Analysis of Light Comfort and Thermal Protection of a Building Taking into Account Changes in the Geometry of the Window Slope

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Abstract. The article presents an analysis of the influence of the geometry of the window slope on the parameters of light comfort in the premises of buildings and the general heat loss of the building. It is shown that an increase in the opening angle of the outer slopes increases the parameters of daylighting, insolation and visual comfort without increasing the area of the window glazing. Changing the angle of the outer slope at the same time increases additional heat loss through this fragment of the facade. Combined consideration of the parameters of light comfort and thermal protection shows that this solution is effective at any level of thermal protection. The most total effect is observed in the wall with the largest.

Keywords: Thermal protection · Daylighting · Visual comfort · Thermal protection · Windows slope

1 Introduction

1.1 Relevance

Windows are an important part of any building in which people are constantly present. Windows are necessary to create light comfort in rooms as it provides positive psychological, mental and physiological effects on building occupants [1–5]. Solar radiation has a healing effect on the inhabitants of the building due to the penetration of UV radiation [6, 7]. In design practice, the daylight factor and the duration of insolation determines the light comfort in the rooms. To improve these indicators, it is necessary to increase the area of windows or select structures with high light transmission coefficients [8–11].

On the other hand, windows also affect the thermal and acoustic comfort of the room [12–15]. A large area of windows generally worsens the thermal balance of a building due to the low resistance to heat transfer of windows [14, 15]. Sound comfort is also reduced, as the sound insulation of the windows is much less than the sound insulation of the blank walls. The higher the area of the windows, the higher the performance characteristics must be applied to maintain thermal and acoustic comfort. The above parameters are typical for the design of any building.

With the current approach to the design of buildings, it is necessary to take into account other parameters that affect the quality of architecture and comfort in the rooms.

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One of these parameters is visual comfort, which is also determined by the area of the windows. The BREEAM building certification system, widely used in the world, takes into account the view from the windows along with other components. The view from the windows in this system means the relationship between the distance from the window to the workplace and the window area as % of the surrounding wall area. The further the workplace is located, the larger the window area should be [16]. Thus, the design of windows is a rather complex task, which must be considered taken together of various parameters [17–23].

When designing the area of windows, a large number of researchers pay attention to the optimal window-to-wall ratio in buildings for various purposes [24, 25]. As a rule, an increase in the coefficient of glazing of the facade leads to an increase in heat loss, if at the same time the thermal performance of the glazed part is not proportionally increased. However, the thermotechnical qualities of glazed structures have their own limitations both in technological terms and from an economic point of view.

1.2 Aims and Objectives

However, it is worth noting that only the window area and the window-to-wall ratio affect heat loss and sound insulation. In addition to the window area, light and visual comfort is also influenced by the viewing angle from the window. With a large wall thickness (in northern regions with large thermal insulation), the viewing angle can be significantly reduced, which reduces the flow of daylight and sunlight into the room. In this regard, it is possible to hypothesize that changing the angle of visibility through the windows without changing their area can increase the flow of daylight and solar radiation without deteriorating the quality of thermal protection and sound insulation of the entire facade as a whole. The main solution to this problem is to change the angle of the window slope in relation to the plane of the facade.

In world practice, there are examples of increasing the angle of visibility from windows with a large wall thickness by changing the angle of the window slope to the plane of the facade. This is mainly typical for historical buildings (Fig. 1a) [26]. In modern architecture, this technique of facade plastics is also known (Fig. 1b) [27]. However, the scientific rationale for this solution is often not presented: there is no method for calculating the intake of solar radiation with different geometry of window slopes. The effect of this solution on the change of heat loss of the building facade has not been sufficiently studied.

Based on the above, this article analyzes the design approach that allows you to increase the angle of visibility through the windows by changing the geometry of the outer window slopes without changing the area of the windows.

Fig. 1. Beveled outer slope in historical and modern architecture.

2 Materials and Methods

The analysis of the influence of the geometry of the outer window slope on the light comfort and thermal performance of the wall structure was carried out for a fragment of the outer wall with a window (Fig. 2) for a typical living space. The angle of the outer slope in relation to the plane of the facade was chosen as the main changing parameter of the structure under study. Figure 2 shows the design scheme of the window.

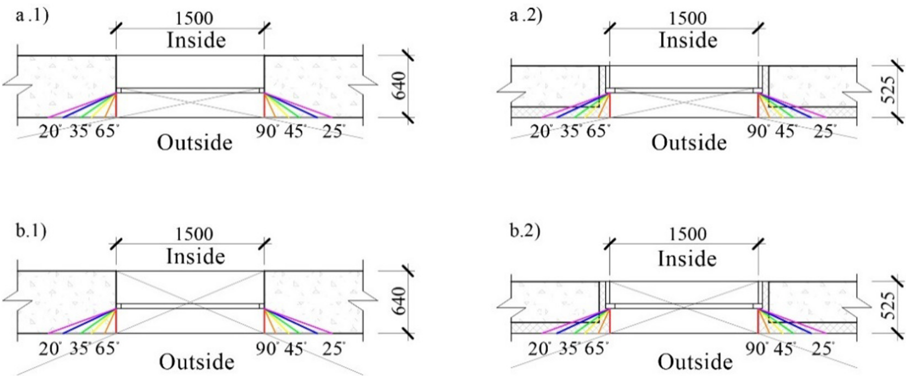

Fig. 2. Design scheme. a.1) single-layer wall, insolation calculation, a.2) two-layer wall, calculation of insolation, b.1) single-layer wall, visual comfort calculation, b.2) two-layer wall, visual comfort calculation

The criteria for evaluating the effectiveness were taken:

a) the calculated geometric daylighting factor. The calculation method was adopted according to SP 52.13330.2016 and SP 23-102-2003 “Daylighting of residential and public buildings”. The calculation did not take into account the light transmission characteristics of the window and the reflection parameters of the room finish. The analysis was carried out for three points of the room: point 2 - in the centre, point 3 - at the outer and point 1 - at the inner walls.

b) the duration of the insolation of the room. The calculation method is based on the tracing of a cartogram for the shading of a window opening and its alignment with a solar map of a certain latitude of the area (48.5N by the example of Volgograd)
c) visual comfort of the room. This parameter was determined through the angle of visibility through the window based on the tracing of the cartogram of the window opening shading. The difference in the shading cartograms of the window opening in points b) and c) consists in different design schemes. When determining insolation, the horizontal shading angle is determined by the outer edge of the slope and the plane of the window (Fig. 1, a.1 and a.2). When determining the angle of visibility, the horizontal shading angle is determined by the outer and inner edges of the slopes (Fig. 1, b.1 and b.2).
d) reduced resistance to heat transfer of a wall section with a window slope. The calculation method is adopted according to SP 50.13330.2012 "Thermal protection of buildings". To compare the effectiveness of the design solution, the analysis of heat loss was carried out for two types of external wall: a uniform 600 mm thick (heat transfer resistance 2.15 $m^2 \cdot °C$ / W) and a two-layer wall with heat-insulating material with a total thickness of 525 mm (4 $m^2 \cdot °C$ / W). The heat transfer resistance of the window is taken as 0.8 $m^2 \cdot °C$ / W. When calculating heat fluxes, the following environmental parameters were taken: indoor air temperature +20° C, outdoor air temperature −22° C.

3 Results and Discussion

3.1 Daylighting

The geometric daylighting factor according to the standard method of SP 23–102-2003 is determined by the product of the rays of diffuse sky light determined by the section (n_1) and plan (n_2) of the room with a window according to Danilyuk's standard graphs:

$$\varepsilon = 0.01 \cdot n_1 \cdot n_2, \ \% \quad (1)$$

Table 1 shows the calculation of the geometric daylighting factor for one room with a constant window area and different angles of the window slope in relation to the plane of the facade. The value of Δ, % shows an increase in the calculated value of the coefficient ε, % in relation to a window with a slope of 90°. The calculation was carried out for three points: point 1 is located at the far wall of the room (at a distance of 1.2 m), point 2 - in the center of the room, point 3 - near the window at a distance of 1.2 m.

As can be seen from Table 1, a decrease in the angle of the window slope relative to the plane of the facade increases the natural illumination of the room along the entire depth (up to 42.2% for point 3 closest to the window and up to 11.8% for point 1 farthest from the window). However, the increase is uneven. Near the window, due to the greater change in the sky visibility angle, the increment is more significant and ranges from 22.2 to 42.2%. At the far point of the room, due to a slight change in the angle, the increase in the coefficient is 11.8%. In addition, for point 3, the coefficient increases until the slope

Table 1. The daylight coefficient of the room at different angles of the window slope

Angle of the window slope	Point 1 (far from the window)				Point 2 (center of the room)				Point 3 (near the window)			
	n_1	n_2	ε, %	Δ, %	n_1	n_2	ε, %	Δ, %	n_1	n_2	ε, %	Δ, %
90°	4.8	16	0.76	–	6	23,5	1.41	–	10	36	3.6	–
60°	5	17	0.85	+11.8	6.6	25	1.65	+17.0	11	40	4.4	+22.2
45°	5	17	0.85	+11.8	7	25	1.75	+24.1	11.8	40	4.72	+31.1
35°	5	17	0.85	+11.8	7	25	1.75	+24.1	12.8	40	5.12	+42.2
25°	5	17	0.85	+11.8	7	25	1.75	+24.1	12.8	40	5.12	+42.2
20°	5	17	0.85	+11.8	7	25	1.75	+24.1	12.8	40	5.12	+42.2

angle decreases to 35°; for point 1, after an angle of 60°, the illumination coefficient does not increase further.

An important conclusion of this analysis is that the change in the shape of the outer window slope insignificantly affects the illumination at the far point of the room. In accordance with this, for premises in which this particular point is normative (living quarters of residential buildings, preschool educational organizations, educational premises of general educational organizations, hospital wards), changing the geometry of the window slope in terms of increasing natural illumination is not an effective measure.

For rooms in which the point in the center of the room is normative (doctors' offices, administrative and office buildings, living quarters of hotels and hostels, etc.), the change of the geometry of the window slope can increase the value of natural illumination up to 24.1%.

It should be noted that in this article, the window is installed near the central plane of the outer wall, which determines the implementation of thermal protection standards. When the window is moved closer to the inner plane of the outer wall, the geometry of the outer slope is able to provide a greater increase in the coefficient of natural illumination over the entire area of the room.

3.2 Insolation and Visual Comfort

As noted in paragraph 2, the duration of insolation and the visual comfort of the room in this article were assessed by the cartograms of the shading of the window opening. Figure 3 shows cartograms with marked shading angles for windows with different slopes. Visually, the cartograms demonstrate that, depending on the differences in the design schemes (Fig. 2, a and b), the influence of the slope geometry is significantly different. From the point of view of the duration of insolation, the increase in the insolation time is not significant. The exact calculation values are presented in Table 2. Table 2 shows that changing the slope angle of the window from 90 to 20° increases the insolation time to 7.6% (for the southern orientation of the window). The spatial angle of visibility with the same changes in the geometry of the window slope increases to 14.9%. On the one hand, these percentages are not large values, but on the other hand, it is important to note that the increase in data by the parameter is obtained with a constant window area.

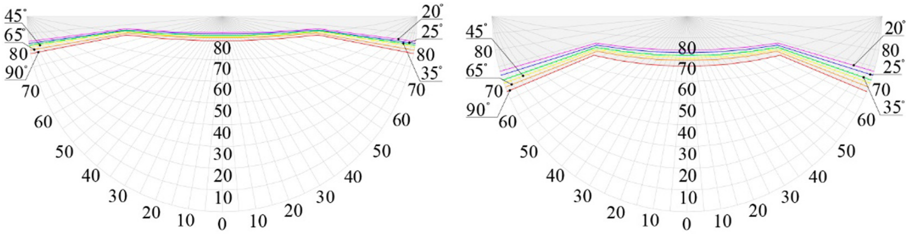

Fig. 3. Window opening shading cartograms a) for calculating the duration of insolation, b) for calculating the angle of visibility (visual comfort)

The last column of Table 2 shows the values of the area of the equivalent window. An equivalent window is a 90° slope window that, for a given wall thickness, produces the same percentage increment in sun duration and angle of view as a beveled slope window. The analysis shows that in order to achieve an increase in insolation time by 7.6% or a total angle of visibility by 15.0%, it is necessary to increase the window area by 120% or change the window slope angle to 20° relative to the facade plane. It is important to note that an increase in the area of the window, and hence the coefficient of glazing of the facade, will certainly lead to an increase in heat loss through the outer shell of the building.

In addition, the ratio between the area of the original window and the thickness of the outer wall should have a great influence on the relative increase in the time of insolation and the angle of visibility. This relationship is not considered in this article.

Table 2. Insolation duration and visual comfort at different angles of the window slope

Angle of the window slope	Insolation duration (increase %)	Visual comfort, increase %	Equivalent window area, increase, %
90°	8 h 20 min (–)	0	0
60°	8 h 34 min (+2.8%)	+4.3%	+24.4%
45°	8 h 40 min (+4.0%)	+6.8%	+40.0%
35°	8 h 45 min (+5.0%)	+9.3%	+59.1%
25°	8 h 52 min (+6.4%)	+12.2%	+90.2%
20°	8 h 58 min (+7.6%)	+15.0%	+120.0%

3.3 Thermal Performance

The window slope (the junction of the window and wall construction) is one of the significant areas of additional heat loss in relation to the heat loss of a flat outer wall.

This is due to the deviation of heat fluxes from a stationary position and an increase in the heat transfer area. With a decrease in the angle of the slope in relation to the facade, the thickness of the outer wall decreases locally, and, consequently, heat loss increases.

Table 3 shows the indicators of specific heat loss per 1 m of slope for different angles.

Table 3. Specific heat loss through the window slope, W/ m·°C

Angle of the window slope	One-layer wall, R = 2.15 m^2·°C / W		Two-layer wall, R = 4.0 m^2·°C / W	
90°	0.090		0.008	
60°	0.110	+22.2%	0.010	+25.0%
45°	0.130	+44.4%	0.014	+75.0%
35°	0.145	+61.1%	0.021	+162.5%
25°	0.172	+91.1%	0.040	+400.0%
20°	0.194	+115.5%	0.057	+612.5%

The values show that with a decrease in the angle of the slope in relation to the facade, additional heat loss increases. Moreover, for a homogeneous wall with low resistance to heat transfer, an increase in additional heat loss when the slope angle changes from 90° to 20° is slightly more than doubled. For a two-layer wall, the same increase occurs almost sevenfold. This difference is due to the difference in the heat transfer resistance of the window (R = 0.8 m^2·°C/W and of the analyzed walls): the higher the difference in the resistances of the elements of the assembly, the greater the contribution to thermal protection is made by the element with high resistance. Thus, if we consider the design method of changing the angle of the window slope from the point of view of thermal protection, then any change in the slope angle below 90° gives an increase in heat losses, and therefore worsens the overall thermal protection of the building. At the same time, the higher the thermal protection of the outer wall is, the more the overall thermal protection will deteriorate.

However, as noted above, the windows should be considered in a combination of different parameters. For this purpose, the calculation of the total heat losses through the windows with the changed geometry of the slope and the windows equivalent in area from the point of view of insolation and visual comfort, indicated in Table 2, was carried out. The calculation was carried out for a fragment of a facade with an area of 25 m^2 with a window with dimensions of 1.5 × 1.5 m. Table 4 shows the result of this calculation.

Analysis of Table 4 shows that, regardless of the thermal protection of the outer wall, changing the geometry of the window slope is a more effective measure for heat loss compared to a straight-sloped window with an equivalent area. The efficiency of a chamfered window slope increases with decreasing angle: from 1.8% to 9.1% in a single-layer wall, from 5% to 22% in a two-layer wall when changing the angle of slope from 60° to 20°. At the same time, the greater the resistance to heat transfer of the outer wall, the greater the energy saving effect is achieved when bevelling the outer slope and

Table 4. Heat flow through a fragment of the facade with different geometry of the window slope, W

Angle of the window slope	One-layer wall, R = 2.15 м^2*C/Вт			Two-layer wall, R = 4.0 м^2*C/Вт		
	Chamfered window	Equivalent window	Increase, %	Chamfered window	Equivalent window	Increase, %
90°	558	558	–	338.48	338.48	–
60°	568.19	578.82	+1.8%	339.93	356.98	+5%
45°	573.29	589.13	+2.76%	340.66	366.24	+7.5%
35°	576.13	600.84	+4.28%	341.98	380.07	+11.1%
25°	581.23	620.54	+6.76%	345.5	403.64	+16.8%
20°	585.39	638.68	+9.1%	348.7	425.52	+22.0%

increasing the light comfort in the room: at an angle of 20° the heat flow saving in a single-layer wall is 9.1%, in a two-layer wall - 22.0%.

This means that when the parameters of light comfort and heat loss through a section of a wall with a window are taken into account together, beveled slopes are an effective constructive means for increasing the flow of light at different levels of thermal protection.

4 Conclusion

The article shows that the geometry of the window slope affects various sanitary and hygienic parameters of the room and the thermal characteristics of the external structure as a whole.

Firstly, the influence of the geometry of the window slope on the daylighting of the room is manifested to a greater extent for areas of the room near the light opening. Moreover, the smaller the angle of inclination of the window slope to the plane of the façade is, the greater the value of illumination will be near the window (up to 40% increase). In the distant points of the room from the outer wall and window, the influence of the angle of inclination of the window slope is not so significant (no more than 12% increase). Moreover, the angle of the window slope is less than 60° to the plane of the facade practically does not affect the increase in illumination.

Secondly, the influence of the geometry of the window slope on the duration of insolation and the spatial angle of visibility is manifested depending on the design scheme. Taking into account the opening angle of the window along the glazing plane, the increase in the angle of visibility when the geometry of the slope changes is insignificant. If we take into account the opening angle of the window as a whole, taking into account the internal slopes, the increase in the total angle of visibility can reach almost 15%.

Thirdly, it is important to note that any change in the angle of the window slope below 90° increases the level of light comfort in the room. The same change in geometry leads to a deterioration in thermal performance. The value of additional heat losses through the window slope unit when changing the angle can increase by seven times, depending on the initial level of thermal protection.

Fourthly, with the combined consideration of the parameters of light comfort and thermal protection, it is possible to achieve overall efficiency. To increase the luminous flux in the room, it is necessary to increase the viewing angle through the window. Increasing the viewing angle by changing the angle of the outer slope with a constant window area is more effective than increasing the window area. Depending on the thermal protection of the wall, this effect can reach 9–22%.

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