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Evaluation and Improvement of Lighting Efficiency in Working Spaces

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Received: 9 March 2018; Accepted: 4 April 2018; Published: 8 April 2018

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Abstract: Lighting is an essential element for modern life, promoting a sense of wellbeing for users. However, bad illumination may produce health problems such as headaches and fatigue, among other vision problems. For that reason, this paper proposes the development of a smartphone-based application to help in lighting evaluation to guarantee the compliance of illumination regulations and to help increase illuminance efficiency, reducing its energy consumption. To perform this evaluation, the smartphone can be used as a lighting measurement tool, evaluating those measurements through an intelligent agent based in rules capable of guiding the decision-making process. As a result, this tool allows the evaluation of the real working environment to guarantee lighting requirements, helping in the prevention of health problems derived from bad illumination and improving the lighting efficiency at the same time.

Keywords: mobile device; lighting management; lighting optimization; luxmeter; intelligent agent based in rules

1. Introduction

Lighting is an essential element in modern life with a high impact on three basic human needs: visual comfort to provide a sense of wellbeing, visual performance to allow the carrying out of visual tasks, even in difficult circumstances and for long periods, and security, reducing the risk of suffering an accident. Despite the many regulations which aim to ensure a correct lighting level, in many cases it can be poor or inadequate for users. This problem happens because the regulations don't take into account all the lighting parameters which influence visual comfort, it being necessary to take the measurements in situ [1]. Furthermore, it must be considered that aspects such as sensitivity or character could influence user lighting preferences [2] as well as cultural differences [3]. If we focus on the concept of lighting in workplaces, it is possible to see how proper lighting is essential, allowing users to see without difficulties the tasks being carried out, increasing productivity [4], and reducing accident risk and fatigue. In the same way, bad lighting can cause eye strain, which may involve problems in the eyes (dryness, itching, or burning), headaches, tiredness, irritability, moodiness, etc. Consequently, correct lighting should allow the distinguishing of shapes, colors, and objects in movement and the appreciation of the relief, and furthermore, allow everything to be done easily and without fatigue, i.e., to ensure visual comfort permanently [5].

The evolution of the technology in lighting aims to accomplish three objectives: better photometrical performance, which allows the improvement of the quality of the light regarding the user's needs, better energy efficiency, offering a higher illuminance with less energy consumption, and improving the performance of users while ensuring the visual comfort in task developing [6].

Moreover, lighting is one of the largest sources of energy consumption in buildings and accounts for 5–15% of the total electric energy consumption [7,8]. For this reason, when we adjust the lighting we have also the opportunity of improving its energy efficiency.

To achieve proper lighting in workplaces, two standards were analyzed: EN 12464-1 [9], which is relative to lighting of indoor workplaces, making special emphasis on the fulfillment of visual comfort and the performance of colors and standard requirements, and EN 12464-2 [10], relative to the lighting of outdoor work places. In both regulations, the lighting requirements are established regarding the activity.

On the other hand, the current mobile phones, or smartphones, are rapidly becoming the primary computing platform for many users [11]. Smartphones have turned out as the key between human interaction and digital devices [12,13].

Keeping in mind the fact of the importance of smartphones, joint with the problems found in lighting management, this research aims to analyze how the development of a mobile application-based intelligent agent based in rules may help to enhance the lighting levels (illuminance) in workplaces, allowing users to manage and assess consumption and providing information about occupational risks prevention.

Mobile applications may create a huge amount of information. To take advantage of this information, a new concept is gaining attention worldwide: open data. This new concept is related to the disclosure and reuse of data for anyone to use to help invigorate society and the economy [14]. The application will be developed with the aim of generating an open data set with anonymous information about lighting measurements performed.

The paper has been divided as follows: Section 2 contains the analysis of prior research made on areas such the existing lighting regulations, lighting evaluation software, or the health problems derived from bad illumination. Section 3 shows the methodology followed to develop the system. Section 4 includes the architecture of the proposed system. Section 5 shows the main results obtained through the mobile application developed and the paper finishes with the discussion and conclusions obtained throughout the research.

2. Prior Research

Prior research has been focused on three different areas. The first point shows European regulations that allow the control of the level of illuminance in different areas. The second point shows the existing software solutions for the lighting evaluation, while the last point carries out a brief study about the health problems derived from bad illumination to highlight the advantages of the proposed tool in the health field.

2.1. Regulations for Lighting Evaluation

Artificial lighting has become in an essential service for modern life. There is no doubt about its benefits, because it allows users to increment the activity in spaces without enough quality of light and also creates a welcoming feeling, making it possible to increment the night activity while reducing crime at the same time [15]. Due to its importance in our lives, it is necessary to control it.

One of the aspects where artificial lighting has a high impact is in energy consumption. Only taking into account the street lighting installations, the amount of energy rises up to 2.3% of the global electricity consumption [16]. To control this amount of energy, different countries have set regulations to help to improve the energy efficiency of its installation. It is the case of the Royal Decree 1890/2008 [17] which established, by the Spanish Government, the standard called EN 13201-5 [18] set by the European Union or the British Standard BS 5489 [19], among others.

Despite energy being an important aspect to take into consideration, mostly in outdoor spaces, there are other regulations to control the amount of light in working spaces in both outdoor and indoor spaces. Here is the case of the EN 12464-1 [9] and EN 12464-2 [10] regulations.

The regulation EN 12464-1 [9] specifies the lighting's requirements for most indoor working places and their associated areas in terms of quantity and quality of lighting. In addition, this regulation gives recommendations for a good practice of lighting through qualitative and quantitative satisfaction.

Another important regulation related to lighting requirements is EN 12464-2 [10]. This regulation allows the guarantee that the visual tasks performed in outdoor spaces can be carried out in an efficient way, especially during night time.

2.2. Light Evaluation Software

There are different programs that must be used to evaluate lighting requirements in different kinds of spaces. Most of those programs allow the performance of a quantitative analysis of scenarios, thanks to their capability of creating a 3D virtual world where lighting effects are recreated and analyzed in both artificial lighting and daylighting scenes [20].

One evaluation software that is used in this field is called RELUX. This software allows users to generate quantitative and qualitative analysis of buildings' lighting thanks to simulation models created with specific materials, colors, reflection factors, and natural and artificial lighting elements to get a closer possible view of reality [21].

Another renowned and well-known tool to evaluate energy efficiency is the SEAD street lighting evaluation toolkit. It can help make better choices regarding street lighting fixtures, which can lead to a maximum of 50% in energy savings [22], by providing an easy way of performing evaluations of light quality, energy consumption, and life cycle costs of efficient street lighting alternatives. This tool is supported by Mexico's National Commission for Energy Efficiency, India's Bureau of Energy Efficiency, Natural Resources Canada, the Swedish Energy Agency, and the U.S. Department of Energy.

Another of the programs used in lighting analysis is called BTwin [23]. It was designed to plan the street lighting installation based on the standard EN 12464-2 [24], as the program can import the manufacturer's luminance information to give more accuracy to the calculations. In addition, an evaluation of the installation's energy efficiency to obtain the energy label before carrying out its implementation can be performed by using the extended feature called AEwin. Vertical obstacles can be considered as well, as they can affect the lighting, and by doing so it is possible to increase the precision of the program.

However, the most important software in this field is called DIALux. The main strength of this software is its complete database about lighting products of the main manufacturers, giving more accuracy to the analysis. It also provides information about power consumption of elements to guarantee compliance with the regulations [25].

2.3. Health Problems Derived from Bad Illumination

Lighting has become one of the most important aspects in efficient building design due to its impact on energy consumption. However, it must be taken into consideration that a good lighting approach should have benefits not only for economic or environmental aspects but also for comfort and health due to its influence on people's quality of life and wellbeing [6,26].

Most office tasks are linked to document processing, whether through paper or digital documents. Therefore, these activities have high visual requirements, making lighting an important factor to prevent discomfort and vision problems.

One of the main lighting problems is derived from over-illumination which occurs due to multiple artificial lights in the ceiling and/or daylight penetrating the room. For example, in a shared space office, the light illuminates not only the cubicle of one worker but also the rest of the cubicles. In addition, the contribution of a light to the light level of the other cubicles is the cross-illumination effect of the particular light. When these effects arise, lighting control requires a regulation between the lights in order to obtain a desired light level across the room [27].

This situation of over-illumination is linked to several negative health effects. Different studies attribute migraine headaches, fatigue, medically defined stress, anxiety, or decreases in sexual function among others to overly intense light [28–31].

Despite most of these symptoms possibly being caused by light that is simply too intense, the color spectrum of fluorescent lighting is another factor that might cause problems, since this sort of lighting is significantly different from sunlight [28,32]. Fatigue is another common complaint from individuals exposed to over-illumination, especially with fluorescent media. For that reason, natural light is preferred over purely artificial light by office workers from both eastern and western cultures [33].

3. Methodology

Along the study and development of the tool, different hypotheses have been proposed to help analyze the process of data acquisition and subsequent presentation of results. The proposed hypotheses are the following:

Hypothese 1 (H1): *The use of mobile applications could help in the prevention of occupational risks.*

Hypothese 2 (H2): *The use of mobile applications may help on energy saving.*

Hypothese 3 (H3): *Mobile devices can be used by any smartphone user as a fairly accurate light meter tool.*

Hypothese 4 (H4): *The use of mobile applications could facilitate the regulations' fulfillment regarding the illuminance in work spaces.*

Hypothese 5 (H5): *The use of an intelligent agent based in rules could help in decision-making about recommended light intensity.*

Finally, we have developed the system and applied it to a real case in order to obtain the level of the user's degree with the proposed implementation. For this task, we have developed an easy-to-use interface which reduces the transitions between screens.

4. System Architecture

The aim of the application developed is to allow users to ease the evaluation of the lighting requirements needed to perform their work without risk to their health. To help in this issue, a mobile application has been developed for Android platforms, called appLux, which is an intelligent agent based in rules that allows the measurement and evaluation of the illuminance level of each space.

To perform this task, the application measures the illuminance to evaluate a wide range of spaces, making it possible to assess both indoor and outdoor spaces. Along with the measurements, the system provides additional information, giving users a new perspective to help them in the decision-making about increasing or decreasing the illuminance levels. The aim is to keep the spaces with an adequate illuminance level for the workers to ensure their eyes' comfort. This is achieved by the integration of a rule engine in the intelligent agent developed.

To accomplish this objective, an intelligent agent based in rules has been developed where the lighting reference level information, which is stored in the device's database, is compared with the real level, obtained through the illuminance measurement. To perform this comparison, an analysis based on a rule engine has been developed, whose objective is to inform the user about the possible actions to adapt the light to the requirements of the specific scenario. To ensure the level of reference, the stored values for the comparison have been obtained from the European Union regulations (EN 12464-1 [9] and EN 12464-2 [10]), where the minimum illuminance is set.

Thus, the proposed system has been divided into five parts, as can be seen in Figure 1: mobile application, database, light sensor, rule engine, and Web server.

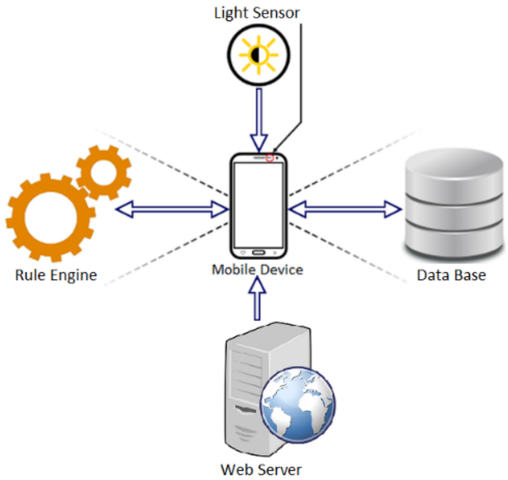


Figure 1. System structure.

4.1. Mobile Device

The application was developed using the Android SDK provided by Google and using Java as the programming language. As the development environment, Android Studio was used since the provided tools integrate seamlessly with IDE using the ADT plugin, which allows debugging code in connected devices and in the emulators included.

At all times, we have followed the design patterns specified by Google for our system, using light colors and maintaining consistency with the rest of the interface devices. The guidance is horizontal because of its greater flexibility of space, and display menus are shown in an intuitive way and leading to a partitioning of space in which several graphs simultaneously are appreciated.

During the development of the application, we have the MVC pattern (Model View Controller), which is very useful to separate the operation of the visual layers. All the logic part was programmed in Java and the visual part was defined with an XML layer, later modified and improved by Java.

4.2. Database

The system is provided with a database used to store information about users' profiles, predefined locations with their light requirements, and information about registered locations and light measurements performed until the date.

The first time the application is running, the database will only have information about the different locations and their characteristics. This information will be the base for the light analysis done by the application.

To ease the use of this tool by different users, it provides a local user register, making it possible to personalize the information about the measurements performed by each user in the same device.

The developed system has two databases. On one hand, a database for the mobile application has been developed using SQLite, since Android has integrated a complete API that allows the management of this kind of database. The main advantages of SQLite, along with the fact that it is open source, are the use of small size records, it meets the SQL-92 standard, and it does not need a server to run [34]. On the other hand, a Web server database was developed to store all the information and share it with other users. At this point, the database was developed using MySQL. In this case, to avoid all the personal information related to the user, it will only store the number of users in the application, making it necessary to check this value each time that a user is registered in the mobile application. In this way, all the information has an anonymous origin, thus fulfilling the Constitutional Law for Data Protection (LOPD) [35].

4.3. Light Sensor

In recent years, smartphones have prevailed as sophisticated, multifunction mobile phones. One of their main advantages is the incorporation of sensors that lets us monitor environmental properties as illuminance or ambient temperature, among others. These sensors are hardware-based and are not available in all of the products; its presence depends on the manufacturer's decision.

An ambient light sensor is a simple sensor included in most of the recent smartphones and is used commonly to control the screen brightness based on the surroundings, therefore saving battery from energy consumption from the screen and at the same time optimizing the visibility [24]. This sensor has been used in different research in different ways to study the color scheme adoption of smartphone displays [36], or to analyze the oscillation movement of coupled springs [37].

Despite the advances performed on this hardware, its accuracy cannot be compared with the accuracy of dedicated hardware devices [34]. However, the results obtained show that it can be useful in practical cases as in the undergraduate physics laboratory [36] where a high level of accuracy is not needed.

Some operating systems, like Android OS, allow the user to obtain the values from the light sensor through APIs which collect data in the runtime of the application. These APIs will return a single value for each data event [24], whereas most motion and static sensors return a multidimensional array of values.

4.4. Rule Engine

The rule engine has a specific function and it may be labeled as the most important piece of the system regarding the application objectives, due to its capability to analyze information and ease decision-making. A rule engine may be viewed as a sophisticated "if/then" statement interpreter. In addition, the rules engine can handle a large number of rules with minimum impact on the normal execution flow of the process [38].

The main task of the rules engine is to ensure that the light values measured by the application are within the proper range. To perform this evaluation, the rules engine has several inputs, such as the measured illuminance, maintained illuminance, or the location characteristics, as well as the XML with the rules to perform the evaluation. Once the inputs have been analyzed, the results will show the recommended actions to guarantee the proper illuminance (Figure 2). Among the actions recommended by the application are: reducing or increasing the power of the lamp to adapt the lighting to the requirements of the regulation, reducing or increasing the distance from the light source, moving closer to or farther from the windows, or using light dimmers.

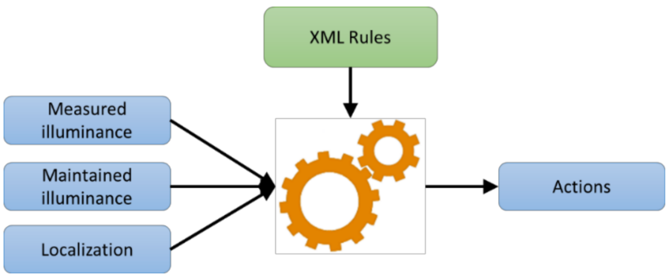


Figure 2. Rules engine working chart.

The selected rule engine was JRuleEngine, due to its open license, availability of source code, and practicality in the development of rules which may be described through an XML file. The Algorithm 1 shows an example of a rule extracted from the XML file. In this case, the rule checks if the level of measured light is correct. To perform this evaluation, the value measured is compared with maximum and average levels of illuminance required by the space regarding its specifications.

As a result, if the measured level is between those two levels, the rule will call to a method that will inform the user that the level is correct.

Algorithm 1. Rule example

```
<rule name="RuleGoodIlluminance" description="Good illuminance control, well done.">
<if leftTerm="illuminati.getE" op="&lt;=" rightTerm="illuminati.getEmax"/>
<if leftTerm="illuminati.getE" op="&gt;=" rightTerm="illuminati.getEm"/>
<then arg1="-1" method="illuminati.addAdvice"/>
</rule>
```

4.5. Web Server

Despite the main aim of the developed application being to help in the evaluation of the lighting requirements of different working spaces, there are others interests behind the development of the application. One of those aims is to evaluate the level of compliance of the directives that regulate the lighting levels through the measurements performed by users. To make this possible, the user must accept sharing voluntarily the information captured by the application for their use in future research projects. To protect users' anonymity, all the data is sent to the server in an anonymous way, according to Spanish Organic Law 15/1999 on the Protection of Personal Data (LOPD) [35].

With the information collected through application usage, it is possible to perform different studies about lighting as well as the effect of climatological conditions on the lighting of the working spaces, or to study the level of regulations compliance in different areas.

To collect the data, a Web server, which was developed as a PHP Webpage where all the information is stored on a MySQL database, was created in [39].

The obtained results can set the basis for future research, as it happened in some studies performed where it was shown that the improvement of the light quality in health centers have a positive impact on the reduction of the hospital stays and increase in the outsourcing of treatment for many patients. For that reason, the server was created with an option to download the information related to the measurements performed with the application. To ease the reuse of the information, the Webpage offers several formats such as .txt, json, xml, xlsx, or csv as is shown in Figure 3.

Figure 3. AppLux Server download option.

5. AppLux Mobile Application

There is no doubt that lighting has an essential role in our lives. For this reason, the application developed aims to control the minimum lighting levels in order to guarantee eye comfort at the same time that it helps reduce energy consumption derived from over-illumination. To carry out this task, the application measures the illuminance level of a space and compares it with the minimum level required by regulations according to the locations profiles.

To ease the use of the application, it has been developed with a user register. Thus, the application adapts to the user requirements, showing only the relevant information about the evaluations performed previously, making it possible for the application to be used by more than one user. Due to the high investigation interest, when a new user is registered in the system, he agrees to give the measurement information for research purposes.

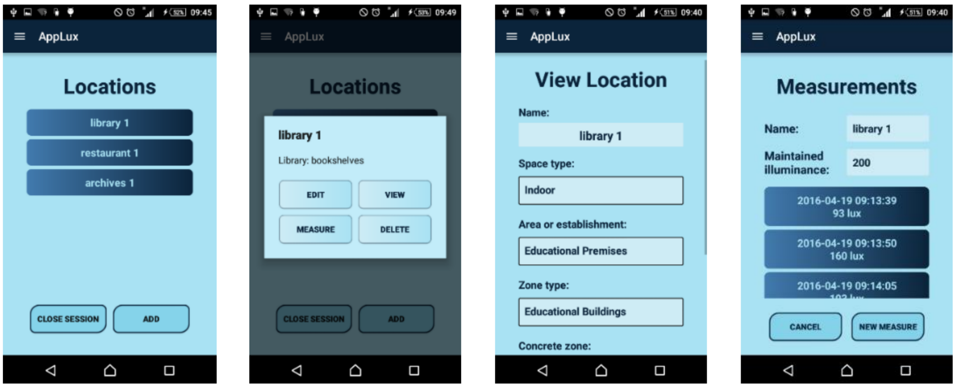
From the application, any user can manage their own information through the following options:

- *Create a new location*. Whenever a user wants to perform the analysis of a location that is not in the list, it is possible to register a new one. To create a new location, the following information is required:
    - *Name*. Helps the management of different areas stored on the device.
    - *Space type*. Defines where the activities are carried out, indoors or outdoors.
    - *Area of establishment*. Defines the general purpose of the area.
    - *Zone type*. Regarding the previous value, helps to clarify the task performed in the area.
    - *Dimensions of the space*. To know the amount of measurement points to calculate the average illuminance of the space.
- *Manage location list*. All the locations registered by the user will be shown in a list (Figure 4a). To act on a given location, its name should be pressed. After that, a list of the following actions is shown (Figure 4b):
    - *Edit location information*. It is possible to see and edit the characteristics of the selected location. In addition, the information about the different measurements done in this location can be displayed but never edited.
    - *View location information*. It is possible to access the location information through this option, including the historic values of the light measurements performed on it (Figure 4c).
    - *Measure and evaluate light quality*. To evaluate the illuminance level, a process of measurement is needed (Figure 4d). To start it, the first task is to choose the method to read the illumination from a selector, where there are two options:
        - Manual input.
        - Mobile's ambient light sensor.

      Once the lighting sensor is selected, it is possible to perform the evaluation, comparing two values which are displayed by the application:
        - *Maintained illuminance*: The minimum illuminance required by the regulations for a location.
        - *Current illuminance*: The value registered by the selected sensor.

      To carry out the evaluation, with the values displayed on the screen, it is required that the previous result of the measurement is stored. Once we pulse the button to start the evaluation, the result will be shown in an alert dialog.
    - *Delete locations*. When this option is pressed, all the information related to this location (description and measurements) will be deleted.

One of the most important points of the application is the method to perform the measurement of the illuminance to be able to carry out the evaluation. The importance of performing a good measurement is an important point to be able to compare with those specified in the regulations. To calculate the illuminance of an area, it is necessary to perform different measurements distributed on a grid to guarantee the compliance of the regulation in all the areas. To know where to perform those measurements, the application will give the number of points and their distribution in the area. Thereby, the program will calculate the value as average maintenance illuminance to compare with those defined by the regulations. In addition, the need to enter multiple measured points allows the uniformity of the area to be calculated. This point is important to guarantee eye comfort and it is another parameter determined by the regulations.



(**a**) (**b**) (**c**) (**d**)

Figure 4. AppLux application's screens. (**a**) Location list; (**b**) Location options; (**c**) View Location; (**d**) New Measurement.

6. Evaluation of the System

As a feedback step, and in order to check the application, it was essential to make a validation to verify its effectiveness. To perform this task, the following reviews were carried out:

- *Lighting measurement evaluation*: Despite allowing the value of the average illuminance to be inserted in the application manually, the application allows users to perform the measurement directly with the smartphone. The method used to measure the illuminance with the device has been tested to check its accuracy.
- *Lighting requirements evaluation*: Studies if the application evaluates properly the lighting requirements, evaluating also the compliance of regulations, in different scenarios.
- *Users' evaluation*: The application is tested by real users to know if it is easy and interesting enough to be used as a lighting evaluation tool.

6.1. Evaluation of the Lighting Measurement

There is no doubt that the data acquisition has an important role in the developed application. For that reason, an evaluation of the accuracy of the application's measurements has been performed. The measurement methodology evaluated is based on the ambient light sensor.

To ensure that the obtained information is as accurate as possible, all the measurements were performed in the same scenario, in a dark room with a light bulb and a dimmer. The light source was a 220 W dimmable incandescent light bulb and it was connected to a dimmer, which controlled the light intensity level as desired. As a reference value for the measurements, the authors used a standard lux meter modeled PCE-174 () [40], which has an accuracy of 5% of reading, which had been previously calibrated.

When the measured data obtained with the smartphone was compared with the data acquired from a reference lux meter, an absolute error of 39.08% was obtained, which was not good enough. Despite this huge difference, when analyzing the data, it is possible to appreciate that the tendency of this measure is similar to the data obtained from the lux meter. This indicates that it is necessary to make the sensor go through a process of calibration to adjust the model developed to the characteristics of the devices. To ensure the accuracy of this calibration, all the measured points were used in order to have a good sample of data, where different lux levels were measured to find the calibration factor of the device. The calibration defines which digital output value relates to which luminance input signal. This relationship between scene luminance and digital output levels of a digital image capture system is called optoelectronic conversion function (OECF) [21]. Once the calibrated factor is obtained to acquire the real measured data, it is necessary to multiply the measured value by this factor as Equation (1) shows.

$$Lux_{real} = Lux_{measured} \times C_{calibration} \quad (1)$$

After calibrating the measures performed with the calibration factor, the absolute error of the measurements was reduced to 13.74%. However, if we analyze again the accuracy of the data, it is possible to sort out different groups. In the case of the mobile phone used, it was possible to divide the measurements into three groups and recalculate the calibration factor of each one separately, and the accuracy of the sensor can be increased showing an absolute error of 8.41%. The number of groups and the range of the values may vary depending on the device used. Figure 5 shows the data analysis of this measurement methodology.

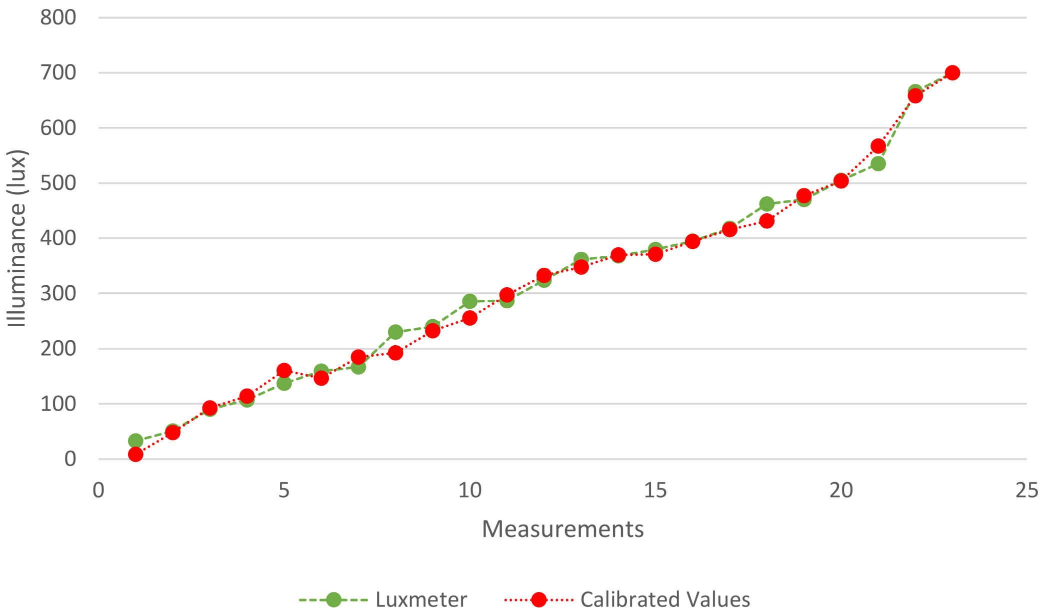


Figure 5. Mobile ambient light sensor vs. Luxmeter.

Due to the importance of good calibration, an option has been integrated into the application to calibrate the ambient light sensor, reducing the error of the measurements.

6.2. Evaluation of the Lighting Analysis

To answer the second question, a practical evaluation of the developed tool was performed. This time the validation was focused on testing if the application was able to analyze the lighting requirements of a working space. Therefore, two different kinds of scenarios were selected:

- *Offices*. In this area, are carried out the tasks of writing/reading documents, mainly with a computer.
- *Common areas*. These sorts of areas are opened to all users of the building. In the case of the evaluation, the sort of common areas used were different halls in the same building.

Despite having shown that it is possible to use the mobile phone as measurement tool, for this evaluation the measurements were taken with a calibrated luxmeter and incorporated into the mobile tool to perform the analysis. As a result, a total of 30 evaluations were divided as shown in Table 1.

Table 1. Lighting evaluations performed.

Sort of Space	Number of Evaluations
Offices	20
Common Areas	10

In order to make a complete evaluation of the analysis performed by the developed tool, and to also evaluate the user satisfaction with the results, the study was divided in two, one for each sort of scenario evaluated.

6.2.1. Offices

To select the scenarios, and in order to evaluate real cases, a survey was performed where users were asked about their interest in checking the lighting conditions of their workplace and if they thought that their level of light could be improved to achieve a better lighting quality. From the survey's respondents a total of 20 random cases were selected from the users who were interested in checking their lighting conditions and who thought that these conditions could be improved.

Once the scenarios were checked with the application, the results were divided into three different groups: places with a correct level of light, places with excess light, and places with a lack of light. Table 2 shows the number of cases selected for each.

Table 2. Lighting evaluation on offices.

Correct Light	Excess of Light	Lack of Light
7	6	7

The first point that must be highlighted is that 35% of the evaluated cases has a level of light in compliance with the standards, even when the users think that the lighting conditions could be improved. On the other hand, the rest of the evaluated cases shows a problem with lighting, where 35% have a lack of light and the other 30% have an excess of light.

As it was said, when the application detects that the lighting requirements do not comply with the lighting regulations, different tips are shown in order to solve the problem. On one hand, in cases of a lack of light, those tips go from the substitution of the lamp for others with higher illuminance, showing as a recommendation LED lamps which have high energy efficiency, to the removing of the protector of the fluorescent lamps. On the other hand, the recommendation in cases of excess illumination are the substitution of the lamp for another with lower illuminance, decreasing at the same time the energy consumption. In the case of the study performed, the replacement of the lamp protections in cases of a lack of light and the substitution of the lamps in cases of excess light were enough to ensure the regulations' compliance. At the end, the solutions carried out not only improve and correct lighting conditions, but also help to reduce the energy consumption.

A few days after correcting the lighting problems, a new survey was conducted to analyze the user satisfaction with the lighting changes. In this new survey, when asked if they could detect the changes in lighting conditions, 69.23% of the respondents detected the differences in the lighting level of their workspaces. After, they were asked about the feeling of improvement of the lighting quality, and 53.84% of the respondents said that the new conditions were better, helping them feel less stress on the eyes. If we make a distinction between cases of excess and lack of light, it is possible to see how the users with a lack of light detect easily the differences in the light, detecting also an improvement in the quality of lighting conditions.

6.2.2. Common Areas

The second kind of scenario selected was common areas. In this case we focused the evaluation on different corridors of the same building with a large influx of users because they connect areas such as coffee shops and classrooms.

To select the specific scenarios to evaluate, a new survey for the users of the building was also performed. This survey asked them about the lighting conditions of different halls of the building and if they thought that their level of light could be improved to achieve a better lighting quality. From the answers of the survey, 10 cases in which users thought that the lighting conditions could be improved were selected.

After checking the scenarios with the developed application, the results were divided once again into three different groups: places with a correct level of light, places with excess light, and places with a lack of light. Table 3 shows the number of cases selected for each.

Table 3. Lighting evaluation on common areas.

Correct Light	Excess of Light	Lack of Light
4	2	4

In this case, 40% of the evaluated cases had a level of lighting that was in compliance with the standards, even when the users thought that the lighting conditions could be improved. On the other hand, the rest of the evaluated cases showed a problem with lighting, where 40% had a lack of light and the other 20% had an excess of light. In cases where the application detected that the lighting requirements did not comply with the lighting regulations, the same corrections as for the office's study were adopted.

After a few days to correct the lighting problems, a new survey between the installation users was conducted to analyze the user satisfaction with the lighting changes. When they were asked if they could detect the changes in lighting conditions, 50% of the respondents claimed that they could detect the difference in the lighting level of their workspaces. Therefore, they were asked about the feeling of improvement of the lighting quality, and only 25% of the respondents said that the feeling was that the lighting conditions had been improved. The most interesting point is that, in areas with an excess of lighting, there was no feeling of improvement of the lighting. This could have happened due to, in most cases, the perception of a lower level of light in common areas being associated with a feeling of insecurity.

6.3. Users' Evaluation

Once the application was developed and had passed through a practical validation, the next step was to perform a validation from the point of view of the user. To perform this evaluation, an experiment where 20 subjects tested the tool was conducted. To be sure about the developed application being easily understood, the selected users had different levels of knowledge about lighting analysis.

During the first step of this evaluation, the application was given to users in order to check the lighting quality of their workspaces. Once the users finished the evaluation, they had to fill out a Likert scale questionnaire (1 to 5) [41] of 9 questions with several questions to evaluate and give their opinion about the application.

Analyzing the results of the questionnaire, it is important to highlight how users qualified the complexity of use of the developed tool as medium, even when users had little knowledge about lighting analysis. Regarding the interoperability with the interface, users marked the application with a 4.37, highlighting the easy use of the application. When they were asked about the reason for their answer, 60% of the respondents highlighted how the interface and the messages shown in the application helped them to use it correctly, rating with a 4.47 the accessibility of the information.

Regarding the question about whether the proposed mobile application reached the aim of easing the measurement of work space illuminance, it was punctuated as 4.72. On the other hand, when asked if the developed application was handy to have as a reference about the level of compliance of the European Standards EN 12464-1 [9] and EN 12464-02 [10], the respondents answered affirmatively with a mark of 4.62. To conclude the questionnaire, the respondents were asked if the recommendations given by the application improved the working lighting environment, which users marked as 4.47.

7. Discussion and Hypotheses Validation

At a methodological level, this work contributes with the presentation and the implementation of an engine of rules that facilitates decision-making in an efficient way, telling users if the lighting complies with the European standard and, in the case of deviation, indicating the value of this.

Regarding the hypotheses proposed previously, they can be answered thanks to the research performed in the study. As for the first hypothesis (H1), which stated that the usage of mobile applications could help in disease prevention, it has been observed along the study that this tool eases occupational health and safety prevention related to lighting. This is possible due to the developed application allowing users to evaluate their lighting levels regarding the task that they perform in the evaluated area, allowing them to obtain a better working environment, and preventing at the same time the possible damage derived from bad illumination. Analyzing the studies performed on real scenarios, it is possible to observe that, in most cases when the lighting has been improved, the users noticed the changes in the lighting and also recognized the improvement of the lighting. This feeling is higher in the case of offices, where 53.84% of users saw the improvements, also recognizing having less eye problems once the lighting requirements were improved.

Regarding the second hypothesis (H2), we can assert that the use of mobile applications may help on energy saving as was probed along the practical evaluation of the tool. It must be taken into consideration the power of this sort of application not only in the evaluation of the measurements, but also in giving tips to improve them. In the case of the application developed, the tips shown in cases of noncompliance of the regulations assisted in the improvement of the lighting quality as well as in the reduction of energy consumption. If we analyze the corrections performed in the cases of study, the results highlight a reduction of energy consumption thanks to the tips offered by the application.

In relation to the third hypothesis (H3), which stated that mobile devices can be used as a fairly accurate light meter tool, we can assert that it is not possible. Despite the study highlighting the use of mobiles devices as measurement tools, the process of calibration could be difficult to be performed by any user, as well as necessitate the use of a calibrated luxmeter as a reference, a device that not all users have at their disposal. Besides, the differences of the hardware of each smartphone model makes setting a process of calibration harder. For these reasons, mobile phones should be used as light measurement tools with medium accuracy and should not be used for situations where high reliability is required unless calibrated.

Concerning the fourth hypothesis (H4), which stated that the mobile applications could facilitate the compliance of lighting regulations in working spaces, along the validation of the study's results, it was observed that the use of this sort of application helps in light measuring tasks and gives more information in order to improve the lighting by providing an orientative value by using the ambient light sensor and a measure of quality by using external sensors.

The last hypothesis studied (H5) stated how the use of an intelligent agent based in rules helps in decision-making, providing information to the user. Along the validation, it was observed that the use of rule engines in the mobile applications allows the user to detect the illuminance variation in working spaces regarding the regulations, making it possible to recommend different alternatives to improve the quality of the light.

On the other hand, the use of a rule engine has allowed the development of an intelligent agent based in rules that compares the values acquired by the sensors with the values of the UNE regulations, helping users to adopt the better option to improve the lighting level.

8. Conclusions

In this research we have designed, developed, and evaluated a new tool based on the usage of lighting sensors, which allows users to evaluate the level of illuminance in both working spaces, outside and inside. So, it allows users to know the degree of compliance of UNE standards, allowing its use in the prevention of occupational risks.

The results suggest that the usage of this tool allows users to obtain, with enough accuracy, the value of the illuminance in a working place. In addition, the rules engine implemented offers useful information through recommendations for improvement, helping with decision-making tasks, allowing the decrease in the number of sick leaves caused by bad lighting in the workplace.

The developed system was evaluated by professionals from two points of view: practical and technical. The results offered some feedback and suggestions about the system. The feedback from caregivers showed that the proposed system can streamline and improve the process of risk prevention due to illumination of jobs and workplaces.

The use of a Web server where all the measurements are performed with the application allows us to collect information about the level of compliance with the standard, and to use this information in other future studies about the compliance of regulations among others.

Acknowledgments: The authors want to thank the effort and the support that University of Alcalá and University Rey Juan Carlos have offered to the Department of Computer Science of UAH and Business Economics Department of URJC in the "CEI 2017 Intelligent Energy" project. V638.

Author Contributions: Ana Castillo-Martinez and Jose-Amelio Medina-Merodio have developed the mobile application used along the experiments and performed the analysis of the results obtained on the different experiments; Jose-Maria Gutierrez-Martinez and Juan Aguado-Delgado have been in charge of the experiments performed, and Carmen de Pablos-Heredero and Salvador Otón have coordinate the work and validated the results.

Conflicts of Interest: The authors declare no conflict of interest.

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