The shadow masks’ use in the sunscreens design

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Abstract. This article is devoted to the search for the most effective design of sun protection devices (SPD) using solar maps and shadow masks. The design algorithm of the SPD using solar maps and shadow masks is considered. At the same time, the position of the shading elements - lamellas depends on the facade orientation. The examples of calculating the SPD geometric parameters with the vertical, horizontal and inclined position of the lamellas are given. A number of SPD projects are implemented in the buildings in Crimea.

Introduction

Sun-protection devices make it possible to adapt the windows and facades’ properties to weather conditions and the residents’ needs. Proper design of these systems can maximize the increase in solar heat in winter - therefore, reduce heat loads - and minimize this heat increase in summer - therefore, reduce cooling loads, while at the same time providing good visual comfort for the residents.

Analysis of the latest achievements and publications

Currently, the architect can dispose a wide variety of shading devices, in which it is necessary to take into account both comfort and energy problems. There are too many parameters considered, but no significant effort has been made so far to classify and characterize these devices. One of the goals of the article [1] is to highlight this complex task and lay the foundation for a simple categorization from which to start.

The sun protection device can be external, internal, stationary, motorized or located between the external glazing and the internal facade in the systems with a double facade. A good shading system makes it possible to reduce the level of artificial lighting, because an eye can adapt without voltage to the function in a wide range of illumination [2].

A sun protection device significantly reduces the need for primary energy for orientations other than the northern ones in Madrid [3]. In this case, the lowest primary energy requirement is achieved by using a combination of sun glazing and external solar shading. The combination of sun glazing with a sun protection device is an unusual choice. Generally, sun glazing is considered an alternative to external shading. In this case, the primary energy requirement for an office equipped with sun glazing and shading from the sun is about 30% lower than for the same office equipped with only sun glazing.

Modeling in daylight showed that an external fixed shading system in combination with internal shading give satisfactory values of the daylight coefficient and a uniform distribution of daylight in the...
southern office [4]. According to the users, external fixed shading is a good system for southern offices when local glare problems can be resolved using the internal louvres.

For many architects, the accurate development of even basic manual shading devices can be a time-consuming task, especially in a building with many different facades or types of windows that need to be considered. As a result, many projects get at best only a superficial consideration of shading. Even with the help of computer programs capable of projecting the shadows onto three-dimensional models of buildings, developing an effective system can be a difficult trial and error process [5]. The article shows that for the relatively simple cases, a more generally applicable, although less accurate, approach can provide as much, if not more, information useful to the designer.

The Building Code of Rules BC 370.1325800.2017 “Sun-protection devices for buildings. Design Rules” sets out the basic requirements for sun protection devices in buildings, as well as the rules for their design in the construction, reconstruction and overhaul of residential, public and industrial buildings. Recommendations are also given on the SPD use for various facades’ orientations.

Depending on the orientation of the translucent structure, the following SPD types should be selected (according to the shading elements’ location):
- horizontal - most effective for south-facing windows;
- vertical - it is advisable to use when orienting the windows to the north, northeast and northwest;
- combined - most effective in southwestern and southeast orientations;
- SPD of general use - suitable for south-west, west and south-east orientations;
- universal sun shields - can be used for any orientation of the facade.

Heating periods form a zone of desirable insolation on the solar map, and the periods of overheating form a zone of unwanted insolation or an overheating zone (Figure 1.). These maps are given in the Building Code of Rules [6].

This article is devoted to the search for the most effective design of SPD using solar maps and shadow masks.

**Solar maps and shadow masks in the SPD design**

The location of the sun-protection devices’ shading elements is determined using a solar map and shadow masks, depending on the terrain latitude and the facade orientation [6].

Let us consider the SPD design with different positions of the shading elements - lamellas.

![Figure 1. Integrated map with areas of desirable and unwanted insolation for the city of Yalta](image-url)
The purpose of the article is to describe the methodology for designing the sunscreen devices using shadow masks.

**The vertical position of the lamellas.**

Facade orientation northwest, azimuth $335^0$, vertical arrangement of shading elements, Pyatigorsk.

The facade is located to the northwest, azimuth $335^0$ (Figure 2). In accordance with the diagram [6] of the preliminary SPD selection, a vertical arrangement of lamellas with an angle of inclination $\theta$ to the facade plane $60^0$ is recommended. We apply the shadow goniometer for the vertical lamellas to the integrated solar map for the city of Pyatigorsk. The shadow angle should be such that the shadow mask of the SPD covers the zone of unwanted insolation. According to the shadow goniometer we determine: the opening angle $\delta$ is equal to $35^0$, shadow angle $\eta$ is equal to $90^0 - 35^0 = 55^0$. The reverse opening angle is $\delta_Z = 67^0$.

Result: unwanted insolation is shielded by the SPD with vertical lamellas during the building overheating.

**Horizontal position of lamellas.**

Based on the BC 370.1325800.2017 “Sun protection devices for buildings. Design Rules” recommendations, the position of the SPD shading elements on the southern facade is horizontal (Figure 3.)

Provided that the full screening of the light transmission by the sun-protection device should be before September 22 for the zones IV and V [7], the lamellas should be located so that at an angular height of the sun $45^0$ the Sun’s rays still did not fall on the translucent structure. When placing the lamellas at an angle $45^0$ to the plane of the facade, the distance between the lamellas is equal to the width of the lamella multiplied by the square root of two (Figure 4 c).

The lamellas are perpendicular to the facade plane. When placing the lamellas at an angle $90^0$ to the facade plane, the distance between the lamellas is equal to the lamellas’ width (Figure 4 b).

The sun protection devices were installed on the windows of the southern facade in the main building of the Academy of Construction and Architecture of the Crimean Federal University named after V.A. Vernadsky (Figure 3).

![Figure 2. A solar map for the city of Pyatigorsk on the left, a shadow mask for the vertical SPD on the right](image-url)
For the SPD with horizontal and vertical sun-protection elements, the inclination angle of the lamellas to the facade plane $\theta$ should be equal to the opening angle $\delta$ [8]. From a set of brackets manufactured by the industry, a bracket with the lamella installation angle closest to the design is selected.

**General position of lamellas**

The facade is located to the west, azimuth $270^\circ$ (Figure 5). In accordance with the SPD preliminary selection diagram [6], an inclined arrangement of shading elements is recommended. Figure 5 shows two options for the shading elements’ oblique arrangement.

The sun protection devices on the western facade windows were installed in the main building of the Academy of Construction and Architecture of the Crimean Federal University named after V.A. Vernadsky (Figure 6).

In option a) the shading elements’ guide (in the section A, Figure 7.) is inclined at an angle $15^\circ$ to the vertical. The unwanted insolation zone is completely closed, which protects the room from overheating during the building’s cooling period. However, in this embodiment, the desired insolation zone is closed during the building’s heating period.

In option b) the shading elements’ guide is inclined at an angle $45^\circ$. The unwanted insolation zone is completely closed, and the desired insolation zone is open, which will provide additional heating of the room during the heating period.
Figure 5. Orientation of the facade west, azimuth $270^0$, $a$ - the inclination angle of the guide lamellas $15^0$, $b$ - tilt angle of guide lamellas $45^0$.

Figure 6. Inclined SPD on the eastern facade of the building in the Academy of Construction and Architecture.

Figure 7. The geometric parameters of the inclined SPD: $\eta_1$ and $\eta_2$ - shading angles; $\mu$ - the angle of the shading elements; $\gamma$ - insolation angle.
Thermal Solar Energy Reduction Ratio

Solar insolation incident on the building’s facade consists of direct, diffuse and reflected insolation. Reflected insolation depends on the specific situation in which the building is located and it is extremely difficult to take it into account when designing.

With sufficient accuracy for the evaluative calculations, we can assume that only direct solar insolation is shielded by a sun protection device. This is consistent with the provision of ISO 52016-1: 2017 Energy performance of buildings - Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads - Part 1: Calculation procedures, according to which: “Unless otherwise specified at the national level, calculation reducing shading factors should be based on the following simplifications. Direct solar insolation is absorbed by the barrier; diffuse insolation and insolation reflected from the earth remains unchanged. This is identical to obstacles that reflect the same amount of solar insolation as they absorb”. If the SPD shields direct solar insolation, the coefficient of reduction of thermal solar energy \( g_{SPD} \) is equal to scattered insolation ratio \( I_{scat} \) to total insolation \( I_{total} \).

\[
\begin{align*}
g_{SPD} &= \frac{I_{scat}}{I_{total}} \\
I_{total} &= I_{dir} + I_{scat}
\end{align*}
\]

For example, for the month of July in Simferopol \((44^\circ)\) on the southern facade, direct insolation is equal to 1597, scattered 1267, total 2864, \( g_{SPD} = 1267/2864 = 0.44 \).

Table 1 shows the values of direct, scattered and total insolation and the coefficient \( g_{SPD} \) shows the reduction in solar thermal energy. Figure 8 shows the change in this coefficient over the months of the building’s cooling period.

Table 1 shows the values of direct, scattered and total insolation and the coefficient \( g_{SPD} \) shows the reduction in thermal solar energy.

Summary

To make the right choice in terms of facade design when designing a new building or preparing work for an existing one, it is necessary to take into account the sunscreens’ characteristics.

| Month   | Direct | Scattered | Total | Coefficient \( g_{SPD} \) |
|---------|--------|-----------|-------|---------------------------|
| April   | 2902   | 1292      | 4194  | 0.3                       |
| May     | 1968   | 1303      | 3270  | 0.4                       |
| June    | 1485   | 1205      | 2690  | 0.45                      |
| July    | 1597   | 1267      | 2864  | 0.44                      |
| August  | 2353   | 1250      | 3603  | 0.35                      |
| September | 3482   | 1129      | 4611  | 0.25                      |
Figure 8. Schedule changes in solar insolation in the SPD presence

The geometric parameters of the SPD, such as the lamellas’ inclination to the facade and to the horizontal plane, the width of the lamellas should correspond to the building’s properties, its location and orientation. The calculations are based on solar geometry, the parameters of which depend on the construction site.

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