Implementing a Mobile Application for Street Lighting Evaluation

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Abstract

Nowadays, energy consumption is on the rise. This is not sustainable in the long run. The highest energy use in Town Councils takes place in street lighting installations. In order to help in this problem, we present a mobile service to evaluate the electrical consumption of these infrastructures. This new tool is able to make an estimation of energy demand of installations; on an easy and intuitive way thanks to an evaluation methodology which reduces the need of a large list of parameters used by other programs. As a result, the developed application also gives users the opportunity to compare the efficiency of the installation evaluated with others previously evaluated to increase energy efficiency. The application was tested with two different experiments to ensure its correct running and to evaluate both the estimation accuracy and usability.
Keywords: Energy Consumption, HTML5, Smartphone, Usability.

1. Introduction

Energy saving has become the most urgent environmental problem to be addressed by all societies. Street lighting is one of the main energy consumption in local governments. It typically accounts for 30-60 percent of greenhouse gas emissions [20]. Nevertheless, evaluation and operation of electric lighting design shows that the improvements could save up to 50% of energy [14]. There are many possibilities to achieve this reduction, such as reducing high illumination level, improving quality of lighting, removing light pollution or changing standards [4]. However, these improvements often require large investments, complicating their implementation.

At present, the average consumption of Spanish lamps is one of the highest in the European Union countries, with an approximate consumption of 157W per lamp, well above United Kingdom, 76W, or Netherlands, 61W [17].

Once the government realized this overuse, the Royal Decree 1890/2008 [16] was established to improve efficiency and energy saving. However, not all the Autonomous

Communities have implemented dimmable lighting systems as Andalusia, where the percentage of installations without this system obligatory is 64% [8].

Another possible cause of the problem about the excess of energy consumption could be the lack of awareness of maintenance managers. To solve this, there are some programs to calculate the efficiency of energy consumption, but all of them have been developed as computer applications and not mobile phone. However, Town Councils do not take advantage of them, sometimes because of the lack of qualified employees or because the program is only linked to a specific manufacturer, limiting a full performance.

Keeping in mind that mobile systems, such as smartphones, have become the primary computing platform for many users [2]. We have developed a mobile application which estimates electrical energy consumption on street lighting installations, independently of manufactures, and gives the opportunity to compare with other.

The purpose of this system is to give users the possibility to make an estimation of the consumption of installation in a simple and intuitive way. To check the correct running of the application developed, it was tested in two different ways: an evaluation of the estimation accuracy with real installations, and a study of the usability of this tool.

2. Related Work

Nowadays, there are plenty programs to evaluate energy consumption in buildings. However, similar systems applied to street lighting are not common and, in most of cases, the level of knowledge required is too high. So far no mobile applications are known. Nevertheless, the study of the existing programs can be used as a base to improve the application scope.

One of the most renowned programs is DIALUX, which allows creating a 3D virtual world where real lighting effect may be recreated. It also gives information related to power consumption of each element to guarantee the compliance of regulations [7]. The strength of this tool is the database with information from the main lighting manufacturers, providing more accurate evaluations.

Another tool is CALCULUX, helping lighting designers to select and evaluate lighting systems [12]. The program allows predicting financial implications; including energy, investment, lamp and maintenance costs for different luminaire arrangements. Although, it main weakness again is the exclusive relation with Philips products.

RELUX is a light calculation program. It is based on the solid angle projection procedure, to calculate street lighting as per different standards in order of the kind of lighting evaluated. In the case of street lighting the normative used is EN 13201[3].

After studying the features of them, it was observed that their complexity was not compatible with mobile devices. In this context, usability and compactness of the information displayed has a significant role.

The main usability hurdles for mobile devices are small screens, awkward input, download delays and mis-designed sites [15]. Knowing these disadvantages, before starting to develop the application, it is necessary to perform a study to reduce as much as possible the information needed to make the evaluation. Therefore, a study was conducted to obtain the minimum requirements to make a correct evaluation.

3. Energy Consumption Analysis

The methodology used to estimate the electrical energy consumption of street lighting systems is as follows: Firstly, it analyzes the main components which affect to the energy consumption. Secondly, it describes how the application calculates the electrical energy consumption.

3.1. Components Influencing Energy Consumption

Street lighting installations are mainly formed by lamps, ballast, street lighting control system and dimmable lighting system. To ensure about the influence of each one in final energy consumption, they have been studied individually.

The most important component in street lighting is lamps. Depending on the technology used, different sorts of lamps can be found: stand mercury vapor, high pressure sodium, low pressure sodium, high pressure ceramic metal halide and led lamps. Each kind has a different response to external factors [22]. After studying them, it was discovered that the most important factor is the lamp voltage, which defines the final lamp power. This factor influences differently depending on the type of lamp.

Analyzing the voltage separately shows how this factor is not constant over time. The fluctuations on voltage may vary the power of the lamp up to 0.5% [19]. In spite of nominal voltage is 220V, the fluctuations may even reach values up to 249V. This overvoltage situation shortens the lifetime of lamps, dissipating more power than its rated power.

To solve overvoltage problems, street lighting installations use dimmable lighting systems, which are able to control the voltage. At present, these systems allow saving energy thanks to the configuration of the input voltage, being capable of reducing it based on some parameters like traffic flow or weather conditions [23]. All these features enable the evolution to adaptive lighting systems where the luminous flux of the installation can be controlled. The minimum luminous flux level was established on 50% because this dimming has no influence on observers and drivers visibility [1].

Another component associated with the consumption is ballasts. This device is required to control the lamp. There are three sorts: electromagnetic, inductive and electronic. In spite of the main difference between them is the electrical energy consumption, there are other differences to be taken into account, such as losses caused by iron and copper or losses in the magnetic choke [18]. If the value of the power associated to this element is unknown, the Royal Decree defines a maximum value depending on the sort of lamp.

The running time of the installation is managed by the street lighting control system. There are two different options in the market: astronomic time switch, twilight switches. The burning hours of the devices is different due to the differences on working criteria on the devices. While astronomic time switch allows controlling the switch on and off according to sunrise and sunset hours [21]. Twilight switches measures the amount of natural light available and turns on and off the lamps on a specific level of light [10].

3.2. How the Application Calculates the Electrical Energy Consumption

After understanding the performance of the components which affect in energy consumption, an estimation of total energy consumption can be calculated. To do this, the methodology used estimates the final consumption of installation as the sum of all of the streetlights. To calculate the energy of each luminaire, knowing the ballast power ($P_{ballast}$) is necessary, but also the nominal lamp power (P_{lamp}), the impact of the current voltage over it (V_{impact}) and the number of burning hours (N_{hours}), as is shown below:

$$E_{consumption} = \left(\left(P_{lamp} * V_{impact}\right) + P_{ballast}\right) * N_{hours} \tag{1}$$

4. Proposed System

To evaluate the energy consumption, a new application (SOLE - System to evaluate the Outdoor Lighting Energy demand) is proposed in this paper. The application has been developed as a Smartphone application, so that maintenance managers can conduct energy-estimating operations easily and quickly. The main aim of this application is to evaluate street lighting, showing the prediction of energy and number of burning hours. To create energy awareness, the tool also shows a comparative chart in which the average of their power lamps is compared with other evaluated by the system. The application architecture and its use are explained in the following sections.

4.1. Application Architecture

The main problem observed to develop a mobile application is the number of existing platforms in markets. The variety of systems hinders developing native applications valid for all devices due to their differences on programming languages [5].

Developing native applications has, in some cases, a cost associated with the development and deployment in certain platforms. However, mobile applications built on HTML5 allow cut down the development time and cost with the advantage of being portable not only between mobile platforms, also giving the opportunity to develop a webpage, which can make the application available to be used by mobile devices without having to install new programs. Nevertheless they also have some limitations. While HTML5 offers many JavaScript APIs that give access to several device services, the reality is that their implementation in mobile devices is not always complete [9]. Maybe HTML5 applications do not achieve the same performance as native applications, but the lower cost and cross-platform availability of web applications are clear advantages [11]. For these reasons, and after analyzing the needs of the application, we have created a new HTML5-based mobile application where the user can check the energy behavior of a street lighting installation.

The most important factor for mobile users is the battery life [13]. For that reason, and to ensure the computation of the energy evaluation is not too intensive to be performed on a mobile device, the computation is performed in the server. In this way, the changes made on the database or on the calculation methodology do not affect the application behavior.

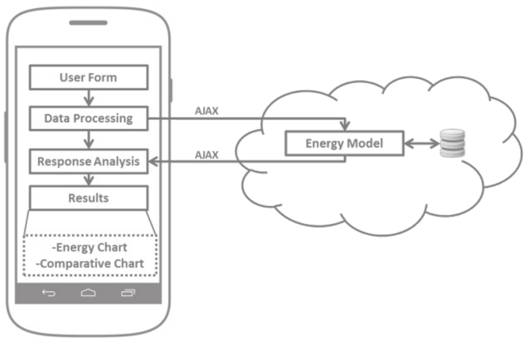

Fig. 1. App Architecture

4.2. Displaying Energy Consumption

The first screen shows an introduction of the tool, where you can find also information related to the aim of the application (figure 2(a)). It is possible to come back to this screen from anywhere of the program thanks to the navigation toggle button placed at the top of the screen.

When users start the installation evaluation of the installation, the first thing to do is to register all the features of the equipment devices (city, lamps and so on) by means of the form showed on figure 2(b). As it is known, the screen size may hinder the input of data. For that reason, the form was divided into three different parts. Thereby the user has to pass through them to enter all the information.

When the information is set, the application sends the information to the server and waits for the energy evaluation. After receiving the server's response, the user obtains the results. The intention is that the incorporation of simple interactive graphics, which are supplemented by small portions of relevant information, gives users the opportunity to check the data [6]. As it happens with the input form, the result has been divided into two different screens to simplify the use of the tool. To switch between these options, two buttons are placed, one for each section of results:

- In the first section, two charts with the information about the energy consumption and the burning hours can be observed. If the user introduces real consumption values, these data will be shown in the same chart together energy estimation (Figure 2(c)).

- The last section shows a comparison between the average of power per lamp of the infrastructure and the average of other installations of the same province which has been previously evaluated by the system. Besides the chart, the distribution of lamps according to the kind of technology used is shown (Figure 2(d)).

(a) Index (b) Input Form (c) Energy evaluation (d) Energy comparison

Fig. 2. Application screenshots

5. Results and Discussion

Two experiments were conducted to evaluate the application from the following viewpoints:

- **Capability to evaluate energy consumption:** Could the application estimate energy consumption of street lighting installations?
- **Usability for sustainable operations:** Is the application easy and interesting enough to be used as an energy evaluation tool?

5.1. Capability to Evaluate Energy Consumption

To answer the first question, it was obtained information related to street lighting installations in 4 different municipalities (Villaluenga de la Sagra, Tielmes, Tardajos and Rabanales) in order to check the application. The collection of information related to energy consumption was obtained thanks to energy bills. It is worth stressing the absence of dimmable systems in all the installations evaluated. Once the information was collected, the main drawback observed in most cases was the lack of information related to the number of burning hours, or the information about the ballast power. In these cases the application solves the problem giving an approximation of these values thanks to the study made previously about each device.

As a result, an average error produced on complete simulations up to 5% was observed. On the other hand, when the data has lack of information about the installation, the error could increase up to 10%. That error may be due to different factors such as fluctuations on voltage or the characteristics of components. Figure 3 shows a chart with a real comparison between the energy estimation and the real energy value on the municipality of Tardajos, Burgos.

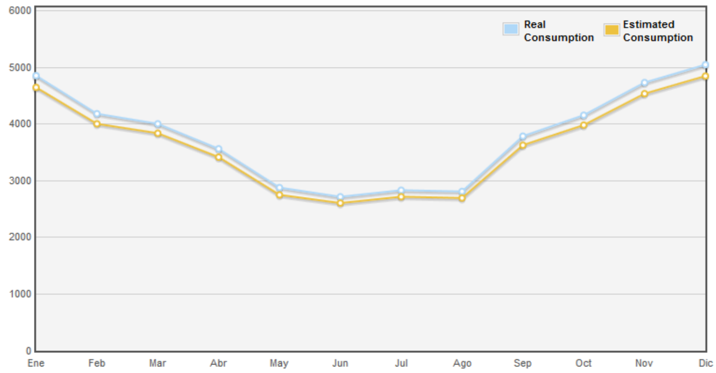

Fig. 3. Differences between estimated and real energy consumption in the municipality of Tardajos, in the province of Burgos

5.2. Usability for Sustainable Operations

The next experiment was made in order to check the level of users' acceptance of the tool, where 8 subjects tested the tool. To be sure about the understanding of the developed application, the selected users have different levels of knowledge about street lighting.

During the experiment, a sheet with different parameters of an installation was given to users, who had to introduce the information in the application. To analyze how users insert the information, the sheet had more information than required on the application form. The experiment was carried out using two devices with different characteristic with the purpose of obtaining more information about the influence of the screen size on the usage of the tool. Each user performed the experiment only with one of the devices. The devices used were:

- 7 inches tablet (BQ Pascal Lite C).
- 3.5 inches smartphone (Samsung Galaxy Ace).

Once the experiment finished, the users had to fill out a questionnaire with several questions to evaluate and give their opinion about the application.

Thanks to the questionnaire, we have realized that difficulty of use increases when the device has a small screen. The main reason is the need of use the keyboard, which occupies most of the screen; and the presence of a list of buttons at the bottom of the screen, which hampers displaying the form fields. In spite of that, it is important to highlight how users qualify the complexity of use as medium (3), even with low knowledge about street lighting. The 60% of the respondents highlight how the interface is helpful to follow the steps to complete the experiment.

When they were asked about the result of the evaluation, 75% of the respondents indicated as high point the quality of the charts, which gives the opportunity to display information by month just touching the value points. Moreover, the interviewed stand out that this developed tool should raise the energy awareness. Figure 4 shows the main results of the questionnaire made following the Likert scale.

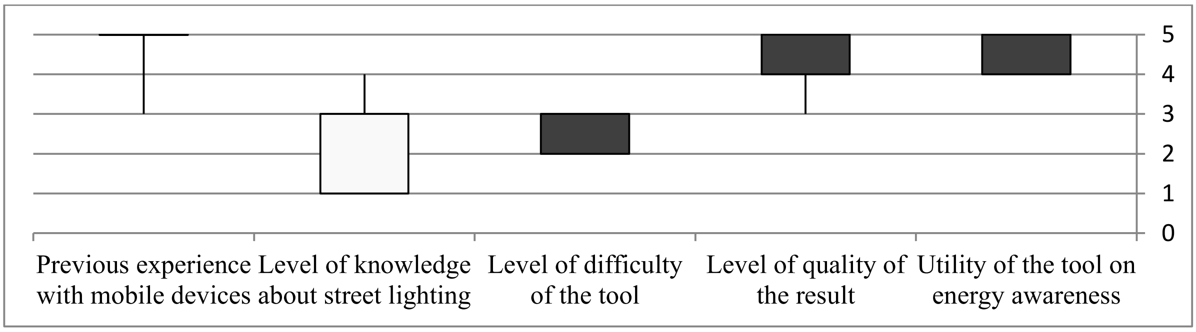

Fig. 4. Results of the questionnaire evaluated using a Likert scale (1-Low, 5-High)

6. Conclusion

High energy consumption of street lighting systems has propitiated the development of programs to evaluate them. However, their complexity makes difficult their use by inexperienced users. These programs create a simulation of a detailed scenario to be able to perform the evaluation, needing the input of a long list of parameters, most of them without impact on energy consumption.

The main benefit is the contribution of an unique mobile application, known as SOLE (System to evaluate the Outdoor Lighting Energy demand), which simplifies the evaluation of street lighting energy consumption. The result is a manageable and intuitive application that estimates the electrical energy consumption and the number of burning hours without the influence of a specific manufacturer. It should be noted that the comparison chart among installations was the better evaluated in the form because users realize of their real situation.

Throughout the experiment conducted to check the usability of the tool, we observed how an intuitive interface may help users to solve the drawback of a low level of knowledge on street lighting installations.

Finally, we would like to point out how the size of the screen was the main drawback to be solved on the developing stage. As a result on the last test we realized that the complexity of the application increases when users use a device with small screen. The main reason is the need to use the keyboard and a list of buttons at the bottom of the screen, thus hampering the display of the fields.

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References

1. Bacelar, A.: The influence of dimming in road lighting on the visibility of drivers. J. of Light & Visual Environment. 29 (1), 4-49 (2005)
2. Bajad, R. A, Srivastava, M., Sinsha, A.: Survey on Mobile Cloud Computing. J. Engineering Sciences & Emerging Technologies. 1 (2), 8-19 (2012)
3. Bhavani, R.G., Khan, M.A.: Advanced Lighting Simulation Tools for Daylighting Purpose: Poweful Features and Related Issues. J. Trends in Applied Sciences Research. 6 (4), 345-363, (2011)
4. Boyce, P. R., Fotios, S., Richards, M.: Road lighting and energy saving. J. Lighting Research & Technology. 41 (3), 245 – 260 (2009)
5. Charland, A., Leroux, B.: Mobile application development: web vs. Native. Communications of the ACM. 54 (5), 49-53 (2011)
6. Costello, G.J., Clarke, R., Donellan, B., Lohan, J.: Development of a Prototype Knowledge Discovery Portal for Energy Informatics. In: Proceedings of the 20th International Conference on Information Systems Development, pp. 129-141. Springer, Edinburgh (2011)
7. Gómez-Lorente, D.: A new methodology for calculating roadway lighting design based on a multi-objective evolutionary algorithm. J. Expert systems with applications. 40 (6), 2156-2164 (2013)
8. Guia de ahorro y eficiencia energética en municipios (2011) (Guide of saving and energy efficiency in municipalities), (in Spanish). http://www.agenciaandaluzadelaenergia.es/sites/default/files/guia_de_ahorro_y_eficiencia_energxtica_web_def1.pdf. Accessed March 10, 2014

9. Hemel, Z., Visser, E.: Declaratively Programming the Mobile Web with Mobl. In: Proceedings of the 11th International conference on Object oriented programming systems languages and applications, pp. 695-712. ACM, New York (2011)
10. Howell, E.K.: Photoelectric controls for street lights. J. Electrical Engineering. 80 (10), 780-785 (1961)
11. Juntunen, A., Jalonen, E., Luukkainen, S.: HTML 5 in Mobile Devices -- Drivers and Restraints. In: Proceedings of the 46th Hawaii International Conference on System Sciences, pp. 1053-1062. IEEE, Wailea (2013)
12. Kostic, M., Djokic, L., Pojatar, D., Strbac-Hadzibegovic, N.: Technical and economic analysis of road lighting solutions based on mesopic vision. J. Building and environment. 40 (1), 66-75 (2009)
13. Kumar, K., Yung-Hsiang, L.: Cloud Computing for mobile users: can offloading computation save energy? Computer. 43 (4), 51-56 (2010)
14. Loe D. L.: Quantifying lighting energy efficiency: A discuss document. Lighting Research & Technology. 35 (4), 319-329 (2003)
15. Nielsen, J., Budiu, R.: Mobile usability. New Riders, United States (2013)
16. Real Decreto 1890 (2008). Reglamento de eficiencia energética en instalaciones de alumbrado exterior. (In Spanish) (Royal Decree 1890. Energy Efficiency for Outdoor Lighting Installations). http://www.boe.es/boe/dias/2008/11/19/pdfs/A45988-46057.pdf. Accessed March 10, 2014.
17. Sánchez de Miguel, A.: Differential Photometry Study of the European Light Emission to the Space. In: Proceedings of World Conference in Defence of the Night Sky and the Right to Observe the Stars, pp. 379-383 Las Palmas (2007).
18. Shu-Hung, H., Ngai-Man, H., Yan, W., Wai Tam, P., Hui, S.Y.: Comparison of Dimmable Electromagnetic and Electronic Ballast Systems—An Assessment on Energy Efficiency and Lifetime. J. IEEE Transactions on Industrial Electronics. 54 (6), 3145-3154 (2007)
19. Street Lighting Load Research Report 2 (2013). http://www.elexon.co.uk/wp-content/uploads/2012/03/StreetLighting-Load-Research-Report-2-2013.pdf. Accessed March 10, 2014
20. Street Lighting Strategy (2011). http://www.energyrating.gov.au/wp-content/uploads/Energy_Rating_Documents/Library/Lighting/Street_Lighting/Draft-streetlight-Strategy.pdf. Accessed March 10, 2014
21. SunriseSunset, http://www.sunrisesunset.com/ Accessed March 10, 2014.
22. Yan,W., Hui,S.Y.R., Chung, H.S.H.: Energy saving of large-scale high intensity discharge lamp lighting networks using a central reactive power control systems. J. IEEE Transactions on industrial electronics. 56 (8), 3069-3078 (2009)
23. Zotos, N., Stergiopoulos, C., Anastasopoulos, K., Bogdos, G., Pallis, E., Skianis, C.: Case study of a dimmable outdoor lighting system with intelligent management and remote control. In: Proceedings of the International Conference on Telecommunications and Multimedia, pp. 43 – 48. IEEE, Chania (2012)