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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[?] 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[?]. 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[?]. 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[?], 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, is not dependant on the test room and will therefore not be included into calculations.

Lighting System Quality Evaluation

Evaluating the model room's lighting system quality in terms of standard[?] requires observing four parameters. As

[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

mentioned in the previous section, only maintained average illuminance $\overline{E}_m$ and uniformity U_0 will be included into calculations in this project.

Uniformity can be calculated from 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 are acquired by measurements or calculations in defined points of working planes chosen in accordance to the purpose of the indoor space[?]. Calculating illuminance in a given point of the working plane requires summing up all partial contributions of illuminances from light sources illuminating this point. Illuminance can be obtained from luminous intensity of the light source pointing towards the measurement point P of plane ρ (Figure1):

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

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.

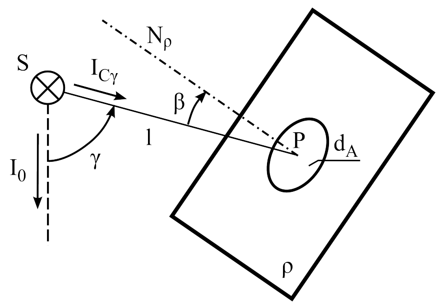

Figure 1. Light source S illuminates point P of plane ρ.

Luminous intensity curves (Equation 2) can be found in Eulumdat files of luminaires to enable light scene calculations. Most Eulumdat files of indoor luminaires use the $C - \gamma$ angular coordinate system (Figure 2).

To bring simulation results closer to real conditions, interaction of light and surfaces has to be included into calculations the most affecting the light scene in this project being light reflection. In case of the model room light active

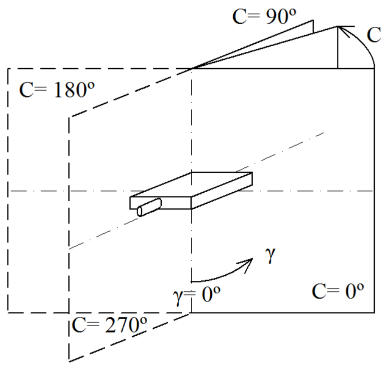

Figure 2. $C - \gamma$ polar coordinate system with luminaire in center.

surfaces are walls, ceiling and floor becoming after light impact secondary light sources. Using the finite element method, surfaces of the model room are divided into smaller facets each becoming a point light source illuminating other facets leading to multiple reflections (Figure 3). Every time light is reflected, a portion of incident luminous flux is consumed by the surface defined by reflectance value ρ. After several reflections the reflected luminous flux becomes negligible.

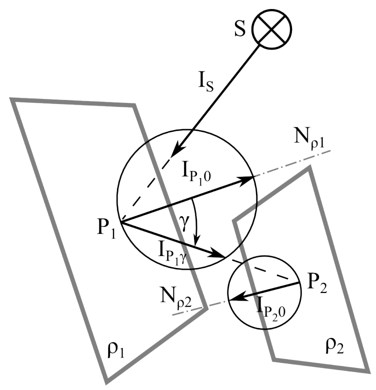

Figure 3. Multiple reflections between planes $\rho 1$ and $\rho 2$ with Lambertian reflectance.

Most common indoor wall and ceiling surfaces exhibit near Lambertian (diffuse) reflectance. The spacial luminous intensity distribution of purely Lambertian surfaces is dependent only on the amount of reflected light and on angle γ between the facet's normal N_ρ and the observed direction of the outgoing light ray (Figure 3, Equation **??**). For simplification reasons all surfaces including the floor of the model room exhibit purely diffuse reflection. Such surfaces become secondary light sources of luminous intensity in direction $\gamma = 0°$ according to[?] as follows:

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

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.

Calculating resulting luminous intensities of all available facets of the model room is achieved in several steps.

- Primary light sources emit light incident on visible facets (direct illumination). Initial illuminance $E_{0\rho}$ of facet ρ is obtained by summing up all partial illuminances from all primary light sources (Equation 2).
- Facets become secondary light sources. Their spacial luminous intensity distributions can be obtained from Equation 3 and **??** using initial illuminance E_0. Facet's ρ illuminance $E_{1\rho}$ is obtained using Equation 2 and all visible facets as light sources.
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First of all primary light sources emit light incident on those facets. Using Equation 2 facets' illuminances can be calculated.

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:

- the minimal count of luminaires (efficiency),
- symmetry of the luminaires placement,
- the placement restricted only in specific area,
- placement in specific shape of groups of luminaires,
- higher illuminance or uniformity etc.

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

Fitness Function

Luminaire Placement Problems

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