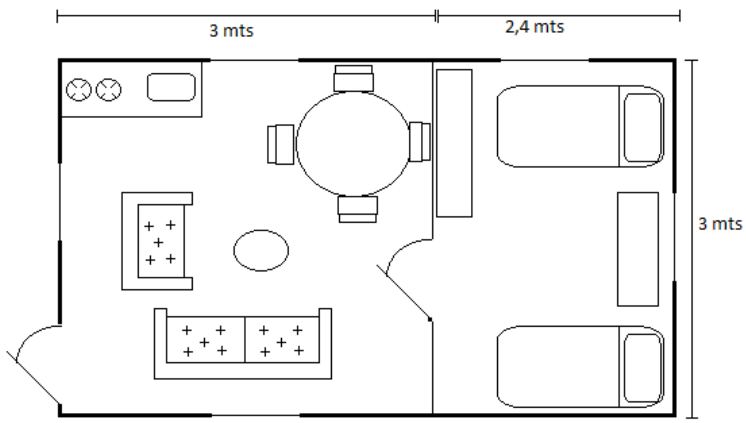


Figure 2: Áreas a iluminar

Since the house has two zones, the calculations for each one are:

A. Room

$$k = \frac{3 * 3 * 2.4}{2 * 2 * (3 + 2.4)} = 1$$

For the ceiling , walls and floor reflection coefficients are taken as 0.5, 0.5 and 0.3 respectively, giving a use factor of *n=0.5.* Taking a conservation factor of 0.8 (which corresponds to a clean structure)

B. Main zone

$$k = \frac{3 * 3 * 3}{2 * 2 * (3 + 3)} = 1.125$$

Taking again the color of ceilings, floors and walls as the base to obtain reflection coeficients, values of 0.5, 0.5 and 0.3 were obtained; given the variation of *k* the new use factor was *n=0.545.* if the the same conservation factor was taken and the average illumination was 200, the total illumination flux is:

$$\Phi T = \frac{200 * 9}{0.545 * 0.8} = 4128.44$$

In roder to build the led bulbs, individual Lambertian, EDIXEON ARC Series, white LEDs were used. These, generates 120 lumens with a 350 mA nominal current. If one bulb is made from 6 LEDs, it could generate 720 lumns, so the required number of bulbs per room is:

$$\text{NB\_room} = \frac{1764.7}{720} = 2.45 \cong 3$$

$$\text{NB\_mainzone} = \frac{4128.44}{720} = 5.73 \cong 6$$

Therefore, the power required to supply nine bulbs is:

$$p = 18V * 0.35 * 9 = 56.7\ W$$

Given that the expected time of use is of about six hours, the consume would be of 340 W per day.

3. Photovoltaic system design

The design of the photovoltaic system allows calculating the number of solar panels required, in function of the solar radiation peak hour (HPS) and the real energetic consume (Er), which is given by equation 3:

$$\text{Er} = \frac{ET}{R} \quad (3)$$

Where ET corresponds to the theoretical energetic consumption of the illumination system, while R corresponds to the efficiency factor of the photovoltaic system, which given by equation 4:

$$\text{R} = (1 - (Kb + Kc + Kv)\left(1 - \frac{Ka * N}{Pd}\right) \quad (4)$$

Kb in systems of deep discharge, takes a value of 0.1,; Kc depends of the inverter, which in this case corresponds to 0, since this is a DC-Dc system; Kv represents the non-characterizable losses, and which values is 0.005; N corresponds to the desired days of autonomy, which is 0.25 for this case; finally Pb corresponds to the daily amount of discharge, which in this case is 0.7:

$$\text{R} = \big(1 - (0.1 + 0 + 0.005)\big) * \left(1 - \frac{0.005 * 0.25}{0.7}\right) = 0.893$$

Then, Er=380 Wh and thus the capacity of the battery rack should be of:

$$\mathrm{CB} = \frac{Er * N}{V * Pd} = 7.54Ah$$

Under these considerations, the number of panels is calculated using equation 5:

$$\mathrm{NP} = \frac{Er}{0.9 * Wp * HPS} = 2.64 \cong 3$$

So, 3 panels of 40W (Wp), and an average of 4 solar radiation peak, are required to operate the system.

4. Results analysis

General scheme of the proposed system is showed at figure 3; for this system several test were made in order to estimate its performance; these test include charge and discharge of the battery rack and behavior under several weather conditions

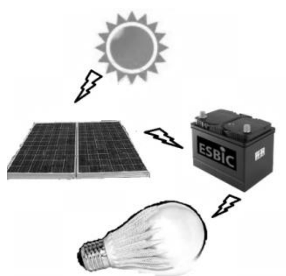


Figure 3: Esquema general

From these tests it was observer that on days with a couple of sunny hours the batteries charged fully, but on partially sunny days (where fuzzy radiation prevailed) it only happens 65% of the time. Some of the most important charging behavior are presented at figure 4, in which its observed these behaviors under three different weather conditions; the first one was a sunny day, in which the batteries fully charged near 2 pm; the second where clouds were present the whole morning until midday, from where solar radiation were at his full, but due to the relative inclination relative to the panels the batteries didn't get fully charged; in order to alleviate this situation, in a day with a similar weather, the panel was inclined 10° on the sun location (afternoon), this time achieving a full charge;

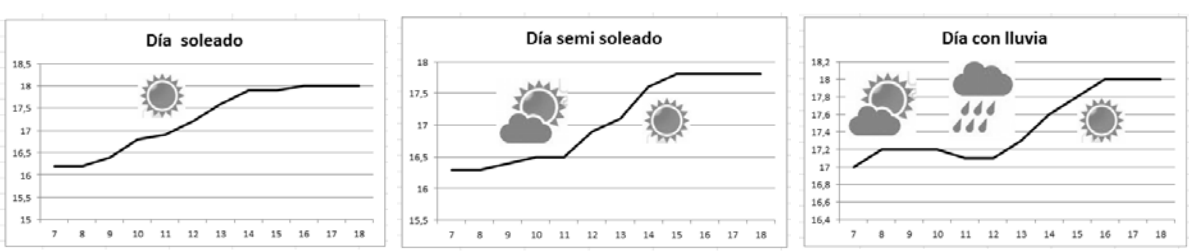


Figure 4: Comportamiento de carga de baterías

System performance was tested through the use of predetermined bulb turning on setups. Three of test that gave the most significant results were: one where the lights of the main zone were on from 6 pm to 12 am; the other in same time schedule, the lights of the rooms were on, and the other were both, the main zone and the rooms light were on; the levels of discharge were respectively 47, 29 and 86%, which means that the system far exceeded the expected operation time, in about 16 %

5. CONCLUSIONS

Calculations for the design of the lighting system so as for the photovoltaic, allowed to obtain a working implementation of residential use for a particular rural environment, energetically self-sustaining.

Variations of the measures of the place changed the lighting conditions inside the home, if the changes are not very significant (about +10% of the dimensions); if the dimensions grow, the approximations made in the calculation of the bulbs allow a good lighting of the room. If instead the dimensions decrease, the obtained design will clearly oversize.

It is expected given the behavior of battery, that in winter times the system can't achieve a maximum load, which will reduce the time for intensive lighting (setup 3). A conventional use which can turn up individually each bulb , clearly increase the energy independence of the system.

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