

Natural lighting of interiors and sun protection of premises with roof lighting system

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Abstract. The article describes the contemporary issues of natural lighting of interiors of civil and industrial buildings. The major attention is given to the roof lighting system of the buildings in question, as far as this system provides not only increased levels of natural lighting, but sometimes an undesirable heat gains, due to prolonged insolation period and hence, extra solar radiation. It is noted that this reason leads to design and construct the means of natural lighting in such a way that to provide interiors with sufficient natural illumination and efficient sun protection at the same time. Some principal conclusions and recommendations were made as a result of analytic studies, presented in the article. For example, it was competently proved that the best solar standing solution for roof lighting installations are sheds or sawtooth roof structure. The worst solution, to protect interiors from solar overheating are roof skylights. These skylights require extra sun protection in form of jalousies, blinds, etc. The same additional solar shading, though to less extend, is needed to provide additional sun protection for roof monitors.

1 Introduction and theoretical background

Lighting inside a building must fulfill two main functions: to illuminate an interior and to illuminate a task appropriately so that visual mechanism can function efficiently. According to the nature of light, three basic systems of illumination can be distinguished:

- I – natural lighting system;
- II – artificial lighting system;
- III – joint lighting system, or integral lighting (i.e. natural plus artificial lighting).

Artificial part in joint lighting is usually called “supplementary artificial lighting” in order to underline primary role of natural lighting in the system.

According to the position of source of a light, one can distinguish the following schemes within the above systems:

- I – one-side natural lighting;
- II – two-sides natural lighting;
- III – roof, or overhead natural lighting;
- IV – combined natural lighting (side plus roof natural lighting);
- V – general artificial lighting with use of ceiling – mounted luminaries;
- VI – task’ artificial lighting with use of desk-mounted luminaries;

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VII – combined artificial lighting, i.e. general and task' artificial lighting.

In practice it is most useful to base day-light design on concept of so-called “daylight factor” (D.F.). Daylight factor is simply defined as ratio of indoor illumination to outdoor illumination and expressed in percentage. In order to have standard terms to estimate and measure a D.F., it is found convenient to make an assumption that the sky is overcast and sun is obscured by clouds completely. In this case so-called “standard overcast sky” has uniform luminance (brightness) with zenith luminance three times that near horizon. Such an assumption means, that natural lighting of interiors through roof – arranged installations for natural lighting is much more efficient, as compared with ordinary side openings, i.e. windows. Roof-arranged installations provide more illumination, or require less glazing (Figure 1) [1-4].

But, in sunny climate which is typical for southern regions, the luminance distribution over the sky is completely different (Figure 2). The luminance of the sun is extremely high, while the luminance of the another portions of the sky vault is very low. Such a sky vault' state is called “clear sky” and it determines the different conditions of natural lighting' design, which is not considered in this article [5-9].

The points to be discussed below, are dealing mainly with the structural offerings, aimed mainly on increase of natural lighting of interiors and reducing insolational heat gains due to solar radiation.

2 Desk studies and analysis of design solutions

Basic assumption for daylight calculations is to consider daylight flows reaching a design point in a premise as consisting of the following components:

- I – sky component;
- II – externally - reflected component;
- III – internally - reflected component.

For roof lighting system, the components in question are shown on Figure 3.

The ratio between sky component and reflected components depends upon a type of roof lighting installations, character of outdoor natural illumination, orientation aspect, etc. With an overcast sky conditions every component is useful to achieve desired values of a D.F. No problems occur with negative action of insolation – such as overheating, contrasts and glare. On contrary, with clear sky conditions insolation should be either provided or excluded. The provision of insolation is needed for residential and some kinds of public buildings, while exclusion is needed mainly for industrial buildings [1, 5, 6, 10-15].

The minimization or exclusion of insolation can be achieved by orientation of glazing, sun-protective devices and so on. The main challenge here is to exclude the undesired insolation without reducing D.F. values in interiors. This can be relatively easy done by disactivation of straight sun rays and, at the same time, activation reflected components of natural lighting, as shown on Figure 4 [2-4, 10-16].

Another problem here is connected with the luminance of sky portion, left to provide natural lighting after installation of sun-protection or proper orientation aspect of roof lighting installations glazing. First, these portions are rather small and second – they have low values of luminance. Such a situation is shown on Figure 5 for different examples of roof lighting installations, provided with sun protecting devices, or having the desired orientation aspect. As one can see from Figure 5 and Table 1, the luminance of a sky vault under a clear sky conditions, expressed by the factor “q” greatly differs from this for overcast sky, especially at high angles to a horizon [9, 10, 12-16].

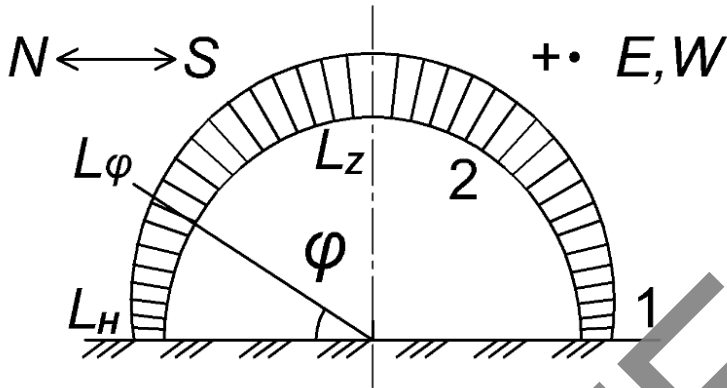


Fig. 1. Relative luminance distribution of standard overcast sky. Key: 1 – ground level; 2 – sky vault; LZ – luminance in zenith; LH – luminance on horizon; $LZ = 3LH$; L_{φ} – luminance at angle “ φ ” to the horizon.

This scheme illustrates the principal law of lighting engineering, called “Moon-Spencer law” (after the famous American researchers in this field of science – R. Moon and D. Spencer). The design expression for the law looks like:

$$L_{\varphi} = \frac{L_z(1+2\sin\varphi)}{3}, \quad (1)$$

and is a basis to assume the universal design conditions of a sky vault luminance (so called “overcast sky” or “standard sky”) [1, 4].

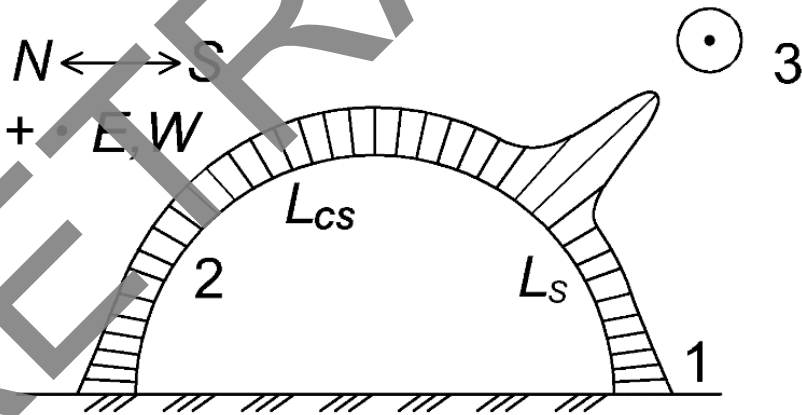


Fig. 2. A principal scheme of relative luminance distribution of a clear sky. Key: 1 – ground level; 2 – a sky vault; 3 – the Sun; L_s (luminance of the Sun) \gg L_{cs} (luminance of any part of clear sky).

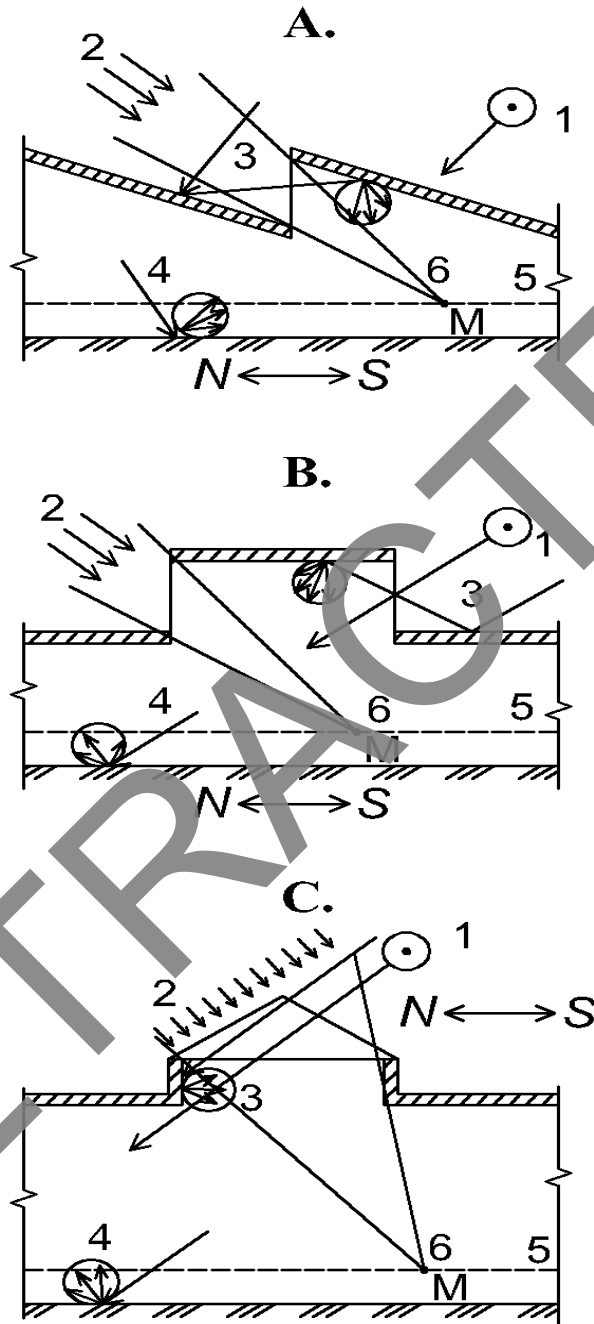


Fig. 3. Components of a lighting factor for different installations of roof lighting system. A – saw tooth roof lights (sheds); B – monitor lights (penthouses); C – skylight (domes). Key: 1 – Sun; 2 – light flows from a skywaylt (sky component); 3 – light, reflected from external units and structures (externally-reflected component); 4 – light, reflected from internal planes (internally-reflected component); 5 – working plane' level; 6 – design point "M".

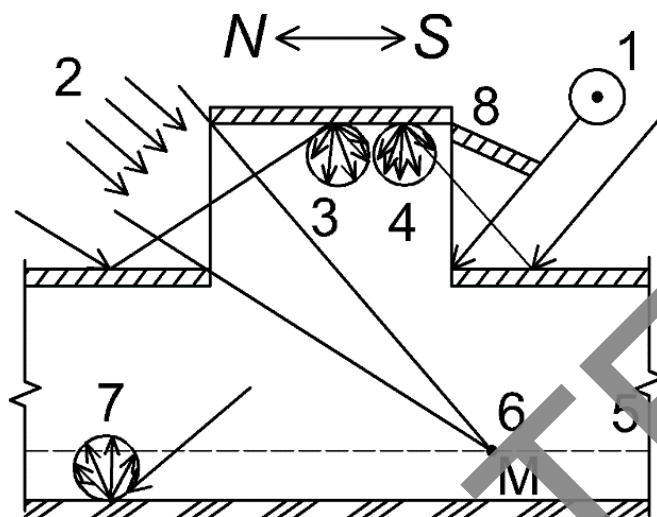


Fig. 4. Light distribution in a premise with roof lighting system in front of monitor light with sun-protecting canopies. Key: 1 – Sun; 2 – light flows from sky vault (sky component); 3 – reflected light due to clear sky; 4 – reflected light due to the Sun; 5 – ‘working plane’ level; 6 – design point “M”, 7 — light, reflected from internal planes (internally — reflected component); 8 – Sun-protecting canopy.

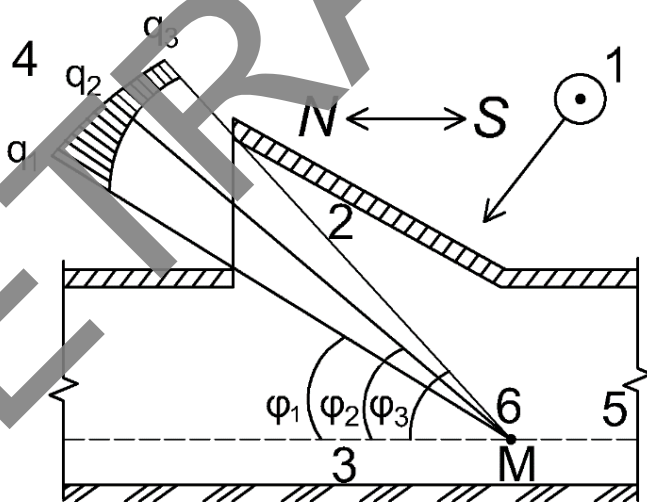


Fig. 5. An example of sky luminance’ distribution for sawtooth roof with shed lighting installations under clear sky. Key: 1 – the Sun; 2 – a shed; 3 – angles of clear sky’ observation from a design point; 4 – values of relative luminance factor “q” for clear sky; 5 – working plane’ level; 6 – design point “M”.

Legend: $\varphi_1 = 30^\circ$; $\varphi_2 = 40^\circ$; $\varphi_3 = 50^\circ$; $q_1 = 0,43$; $q_2 = 0,38$; $q_3 = 0,34$ (φ — angle of observation, see Table 1).

Table 1. Values of a “q” factor for clear sky conditions.

Angle “φ”, degrees	Values of a “q” factor with different orientation aspect of window opening					
	E, W	N	NE, NW	SW	S	SE
1	2	3	4	5	6	7
10	0.93	0.79	1.14	1.4	1.21	0.94
20	0.67	0.57	0.79	1.02	0.63	0.65
30	0.52	0.43	0.59	0.79	0.62	0.48
40	0.43	0.38	0.47	0.63	0.48	0.38
50	0.38	0.34	0.39	0.52	0.40	0.32
60	0.34	0.31	0.34	0.45	0.34	0.29
70	0.33	0.31	0.32	0.39	0.32	0.29
80	0.32	0.31	0.31	0.33	0.31	0.28
90	0.33	0.32	0.33	0.35	0.33	0.32

Appendix to table 1 (with no account to an orientation aspect):

Values of a “q” factor for standard overcast sky change from 0,52 to 1,29 for viewing angles φ changing from 2° to 90° respectively (see Table 2).

3 Discussion

All the efforts to create a comfortable microclimate in interiors on basic criteria of natural lighting and insolation/sun protection, offered above, belong to passive (natural) design method. And here we can offer the additional source of natural lighting, formed by sun rays, reflected by the inner and outer planes of a building assembly. This source can be termed “supplementary natural lighting”. For a top-lit premise they are roof covering, monitor and solar screening structures and some of an interior’ surfaces, as shown on Figure 4. For a side-lit premise, facades of surrounding buildings and adjacent ground surface should be added. In this case, the general formula to calculate a daylight factor (DF) is as follows:

$$e_T^D = e_{cs} + e_{ER} + e_{ir} + e_s, \tag{2}$$

where e_{cs} , e_s – daylight factor from the light of clear sky and sun, and e_T^D – design value of daylight factor under top natural system, adopted in the building.

e_{ER} , e_{ir} – externally and internally-reflected components of a daylight factor [17, 18]. Usually direct sunlight in practice must be excluded, so direct component in majority of cases is presented only by the light of a clear portion of a sky vault.

The exclusion is made either by orientation of a light’ openings or by protection on devises.

If we compare the data from Table 1 with typical values of “q” factor for standard overcast sky from Table 2 we can easily see a great difference between them.

The clear sky has much less luminous potential than a cloudy skyvault, which generates a sufficient amount of diffused light in all its portions.

Table 2. Values of “q” factor for standard overcast sky conditions.

№	Angle “φ”, degrees	Values of a “q” factor for any orientation aspect
1	2	3
1	10	0.58
2	20	0.72
3	30	0.86
4	40	0.98
5	50	1.08
6	60	1.17
7	70	1.23
8	80	1.275
9	90	1.29

For example, the difference between “q” factor, obtained for angle “φ” chosen in two different cases considered is 2 to 3 times and resulting values of a daylighting factor sufficiently change, too. To improve the situation the most fast, easy and cheap method is to increase the external reflecting component of natural lighting, providing, for example, more efficient level of reflection from roofing materials to the interior through the openness in sheds or monitors.

According to [8, 9, 14, 15], generally, for a roof natural lighting we can use the following formal, described the “clear sky” conditions of natural illumination:

$$e_{gt} = (e_{TR} + e_{LC} + e_{LM} + e_{CS} + e_{is}) + (e_{TR} + e_{LC} + e_{LM} + e_{CS} + e_{is})(r_2 - 1), \quad (3)$$

Where:

e_{gt} – the general value of a daylight factor for a top-lit interior under a clear sky state of a sky vault;

e_{TR} – a DF constitutional part, reflected from roofing for a top-lighting system under a clear sky state of a sky vault;

e_{LC} – a DF constitutional part, reflected from lower part of a sun-protecting canopy for a top-lighting system under a clear sky state of a sky vault;

e_{LM} – a DF constitutional part, reflected from lower part of a monitor or shed, for a top-lighting system under a clear sky state of a sky vault;

e_{CS} – straight DF constitutional part from a clear sky’ portion of a sky vault;

e_{is} – a DF constitutional part, reflected from inner surfaces of an interior;

r_2 – a quotient, which takes into account the increase of DF values, due to the light, reflected from internal surfaces of a premise under a top-lighting system of natural illumination.

4 Conclusions

1. – The best design solutions of roof lighting installations to satisfy both sun- protecting and natural lighting requirements are sheds, which are the major part of so-called “sawtooth roof”. The advantage of sheds is that half of above-mentioned requirements could be easily fulfilled only by the proper orientation aspect of the window openings. This conclusion is mainly referred to a sun-protection.

2. – As for a daylight factor’ levels, they could only be increased by implementation of supplementary natural lighting, or supplementary artificial lighting of interiors. Such a conclusion is possible, because the simple increase of glazing’ area of sheds is not efficient

due to low volumes of a “q” factor at the angles of a sky vault’ observation from a design point “M”.

3. – The worst case of roof lighting installations as regards sun-protective properties is skylights in forms of domes, pyramids, etc. These installations should never be used in hot and sunny regions or, at least they must be provided with sun- protective blends of sufficient area, which unfortunately highly reduce the natural lighting of interiors.

4. – The mutual functional efficiency of roof lighting’ monitors as regards to their solar-shading and lighting properties combined, can be evaluated as average. For this reason, it is better to provide monitors with stationary sun-protecting canopies on the southern quarter of a sky vault. The lack of a natural illumination in this case, can be efficiently improved by the north – oriented openings of the monitor, provided the roofing surface adjacent to the monitors is covered with material with high light-reflecting capacity.

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