Chapter

Roof Lighting with Recycled Plastic Bottles

Nancy Varela Terreros and Daniel Espinoza Díaz

Abstract

The carbon footprint currently produced on the planet forces universities and government entities to seek solutions to basic services and other social needs, which are positive with the environment. One of these solutions is linked to indoor lighting without electric power consumption. The Moser lamp offers a solution that takes care of environmental health and at the same time is accessible to social sectors with lower purchasing power. This lamp consists of a water bottle with chlorine exposed to sunlight. The test carried out by the authors collects data that coincide with those obtained by Moser, in the sense that they generate the lighting required for housing. The criteria of the authors are that more controlled trials should be carried out in order to determine the replicability of the exercise, as well as experiment with other elements to obtain chemiluminescence, mainly at night, since the Moser lamp can only be used together with the sunlight. Examples of these elements are luminol and synthetic luciferase and luciferin, which can chemically provide luminescence indoors.

Keywords: Moser, lamps, illuminance, bottles, chlorine, water, sunlight

1. Introduction

According to data from the Latin American Energy Organization (OLADE), in Latin America, there are areas that still lack electricity supply [1]. Simultaneously, there is a growing carbon footprint in the region [2], while the entire population does not have the basic economic means for subsistence.

The above is evident in Ecuador, where there is no 100% electrical coverage, mainly in rural areas [3, 4], and there is a significant percentage of the population that fails to cover the basic basket of foods. This indicator refers to the set of goods and services that are essential to meet the basic needs of the typical household composed of four members with 1.6 income earners who earn the unified basic remuneration [5]. In this context, it is imperative to propose solutions for the satisfaction of basic services that are friendly to the environment.

This document analyzes the proposal for an alternative solution to the supply of electricity, low cost and made with recycling materials. This is the Moser lamp, designed in 2002, by the Brazilian mechanic Alfredo Moser, who devised a lighting system made with plastic bottles, water, and chlorine [6].

The objective of the chapter below is to analyze the viability of this system in Ecuador. For this, its theoretical foundation and the possibilities of its use in the country are analyzed. The chapter also presents the results of an experimental test carried out by the authors, in a controlled environment.

2. Socioeconomic context

2.1 Electricity coverage in Ecuador and Latin America

OLADE defines the electric coverage indicator as the total observation units served divided by the total observation units in the country, according to Eq. (1):

$$IC_j = 100x \frac{j_{EE}}{j_T} \quad (1)$$

where
IC_j coverage index with reference to the observation unit *j*
j observation unit: houses, homes, or people
j_{EE} number of observation units with electricity service
j_T total number of observation units

According to OLADE, for the year 2010, in Latin America, the percentage of electrical coverage is calculated from the number of electrified homes with reference to the number of occupied homes. The highest percentage was 99.75% for Uruguay. According to this study, Ecuador had a coverage of 93.35% for the year 2010. Among the 27 member countries, 13 countries have coverage greater than 95%, 4 have coverage between 90 and 95%, 8 have coverage between 75 and 90%, while 2 countries have coverage below 75%: Nicaragua, 60%; Haiti, 28%. The overall percentage for the region is 92% [1].

In Ecuador, according to the official data presented by the Electricity Regulation and Control Agency (ARCONEL), the annual coverage of the electric service increased between a national total of 93.80% for the year 2008, and 97.33% for the year 2017 [3]. These data are consistent with OLADE, and with those obtained by the National Institute of Statistics and Census (INEC), which indicate that the electricity service by public grid for the year 2014, at the national level was 98.4%, breaking down this percentage into 99.7% for the urban area and 95.6% for the rural area [7].

The analyzed data indicate a reality: there is no total coverage of the electricity service in the Latin American area in general, and in Ecuador, in particular, and as indicated by census data, this lack of coverage would occur mainly in the rural area. As a comparative fact, note that by 2014 the water coverage by public network in the urban area was 92.5%, while in the rural area that coverage was 46.0%, that is, half that in the urban area The sewer system by public network had a coverage of 77.1% for the urban area and 22.3% for the rural area [7]. This scenario occurs in a country where the National Basic Basket of Foods is USD 735, with an estimated minimum monthly electricity consumption of USD 15, and a unified basic salary of USD 396 [5].

2.2 Carbon footprint

Belmaña defines the carbon footprint as "an indicator that allows accounting for all greenhouse gases emitted by direct or indirect effect by an individual, organization, event or product" [8]. In relation to the production of CO_2 that is generated as a function of electricity consumption, Ignacio Cruz found in his study conducted in Mexico D.F. that, in residential consumption, the production of CO_2 went from 3.7 tons for the year 1990, to 4.4 tons in the year 2010 [9]. If it is estimated that a 50-watt bulb lit for 14 hours a day for a year produces 200 kg of CO_2, and it is expected that in his daily life a person will light more than one bulb at a time, it is of interest to find an alternative system for domestic lighting.

The World Bank, for its part, points out which main countries are in relation to the production of the carbon footprint. The highest value is presented by Qatar in 2014, with 43.9 metric tons per year per individual, while for that same year the lowest values are shared by Burundi, Somalia, and Sudan, which register zero production, and Chad, Democratic Republic of the Congo, Ethiopia, Madagascar, Malawi, Mali, Niger, Central African Republic, Rwanda, South Sudan, and Uganda, with 0.1 metric tons per year per individual. Ecuador has a production of 2.8, which is consistent with the average of Latin America and the Caribbean, of 3.1, for the year under study [10].

2.3 Proposal of a lighting system

With this background, this research is outlined on a natural lighting system, which reduces the cost of housing for low-income families, and that simultaneously supports the reduction of the carbon footprint on the planet, through the use of recycled plastic bottles and chlorine for daytime lighting. This system does not produce CO_2, and its cost is minimal in relation to electricity consumption, since only 10 ml of chlorine is required for the production of a light unit or bulb. It is estimated that in Ecuador the gallon of chlorine has an approximate cost of 2.50 USD, while electricity costs around 0.08 USD/kWh at the lowest level of consumption [3], as of the date of the present study. The practical reference used is the Moser lamp, authored by the Brazilian Alfred Moser. The test detailed below will be based on this reference.

The beneficiaries of this research are expected to be:

- The inhabitants of rural areas in Ecuador that are not connected to the public lighting network, or who want an alternative lighting system in order to reduce housing maintenance costs

- Companies that want to innovate in lighting their roofs, warehouses, or storage sites

- People without lighting service, anywhere on the planet

3. Moser lamp

Alfredo Moser is a mechanic from Sao Paulo, Brazil, who designed a lamp that works without electricity. The formula proposed by Moser consists of filling a recycled plastic bottle of 2 L with water, plus 10 ml of chlorine, and placing it in the hole in the roof of a house [6]. According to an interview conducted by the BBC in 2013 to the inventor of this technology, a lamp so designed produces between 40 and 60 watts, depending on sunlight. According to the BBC, this invention has already been implemented in the Philippines, where 140,000 homes benefit from this new technology. It has also been implemented in other countries such as India, Bangladesh, Tanzania, Argentina, and Fiji [11].

Although the cost of implementing this technology could be subsidized by the government, the criteria of the authors of this research is that this lighting solution may well be assumed by the beneficiary families themselves, as it is based on the use of components within reach of most of them:

- Recycled bottle of 2 L: this element can be acquired for this object or achieved by recycling own bottles or other people's bottles. In this sense, the user can also be part of the solution for recycling other users' plastics.

- Chlorine: 10 ml of chlorine is required to achieve the illuminance corresponding to a focus between 40 and 60 watts. In a minimum housing unit of 40 m^2,

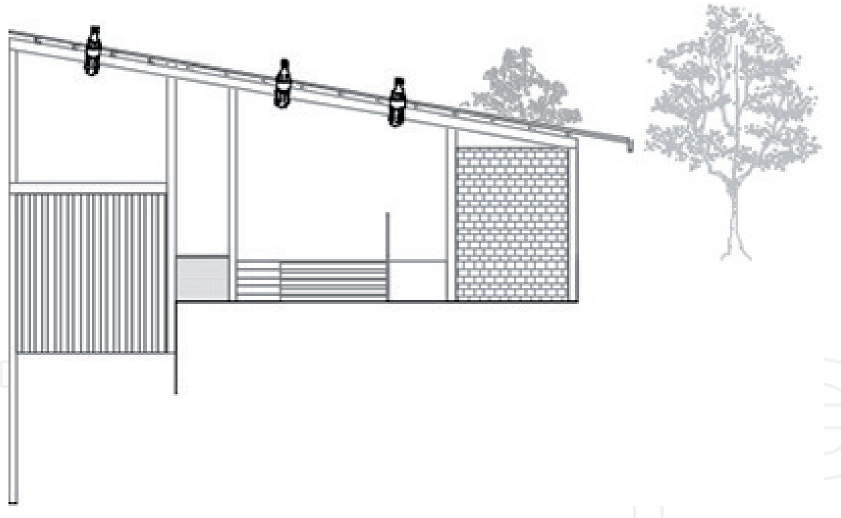

Figure 1.
Scheme of the use of the Moser lamp.

10 bulbs of 40 watts, that is, 100 ml of chlorine, can be used to generate acceptable illuminance. Since the gallon of chlorine, or 3785 ml of this chemical, has an average cost of USD 2.50, the cost necessary for this component of the total lighting of the house is less than USD 0.10, which is affordable for a family of limited resources.

- Water: based on the premise that homes are connected to the drinking water system, it is expected that they can achieve this component easily and economically. In addition, rural areas of Ecuador are geographically close to rivers and other bodies of raw water that can provide free supply to areas of extreme poverty that have no supply from the public drinking water network (**Figure 1**).

4. Carbon footprint in Ecuador

According to the World Wild Fund (WWF), the ecological footprint "adds all the ecological services that people demand that compete for space" [12]. In Ecuador, the Ministry of Environment notes that "the ecological footprint measures the amount of biologically productive land and water that an individual, a region, all of humanity, or a certain human activity requires to produce the resources it consumes and absorb the waste generated" [13]. One of the components of this ecological footprint is the carbon footprint. The Economic Commission for Latin America and the Caribbean (ECLAC) accepts the definition of carbon footprint as "the amount of emission of gases relevant to climate change associated with the activities of production or consumption of human beings" and also indicates that this is the "amount of tons or kilos of carbon dioxide equivalent of greenhouse gases, produced every day, generated from the burning of fossil fuels for energy production, heating, and transportation among other processes" [2].

In Ecuador, according to the Ministry of Environment, the ecological, individual footprint of an Ecuadorian, until 2013, was 1.8 times lower than the world average. However, within this component, the carbon footprint comprises 42% of the total [13]. Hence, it is important to review the production of this component, based on environmental care.

5. Test performed

As part of this research process, the authors conducted a test in order to verify the effectiveness of the Moser lamp. The test consisted in the elaboration of a scale model elementary dwelling, made with basic materials, on whose roof three plastic bottles of the Moser type were placed in order to measure the luminescence inside the building.

The elements that were used were:

- Materials for scale model dwelling: the housing model was built with a wooden recycling structure. The roof was made with pressed cardboard structure and plastic cover.
- Bottles: the bottles used were 250 ml plastic containers for recycling.
- Chlorine.

The experiment sought to measure the luminescence produced by means unrelated to electrical energy and compare it with that produced by natural light.

The first references to luminescence were made by Eilhard Wiedemann in 1988 and Henry Joseph Round in 1907. Luminescence is defined by the EcuRed online encyclopedia as "the emission of light by a substance without being motivated by heat, so it is a form of length in cold" [14]. The Wolfram scientific dictionary defines it as "any process in which energy is emitted from a material in a wavelength different from that to which it is absorbed" [15].

Since the experiment sought to produce a light emission, the measurements were made in lux (lx), which is the unit of the International System of Units (SI) that measures the level of illuminance and is equivalent to lumen/m^2. The lumen (lm) is the SI unit that measures the luminous flux, which is a measure of the perceived light output. Contextualizing, according to the Spanish Lighting Committee (CEI), natural light outside produces "approximately 1000–2000 lux on a gray day and 100,000 on a sunny day" [16]. The Ecuadorian Construction Standard (NEC) recommends a minimum lux level of 100 for bedrooms and a maximum of 750 lux, for study or work rooms [17].

A Moser type test was performed to produce luminescence inside a home. An experimental house was built, and the illuminance was measured in the following situations:

- Outside, on a sunny day, prior to the test.
- Inside, before performing the test
- Inside, performing the test only with water
- Inside, performing the test with water and chlorine

The equipment used was a cell phone that used the Spectrum Genius Mobile Plus (SGM +) application of AsenseTEK, which is a free software used for lighting measurement. Since this is not a lux meter, 100% or accuracy should not be expected.

The test was carried out outdoors, at an altitude of 37 m above sea level between 1:00 pm and 2:30 pm on a sunny day. The results obtained were (**Figures 2–5**):

Figure 2.
Scale model of the house, without roof, used in the test.

Figure 3.
Scale model of the house, with roof, before the test.

Figure 4.
Test with one bottle of water.

Figure 5.
Test with three bottles with water and chlorine.

- Outdoor measurement:
    - 147.743 lux (13h23)
    - Range between 46.781 and 48.852 lux (13h44)
    - 136.453 lux (14h11)
    - 67.455 lux (14h21)
- Measurement inside, before carrying out the test:
    - 9 lux (13h23) unsupported measurement equipment
    - 28 lux (13h37) measurement equipment on the floor
    - 64 lux (13h37) measurement equipment supported on the roof beam
    - 16 lux (13h44) unsupported measurement equipment
    - 26 lux (14h11) measurement equipment on the floor
    - 72 lux (14h11) measurement equipment supported on the roof beam
- Measurement outside, with bottles filled with 200 ml of water:
    - 853 lux (13h40) with one single bottle
    - 924 lux (13h42) with two bottles
- Measurement outside, with bottles filled with 200 ml of water plus 10 ml of chlorine:
    - 1739 lux (14h13) with three bottles
    - 1033 lux (14h12) with two bottles

From what has been observed, the illuminance value obtained on average with the use of chlorine, and without the use of chlorine, is within what is required for indoor lighting. However, as a continuous solution, it is appropriate to use chlorine to prevent the proliferation of bacteria inside the bottle that would dull the reflection of light.

6. Conclusions

There are three positive conclusions obtained from the test performed:

- The production of luminescence is the result only of the interaction between water and the sun, with the participation of chlorine to prevent the flowering of bacteria. In addition, it was experimentally proven that although there was significant illuminance only with the use of water, it was superior if chlorine was added. None of these elements result in the production of the carbon footprint. Therefore, its use is feasible and positive in relation to the care of the environment.

- The material used for the bottles was recycled, and as stated earlier, water in rural areas is freely accessible to many families or has a low cost. For research, only a minimum value was invested for the acquisition of chlorine. This means that families with lower resources have, in Ecuador, the option of using this alternative to avoid or decrease the use of electric energy for lighting inside homes. This can be used in remote rural areas, where by the year 2019 there is no 100% coverage of the electricity service. This study has not analyzed the socioeconomic reality of other Latin American countries; however, it is expected that it can be used in other sectors of the region, with the unmet need for lighting at home and with low economic resources.

- The previous conclusion implies a reduction in the basic basket of food as the cost of electricity is reduced and in extreme cases, the cost of installing the electricity service. Even if only this alternative is used for lighting, while using electric power for other daily activities, this use reduces the monthly cost for electricity consumption.

- The material used is not flammable; therefore, the risk of fire, which all electrical connections entail, is reduced. This point is of special interest in rural areas, which may be more prone to such events.

A negative conclusion that should be considered is that this solution is only viable during daylight hours, since it depends on sunlight outside. Therefore, the position of the authors is that more studies should be carried out on this subject. It is possible, for example, to find sources of luminescence through the use of luminol or with the use of synthetic luciferin and luciferase, among other chemical reagents that produce longer lighting time and which, being the result of a chemical reaction, do not require sunlight.

7. Recommendations

- The perforations of the ceiling plates selected for lighting should be completely covered, in order to avoid subsequent damage to the roof, the entrance of insects, or other small animals to the house and avoid rain or snow filtration.

- The correct bottle size must be studied so that the roof does not collapse due to fatigue. A maximum size of 2–2.5 L is viable without reinforcement. For a larger size, it is suggested to reinforce the support structure.

- It is suggested to study the position of the sun with respect to the house to be illuminated in order to find the appropriate angle that generates efficient lighting.

- The test was carried out with colorless, transparent plastic. The point of view of the authors is that a colored plastic would produce less lighting. Its use is not suggested for this system.

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