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A new approach for examination of performance of interior lighting systems

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ABSTRACT

This paper presents a new approach for examination of insufficiency of a current lighting system and for performing maintenance plans of a lighting installation. Thus, a numerical algorithm based on finite element method (FEM) that ensures the required accuracy for illuminance calculations according to international lighting standards was developed. Experimental measurements were recorded in a controlled environment for the purpose of measuring the effectiveness of the algorithm. The average illuminance calculated according to CIBSE Code 1994 published by the Chartered Institution of Building Services Engineers (CIBSE) was obtained by error of 5.3% compared to the experimental measurements. Illuminance values of 894 points were calculated as 0.3% error according to the actual experimental measurements by proposed numerical algorithm that uses 36 pieces measurement data. Less experimental measurements provided more accurate results. The results obtained indicate that the suggested numerical model is very effective and usable in calculations of illuminance. In this way, this model will eliminate the requirement for long experimental measurements in lighting system controls that must be carried out periodically.

1. Introduction

Electric energy savings have become a subject that gains importance every passing day and on which considerable studies are conducted. Artificial lighting systems are one of the culprits of the most significant consumption of electricity in buildings. This is due to their properties [1–6]. These systems are also used continuously in daytime as they increase work performance and comfort, especially in industrial operation and work environments. In the design of lighting systems, appropriate illuminance on a working plane without unnecessary illumination is intended continuously obtain.

The productive use of energy in artificial lighting systems depends on decisions to be taken in design and operation phases. In the installation phase, the load of the lighting system can be decreased by designing it in accordance with its purpose and by using energy efficient lighting devices. In the usage phase, energy savings can be obtained by minimizing the period of use of the artificial lighting system and through regular maintenance and cleaning [5,7]. However, planned energy savings in lighting systems are made during the installation phase. During the usage phase, where energy consumption is highest, maintenance of lighting systems is overlooked because of cost and ignoring. This is why failed lamps and ballasts are not changed for months. However, what is expected from artificial lighting systems is to continuously ensure the necessary illuminance during work hours after installation.

Illuminance significantly affects the speed, ease and reliability with which visual tasks can be performed. However, illuminance that is created by a lighting system on a working plane decreases in time. There are four reasons for this decrease [1,2,8–12]:

- lamp and ballast failure;
- lamp lumen depreciation;
- luminaire dirt depreciation;
- room surface dirt depreciation.

Because the human eye can easily adapt to a reduction in illuminance that occurs gradually, most users are unaware of changes to lighting conditions. But diminished illuminance affects the appearance of the environment as well as the productivity, visual comfort and safety of the occupants [13–16]. Lighting designers consider this reduction in their designs by turning to the maintenance factor.

$$\text{Maintenance factor (MF)} = \frac{\text{Maintained illuminance}}{\text{Illuminance on installation}}$$

The maintenance factor is the ratio of illuminance on a working plane at the end of a definite period of service divided by the illuminance upon installation [5]. With the maintenance factor, negative effects such as failed lamps, depreciation in lamp light flux, dirt

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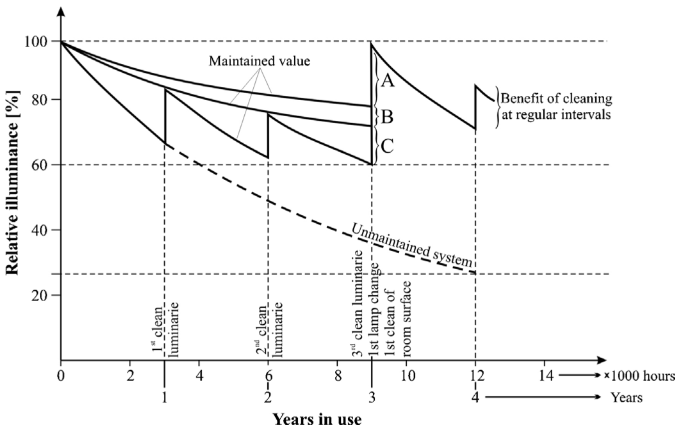

Fig. 1. Effects of maintenance and replacement process on the lighting efficiency: (A) increase in illuminance by painting of internal surfaces of environment, (B) increase in illuminance with replacing of lamp, (C) increase in illuminance with cleaning of luminaires.

accumulation on room surfaces and luminaires are taken into consideration [17]. The maintenance factor varies depending on the type of luminaires and lamps, the pollution of the used volume and maintenance frequency. In many cases, not enough is known at the design stage about the operating conditions likely to impact a lighting installation. So, assuming a three-year maintenance interval, the following maintenance factors are generally applied:

- in clean rooms: maintenance factor 0.67;
- in dirty rooms: maintenance factor 0.5.

Consequently, the maintenance factor is a given. Selecting a low maintenance factor means using more lighting devices and more illuminance at the beginning, which translates into more energy consumption [18]. More frequent and reliable maintenance makes it possible to obtain an energy efficient lighting design [9,10,19]. Fig. 1 shows the effects of the suggested maintenance and replacement procedures on illuminance [20–22].

Provided is the relative variation of illuminance over time on a working plane, taking into consideration the lamps' total initial light flux. Illuminance falls to 36% of its initial value in a lighting system without regular cleaning and maintenance.

As shown in Fig. 1, cleaning luminaires only once a year increases the lighting level by about 15%. At the end of a lamp's lifetime, by cleaning the luminaire, changing the lamp altogether or painting the inner wall surfaces of the environment, illuminance may be brought to its initial value. Healthy maintenance and replacement of parts in lighting systems without incurring unnecessary costs is only possible by controlling illuminance at regular intervals. This method requires time-consuming experimental measurements. Therefore, most failed luminaires are not replaced or undertake maintenance until users in the environment are unable to perform their jobs [23]. Sometimes a problem that can be eliminated through the cleaning of a luminaire may make an unnecessary replacement of a lamp or luminaire. It is for this reason that a well-planned maintenance program can assist keeping service illuminance within or above the proposed value. It increases user work performance by assisting in maintaining the performance of the lighting system [19].

This study suggests an algorithm that ensures the sensitive determination of the average illuminance and light flux distribution in any ambient environment by making fewer measurements. The suggested numerical model has been developed as part of a lighting maintenance management strategy designed to create healthy visual environments and ensure energy saving. The algorithm is a FEM base algorithm that uses a fifth degree approach function. To check the accuracy of the numeric method used and to calculate the average illuminance according to international standards, illuminance measurements were correspondingly taken in the working plane in accordance with the standards. The distribution of illuminance in the environment was obtained graphically by drawing isolux curves according to the measurement results. Illuminance curves drawn by measuring and calculated by using the suggested FEM base model were compared. Consequently, it was determined that the suggested model produced remarkably accurate calculations for illuminance analysis in interior environments.

Fig. 2. An overview of the laboratory that done measurements.

2. Experimental setup

This study was carried out at the "Circuit Elements and Measurement Laboratory" of Marmara University, Faculty of Technical Education, Department of Electrical Education. The laboratory measured 10.35 m × 10.35 m × 3.7 m (width × length × height). The ceiling and walls of the test environment are white, while the floor is covered in gray ceramic tiles. Fig. 2 includes a view of the laboratory.

The lighting system consists of twelve luminaires without a reflector (TMS022). Each luminaire has two 36 W daylight fluorescent lamps and two magnetic ballasts. The luminaires are positioned in four rows perpendicular to the windows and surface-mounted on the ceiling. A view of the luminaires is given in Fig. 3a. A total of 930 measurements were made to determine the illuminance distribution in the working plane and the isolux curves. Measurements were made on a working plane at the height of 0.8 m from the ground; there were no tables in the environment [7].

To carry the lux meter, a wheeled pad was used as seen in Fig. 3b. For the measurements, the floor tiles were planned as a finite elements mesh. According to CIBSE Code 1994, measurements with a lux meter must be made at a distance of at least 0.5 m from fixed objects like column, walls and screens [22,24]. Therefore, in determination of measurement points for the mesh application, this situation was taken into consideration. The corner of the drawn mesh at the entrance door was accepted as the starting point. These points were marked on the floor previously with chalk, as seen in Fig. 3c. The measurement points were defined by being assigned numbers on paper. A guide bar was placed at the base of the lux meter carrying an apparatus to observe the marked points, as seen in Fig. 3d. The intersection of measurements points was quite ensured by bringing the bar and sensor axis into alignment.

As it is necessary to measure lighting in the dark in order to evaluate an electrical lighting system, lighting level measurements were begun at 22:00 o'clock in complete darkness. As the laboratory