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Indoor Ligthing System Design Considering Reflections

Rudolf Bayer[1] and Michal Brejcha[2]

Abstract

The paper deals with problems concerning indoor luminaire placement by genetic algorithm. In contrast to outdoor illuminance calculations multiple reflections from walls must be taken into account. Therefore a basic reflection calculation has been proposed and a genetic algorithm script tested in software MATLAB on a model room. It appeared that requirements laid out by the Czech national standards do not restrict solutions of luminaire placement too much, hence several solutions met the requirements. The most suitable solution is always chosen by the designer's preferences. Implementing these preferences into the algorithmic solution is quite a big deal, nonetheless some methods how it can be accomplished are presented in the paper.

Keywords

Genetic Algorithm, Lighting, Luminaire placement, Illuminance

Introduction

While designing lighting systems for indoor working places the designer must take into account several requirements, of which the main would be to provide enough light for the given purpose of the interior space at a reasonable power consumption. These and more requirements are set by the Czech national standards[1] mandatory on the territory of the Czech republic.

Within the framework of this project a test model room has been chosen of dimensions 5×10 meters, 4 meters high with luminaires 3.5 metres above the floor. The model room's purpose was to provide for handwriting, writing on typewriters, reading and processing data according to reference number 5.26.2 in[1]. There are several conditions required by the standard that have to be met by the lighting system:

- $\overline{E}_m$ Maintained Average Illuminance of 500 lux
- UGR_L Unified Glare Rating 19
- U_0 Lighting Uniformity 0.6
- R_a General Color Rendering Index 80

The model room will meet the stated requirements if the reference plane's average illuminance will not drop below $\overline{E}_m$ over the course of operation of the lighting system. Calculating the initially needed illuminance values can be achieved by using the Maintenance Factor MF as in[2]. MF defines the depreciation of the reference plane's illuminance at the end of the maintenance period. For the model room MF has been chosen to be 0.75. Reference planes, as suggested in[1], represent for the chosen model room's function writing desks and should therefore be placed horizontally 75 cm above the floor. To calculate UGR_L the task area and occupants' view directions must be known, which is beyond the scope of this project. Furthermore a room of this size using ordinary office luminaires would most probably not yield values higher than the limiting top value UGR_L. R_a is a parameter of light sources and luminaires dependant on their light spectrum and will therefore not be included into calculations.

Photometric Value Calculation

To evaluate the lighting system's quality of the model room in terms of standard[1] four parameters have to be observed listed in section **??**. In this project only uniformity and

[1]CTU in Prague, Faculty of Electrical Engineering, Department of Electrical Power Engineering
[2]CTU in Prague, Faculty of Electrical Engineering, Department of Electrotechnology

Corresponding author:
Rudolf Bayer, CTU in Prague, Faculty of Electrical Engineering, Department of Electrical Power Engineering, Technick 2, Praha 6, 166 27, Czech Republic
Email: bayerrud@fel.cvut.cz

illuminance will be used. Uniformity U_0 is calculated by the following equation:

$$U_0 = \frac{E_{min}}{\overline{E}} \quad (-; \mathrm{lx}, \mathrm{lx}) \tag{1}$$

where:

E_{min} is the minimum illuminance of the working plane,

$\overline{E}$ is the average illuminance of the working plane.

Illuminances can be acquired by measurements or calculations in certain points of working planes that are chosen in accordance to the purpose of the room. To calculate the illuminance in a given point of the working plane contributions of all light sources illuminating the given point have to be summed up. This can be achieved by using luminous intensities of all the light sources pointing from the light source towards the point (as seen in figure 1):

$$E_{P\rho} = \sum_i \frac{I_{C\gamma i} \cdot \cos\beta_i}{{l_i}^2} \quad (\mathrm{lx}; \mathrm{cd}, -, \mathrm{m}^2) \tag{2}$$

where:

$I_{C\gamma i}$ is the luminous intensity of the light source pointing towards point P of plane ρ, i.e. luminous intensity of plane C at angle γ ($C-\gamma$ angular coordinate system),

β_i is the angle between the normal of plane ρ and the light ray from light source S_i,

l_i is the distance of point P from the light source.

Figure 1. Light source S illuminates point P of plane ρ.

Luminous intensity curves are stored in eulumdat files supplied with luminaires to make light scene calculations possible. For most indoor luminaires the $C-\gamma$ angular coordinate system is used as found in figure 2.

Figure 2. $C-\gamma$ polar coordinate system with luminaire in center.

To achieve more accurate simulation results of light scenes, reflections have to be included. From point's P point of view (figure 1), walls, ceiling and floor will become light sources of reflected light. Using the finite element method, surfaces of the model room will be divided into smaller facets. These facets, after illuminated, will become secondary light sources (figure 3). The process of reflections can be repeated as many times as needed. During each reflection a portion of the incident luminous flux is consumed by the illuminated surface as defined by its reflectance. Therefore after several reflections the reflected luminous flux becomes negligible.

Figure 3. Multiple reflections between planes $\rho 1$ and $\rho 2$ with Lambertian reflectance.

Most common wall and ceiling paints exhibit near Lambertian reflectance properties as depicted in figure 3, meaning that the spacial luminous intensity distribution curve of the facet will only depend on angle β, being the angle between the facet's normal N_ρ and the line of center points of both facets. The model room's surfaces, including the floor, have been chosen to exhibit purely Lambertian reflectance.

After a facet has been illuminated by primary light sources and all the illuminances have been summed up (equation 2), the facet becomes a Lambertian secondary light source of luminous intensity[3]:

$$I_0 = \frac{\rho \cdot E \cdot dA}{\pi} \quad (\mathrm{cd}; -, \mathrm{lx}, \mathrm{m}^2) \tag{3}$$

where:

I_0 is the luminous intensity of the facet in direction of the facet's normal,

ρ is the facet's integral reflectance,

E is the facet's illuminance,

dA is the facet's area.

After obtaining I_0, the luminous intensity curve of a facet of Lambertian reflectance will be:

$$I_\gamma = I_0 \cdot \cos(\gamma) \quad (\mathrm{cd}; \mathrm{cd}, -) \tag{4}$$

where:

I_γ is the luminous intensity in direction γ,

I_0 is the luminous intensity in direction of facet's normal,

γ is the angle between the facet's normal and the line of center points of the source and destination facet.

Model Room Illuminance Calculation

Genetic Algorithm Introduction

The genetic algorithms (GA) are the part of the evolutionary computing. Similar to the living organism are the solutions represented by their genotype, that represents the genetic coding and by phenotype, that represents behavior, response and features of the solutions. Each solution is considered according to its phenotype.

Design Requirements

The design results must involve all requirements given by standards. Therefore the first task is always to obtain at least the minimal level of illuminance and uniformity. Several designs overpass the minimal values and fit the requirements. Better specification and other restrictions for the results must be done. Some specifications are obvious from the designer's preferences. The solutions with higher efficiency are the better for example. Other examples of designer's preferences can involve:

1. the minimal count of luminaires (efficiency),
2. symmetry of the luminaires placement,
3. the placement restricted only in specific area,
4. placement in specific shape of groups of luminaires,
5. get the highest illuminance for given uniformity etc.

The result must also respect the luminaires dimensions. Proximity among luminaires can be unfeasible.

The genetic algorithm can handle the requirements in two ways. First introduces the requirements as a part of the fitness function. It is the case, where the requirements are some part of the phenotype. This is very common and it can be used for example in case of target illuminance and uniformity accomplishment. It will be described in the next section. The second way uses the restriction in the space of allowed solutions.

Fitness Function

Luminaire Placement Problems

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