# Energy Saving Lighting with Light guides

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*Abstract:* - Daylighting of internal parts in buildings an architectural and technical problem. Visual comfort in buildings is the main demand for quality of indoor environment that is superior even energy saving requirements. The windowless parts of buildings must have artificial lighting in a permanent service. Tubular light guide systems represent daylighting possibility and also energy saving alternative in a comparison with classical artificial lighting systems. The evaluation of internal illuminance from light guides of different dimensions and estimation of the light guides efficiency is presented in the paper.

*Key-Words:* - Light guides, Daylighting, Energy savings, Light transmittance, Light reflectance, Indoor climate.

## 1 Introduction

Light guides represent energy saving alternatives which can compare to artificial lighting systems in buildings. They could not properly substitute windows but they present a modern way of auxiliary lighting systems for internal parts of buildings with permanent artificially lighted rooms.

Daylighting in buildings and indoor illuminance is actual task and it has been topic of many investigations [1], [3]. The study focused on indoor illuminance in a reference room was evaluated. The program Radiance [2] was used for the daylight simulations in a reference room illuminated by light guides of difference sizes. The final evaluation of radiant and luminous flux transporting through the light guides was also completed.

## 2 Computer simulations

The computer daylight simulations were completed for the following outdoor conditions - sky types:

- Overcast sky: winter ($21^{st}$ December – 12:00),
- Sunny sky with sun: summer ($21^{st}$ June –12:00).

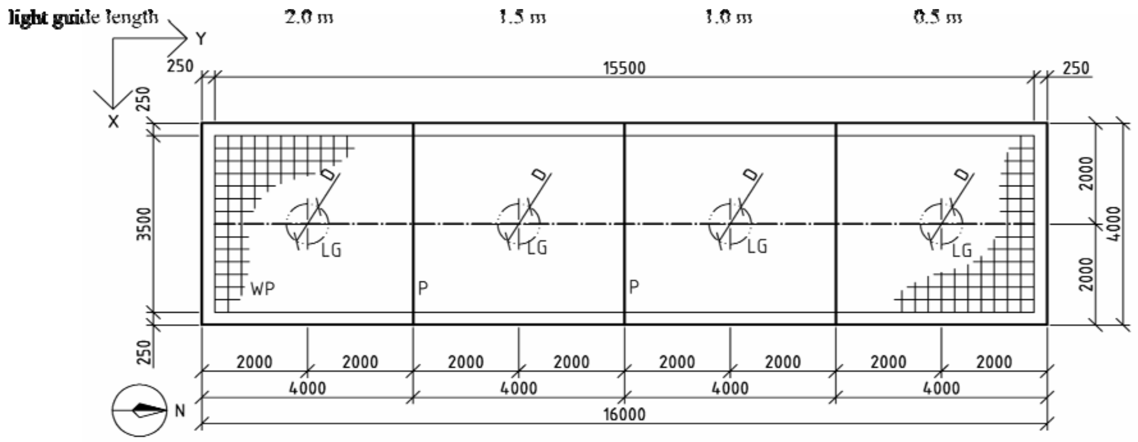
A reference room with plan dimensions of 4.0 m x 16.0 m together with a clearance height of 3.0 m was used for the simulations. The scheme of the room is shown in Fig.1. The windowless room is divided into four identical sections by partitions. Reflectance ρ [-] of partitions and all internal surfaces in the room is very low ρ = 0.01–black light absorbing surfaces. It means illuminance distribution from the light guides in individual sections is not influenced by light gains from neighboring light guide installations. The simulations were carried out to compare daylighting with light guides of different sizes. Dimensions of the used light guides are:

- Length: 0.5, 1.0, 1.5 and 2.0 m
- Diameter: 0.6, 0.8, 1.0 m

The light guide ceiling cover consists of the glass pane with polished stainless steel lamellas. These lamellas cause light scattering and more uniform daylighting in the investigated place.

Calculations of internal illuminance were carried out on the horizontal working plane which was represented by a reference grid in the position 850 mm over the floor level (2.25 m under the investigated light guide ceiling cover). The grid has a starting point at coordinates x=250mm, y=250 mm, z=850 mm from the origin (in the room the right hand side corner on the floor) – Fig.1 The horizontal grid dimensions in x-axis direction 3.5 m (divided by 14 segments), in axis y 15.5 m (divided by 62 segments).

Graphical distribution of the internal illuminance on the work plane is presented in Fig.2 for sunny sky conditions. Results of the computer simulations are compared in Table 1 for both outdoor conditions sunny and overcast sky. The summary of the simulation results–maximal, minimal and average values of internal illuminance on the horizontal work plane are presented in this table. These results give information about the distribution of indoor illuminance and daylight uniformity. Internal illuminance on the horizontal work plane from the investigated light guides of diameters 0.6, 0.8 and 1.0 m and lengths between 0.5 and 2.0 m could reach from minimal values to 432 lx determined for clear sky conditions on $21^{st}$ July.




LG ... light guide, D ... diameter of the light guide, WP ... horizontal work plane for internal illuminance determination, P ... partition

Fig. 1 Reference room with light guides - plan

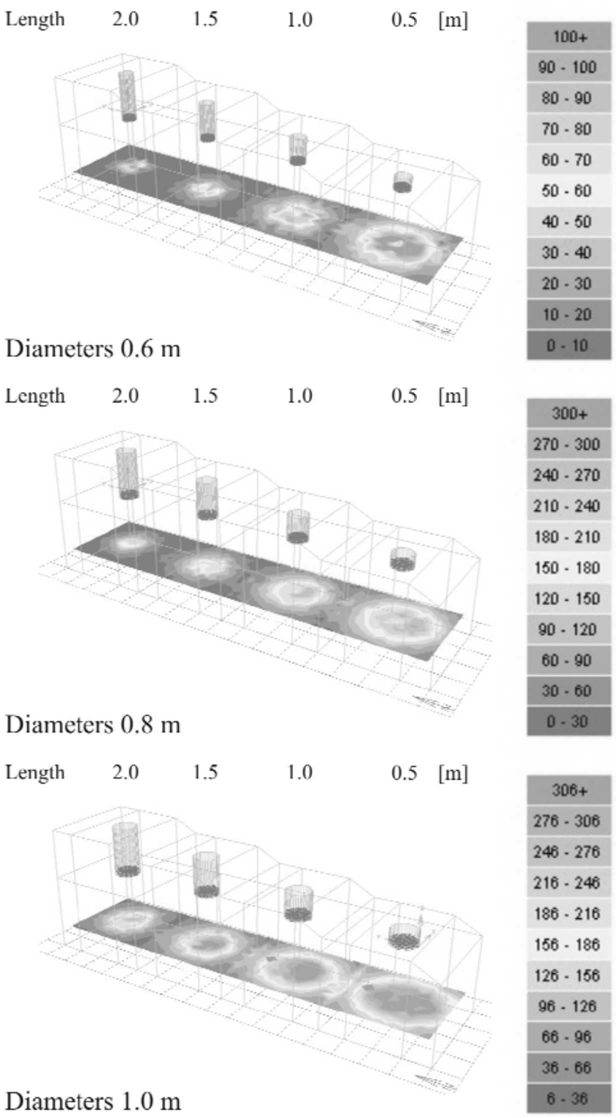



Fig. 2 Illuminance on the working plane 850 mm

Tab. 1 Illuminance under light guides – sunny sky

| Diameter [m] | Illuminance **E [lx]**, Sunny sky 21st of June, 12:00 | | |
|---|---|---|---|
| | Maximal E | Minimal E | Average E |
| Light guide length 0.5 m | | | |
| 0.60 | 124.92 | 4.93 | 58.35 |
| 0.80 | 242.27 | 35.59 | 120.80 |
| 1.00 | 391.39 | 39.87 | 192.70 |
| Light guide length 1.0 m | | | |
| 0.60 | 117.69 | 2.85 | 42.43 |
| 0.80 | 242.15 | 29.00 | 110.76 |
| 1.00 | 409.05 | 56.97 | 197.47 |
| Light guide length 1.5 m | | | |
| 0.60 | 97.06 | 2.74 | 27.40 |
| 0.80 | 255.70 | 12.46 | 95.59 |
| 1.00 | 432.03 | 45.70 | 191.38 |
| Light guide length 2.0 m | | | |
| 0.60 | 69.71 | 0.01 | 14.84 |
| 0.80 | 184.61 | 7.23 | 68.35 |
| 1.00 | 374.08 | 38.74 | 172.47 |

Tab. 2 Illuminance under light guides – overcast sky

| diameter [m] | Illuminance **E [lx],** CIE Overcast sky 21st of December, 12:00 | | |
|---|---|---|---|
| | Maximal E | Minimal E | Average E |
| Light guide length 0.5 m | | | |
| 0.60 | 52.30 | 38.32 | 0.01 |
| 0.80 | 92.83 | 76.09 | 8.75 |
| 1.00 | 152.55 | 123.41 | 15.00 |
| Light guide length 1.0 m | | | |
| 0.60 | 33.07 | 27.80 | 0.00 |
| 0.80 | 72.92 | 55.84 | 3.77 |
| 1.00 | 116.15 | 92.66 | 6.63 |
| Light guide length 1.5 m | | | |
| 0.60 | 26.75 | 18.79 | 0.35 |
| 0.80 | 53.57 | 41.20 | 1.54 |
| 1.00 | 93.80 | 77.07 | 4.39 |
| Light guide length 2.0 m | | | |
| 0.60 | 16.80 | 12.90 | 0.30 |
| 0.80 | 37.78 | 30.50 | 0.48 |
| 1.00 | 73.17 | 61.87 | 2.92 |

For winter overcast sky (on the 21st December) internal illuminance on the work plane under light guides of the same dimensions could vary from very low level to 152.55 lx. It practically means that internal illuminance from light guides of the studied dimensions could be nearly four times greater for summer, spring or autumn period for sunny clear sky in comparison with standard daylight evaluations based on the supposition of winter overcast sky conditions.

## 3 Energy savings

Determination of radiant and luminous flux going through the light guide is important for estimation of electric energy savings. The estimation of radiant flux going through the light guides with diameters of 0.6, 0.8 and 1.0 m determined on the basis of daily values of global solar radiation is presented in Table 3. The light guide efficiency $\eta$=0.5 (light guide length 1 m).

Table 3 Radiant flux through the light guide

| Season sky condition | Energy of solar radiation [3] $[kWh.m^{-2}day^{-1}]$ | | Radiant flux $\Phi_e$ [W] through the light guide of diameter | | |
|---|---|---|---|---|---|
| | UV-VIS-NIR | VIS | 0.6 m | 0.8 m | 1.0 m |
| *Summer season* | | | | | |
| Clear sky | 7.41 | 5.56 | 49.22 | 87.56 | 136.38 |
| Partly cloudy sky | 6.72 | 5.04 | 44.65 | 79.29 | 123.65 |
| Overcast sky | 0.95 | 0.72 | 6.68 | 11.36 | 17.75 |
| *Winter season* | | | | | |
| Clear sky | 2.3 | 1.73 | 24.61 | 43.55 | 67.90 |
| Partly cloudy sky | 1.01 | 0.76 | 10.90 | 19.17 | 29.90 |
| Overcast sky | 0.13 | 0.10 | 1.41 | 2.60 | 4.05 |

- Assumed time of solar radiation 16 hours in summer and 10 hours in autumn
- UV-VIS-NIR … ultraviolet – visible - near infrared ranges, VIS … visible light of solar radiation spectrum
- Assumption: light guide efficiency $\eta$ = 0.5

Determination of luminous flux $\Phi$ [lm] going through light guides serves for the evaluation of electric energy savings. Luminous flux derived from solar radiant flux $\Phi_e$ [W] is expressed by the following formula [4]

$$\Phi = K_m \int_{380}^{780} \frac{d\Phi_e}{d\lambda} V(\lambda) d\lambda \quad [lm]$$

Where:
$K_m$ = 683 $lm.W^{-1}$ … photopic vision constant, max value of light efficiency for $\lambda_m$ = 555 nm
V ($\lambda$) … relative light efficiency of visible light at the wavelength $\lambda$

The luminous flux for the evaluated light guides with an efficiency $\eta$=0.5 was calculated for different exterior illuminance conditions from CIE overcast sky $E_h$=5,000 lx up to clear summer sky illuminance $E_h$=100,000 lx (table 4).

Table 4 Luminous flux through the light guide

| External Illuminance [lx] | luminous flux $\Phi$ [lm] through the light guide of diameter | | |
|---|---|---|---|
| | 0.6 m | 0.8 m | 1.0 m |
| 5 000 | 706.5 | 1256 | 1962.5 |
| 10 000 | 1413 | 2512 | 3925 |
| 20 000 | 2826 | 5024 | 7850 |
| 40 000 | 5652 | 10048 | 15700 |
| 60 000 | 8478 | 15072 | 23550 |
| 80 000 | 11304 | 20096 | 31400 |
| 100 000 | 14130 | 25120 | 39250 |

The results from the table can be taken for the estimation of artificial light sources which can be substituted by 1 light guide with efficiency 0.5. For example an incandescent bulb lamp 12 $lmW^{-1}$ can be substituted by 1 light guide of diameter 0.6 m.

## 4 Conclusion

The advantage of the light guide systems compared to artificial lighting is in energy savings which results reduction of cost for energy, which should not be neglected. On the other hand the payback period of light guide systems is very high compared to the investment price. The main contribution of these systems is the improvement of visual comfort and the possibility of dynamic daylighting in buildings. Daylighting as a natural energy source can't be substituted by artificial lighting.

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