Estimation of Energy Consumption in Street Lighting using Mobile Devices

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Abstract

The growing energy consumption is not sustainable in the long run. Taking into account that street lighting is one of the highest energy consumers in cities, this paper aims to develop a methodology to estimate the energy consumption of these installations with as few input variables as possible. In addition, the paper presents a mobile application developed to help lighting managers not only on the energy consumption evaluation, but suggesting the possible improvements on current systems which can save energy in case that they are implemented.
Keywords: Street-lighting, Energy-consumption, energy-saving, light methodology, mobile

1. Introduction

Street lighting plays an important role in cities promoting comfort, as well as enhancing safety and security [29]. However, this service is one of the main energy consumers in local governments' areas with 30-60 percent of greenhouse gas emissions [13]. Such high level of emissions, joined with the fact that energy saving has become an urgent environmental concern to be addressed by current society, have caused advances on the technology used by street lighting devices, improving quality of lighting, removing light pollution or changing standards. If we analyze the case of Spain, energy consumption by street lamps is one of the highest in the European Union, with an average of 157W per lamp, well above the United Kingdom's 76W or Netherland's 61W [33]. Furthermore, most of towns do not have dimmable lightings; to give an example, the percentage of installations in Andalusia without this kind of systems is 64%

[18]. This situation is not sustainable in the long run. This is why the Spanish government has created the Royal Decree 1890/2008[32] in order to improve energy efficiency of this kind of installations.
Although there are several tools to evaluate the energy efficiency, most of Town Councils do not take advantage of them, sometimes because of the lack of knowledge of these systems or because they are linked to a specific manufacturer, limiting a full performance. It is noted that all of them have been developed as computer applications and not as mobile applications. Keeping in mind that mobile systems, such as smartphones, have become the primary computing platform for many users [3], in this paper we focus to develop a new mobile application and associated methodology that will enable the Town Councils to estimate electrical energy consumption on street lighting installations, independently of manufacturers, and give the opportunity to compare it with other evaluated systems. Finally, it should give the users the opportunity to search for improvements on their installation in order to reduce the total energy consumption.
The remaining sections of this paper are organized as follows: section 2 presents the related work; section 3 describes the methodology; section 4 contains the proposed system; the framework functionality is validated in section 5, and finally, section 6 draws the conclusions.

2. Related Work

Before focusing the analysis of the existing systems, we would like to point out the existing methodologies used hitherto to calculate energy consumption of street lighting systems. The research conducted by Ereu [14] established one such methodology that focuses on lamp power, average loss in ballast and technical losses in the conductor as a result of the joule effect. However, this study did not focus on street lighting control system or dimmable lighting systems, which are very important to estimate the burning hours and the final lamp power. On the other hand, the research done by Gomez-Lorente [17] developed a new methodology for calculating roadway lighting design based on a multi-objective evolutionary algorithm. The objective of this algorithm is to maximize parameters as the overall illuminance uniformity and efficiency. However, the efficiency only takes into account the illuminated area, the electrical power installed and the average illuminance but not the hours of operation. Finally, Janiga [21] described a method of calculating the power lights in the network with the lamp connected between phase and neutral. However, this method is only valid if the installation has a smart meter. Therefore, we have developed a new methodology which enables the estimation of the energy consumption keeping in mind the control system.
Similarly, although there are several tools that can be used to calculate energy consumption of street lighting systems, the level of knowledge required for their use is too high. Hence, the study of the existing software programs can be useful 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 [17]. The strength of this tool is the database with information from the main lighting manufacturers, providing more accurate evaluations. Another tool is Calculux, which is designed with the purpose of helping lighting designers to select and evaluate lighting systems [23]. This software program includes functionality of prediction of financial implications, such as energy, investment, lamp and maintenance costs for different luminaire arrangements. However, its main weakness is the exclusive connection with Philips products. The third software product - Relux - is a light calculation tool based on the solid angle projection procedure and it can be used, among other functionalities, for calculation of street lighting as per EN 13201[4].
After studying the features of the previous systems, it was observed that their complexity was not compatible with mobile devices. Moreover, so far no mobile applications with similar purpose are known. In this context, usability and compactness of the displayed information has a significant role, because the main usability hurdles for mobile devices are small screens, awkward input, download delays and not-well-designed sites [30]. Knowing these

disadvantages, it is necessary to perform a study to reduce the information needed to make the energy consumption evaluation before starting to develop the mobile application. Therefore, this study was conducted mainly to understand the implications of each street lighting device on final energy consumption in order to reduce the number of required parameters of the evaluation.

3. Energy consumption analysis

To develop a new calculation methodology which can be used in mobile applications, the number of parameters must be kept minimal. Thus, the analysis of the main components is necessary to understand how they have an effect on the final energy consumption. These components are divided as follows: lamps, ballasts, street lighting control systems and dimmable lighting systems. To be sure about their implication on the final energy consumption, each component was studied individually in order to identify the possible improvements of the system in case of changing any of the components.

Lamps

There is no doubt that lamps are the most representative component of street lighting systems. There are several types of lamps in the market which can be used in this kind of installations, among which there are mercury vapor, high pressure sodium, low pressure sodium, high pressure ceramic metal halide and led lamps. If we pay special attention to the characteristics sheet, containing the information given by lamp manufacturers, it can be seen how lamps are especially sensitive to voltage variations.

The most important factor to search an alternative lamp is the power consumption, but it is also important that the change does not decrease the amount of output light.

The study of Nathasri [27] defined three indices to measure the lamp performance: utilization factor, efficiency and surrounding ratio. Utilization factor is defined as the function of the luminous flux on roadway and the total luminous flux of a luminaire, the efficiency is the ration of the total luminous flux of a luminaire and total luminous lux of lamp. Nevertheless, the information required to make this evaluation is difficult to obtain, for that reason it was not taken into account in the program.

Paying attention to the lamp manufacturers' data sheets we can see information related to lighting efficiency of lamps which shows the amount of energy used per lighting unit (lum/W). Using this value it is possible to ensure that the amount of light do not decrease with the change. By following this approach it is possible to find lamps with the same of higher luminous flux and less power consumption.

Ballasts

Each and every sort of lamps requires a ballast to operate correctly. For that reason, the presence of this device in street lighting systems is indispensable in order to ignite the discharge and control the lamp. Ballasts can be divided into two main groups: electromagnetic and electronic. The main difference between them is their electrical energy consumption.

It is usually thought that electronic ballasts are more energy efficient than electromagnetic ballasts. Reason for that is that electronic ballasts have been promoted as replacements for electromagnetic ballasts, to the point that some governments have changed their regulations to encourage their use [9].

Manzano [25] studied the energy savings, replacing inductive control ballast to electronic control ballast. The most relevant conclusion was that the use of electronic control ballast instead of inductive control ballast produces 28% energy saving. Analyzing the research did by Dolara [11], which used the same lamp (HPS 150W), it is possible to see that if the luminaire uses electronic ballast the illuminance stays constant.

Street lighting control systems

These devices are required to automatically turn on and off the light in the streets. The current Spanish regulations [32] recognize three possible devices with this purpose: astronomical time switches, twilight switches and remote management systems for electrical boards. The main difference is in the used technology which makes them behave differently, especially in the number of burning hours.

Astronomical time switches turn light on and off with a fixed time offset from sunrise and sunset. To estimate the daily hours of sunrise and sunset, and because of the movement of the sun, latitude and longitude are needed.

Twilight switches measure the amount of natural light available, and regarding its level, turn on and off the lamps. As it also happens with astronomical time switches, it is possible to establish an approximation of number of burning hours using the latitude and the level of natural light required to turn the system on or off [20]. However, weather conditions are even more significant than latitude in cloudy days. Despite the fact that these systems may seem more adaptive to the light environment, the current normative does not allow their installation when the total power is higher than 5 kW. This restriction builds on the fact that twilight switches are more exposed to the environment needing more maintenance to ensure their correct working.

Remote management system is composed of a server–client architecture system for monitoring, detecting, controlling and communicating problems instantly to a central control room or directly to maintenance technicians [2]. These systems usually use a combination of the previous two systems to ensure the correct behavior. On the other hand, tele-management integration in street lighting networks of small cities has been hardly developed both in conceptual and applicative way, especially due to limited economical resources of local communities which became responsible of too many new tasks, public illumination being one of them [32]. For that reason, the application will not take into account this kind of systems.

According to the research made by Manzano [25], where he analyzed the energy savings by replacing photocells to astronomical programmable clocks, the use of programmable astronomical clocks instead of photocells produces 11% of energy saving because of schedule set for on and off based on actual time.

Dimmable lighting systems

Regulators and stabilizers are able to control the voltage according to different magnitudes such as the number of vehicles per hour [26], weather conditions or the presence of pedestrians [34]. Their operation consists of changing the main input voltage to a variable voltage within the range from 220 to 170 V [34]. Those changes are accompanied by variations on illuminance and lamp power. Figure 1 shows the behavior of this kind of systems, where it can be seen their potential on energy savings.

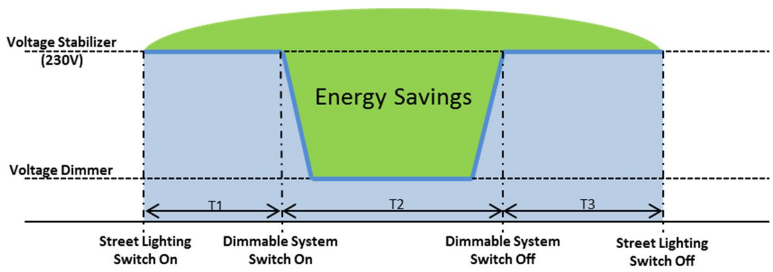


Fig. 1. Dimmable lighting systems behavior

The main advantage of usage of stabilizers in lighting systems is to avoid the overvoltage. The research carried out in China [8] showed how, despite the nominal voltage is established on 230V, it reached values as high as 246 V. This overvoltage situation is the main reason of the shortening of lifetime of the lamps. Regulation EN 50160 [15] defines the main voltage's characteristics which have to be satisfied by supply company. Therefore, the voltage

fluctuations can vary up to 10% during the 95% of the week, if the installations do not include dimmable lighting system.
On the other hand, regarding to Bacelar [1], the minimum luminous flux level should be established on 50%, as it was discussed that such dimming does not seem to have a great influence to the visibility of observers nor drivers. Analyzing in detail the research conducted by Yan [34], which studied the characteristics of HPS lamps of 50, 70, 100, 150, 250 and 400 W dimming the voltage, color temperature does not change significantly for the voltage range from 220 to 180 Vac.

4. Requirement Analysis and System design

To evaluate the energy consumption, a new application called SOLE (System to evaluate the Outdoor Lighting Energy demand), is proposed in this paper. This tool has been developed as a Smartphone application, so that maintenance managers can conduct energy-estimation operations easily and quickly. The main aim of this application is to evaluate street lighting consumption, showing the prediction of energy use and number of burning hours. To encourage energy saving awareness, the tool also shows a comparative chart in which the average of their lamp power is compared with one proposed by the system. The calculation methodology, among the application architecture and its use along with a study about its usability are explained in the following sections.

Energy consumption calculation

Understanding the performance that each component has in final energy consumption, it is possible to make an estimation of the amount of energy consumed by the street lighting system. To make this possible, the proposed methodology includes the evaluation of each streetlight, and the sum of all of them makes the final energy consumption of the system. Equation 1 shows the procedure to calculate the consumption of each luminaire:

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

Where:

- P_{lamp} is the nominal lamp power
- V_{impact} is the impact on the lamp consumption of the current voltage
- $P_{ballast}$ is the ballast power
- N_{hours} is the number of burning hours

To obtain the real lamp power, the information on voltage is required. In case of lack of this information, the estimation can be done according to the criterion established in UNE-EN 50160 standard [15]. As it will be presented in later chapters, our proposed application also has the possibility of estimating this value.
In case of systems including dimmable lighting system, it is needed to make one calculus for each of the dimmable levels established. Figure 1 shows three such periods. In that case, the luminaire energy consumption is the sum of each of the consumptions calculated.

Criteria to improve the systems elements

One of the aims of our proposed methodology and application is to provide the best alternative to decrease the energy consumption. Thus, it is necessary to establish the search requirements for each case.
According to Boyce [5], there are four sections to save energy: changes in technology, changes in patterns of use, changes to standards and changes to the basis of design. Changes to standard can take a long time to achieve, as the case of Royal Decree 1890/2008, and to make a difference because they tend to be applied only to new installations; a good example are the observed municipalities which do not have dimmable lighting systems. Changes to the basis of design of road lighting require a careful reconsideration of their goals and how they might best achieve those aims. Ceclan [6] added a new recommendation to decrease electrical energy consumption, proposing to adopt a special price based on duration of the night. But from our point of view,

the previous recommendation does not decrease the energy consumption; it only reduces the final budget. Therefore, the alternatives proposed are focused on changing technology (lamps, ballasts and dimmable lighting systems) and changing in patterns of use (lighting control systems).

Application Technology

First problem to face with when developing a mobile application is the number of existing platforms in market. Each of these platforms has different requirements in terms of development of native applications due to their differences on programming languages [7].
The ideal scenario is to develop an application once and use it on multiple platforms. This is possible thanks to emerging standard HTML5 [34]. There is a wide range of frameworks available to help developers to create mobile applications as if they were websites for the mobile devices. The framework used to create this application is called PhoneGap [31]. Although this development approach allows cuts in development time [22], it has some limitations as the incomplete development of JavaScript APIs providing access to several device services [19].
The advances in smartphones' Internet connection have caused the evolution of a new model of ubiquitous access which can provide shared pool of configurable computing resources with minimal management effort or service provider interaction: Cloud computing [28]. Some of the benefits that cloud computing may bring to mobile Web services include the ability to improve service availability, reliability, and quality of service, at the same time reducing the battery consumption [12], which is one of the most worried factors for mobile users [24]. For those reasons, we decide to put the computation algorithms to be performed on the server. Also, in this way, later changes made on the database or on the model will not affect the application behavior. Figure 2 shows an abstract architecture of the application developed where it can be appreciate how the mobile application send the information through the Internet to the energy model, and the results obtained to the energy consumption evaluation helps in the search of improvements.

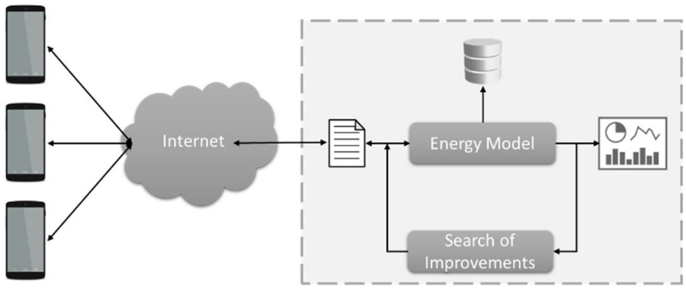


Fig. 2. Application architecture

5. Results

As a result, the application has been divided into 3 different parts: Introduction, input of installation's characteristics and results of the evaluation. Following it is detailed each of these sections.

Access Screen

The first screen shown when the application is started is an introduction of the tool, where it can be found information related to the application. This screen is also the access point to the evaluation as there is a navigation toggle button placed at the top of the screen. This button allows the movement between two different sections: evaluation of energy consumption and contact details. This last section shows an email address to contact with the developers.

Input of System Information

When users start the evaluation of the street lighting system installation, the first thing to do is to register all the features of the equipment devices (city, lamps and so on). As it is known, the screen size may hinder the input of data. For that reason, the form was divided into three different parts: location (Figure 3(a)), characteristics of the control panel (Figure 3(b)), and luminaire (Figure 3(c)). Thereby the user has to pass through them to enter all the information.

(a) Location input (b) Control Panel input (c) Luminaire input

Fig. 3. Data input screens

Evaluation of Energy Consumption

Once 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 was to incorporate simple interactive graphics, which are supplemented by small portions of relevant information, giving users the opportunity to check the data [10]. To ensure the quality of charts, we used an open source JavaScript library called Flotchart [16], which allows the interaction between user and charts. Similarly to the input form, the result form has also been divided into three different screens to simplify the use of the tool. To switch between these options user can use appropriate navigation options, one for each section of results.

Calculated Energy Consumption

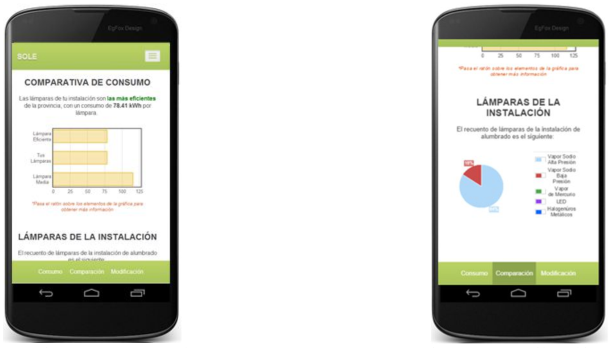
In the first section, two charts with the information about the energy consumption (Figure 4(a)) and the burning hours (Figure 4(b)) can be observed. If the user introduces real consumption values, these data will be shown in the same chart together with energy estimation.

(a) Energy consumption (b) Burning hours

Fig. 4. Calculated Energy Consumption screen

Energy Consumption comparison

The second section shows a comparison between the average lamp power of the infrastructure and the average of other installations in the same province which have been previously evaluated by the system (Figure 5 (a)). Beside the chart, the distribution of lamps according to the type of technology used is shown (Figure 5 (b)).



(a) Power lamp comparison (b) Lamp distribution

Fig. 5. Energy consumption comparison screens

Improving Street Lighting Installations

The last section provides the user with the opportunity to search for alternatives on the elements of the installation in order to find the best option for the system. To ensure the scalability of the modifying the installation the user is provided with the opportunity of select the element to change between three different options: luminaires, control systems and dimmable lighting systems.

Once the search is done, the application shows a comparison of the consumption between current installation and the new installation. This comparison is shown in three parts: Energy consumption (Figure 6(a)), number of burning hours (Figure 6(b)) and list of modifications to obtain this results (Figure 6(c)).

(a) Energy consumption (b) Burning hours (c) System modifications

Fig. 6. New system comparison screens

6. Discussion

In order to make a deep analysis of the application it was evaluated from two viewpoints:

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

Application usability

An experiment was conducted in order to evaluate the application. This experiment was made to check the usability 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 and mobile devices.

To analyze how users insert the information, the sheet of information given to the users have information of a different real installations, some of them with a lack of information. The idea was to perform an evaluation with as real as possible. The experiment was carried out using two different devices 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. These questions are designed to rate the user opinion about the application with a Likert-scale questions with responses ranging from 1-5 points, where 1 is the lower mark and 5 the highest.

The first question asked about the level of experience with mobile device. The results show a high level of knowledge about the use of this kind of electronic devices, with an average of 4.1 in the Likert scale.

The second aspect evaluated was the level of knowledge about the operating of street lighting systems. In this situation the results show a low level, with an average of 2.2. When they were asked about the level of difficulty of the tool users marked it as medium, with an average of 2.5. It is noteworthy that despite the level of knowledge on this kind of installations all the users finished the experiment. When they were asked about the reason, respondents highlight how the interface was helpful to follow the steps to complete the experiment.

When they were asked about the result of the evaluation, 62% 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, most of the interviewed stand out that this developed tool should raise the energy awareness.

Thanks to the previous experiment, we have realized that users have more difficulty in use 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.

Capability to evaluate energy consumption

To check the proposed methodology, and to be sure on the availability of the values to be collected, a study was conducted with data from four different municipalities of Spain, all of them without a dimmable lighting system. This information has been obtained through different energy audit performed on some of the municipalities in some cases, and directly to the maintenance workers in others. Table 1 shows the number of switch boards of these municipalities.

Table 1. Switch boards analyzed

Municipality	Population	Number of switch boards
Villaluenga	4083	20
Tielmes	2616	12
Rabanales	654	7
Tardajos	834	6

The main drawbacks noticed in most cases were the lack of information related to the number of burning hours and the ballast power. In these cases, and thanks to the previous studies, the approximation of the values was used taking into account the different elements that compose the installation as lamps, ballast, dimmable systems, etc.

When the energy consumptions of the different installations are checked with the results of the energy consumption model created for this application, the results show an average error experienced in simulations with complete data up to 5%. On the other hand, in the case of lack of information about the installation as ballast power or number of burning hours, the error increases up to 10%. That error may be due to different factors such as fluctuations on voltage or the characteristics of components.

As said previously, Spanish street lighting systems are, in most cases, outdated. However, it is possible to save a huge amount of energy in these cases with changes in the systems. To show this capability of improvement, it was used to find alternatives on the installation. As an example of the enhancement level of the Spanish installations, it has been evaluated one of the real installations where it can be see how it is possible to save up to 80% of the energy consumption in case of the implantation of the improvements suggested by the application as lamp changes or incorporation of dimmable systems (Figure 7).

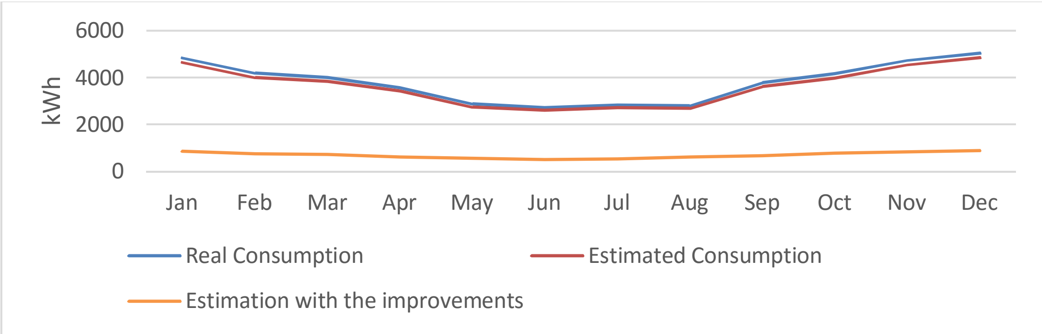


Fig. 7. Differences between estimated and real energy consumption in the municipality of Tardajos

7. Conclusion

The main contributions of the paper are summarized as follows.
Proposal of a new methodology to estimate energy consumption of street lighting which takes into account the street lighting control systems. If we take a look to the different evaluation methodologies, most of them overlook this parameter despite of its influence on the final energy consumption.
Moreover, as can be seen along the paper establishment of criteria to save energy on basis of each system allowing the study of each element separately, making possible the analysis of their share on the final evaluation system.
The most important factor to know about the lamp power is the voltage. According to the current standard, voltage magnitude does not stay constant along the time, reaching values as high as 253 Vac. Therefore, from our point of view, all installations should include the overvoltage protection devices to avoid the overvoltage and save energy. However, the cases analyzed did not have these devices to correct this drawback.
Some authors believe that considering the latitude and the longitude is sufficient to establish the number of street lighting burning hours. However, this research corroborated that weather conditions are even more important than geo-location in cloudy days.
The primary aim of lamp manufacturers is to save energy. Nevertheless, they have not checked the influence on visibility of passengers nor drivers. Therefore, the minimum voltage cannot be 180Vac for high pressure sodium and metal halide lamp.
In this situation, a new mobile application was developed to ease the energy evaluation of street lighting systems. Therefore, the proposed application allows to show the results before and after applying the best practice, allowing to raise the user's environmental awareness through an evaluation of each system.
Finally the experiment we performed to check the usability of created tool showed that, despite the fact that examinees had a low level of knowledge on street lighting installations, all of them successfully finished the experiment, thus proving the tool usability and applicability. However, we also realized that users had more difficulties using it when the device had small screen, so some improvements in application adaptability to various screen sizes are necessary.

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References

1. Bacelar, A.: The influence of dimming in road lighting on the visibility of drivers. Journal of Light & Visual Environment, 29(1), 44-49. (2005)
2. Baenziger, T. D.: Effective lighting control system for public spaces. Light & Engineering 15(2) pp. 45-52, (2001)
3. Bajad,R.A., Srivastava, M., Sinha,A.: Survey on mobile cloud computing. International Journal of Engineering Sciences & Emerging Technologies, 1(2), 8-19. (2012)
4. Bhavani, R. G., Khan, M. A.: Advanced Lighting Simulation Tools for Daylighting Purpose: Powerful Features and Related Issues. Trends in Applied Sciences Research, 6(4), 345. (2011)
5. Boyce, P. R., Fotios, S., Richards, M.: Road lighting and energy saving. Lighting Research and Technology, 41(3), 245-260. (2009)
6. Ceclan,A., Micu,D.D., Simion,E., Donca,R.: Public lighting systems an energy saving technique and product. International Conference on Clean Electrical Power (2007)
7. Charland, A., Leroux, B.: Mobile application development: web vs. native. Communications of the ACM, 54(5), 49-53. (2011)
8. Chung, H. S. H., Ho, N. M., Hui, S. Y. R., Mai, W. Z.: Case study of a highly-reliable dimmable road lighting system with intelligent remote control. In Power Electronics and Applications, 2005 European Conference on (pp. 1-pp). IEEE. (2005)
9. Chung, H. S. H., Ho, N. M., Yan, W., Tam, P. W., Hui, S. Y.: Comparison of dimmable electromagnetic and electronic ballast systems—An assessment on energy efficiency and lifetime. Industrial Electronics, IEEE Transactions on, 54(6), 3145-3154. (2007)
10. Costello, G. J., Clarke, R., Donnellan, B., Lohan, J.: Development of a prototype knowledge discovery portal for energy informatics. In Information Systems Development (pp. 129-141). Springer New York. (2013)
11. Dolara, A., Faranda, R., Guzzetti, S., Leva, S.: Power quality in public lighting systems. In Harmonics and Quality of Power (ICHQP), 14th International Conference on (pp. 1-7). IEEE. (2010)
12. Elgazzar, K., Hassanein, H. S., Martin, P.: DaaS: Cloud-based mobile Web service discovery. Pervasive and Mobile Computing, 13, 67-84. (2014)
13. Equipment Energy Efficiency (E3) program. Street Lighting Strategy:.http://www.energyrating.gov.au/wp-content/uploads/Energy_Rating_Documents/Library/Lighting/Street_Lighting/Draft-streetlight-Strategy.pdf. Accessed April 5, 2016.
14. Ereú, G. M., Mantilla, J. O.: A Methodology to determine electrical energy consumption in street lighting systems. In Transmission & Distribution Conference and Exposition: Latin America, 2006. TDC'06. IEEE/PES (pp. 1-5). IEEE. (2006)
15. European Committee for Standardization: UNE-EN 50160:2011. Voltage characteristics of electricity supplied by public electricity networks. (2011)
16. FlotCharts. http://www.flotcharts.org/. Accessed April 5, 2016.
17. Gómez-Lorente, D., Rabaza, O., Estrella, A. E., Peña-García, A.: A new methodology for calculating roadway lighting design based on a multi-objective evolutionary algorithm. Expert Systems with Applications, 40(6), 2156-2164. (2013)
18. Guía de ahorro y eficiencia energética en municipios: http://www.agenciaandaluzadelaenergia.es/sites/default/files/guia_de_ahorro_y_eficiencia_energxtica_web_def1.pdf. Accessed April 5, 2016
19. Hemel, Z., Visser, E.: Declaratively programming the mobile web with Mobl (Vol. 46, No. 10, pp. 695-712). ACM. (2011)
20. Howell, E. K.: Photoelectric controls for street lights. Electrical Engineering, 80(10), 780-785. (1961)

21. Janiga, P., Gašparovský, D., Beláň, A., Eleschová, Ž., Viglaš, D.: Measuring and evaluating energy consumption in street lighting networks. (2012)
22. Juntunen, A., Jalonen, E., Luukkainen, S.: HTML 5 in Mobile Devices--Drivers and Restraints. In System Sciences (HICSS), 46th Hawaii International Conference on (pp. 1053-1062). IEEE. (2013)
23. Kostic, M., Djokic, L., Pojatar, D., Strbac-Hadzibegovic, N.: Technical and economic analysis of road lighting solutions based on mesopic vision. Building and Environment, 44(1), 66-75. (2009)
24. Kumar, K., Lu, Y. H.: Cloud computing for mobile users: Can offloading computation save energy?. Computer, (4), 51-56. (2010)
25. Manzano, E. R., Carlorosi, M., Tapia Garzon, M.: Performance and measurement of power quality due to harmonics from street lighting networks. In Proceedings of the Conference on Renewable Energies and Power Quality (ICREPQ'09). (2009)
26. Moghadam, M. H., Mozayani, N.: A street lighting control system based on holonic structures and traffic system. In Computer Research and Development (ICCRD), 3rd International Conference on (Vol. 1, pp. 92-96). IEEE. (2011)
27. Nathasri, W., Tayjasanant, T., Chamchoy, C.: Roadway luminaire selection based on luminaire performance indices. In Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON), 9th International Conference on (pp. 1-4). IEEE. (2012)
28. National Institute of Standard and Technology (NIST) U.S. Department of Commerce: The NIST Definition of Cloud Computing. Accessed April 5, 2016.http://csrc.nist.gov/publications/nistpubs/800-145/SP800-145.pdf.
29. Nielsen, J., Budiu, R.: Mobile usability. MITP-Verlags GmbH & Co. KG. (2013)
30. PCE Iberica: Manual datalogging Light Meter PCE-174. http://www.industrial-needs.com/manual/manual-PCE-174-luxmeter.pdf. Accessed April 5, 2016
31. PhoneGap. from: http://phonegap.com. Accessed April 5, 2016.
32. Popa, M., Cepisca, C.: Energy consumption saving solutions based on intelligent street lighting control system. UPB Sci. Bull., Series C, 73(4), 297-308. (2011)
33. Smutný, P.: Mobile development tools and cross-platform solutions. In Carpathian Control Conference (ICCC), 13th International (pp. 653-656). IEEE. (2012)
34. Yan, W., Hui, S. R., Chung, H. S. H.: Energy saving of large-scale high-intensity-discharge lamp lighting networks using a central reactive power control system. Industrial Electronics, IEEE Transactions on, 56(8), 3069-3078. (2009)