Comparison of lighting simulation outcomes for electric lights with real reference

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Abstract: - In recent years, there has been considerable progress in the area of building lighting [1]. Especially in terms of efficiency, durability, and internal lights control possibilities offered by the system. Besides these affairs were conducted further studies focusing on the visual comfort in the indoor environment. The fact is that a considerable number of issues causing some visual discomfort can be solved by appropriately modifying the control logic of the system. For these reasons, a suitable way to control the lighting in this field is crucial. The design of control algorithms can be done in various ways, however, in recent years, very useful tools for performing complex lighting assessments are simulation tools [2]. This article deals with a comparison of the results of simulation tools and real measurements and further discusses the possibilities of using these tools to design lighting control algorithms. This article also describes a newly built lighting laboratory at Tomas Bata University in Zlin whose control system is based on the KNX bus and its components. The primary purpose of this laboratory was to study the interaction of natural and artificial lighting in the view of uniform illumination on the workplace and chromatic distribution through the room. However, as the lab control system is conceived, it is a prerequisite to using the laboratory to verify the various control algorithms based on both direct and feedback control.

Key-Words: - KNX system, DALI, lighting laboratory, lighting control, uniform illumination, lighting simulation

1 Introduction

Research in the field of building lighting can be from general perspective divided into two essential parts [2]. The first one is oriented to the light sources itself, individual components of the whole illumination system and the ways of controlling electric lights and shading elements of indoors. This part of the research aims to achieve the maximum possible energy savings while meeting interior lighting hygienic limits. The second view focuses on the impact of all types of lightning, and its combination, on lighting quality indoors means visual comfort, good colour, uniformity and balanced brightness. Both these approaches go hand-in-hand, and new findings in one part always require further study in the other.

In recent years, a large number of studies have been published to highlight some gaps in the current ways of designing lighting systems. For example in [3], the author states that standard design procedures do not take into account when occupants work with the device containing bright displays. In this case, the author mentions that it is necessary to increase the intensity of the illumination to ensure the proper contrast of the display and the surrounding areas. Furthermore, it has been found that illumination also has a non-visual effect on the human body [4][5][6][7][8][9] such as the biological clock that drives our approximate 24-hour (circadian) rhythms of alertness, core body temperature, hormonal secretion, and affects sleep. A considerable number of issues causing some discomfort can be solved by appropriately modifying the control logic of the system.

There are many ways how lighting can be controlled. Recently, research in this area has focused on electric lighting control with a minimum number of sensors. The primary input parameters are then the solar parameters, the location of the building, the layout of the interior space and the global value of the solar radiation from one sensor or weather station. Afterwards, computer-based algorithms can control electric lighting and shading devices on daylight apertures to provide appropriate space and task illuminance and to limit daylight or sunlight penetration, reduce window luminance and glare, and maintain acceptable levels of visual control [2]. Many manufacturers have tried to create their general algorithm, but this approach subsequently exhibits considerable inaccuracies, because the location and geometry of different spaces are not the same.

The design of the control algorithm is then a very complicated matter that requires extensive computational assessment and also the real illumination measuring the workplace because afterwards, the control runs without feedback. Therefore, the effort is to find a particular relation between all the variables involved in the illumination of the spaces. This suggests a relatively time-consuming process, but this process can be significantly speeded up when using specific software tools.

In recent decades, wide varieties of lighting simulation software or tools have been developed to make interior and lighting designs more efficient. At the same time, a large number of studies (or BESTTESTs), for example [10] [11] [12] [13], have been carried out to deal with the comparison of these simulation tools with each other in many aspects. These studies show very similar calculation outputs of illumination of virtual building reference for almost all programs involved. This, however, does not indicate the usability of these tools in real building reference and they are still often used without enough knowledge about their accuracy or limitations.

Based on the above, this paper studies and compares calculation outputs from selected simulation software and values from the real measurement because these types of research are currently very few. For the purpose of this paper, specialized light laboratory at Tomas Bata University, Faculty of Applied Informatics (FAI TBU) in Zlin was used. This article focuses only on artificial lighting with no daylight involved. This is the first part to be followed by further work in the future.

2 New light laboratory based on KNX platform

The light laboratory was built in 2017 and serves for research and development needs at FAI UTB in Zlin. The primary objective of this laboratory was not to specialize in testing high-end luminaries but to address the impact of their effects on indoor environments such as the interaction of natural and artificial lighting in the view of uniform illumination on the workplace and chromatic distribution through the room. Moreover, as the lab control system is conceived, it is a prerequisite to using the laboratory to verify the various control algorithms based on both direct and feedback control. The equipment of the laboratory was chosen to examine all types of lighting, natural light, artificial light, and their combination. The laboratory is located on the 3rd floor of the building with windows facing south. It is a room of rectangular shape with dimensions of 8.7 x 7.3 x 3.4 meters. There are work desks that define the work area at the height of 0.8 m above the floor. The artificial light source consists of luminaires with dimmable electronic ballasts (12 x LED panel CCT 6060 36W, 3600lm) which are also capable of changing the colour of the light (3000 - 6500K). These luminaires are suspended on a HILTI construction that is sliding to change their vertical and horizontal position. In this situation, the lights were placed at the height of 2.5m above the floor. To control the penetration rate of daylight, there are shutters connected via a blind actor to the KNX. From the inside as secondary dimming elements, there are blinds that are operated manually. This solution allows for complete darkness in the laboratory.

Fig. 1. Interior of light laboratory at FAI TBU in Zlin.

The lighting control is performed by Digital Addressable Lighting Interface (DALI), which is specially designed to control lighting where the KNX DALI-Gateway connects KNX with electronic ballasts equipped with a DALI interface. This interface enables the luminous intensity and colour temperature adjustment for each light separately. The logic itself is based on a control algorithm whose primary objective is to control the inner illumination to a constant level, and the goal is to keep the power consumption for lighting at the

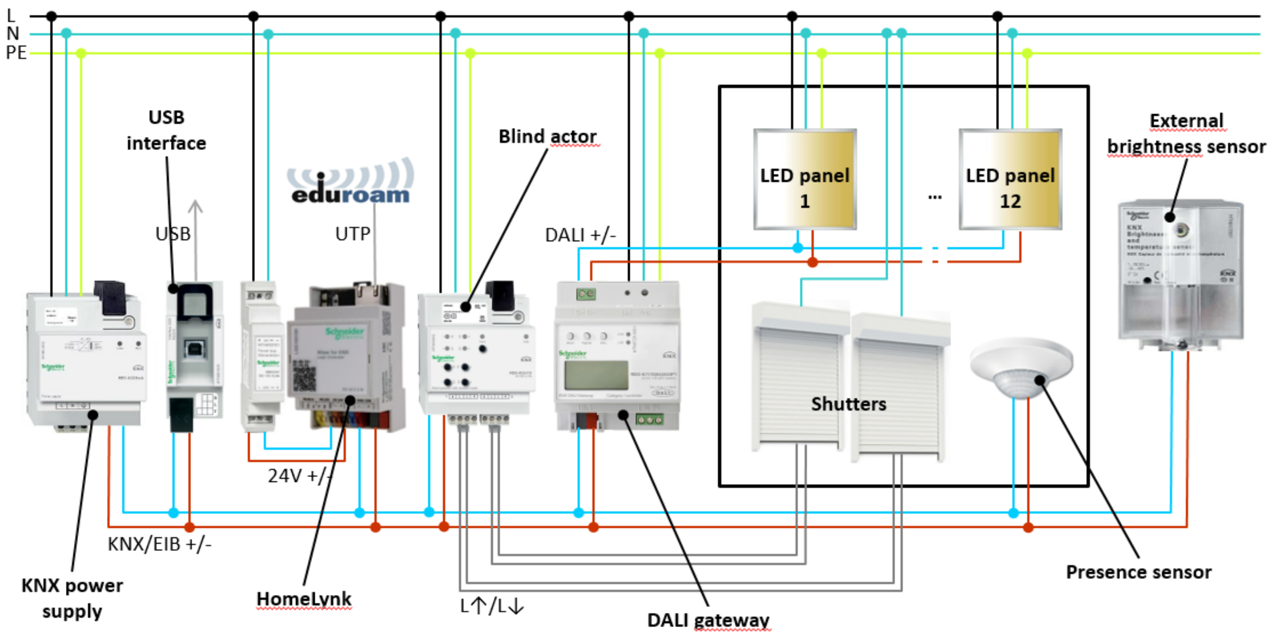

Fig. 2. Block diagram of KNX installation.

minimum level and at the same time, meet the hygienic limits, which are given in [14]. The basic configuration was made in ETS 5. Subsequently, the programming of individual functions was performed in the HomeLynk web environment, as well as the visualization (Fig. 3) defining the interface between the user and the application. It is a future-proof solution, developed by Schneider Electric, that allows remote control of all peripheries via computer or smartphone.

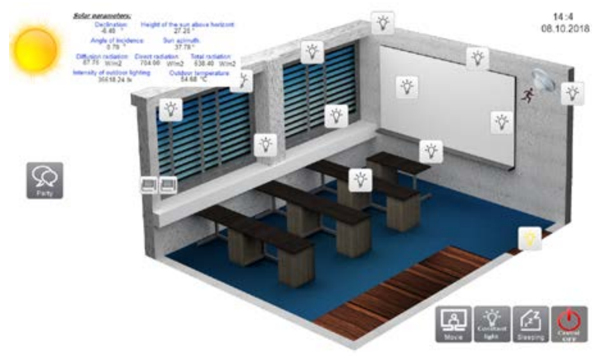

Fig. 3. Visualization for luminaires and shading elements control.

4 Methodology

The measurement and also a comparison was performed only for artificial light with no daylight involved. Evaluation criteria were the horizontal indoor illuminance E [lux] that was collected manually, at specific locations (see Fig. 4), using a measurements set including a datalogger AHLBORN ALMEMO 2390-8 and two light intensity sensors FLA623VL and FLA613VL, both with the accuracy of 5% of the measured value. Measurements were collected in 12 observation points, at the height of 0.8 meters above the floor (see Fig. 5).

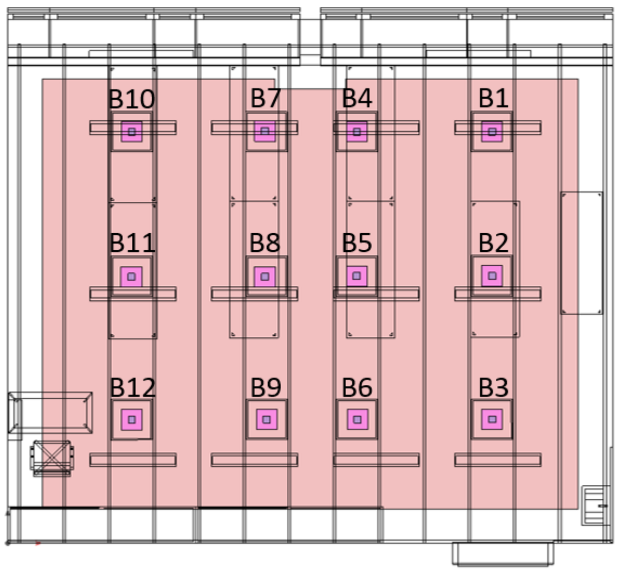

Fig. 4. Model of the light laboratory with the markings of the observed points.

For the purpose of comparison, the DiaLux Evo software was chosen as the simulation tool. This software was developed by DIAL GmbH DIALux and its a widely used commercial package in lighting design, which is available for free through lighting manufacturers' websites. The exact model of the laboratory was created in this program, and the luminaire shape and other luminaire definition in greater detail were downloaded from the manufacturer's catalogue.

In the case of real measurement, the procedure proceeded as follows. At first, the workplace illuminance was measured, where all lights were being controlled together. During these measurements, the lighting intensity of all luminaires changed to 14%, 53%, 72% and 100% of their maximum power and this whole process was repeated for different colour temperatures TC (3000K, 4000K, 5000K and 6000K).

Fig. 5. Model of the light laboratory in 3D with the observation points.

In contrast to the first phase of measurement, the second one concerned the control of each luminaire separately. The goal was to set the luminaire parameters to achieve uniform illumination levels on a work plane throughout the room. Setting the luminous intensity of the lights then depends primarily on their position in the room. Since the luminaires illuminate the space at a certain angle of radiation, it is obvious that if the same luminous intensity is set for all luminaires, there will be greater illumination in the middle than in the rest of the room. For this situation, the luminous intensity values were determined experimentally, and the required illumination on the work plane was 500 lux.

Afterwards, all the measured data from the building were compared with results from the computer simulation runs in order to determine how close the computer predictions were to the field-monitored values. Description of both phases is provided below in the results section.

4 Results and discussion

The results presented below are directed towards the analysis of the degree of accuracy of the DIALux Evo software when applied for real buildings. However, given the fact that conducted studies have found that calculation outputs from various lighting simulation programs are very identical, we assume that the results from other programs would be similar to those of the DIALux Evo. A great deal of emphasis was put on the correct setting of all the parameters of all elements that affect the resulting illumination value, such as the material used regarding surface reflectances, the positions of all elements and the parameters of the luminaires.

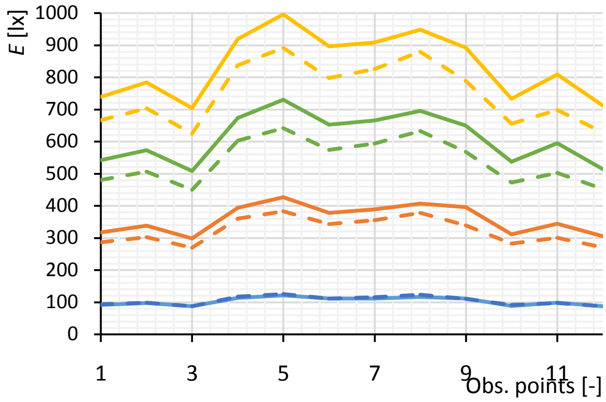

Fig. 6. Illumination values at individual observation points for different luminous intensity, T_c = 4000K, Φ = 3600lm, (continuous line = real measurement, dash line = simulation).

Fig. 6 illustrates the comparison of the results of the workplace illuminance obtained from real measurement and simulation. The comparison is done for four different luminous intensities given in the percentage. As can be seen, the differences in higher luminous intensities are noticeable. In the case of luminaires full power, the measured values on average are about 87 lux higher than the results from the simulation. This is mainly due to the fact that in the case of dynamic LED CCT type of luminaires, luminous flux Φ [lm] can vary widely, depending on the colour temperature [2].

Furthermore, rated luminous flux refers to the initial luminous flux of the new luminaire and also this value should be reached after a certain period of operation [15]; moreover, the value on the luminaire label should indicate the smallest possible value for the entire spectrum of colour temperature, but in general, it is usually given for T_C = 4000K. For this reason, at the beginning of the luminaire operation, we should measure the higher values of the luminous flux than the manufacturer indicates. Therefore, further, it has been tested for which luminous flux value will be obtained similar results to real measurements. The resulting values are 3890 lm for 3000K, 3920 lm for 4000K (see Fig. 7), 3970 lm for 5000K and almost 4000lm for 6000K. From these values, it can be observed that in the case of these luminaires, with the increasing colour temperature, the luminous flux also increases.

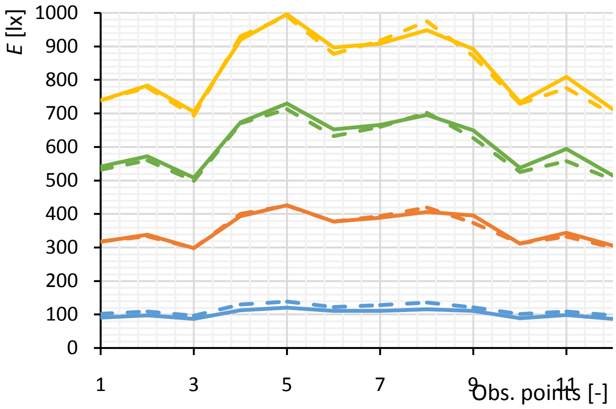

Fig. 7. Illumination values at individual observation points for different luminous intensity, Tc = 4000K, Φ = 3920lm, (continuous line = real measurement, dash line = simulation).

Following are the results of the second measurement phase, concretely lighting control to a constant workplace illumination level of 500 lux. It was desirable to achieve this value only in the task area; it means the place directly below the light. The illumination of the immediate surroundings of the task may be less than the illumination of the task area, more about this is mentioned in [14]. It was therefore desirable to set the luminous intensity of each light so that the illumination levels on a work plane throughout the space was slightly above 500lux. All luminaires were set to the colour temperature of 4000K and maximum luminous flux of 3920lm which was then regulated. The resulting comparison is shown in Fig. 8.

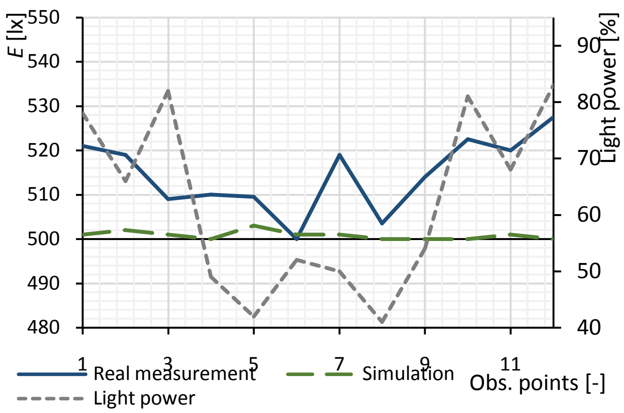

Fig. 8. Lighting control at a constant level of 500 lux and comparison of results.

As can be seen from Fig. 8, the parameters of luminaires, which in the simulation meant almost constant distribution of the illumination, are in reality slightly different. This can be caused by many factors. One of them could be the accuracy of the electronic ballasts in terms of its regulation, which may not be completely linear. Also, the deviations of the luminous flux and the luminance distribution of each luminaire contribute to the resulting differences. However, these are factors that are directly connected to the light sources and the control system also, and it is very complicated to detect their exact impact. In addition, there are inaccuracies that could have been caused by measuring devices and measurement itself. Even though we are confident with measured data, the manufacturer of the used sensors indicates an inaccuracy of 5%, which in this case means 25 lux.

Fig. 9. Example of the illuminance distribution on a work plane throughout the lab.

4 Conclusion

Lighting controls are an essential component of any lighting system, serve multiple purposes, and range from simple user-activated switches to advanced scene controllers with variable electric lighting and shading devices adjustment depending on daylight [2]. Simulation tools used in light analysis provide accurate results, if the sources involved are perfectly diffuse emitters or if the surfaces involved exhibit perfectly diffuse reflection. However, this is in real building reference complicated to achieve; hence real values will always show certain inaccuracies.

This paper is a study of the possibilities of using simulation tools to predict the degree of illumination of the indoor environment, and it is a first part of the supposed long-term study aimed at defining the accuracy and limitation of the lighting simulation tools. For this purpose, several series of measurements and computer simulations were performed. The software outputs were compared with real building conditions and physical model predictions in an aspect: illumination levels on a work plane throughout the space. These results will be used to create the control algorithm for electric lighting and shutters according to solar information from a weather station. At present, the computational algorithm is not complete, so only the comparison results are provided in this article.

The results of this work show that the basic knowledge of lighting technology and its parameters are necessary for the correct execution of simulations. As can be seen from Fig. 6 and 7, when controlling the illumination, the luminous flux values on a luminaire label must be multiplied by a certain coefficient, which in the case of a new luminaire is less than 1 and its value gradually increases as a function of its operation. With this knowledge, it is possible to use the results from simulation tools to perform the calculation of the light power of individual luminaires, while controlling the illumination to a constant level. Furthermore, concerning the accuracy of the simulation, the illuminance value calculation for artificial lighting is found within acceptable precisions, but opportunity remains for complex situations with the inclusion of daylight. Therefore, this is what we intend to deal with in the future.

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