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APPLICATION OF SOLAR MAPS IN DESIGN OF GENERAL-POSITION SHADING DEVICES

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ABSTRACT

For insolation calculations and design of shading devices (SD) comprising plane sections or fins, the method based on solar maps shall be preferred because of its high descriptiveness and universality. The article describes the algorithm of design of a general-position SD using a solar map and a shade clinometer. An example of calculation of SD geometry parameters such as fin slopes with the horizontal plane and the facade plane, distance between the fins with consideration of screening of the translucent structure during the building cooling period and of transmission of solar radiation during its heating period is given in the article. A simplified formula of a general-position SD energy efficiency calculation is proposed.

Keywords: solar map, shade clinometer, shadow mask, shading device geometry parameters, preferable insolation zone, overheating zone, building cooling period

1. INTRODUCTION

The decisive impact on temperature mode in premises is caused by the Sun. Even in moderate climate areas, increase of solar heat through windows may be excessive in summer. In summer, overheating of premises may be lowered by the following means: 1) turning the building's facade with the largest number of windows to the North: in this case, however, passive solar heating through windows significantly lowers in winter; 2) application of special glass units operating as heat filter, which also lowers heat transmission not only in summer but also in winter; 3) application of shading devices (SD) with optimised geometry.

A rationally designed SD screens solar radiation during overheating periods, promotes better application of natural daylight, prevents blinding action and provides transmission of solar heat to the premises in winter.

2. ANALYSIS OF THE LATEST ACHIEVEMENTS AND PUBLICATIONS

A shadow mask is a simple tool for definition of the shaded part of the sky at a specific model point (design point) on a solar map. With any set of shading objects, their shadow mask may be placed onto the solar map to show how the design point is irradiated by the Sun at any time of the year [1]. Shadow masks may be built by means of shade clinometers. They are described in [2] for horizontal and vertical shading elements.

The article [3] describes calculations and analysis of SD protective characteristics which allow us to form preliminary guidelines on energy efficiency of different types of SD. However, it is only possible to define SD energy efficiency correctly by means of comprehensive solar maps identify-

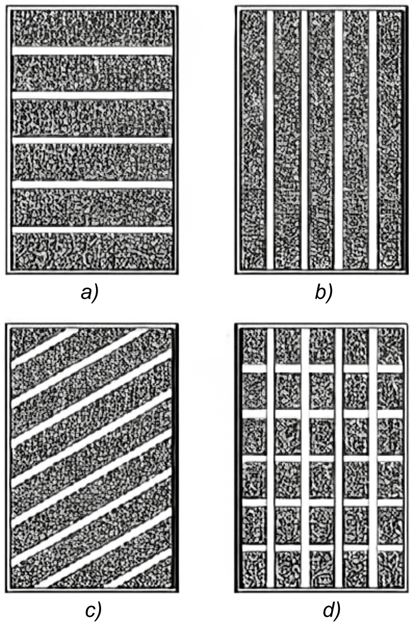

Fig. 1. Different positions of SD shading elements: *a* – horizontal; *b* – vertical; *c* – general position; *d* – combined

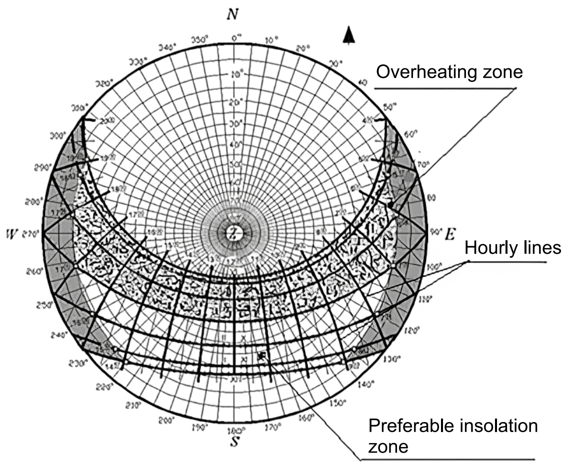

Fig. 2. The solar map with overheating and preferable insolation zones for Simferopol

ing the zones of preferable and non-preferable insolation [4].

The guideline [5] specifies major requirements to SD's of buildings and rules of their design in the Russian Federation applicable to construction, reconstruction and repair of residential, public and production buildings. This regulation specifies major types of SD based on their locations, structural features, materials and adjustment methods to meet standard requirements to heat insulation, solar radiation protection and daylighting in premises for different purposes. The method of solar maps is proposed for design of stationery SDs with rational shape. For insolation calculations and design of SDs comprising plane sections or fins, the method based on solar maps shall be preferred because of its high descriptiveness and universality [5]. The positions of shading elements of SDs, Fig. 1, in this case, are defined by means of a solar map and depend on latitude and facade orientation [5].

Solar maps are used for evaluation of necessity of air heating and conditioning in premises located in different climatic zones. The climatic parameters affecting selection of the type of SDs are considered in the article [6].

The building heating periods form the preferable insolation zone on a solar map and the building cooling periods form the zone of non-preferable insolation or the overheating zone. A solar map with the overheating zone and the preferable insolation zone within the period between March 22 and September 22 with cumulative annual solar radiation on a horizontal plane in conditions of actual cloudiness for the IV and V climatic zones, Fig. 2, is taken from the guideline [5].

This article describes development of the method of definition of geometry parameters of optimised SDs and evaluation of their energy efficiency by means of solar maps and shade clinometers.

3. SOLAR RADIATION AND THE BUILDING COOLING PERIOD

Solar radiation incident on a building facade comprises the direct, diffused and reflected components. Reflected radiation is mostly dependent on surrounding development and it is rather difficult to take it into account in the course of design. The direct and diffused radiation parameters were taken from the climatic handbook [7].

The building cooling periods in Simferopol lasts for almost five months: from May 10 to September 28 [8, Table A.2]. This corresponds to the overheating zone on the solar map (Fig. 2). The article [9] contains the graphs of direct and diffused radiation for these months (Fig. 3), which demonstrate that diffused radiation changes insignificantly during this period.

With accuracy sufficient for evaluation calculations, we may consider that SD screens only direct solar radiation. This corresponds to the guideline in the national standard [10]: "Unless otherwise is determined nation-wide, calculation of shading re-

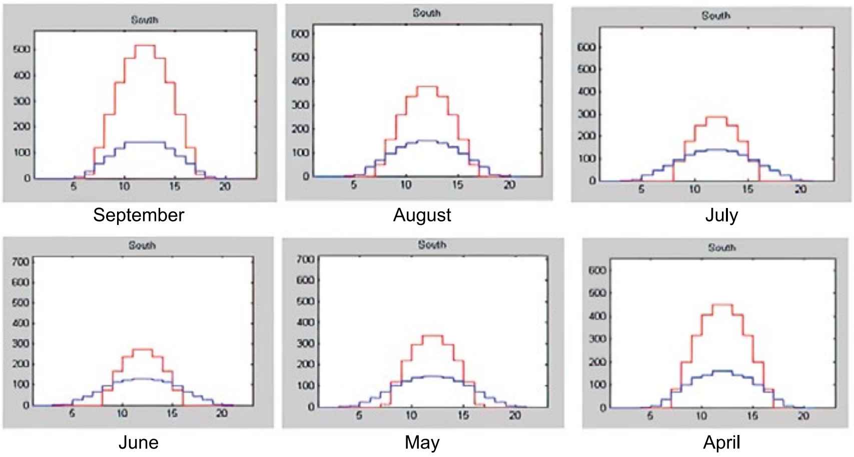

Fig. 3. Direct and diffused radiation with actual cloudiness in Simferopol (W/m^2)

duction factors shall be based on the following assumptions. Direct solar radiation is absorbed by an obstruction; diffused radiation and radiation reflected from the Earth remain unchanged. It is identical to obstructions which reflect the same amount of solar radiation as they absorb.”

In the general case, the SD efficiency coefficient $F_{\mathrm{sh},0}$ is defined as [10]

$$F_{\mathrm{sh},0} = \frac{I_{\mathrm{sol,ps,mean}}}{I_{\mathrm{sol,mean}}},$$

where $I_{\mathrm{sol,\,ps,\,mean}}$ is the irradiance of the surface under consideration due to solar radiation with available shading taken into account, W/m^2; $I_{\mathrm{sol,\,mean}}$ is the average irradiance of the surface under consideration if shading is not available.

The article [11] proposed the formulae for calculation of efficiency coefficients of horizontal (F_{ov}) and vertical (F_{fin}) SDs:

$$F_{\mathrm{ov}} = \frac{S\cdot k + D\cdot\cos\alpha + 0,25\cdot Q\cdot r\cdot(1-\cos\alpha) + R}{S+D+R};$$

$$F_{\mathrm{fin}} = \frac{\left[\begin{array}{l} S{\cdot}k{+}0,5\cdot D\cdot(1{+}\cos\beta){+}0,5\cdot D^{\perp}\cdot(1{-}\cos\beta){+} \\ {+}0,25{\cdot}Q{\cdot}r{\cdot}(1{+}\cos\beta){+}\,0,5\cdot R^{\perp}\cdot(1{-}\cos\beta) \end{array}\right]}{S+D+R},$$

where S, D, R are the values of irradiance of the irradiated surface by direct, diffused and reflected solar radiation respectively, W/m^2; Q is the irradiance of Earth surface by total solar radiation, W/m^2; r is the albedo of the Earth surface (defined with consideration of snow cover); k is the direct solar radiation transmittance factor of SD; $D^{\perp}$ is the irradiance of a fin by diffused solar radiation, W/m^2; $R^{\perp}$ is the irradiance of a fin by reflected (from the Earth surface) solar radiation, W/m^2; α is the canopy shading angle; β is the vertical fin shading angle.

For calculation of $F_{\mathrm{sh},0}$ of a general-position SD, the simplified formula may be proposed:

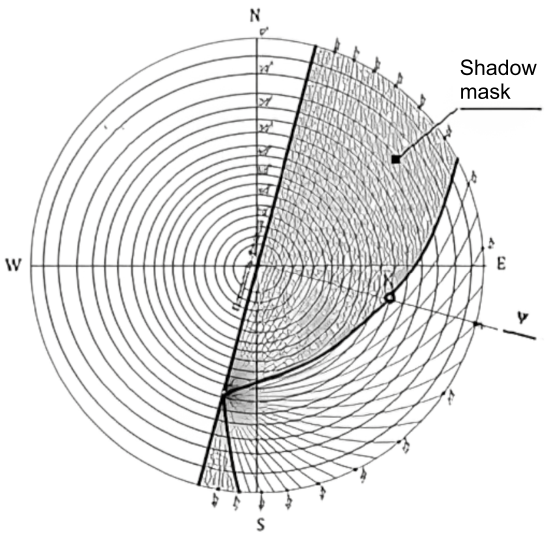

Fig. 4. An example of a shade clinometer for general-position fins with the applied SD shadow mask

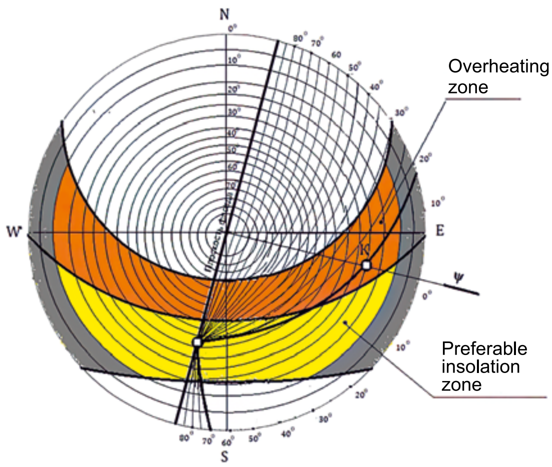

Fig. 5. Example of definition of a rational shadow mask of a general-position SD

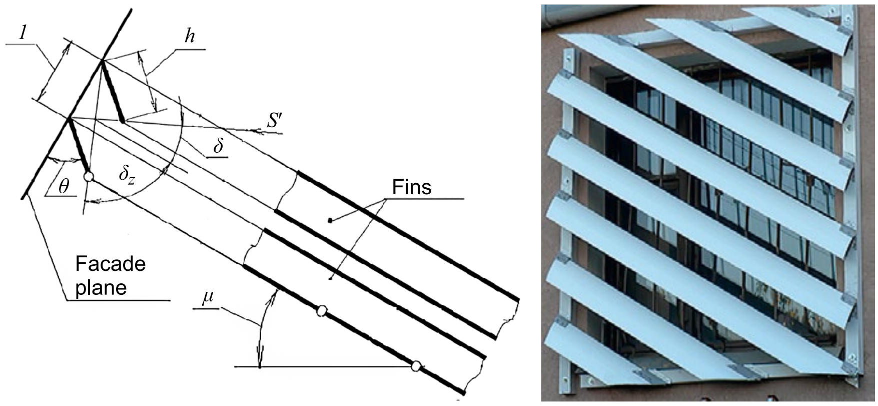

Fig. 6. Geometry parameters and general view of a general-position SD:
h – fin width; l – distance between fins;
δ – aperture angle;
δ_Z – inverse aperture angle; θ – fin slope with the facade plane;
μ – shading element slope with the horizontal plane

$$F_{\mathrm{sh},0}=\frac{S\cdot k+D+R}{S+D+R},$$

where the values of S, D and R are defined with consideration of facade orientation using the handbook [7] or the data of meteorological observations.

4. SD STRUCTURAL PARAMETERS CALCULATION

A solar map is a graphical tool for design of SD and determination of the insolation period. For insolation calculations and design of SD's comprising plane sections or fins, the method based on solar maps shall be preferred [12].

A part of the celestial sphere between the curve of the selected aperture angle and the facade plane is called the shadow mask of SD, Fig. 4. Such insolation angle should be selected the shadow mask of which covers the non-preferable insolation zone the most efficiently with minimal covering of the preferable insolation zone and the neutral part of the celestial sphere.

Example. A SD for windows of a building in Simferopol with azimuth of 105° is required to be designed. ***The algorithm of efficient SD geometry calculation*** is as follows:

1. Shade clinometers are put onto the solar map with the facade shadow mask on it so that the facade plane on the clinometer corresponds to the facade plane on the shadow mask. The shade clinometers for calculation of different SD types are attached to the guideline [5, Annex I].

2. A shade clinometer is selected so that the shadow mask covers the overheating zone to the maximum extent and does not cover the most part of the preferable radiation zone (Fig. 5). For the design facade orientation, general-position shading elements (fins) are necessary to be applied. Fig. 5 depicts application of a shade clinometer with fin slope with the horizontal plane equal to μ = 30 °.

3. The aperture angle δ = 20 ° and the inverse aperture angle δ_Z = 70 ° are defined based on the selected shade clinometer.

4. The fin slope with the facade plane θ is selected (Fig. 6). Nowadays, brackets allowing us to install fins with facade slope of 90 °, 60 ° and 45 ° are manufactured. Using them, the value θ = 45° closest to the value of δ = 20 ° may be provided.

5. If we apply the fin width h = 145 mm (the dimension from the practically applied standard size of fins) in the designed SD, the distance between the shading elements l is calculated as

$$l=h\cdot(\cos\theta+\sin\theta\cdot\mathrm{tg}\delta)=$$
$$=145\cdot\cos45^{\circ}\cdot(1+\mathrm{tg}20^{\circ})\approx 140\ (\mathrm{mm}).$$

Maximum facade insolation will be on the vertical ray plane ψ perpendicular to the facade plane. To design SD with sloped fins, it is necessary to know Solar altitude angle φ on the plane ψ. The latter corresponds to the zero orientation on the shade clinometer. φ on the plane ψ is defined by the almucantarat crossed by the aperture angle curve. In Fig. 5, the point K is the point of crossing of the δ = 20° curve with the plane ψ. In this case, φ = 23 °.

The described SD is installed on an experimental building in the outskirts of Simferopol (Fig. 6).

CONCLUSIONS

The structure of SD shall primarily correspond to the facade orientation providing screening of high solar rays during the building cooling period and transmission of solar rays during the heating period. The method based on solar maps and shade clinometers shall be preferred because of its high descriptiveness and universality. This method allows to define parameters of SD shape and position (in particular slopes of fins with the horizontal plane and the facade plane and the distance between the fins) at which high energy efficiency of SD will be provided.

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