LIGHTING QUALITY EVALUATION
EVALUAREA CALITĂȚII ILUMINATULUI

Florin POP, **Mihaela POP**

The primary function of an electric lighting installation is to enable people to see, in order to perform their tasks comfortably and safely. For avoiding an undesirable outcome from an electric lighting installation which achieves energy-efficiency at the cost of lighting but makes people uncomfortable and puts their safety at risk, it is necessary to consider lighting quality as well as energy-efficiency when designing or evaluating lighting.

The paper is related to the evaluation of interior lighting systems quality. A multi-criteria method provides the means to analyze the relation lighting quality - effective cost - human benefit. It is developed a new working tool ILES - Interior Lighting Evaluation System, with two components - an objective photometric and energetic analysis LQED - Lighting Quality & Economic Diagnose and a subjective survey ULCS - Users' Lighting Comfort Survey.

Our research is toward to develop a method to quantify the qualitative and quantitative parameters of lighting installations**.** The multi-criteria investigation method allows us to consider the lighting installation not only by its photometrics, but also by economic parameters and human behaviour. It is useful to simultaneously estimate photometric and economic (cost and energy) parameters, maintenance program and subjective evaluation of visual comfort. The evaluation system ILES is designed to be inexpensive, simple to administer, score, and easy to interpret. It covers few parameters, but the most important ones, and a rough scale of preferences. A computer program supports the analysis of energy efficiency and quality of lighting systems. Specific modules are related to the objectives of the research study.

Introduction

The developing of a method to quantify the qualitative and quantitative parameters of lighting installations is in support of the objectives of the IESNA Quality of the Visual Environment Committee: "to identify important differences in qualitative assessment of specific lighting applications, and to determine the lighting system parameters that influence such judgments of quality". One of the most important objectives of CIE Division 3 Interior Lighting, presented at the 23-rd CIE Session – 1995 is concerning to the "measures for lighting quality in interiors". It is necessary and useful to discuss lighting quality in context of both human productivity and energy. A link between an improved lighting quality and improved human productivity – not yet proved – should provide a powerful economic reason for acting towards a new quality in lighting, with the final recognition of the need to model the complexity of lighting quality and to distill the results to a form useful for designers. There are many methods of measuring the visibility and visual performance proposed or in use, each of them with some advantages and disadvantages, limitations or difficulties related to their field measurements.

Visibility and visual performance

Visual task is very different related to the developed activity, from the reading of a book to the electronic component assembling. Its characteristics determine the conditions required to the lighting system. A proper design and accomplishment are a priori requirements for a good lighting. The main criteria of the lighting design for a certain application are the *visibility and visual satisfaction*, linked with the *capital and running costs.*

The performance of a certain user for a specified task is determined necessarily both from its ability and devotion to the accomplishment of the task. The lighting, together with the other physical environmental factors may intensify this task. The *visual performance* is the term that evaluates the information processed by the visual system. The speed and accuracy of the accomplishment of the visual task (component of a complex task) measure it. The *visibility* of a visual task is mainly determined by the visibility of the most difficult component to be detected or recognised, named the *critical detail*. The detail visibility is depending of the several factors, such as: its angular dimension, its luminance and color, luminance and color contrasts between the detail and background, available time for observation, position of the detail in the visual field, and so on.

Systems and methods for evaluating lighting quality

The quality of a lighting installation would be described by several parameters: illuminance level and uniformity; direct glare control or avoidance (luminance distribution); appearance color and color rendition; modeling. The qualitative parameters have different weight, related to the room destination and architecture. The accent should be on: *visual performance*, choosing the right illuminance level and the glare avoidance; *visual comfort*, by the colour rendering and the luminance distribution; *visual environment*, by the selection of the light colour and direction and modeling.

Comment:

Lighting quality is a multi-faceted concept. We assess it *directly*, by measuring its photometrical parameters, and, *indirectly*, using behaviour measures – for instance, responses to semantic differential scales or Likert-scale responses to statements of opinion. There are also many research studies proposing new methods and surveys devoted to identify a proper modality to refine visual performance and comfort models. However, since there are yet no comprehensive and objective measures of visual comfort; occupant surveys remain the most accurate way to assess the lighting installation not only by its photometrics, but also by economic parameters and human behavior. It is useful to simultaneously estimate photometric and economic (cost and energy) parameters, maintenance program and subjective evaluation of visual comfort.

Energy efficiency and quality do not automatically go hand in hand Greater lighting comfort for people in offices, for example, is often combined with a higher energy consumption. If a measurable (energy consumption) and a non-measurable (lighting comfort) parameter have to be weighted against each other, the non-measurable parameter comes under pressure [7].

Individual criteria for evaluation. A lighting installation with good quality is energy-efficient whether permits a high level of performance without creating discomfort. *The light quality is not directly measurable, but it is a state generated by the link between environment and users.* A lighting has a good quality when: (1) there is a good visual condition; (2) it permits the accomplishment of the task or determines the behaviour in accordance with the environment; (3) assures the availability of the interactions and desired communication between the participants; (4) contributes to the aesthetics of the space. The evaluation of the lighting quality has to be made by the evaluation of its effect on the people, having in mind all the characteristics of the room space and the users. To consider a good quality, the lighting has to be consider comfortable by the minimum 70% of its end-users - [6].

Global systems for evaluation. CIE, CIBSE and IESNA were developed several methods to assess the degree of the users visual comfort or discomfort glare - *Equivalent Sphere Illumination – ESI, Relative Visual Performance – RVP, Visual Comfort Probability – VCP, Glare Index - GI, Luminance Limit Curve, Unified Glare Rating – UGR.*

The Interior Lighting Evaluation System - ILES

Designed to be inexpensive, simple to administer, to score, and easy to interpret, the ILES covers a reduced number of parameters, but most important ones, and a rough scale of preferences. The system has two components - an objective photometric and energetic analysis LQED - Lighting Quality & Economic Diagnose and a subjective survey ULCS - Users' Lighting Comfort Survey.

(a) Its **objective component – LQED** – evaluates the photometric and energetic of the lighting system. This module may be used for in design to compare different variants and to offer an objective criterion to choose the better one.

Photometrical measurements. The physical data collection includes a general space inventory as well as measures of lighting – illuminance, luminance, daylight factor, and surface reflectance following the CIE standards.

Questionnaire concept. It is proposed a questionnaire following the reference models and answering to the specific questions, presented below.

Room: Destination; Dimensions; Daylight factor – average value; Ceiling/walls reflexivity

Equipment: Luminaires; Lamps - type, power, colour; Ballast; Installed power = Number of lamps x (Power + Ballast loses)

Photometric measurement: Average illuminance - norm/measured (designed); Illuminance uniformity - min/av.; Lighting source luminance; Luminance contrast - source/ceiling

Electric measurement: Voltage

Technical state: Lighting source - clean/dirty/painted; Installed power per unit - W/m^2 and/or $W/(m^2 \cdot 100\ lx)$; Switching control – wall mounted/local, manual/automatic control

Maintenance programme: Is there a scheduled activity? Last date of the change of the lamps/luminaires - Yes / No; Cleaning period of the room/installation - Yes / No

The Quality Value Method. The quality of the lighting installation is influenced by different parameters. They cover the lighting quality – referred by its photometric parameters -, the lighting energy-effectiveness – referred by its economic parameters -, and the benefit of final users – referred by their comfort, pleasantness and productivity. The importance of different parameters varies inside of each of these groups and also between them. Following the Krochmann study [3], there are proposed a method and a model for quantifying them into a final "quality value" number, by weighting the meaning of parameters and by evaluation of their levels.

The photometric parameters targeted to the lighting quality are: average illuminance, illuminance uniformity, modeling (cylindrical illuminance), lighting source luminance, luminance distribution (contrast) on the visual field, reflectance of the room surfaces – walls, ceiling, ground, luminaire protection angle, correlated colour temperature, colour rendering index and a lot of many others. Each of the parameters – noted with x – has a certain importance on the quality assembly, noticed by the *weighting factor* $w(x)$, valued from 1 (lowest) to 10 (highest importance). Each of the parameters is evaluated in function with its effective value, compared with the standard, recommended or optimum value by the *scaling factor* $s(x)$, valued from 1 to 10. Each of the parameters contribute to define the quality value of the lighting installation by the *quality factor* $q(x)$, product of both specific factors

$q(x) = w(x) \cdot s(x)$.

The effective quality factor of the installation is the sum of the quality factors of each component parameters $q_{ef} = å\ w(x) \cdot s(x)$, having the minimum - *min* $q_{ef} = å\ w(x)$ -, and, respectively, the maximum value - *max* $q_{ef} = 10\ å\ w(x)$.

The optimum quality factor of the installation is corresponding to the standard, recommended or optimum values, being the maximum value $q_{opt} = max\ q_{ef} = 10\ å\ w(x)$.

The Quality Value, describing the overall quality of the lighting installation, is the ratio:

$$Q = \frac{q_{ef}}{q_{opt}} \cdot 10 = \frac{\sum w(x) \cdot s(x)}{\sum w(x)}.$$

The scaling factor of each parameter x is defined by comparing the effective value, measured or designed, to the normed value, recommended or admissible, and introducing the minimal/maximal values ratio:

$$s(x) = 10 \cdot \frac{\min(s_{efectiv}, s_{normat})}{\max(s_{efectiv}, s_{normat})}.$$

For example, for *the illuminance level on the working plane*, the scaling factor is

$$s(E) = 10 \cdot \frac{\min(E_{efectiv}, E_{normat})}{\max(E_{efectiv}, E_{normat})}.$$

By using the ratio of the two illuminances, we take into account the following aspects: on one side, an installation which assures an illuminance level lower than the normed value is under standard, but the rules concerning the illuminance are, as we all know, very elastic and conjectural (there are many working installations with illuminance levels well under the normed values, accepted by the users); on the other side, an installation which assures an illuminance level higher than the normed value does this by consuming extra electrical energy over the right balance. In both cases, the lighting installation will be qualitatively under-marked due to the involvement either of the photometrical aspect, or of the energetically aspect. The illuminance measured in a new installation is of 600 lx, designed for a normed level of E_{normed} = 400 lx. Introducing the maintenance factor of 0,8, the effective illuminance is considered $E_{effective}$ = 0,8·600 = 480 lx. The scaling factor becomes ***s(E)*** = 10·400/480 = 8,3.

Of course, we may suppose that an installation is designed, executed or maintained so that its characteristically parameters should conform to the admissible/reasonable specific limits. For example, for offices it is recommended the use of some electrical (fluorescent) lamps with a colour rendering index of at least 80; it is absolutely improbable to design or keep in working state an installation equipped with lamps with an index of 50...60, because we may easily obtain the necessary lighting sources.

Evaluation of the weighting factors. The importance of different parameters is variable. The ILES user, according to the particular data of the room and the importance of the relevant component fixes the values of the weighting factors for the lighting system analysed.

A survey with 100 people revealed the following values for the weighting factors of the quality parameters submitted to their attention:

1) Illuminance level on the working plane	9
2) Illuminance uniformity on the working plane	8
3) Space modeling	7
4) Luminance contrast - light source/ceiling	7
5) Luminance contrast - visual task/background	8
6) Distribution of illuminances in the visual field	8
7) Reflectance of the room surfaces (average weighted value)	6
8) (Correlated) Colour temperature of the lighting sources	8
9) Colour rendering index	7
10) Energetic efficiency	9

A simple computer program allows us to obtain quickly the information necessary to evaluate the analysed lighting installation and its energetic balance.

We would like to identify how lighting condition affect lighting economics and visual comfort of the users. The LQED module will be used to evaluate different variants of designed installations, to compare them on multiple aspects for having an objective criterion for choosing the best one.

(b) The **subjective component – ULCS** – must be simple to administer and score. For this a large number of former proposals have been analysed (some of them are presented in the mentioned bibliography) to identify the most important questions for defining a visual performance and comfort model. The complexity level of the corresponding parameters, and, implicitly, of the questions asked to the users, are determined by the knowledge level and, respectively, of education. It is useless to ask an uninformed user about certain aspects related to illuminance contrasts, colour rendering or interior space modeling.

The fulfillment of the comfort from a lighting installation is determined by parameter values that affect the visual task, visual comfort and environment. Some of them may be accurately measured, but others should be very subjective. *The visual satisfaction* describes on which measure the real visual conditions of the lighting are accepted by the users; it is determined the easiness which the work is performed and the pleasantness of the environment, both in the period when the attention is targeted to the visual task, and in the relax time. Of course, the luminous environment and the individual preferences affect the visual satisfaction.

To obtain the subjective opinions of the users there were selected the following questions. The answers are included in five options: inadequate, acceptable, good, very good, excellent or with two options: Yes/No, Comfortable/Uncomfortable, Disagree with/Agree with:

Is the daylighting sufficient?

Is the electric lighting sufficient?

The illuminance (light) is uniform on the working room surface?

Are you satisfied by the switching on/off modality?

Is the light appearance (brightness) of the luminaires adequate?

How do you appreciate the maintenance schedule of the lighting installation (cleaning, replacement of the failured equipment)?

Is the available light sufficient to read/write by hand/computer use/draw?

How do you appreciate the light environment of the room?

How do you appreciate the work lighting at your place (stand, desk)?

How do you appreciate the lighting in your working room comparing with the others?

Please notify on which room would you like to work/do you like the lighting installation?

Conclusion

The proposed method to analyse the quality of an interior lighting installation allows us to estimate the degree on which the existing (or designed) lighting installation fulfills the required photometrical, economical and human standards. The evaluation system IELS will be the basis of the analysis of a new lighting installation, to know whether the user's needs and preferences are satisfied, and in what extent. Thus, we may adjust the possible unfavorable aspects of the lighting installation. A computer program supports the analysis of energy efficiency and quality of lighting systems. Specific modules are related to the objectives of this research study.

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Dr. **Florin POP**,
Professor, Electrical Installation and Lighting, Department of Building Services
Mihaela POP
Ph.D. student, Department of Electric Power Systems
UTCN - Technical University of Cluj-Napoca
15, C. Daicoviciu St., RO-3400 Cluj-Napoca, Romania
Florin.Pop@insta.utcluj.ro
Mihaela.Pop@eps.utcluj.ro
Fax no.: + 40. 64. 192055