Jan ŠUMPICH, Tomáš NOVÁK, Zbyněk CARBOL, Karel SOKANSKÝ

VŠB-Technical University of Ostrava

Calculation of saving possibilities in interior lighting system using both daylight and artificial light

***Abstract**: This paper describes modelling of possible savings in lighting systems of artificial lighting, working in combination with daylight. The proposed model works with overcast sky daylight (CIE). Based on knowledge of geographical position, day and time, the calculations are done in the conditions of unshadowed outdoor illuminance levels. From this figure (when daylight factor is known) illuminance caused by daylight can be gain in the differents parts of the room. By controlling the artificial lighting (dimming) to constant cumulative value (daylight plus artificial light) in the areas of visual tasks, then it is possible to determine potential of savings in areas with controlled lighting system and without it. According to this model (calculation), we can consider a suitability of the dimmable lighting systems in the specific work areas and make recommendations to reduce energy requirements of buildings in energy audits.*

Streszczenie:** Celem artykułu jest rozwiązanie problemu obliczeń oszczędności energii elektrycznej przy oświetleniu pomieszczeń wewnętrznych systemami światła dziennego oraz sztucznego. Zajmuje się się transformacją modelu dynamicznego jednolicie zachmurzonego nieba, jego udziału w oświetleiu dziennym w konkretnie danych wnętrzach. Obliczenie oszczędności energii wykorzystaniem światła dziennego jest możliwe za pomocą modelowania zmierzchu systemami światła sztucznego, właśnie według symulowanego udziału światła dziennego. Dzięki zastosowaniu modelu jednolicie zachmurzonego nieba możemy eliminować wpływ lokalizacji otworów okiennych. Na podstawie znajomości oświetlenia dyfuzyjnego zewnętrznej prostej powierzchni bez cienia oraz poziomu natężenia oświetlenia i jego rozkład w polu zadania wzrokowego możemy obliczyć udział światła dziennego dla każdego momentu. Następnym krokiem możemy dla konkretnego systemu światła sztucznego podać poziom zmierzchowy poszczególnych elementów oprawy oświetlenia sztucznego tak, żeby był zgodny z z wymogami normatywnymi poziomów dla określonych zadań wzrokowych. Różnica między energią zużytą systemem oświetlenia ze ściemnianiem oraz bez wskazuje na potencjał oszczędności energii w systemach oświetleniowych światła sztucznego z wykorzystaniem światła dziennego.* ***(Obliczanie potencjalnych oszczędności oświetlenia wnętrz wykorzystującego światło dzienne i sztuczne)

Keywords: daylight, artificial light, lighting systems, energy requirements
słowa kluczowe: światło dzienne, światło sztuczne, systemy oświetleniowe, wymagania energetyczne

Introduction

The current economic requirements lead to the reduction of energy consumption in the buildings. In the field of interior lighting these requirements lead to greater usage of daylight in combination with an artificial light. The technical level of the current lighting systems enables the regulation of the flux in the lighting control systems at a constant level of illumination due to the artificial lighting dimming systems. This can put into practice a reduction of electricity consumption.

In order to determine potential savings and return of the dimmable lighting systems, it is necessary to know the level of external light intensity. This intensity is variable, though. Since the daylight factors are calculated under uniformly overcast sky, the specific illuminance calculations will be done considering this situation too.

Based on the determination of usage of a room or a building (type of visual task, the required illuminance, occupation, working hours, shift operation, etc.) you can determine the energy efficiency of the regulated lighting system and the terms of return on investment compared to the unregulated lighting system.

It should be mentioned too that the daylight affects the basic biological processes in the human organism and therefore building standards and health regulations are designed to keep the organism in indoor environment fine and secure as much as possible.

Daylight factor

Contribution of daylight in buildings in areas of visual tasks, are the share of internal illuminance (direct and reflected light) and the illuminance of an outdoor unshadowed flatland in condition of uniformly overcast sky. The contributions of direct sunlight are excluded from the both illuminance. The value of daylight factor includes the glazing effects, pollution, indoor and outdoor shading, etc. On the contrary, due to using uniformly overcast sky is eliminated the influence of windows position in various points of the compass. Daylight factor D is expressed as a percentage and it is calculated according to equation:

(1) $$D = \frac{E}{E_V} 100 [\%]$$

where: E - is the illuminance of the point of internal comparison flatland in lx, E_V - a comparison illuminance in the point of outdoor unshadowed flatland in lx.

Uniformly overcast sky

Uniformly overcast sky is a condition that in fact occurs only a few times a year. However, this situation enables to create a model of the sky which we can work with. This model sets clearly sky luminance behaviour from horizon to zenith. Our model uses uniformly overcast sky on a dark area considering the sky with luminance gradation from horizon to zenith 1:3 (according to CIE). Sky luminance of any point is then given by:

(2) $$L_\gamma = L_Z / 3(1 + 2\sin\gamma) \ [\text{cdm}^{-2}]$$

where: L_γ - the luminance of the sky at an angle above the horizon γ, L_Z - the luminance of the sky at the zenith

Coordinates of the Sun and the solar ray geometry

For determining the specific sky illuminance, which allows the calculation of outdoor unshadowed flatland is necessary to know the position of the Sun to the investigated comparison plane. Only the most commonly used methods of determining the coordinates of the Sun are listed. They are used in the calculation of insolation of buildings.

Analytical calculations of Sun coordinates

The calculation of the apparent position of the Sun in the sky is determined by the geographic location of the specific site on the planet, Earth's rotation and mutual position of the Sun and the Earth in space. For calculations of the daylight and insolation of buildings there is a sufficient substitution the irregular shape of globe. A position of any point on Earth's surface is usually determined by latitude φ and longitude λ_z, see Figure 1.

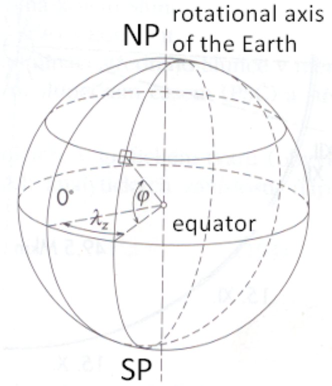

Fig.1 - Coordinates of the point on the Earth's surface. [1]

During the time Earth is spinning around the Sun in slightly elliptical orbit the Earth's equator plane is inclined to the ecliptic plane tipping by 23.45°. See Figure 2.

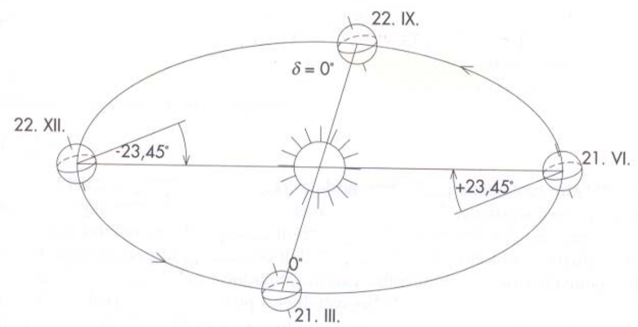

Fig. 2 - Declination for four typical days in a year. [1]

Solar Declination

An angle of Sun rays and the Earth's equator plane is called solar declination δ and it is constantly changing during the year. For specific time information the accurate declination values are given in astronomy yearbooks. For our purposes the declination is determined by mathematical expressions. We consider that the zero declination occurs at midnight before the day of spring equinox on the 21st March. We consider the following equation [2]:

(3) $$\delta = 23.45° \sin\left[\frac{360°}{365}(J-81)\right][\text{rad}]$$

where: J - is the ordinary day of the year

On the day of the winter solstice (usually 22nd December) when the Sun is the most inclinated to the Earth's southern hemisphere the value of solar declination is δ = -23.45 ° and on the summer solstice (usually 21st June) it is δ = 23.45 °. On spring and autumn equinox (March 21st and September 22nd) the Sun is above the equator and the Earth's declination is zero.

Time and the hour angle of the Sun

The length of solar day is the traditional and the most common unit of time in the world. The time equation has a maximum value during 16th May (+3.8 min.) and 3rd November (+16.4 min.) The minimum values are on 12th February (-14.4 min.) and 25th July (-6.3 min.). The local solar time is defined as the central solar time. The local noon occurs when the local meridian passes through the central Sun, then we talk about central afternoon. Each meridian has its own central time. It would be very impractical to change the clock on each meridian. Certain areas have the same time. Central European Time CET is the same as the central solar time on λ_Z = 15° east longitude, and as a zone watch time is used in the range of longitudes 7.5° ≤ λ_Z ≤ 22.5°. The CET determines the genuine solar time according to the relation (3).

(4) $$GST = CET + \frac{\lambda_Z - 15°}{15°} + ET\ [hrs]$$

where: λ_Z - the longitude in degrees, GST - genuine solar time in hours, CET - Central European Time in hours, ET - the time difference between GST - CET in hours [1]

Height of the Sun

Height of the Sun γ_S is the angle formed by the solar ray with a horizontal plane. To calculate the height of the Sun is used the known relation [1]:

(5) $$\gamma_S = \arcsin[\sin\varphi \sin\delta - \cos\varphi . \cos\gamma \cos(15° GST)]\,[°]$$

In technical calculations there are usually neglected the influence of refraction of sunrays in the atmosphere and irregularities in the solar declination, because even in the worst case they cause the mistake less than 1° in determining the solar coordinates.

Calculations of the daily illuminance

Based on the knowledge of the position of the Sun and the brightness distribution of the uniformly overcast sky it can be proceeded to deal with specific illuminance levels of comparison outdoor unshadowed flatland in specific locations and specific days and hours.

Horizontal illuminance

The first step of the calculation is to determine the horizontal illuminance of an imaginary plane at a given location. It sets maximum level of sunlight in the clear (cloudless) sky, thus the reference value to determine the availability of illuminance on the Earth's surface. Extraterrestrial horizontal illuminance E_V will be different every day. Therefore, the luminous solar constant E_{V0} for the equinox must be corrected for the daily distances from the sun to the Earth's using agents of eccentricity ε [1].

(6) $$\varepsilon = 1 + 0.034 \cos\left[\frac{360°}{365}(J - 2°)\right][-]$$

(7) $$E_V = E_{V0}\, \varepsilon \sin\gamma_S\ [lx]$$

where: E_{V0} - light solar constant of 133 334 lx

Diffuse illuminance

Diffuse illuminance D_v, i.e. illuminance of outdoor unshadowed horizontal plane under uniformly overcast sky with knowledge of specific geographical and temporal coordinates can be determined based on the following relation [1].

(8) $$D_V = \left(\frac{D_{Vm}}{E_V}\right) E_{V0}\, \varepsilon \sin\gamma_S [lx]$$

where: D_{Vm} / E_V - permeability coefficient of the skylight

By conversion of this value over the illuminance factor D_v of the daylight illuminance on the indoor working place caused by daylight, we can calculate the required illuminance values. The difference between illuminance caused by daytime component and the required value of illuminance is necessary to subsidize by the artificial lighting.

Modelling of combination of daylight and artificial light

This chapter of article shows example of dynamical modelling of outdoor daylight as base for the determination of dimming level.

For calculation of model room, it is necessary to determine daylight factor. For this task, WDLS software was used. Model room is 3m wide, 6m long and 3m high and has one window 2.8 x 1.8m (on left side in Fig. 3).

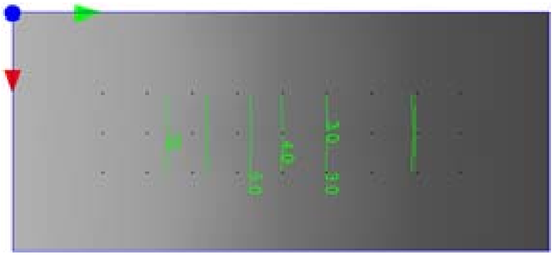

Fig. 3 – Daylight factor in model room

Next step is a project of the artificial lighting system. Our model room is a common office, where maintained illuminance of 500 lx is required in all area, because work place was not set. Lighting system was designed by WILS program. Chosen Luminaires were surface mounted 2 x 36 W with linear fluorescent lamps and electronic ballast. Input power is 72 W per luminaire including ballast. In the model room, there are two columns of luminaires, each column is dimmable separately.

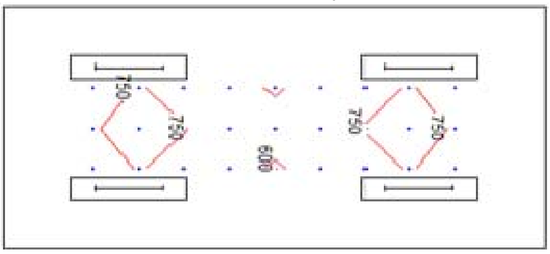

Fig. 4 – Artificial lighting system in model room

In modified WILS a program tool for savings potential estimation was added. Workdays and timework can be set in program to calculate accurately power consumptions. In all area condition, that contribution of daylight plus artificial light must be over 500 lx.

Regulation of artificial lighting system is in 10% steps from 0% to 100%, in this case linear dependency of input power on luminous flux was used. The calculation is quite fast up to four columns of used luminaires. Fig. 5 shows a dimming level of each column respecting outdoor illuminance level. For example for E_{ext} = 10 klx, first column will be turned off and second will work on 60%.

Eext	R1	R2
1 000 lx	0,9	0,9
5 000 lx	0,3	0,9
7 000 lx	0	0,9
10 000 lx	0	0,6
20 000 lx	0	0,3
25 000 lx	0	0,2

Fig. 5 – Dimming level determination

Fig. 6 shows comparison between uncontrollable and dimmable lighting system. Without a regulation consumption is 2.6 kWh per work shift, the regulation decreases this consumption depending on a season. In winter, when there is a minimum of available daylight, 1.8 kWh per shift, compared to summer with the lowest consumption 0.6 kWh per shift.

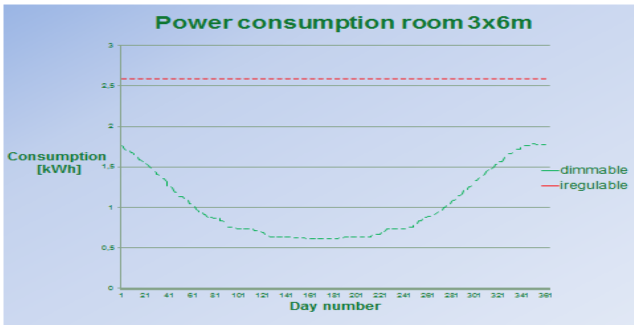

Fig. 6 – Energy consumption of iregulable and dimmable lighting system

Conclusion

The objective of the authors of the article is making software to determine the potential savings in the combined artificial and daylight lighting systems. Its expected usage will be in the design and renovation of the lighting systems, energy audits of buildings and in recommendations of reduction of their energy consumption.

This article was supported by project SP 2012/160: New opportunities of LED technology in lighting.

REFERENCES

[1] RYBÁR, P. a kol.: Denní osvětlení a oslunění budov, ERA 2001.ISBN 80-86517-33-0
[2] DARULA, S. a kol.: Osvětlování světlovody, Grada Publishing 2009, ISBN 978-80-247-2459-1
[3] Program WDLS a WILS
[4] http://www.elkovo-cepelik.cz/stropni-svitidla-prisazena-ip20-ip40Norma
[5] Norma ČSN 73 0580-1 Denní osvětlení budov
[6] Norma ČSN 73 0580-2 Denní osvětlení obytných budov
[7] Norma ČSN EN 15 193 Energetická náročnost budov – Energetické požadavky na osvětlení
[8] Gasparovsky, D., Smola, A., Janiga, P.:Assessment of lighting systems for energy certification of buildings, PRZEGLAD ELEKTROTECHNICZNY,2008,ISSN 0033-2097

***Authors**: Ing. Jan Šumpich, Ing. Tomáš Novák Ph.D, Ing.Zbyněk Carbol prof. Ing. Karel Sokanský, CSc., Vysoká škola báňská - Technická univerzita Ostrava Fakulta elektrotechniky a informatiky, 17. Listopadu 15/2172, Czech Republic, e-mail: jan.sumpich@vsb.cz,tomas.novak1@vsb.cz, zbynek.carbol@vsb.cz, karel.sokansky@vsb.cz*