

Cities of the future: a building typology with optimal daylighting

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Abstract. A novel building typology consisting in the use of optical filters in smart windows to achieve comfortable conditions of natural lighting and insolation indoors is presented. Thin-film chromogenic parallel strips on two surfaces of pane(s) of the window form two gratings providing the angular-selective light transmission. The design and principle of operation of the smart window and methods for calculating filter parameters are briefly described. The principles of using smart windows with optical filters are demonstrated on an example of a complex of three buildings.

1. Introduction

The problems of ensuring comfortable conditions of natural lighting and insolation will always be relevant, including in the cities of the future, since without their optimal solution it is impossible to imagine a building that fully corresponds to the concept of “smart home”. For a separate building, these problems could be solved quite simply by choosing the maximum area of light openings for the northern sector, the minimum for the southern, and the middle for the eastern and western sectors. However, from an architectural and artistic point of view, such a building with different window sizes on different facades can hardly be called a successful solution. It would be even more difficult to imagine a similar approach for a complex of buildings, given their mutual influence on the distribution of sunlight. In modern conditions for a building with identical windows, problems are solved with the use of blinds and other devices for redistributing light fluxes.

Energy-efficient windows with low-emission coatings [1, 2] reflecting infrared radiation are used. More advanced systems are smart windows coated with chromogenic materials. Such windows are more expensive, but they change their optical (reflecting, transmitting, absorbing and scattering) properties or under the influence of the environment - when the temperature changes (thermochromic [3] and thermotropic [4] windows) and when the intensity of the ultraviolet and short-wavelength visible ranges spectrum of solar radiation (photochromic [5] windows), or when a weak direct current is passed through a thin layer coating (electrochromic [6, 7] windows). Chromogenic windows provide significantly more comfortable daylighting and insolation conditions in comparison with conventional window systems with light redistribution devices, and with low-emission windows, due to adaptability to changing the environmental conditions. The use of chromogenic technologies in windows is constantly expanding, especially due to a gradual decrease in cost, that is, the future lies with such technologies. The disadvantage of chromogenic windows is the inability to transmit scattered sunlight when blocking direct radiation. Discomfort in the room is caused by direct rays, and in the active state, chromogenic windows also cease to transmit scattered rays. The functioning of such windows does not



take into account the position of the sun in the sky, that is, the angles of incidence of the rays on the window, although at some angles protection is not required even from direct rays.

This paper presents a novel approach to the use of chromogenic technologies in smart windows, namely, that a thin-film chromogenic coating is applied not over the entire area of one surface of pane, as in conventional smart windows, but in the form of parallel strips on two surfaces of the one or two panes. These strips are a grating optical filter with angular selectivity based on the patented method of regulating light transmission (R. S. Zakirullin, RU Patents 2509324 and 2677069). Section 2 briefly describes the design and principle of operation of a smart window and methods for calculating filter parameters from [8, 9]. Section 3 demonstrates the principles of using smart windows with optical filters on an example of a complex of three buildings. Section 4 provides the conclusions.

2. Smart window with grating optical filter

The filter for a smart window (Figure 1) consists of two thin-film gratings on the surfaces of one or different window panes formed by parallel chromogenic strips, between which are directionally transmissive strips. Unlike horizontal or vertical blinds, the strips of the filter can be adapted to the trajectory of the sun relative to the window taking into account its orientation to the cardinal because of the possibility of setting the slope of the strips at optimum angle. The strips of both gratings are located on the window surface at an angle (as shown in Figure 1 (a)), determined by approximating the trajectory of the sun relative to the window, taking into account its orientation to the cardinal points and geographical latitude.

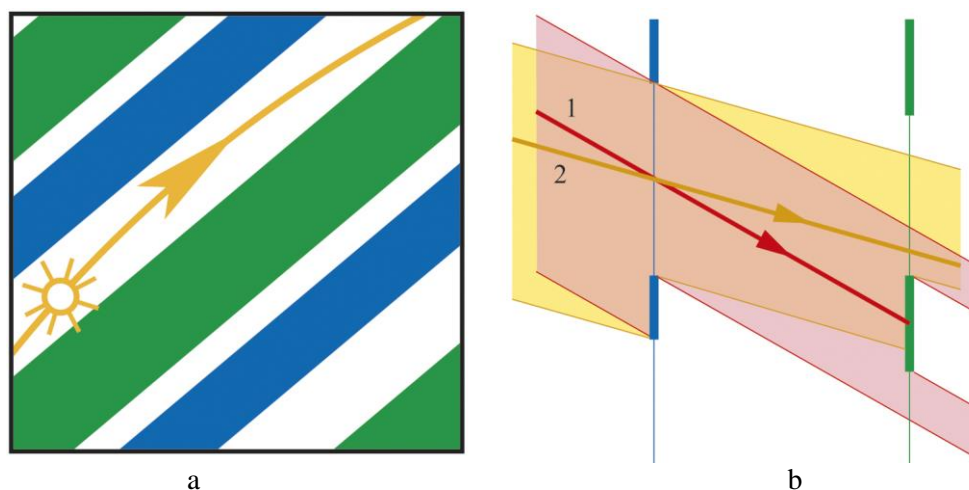


Figure 1. Smart window with grating optical filter: a – the slope angle of the strips of the filter adapted to the trajectory of the sun; b – light transmission of the input and output gratings at different incidence angles of solar beams 1 and 2.

The optimal slope angle of the filter's gratings is determined according to the following algorithm [8]: (1) selecting the calculation date taking into account the local climate (the middle of the hottest period of the year or the day of maximum solar radiation), (2) determining the time of maximum solar radiation for the selected date, (3) calculating the elevation and azimuth of the sun for the selected date through every minute (hour, etc.) relative to the time when the azimuths of the sun and the window are equal, (4) calculating the incidence angle of the solar beam onto the vertical window surface by the special case of first cosine theorem for the trihedral angle when the dihedral angle in front of the calculating plane angle is 90° , (5) calculating the values of the coordinates of trace of trajectory of the sun on vertical plane of the window, (6) plotting the trace of the trajectory of the sun, (7) obtaining the optimal slope angle of the filter's gratings by linear approximation of the curved trajectory of the sun.

Figure 1 (b) shows ray-tracing of two solar beams falling onto the center of transmissive strip of the input gratings, as well as the bandwidths of transmission of direct light through both gratings within the single period of the gratings, that is, the sum of the widths of two adjacent transmissive and chromogenic strips (periods of both gratings are equal). The partial transmission of the light by chromogenic strips in the active state is not shown in the Figure 1 (b), as well as the refraction of beams. Characteristic angle of the filter showing the relative shift of the input and output gratings is the incidence angle of a beam passing through the centers of the alternating strips on both gratings, as the beam 1 in the Figure 1 (b). A comparison of the paths of beams 1 and 2 and the corresponding bandwidths shows that the filter has an angular selectivity of light transmission, that is, at different incidence angles of solar beams, the smart window with such a filter transmits a different amount of direct light. In addition to the characteristic angle, the light transmission of the filter is also affected by the ratio of the widths of the transmissive and chromogenic strips of both gratings. The calculation methods for the characteristic angle and the widths of all strips at a preset required angular dependence of the filter light transmittance are given in detail in [8, 9]. When the chromogenic strips of the filter are activated, the smart window transmits direct light in a predetermined amount in preset angular ranges or completely blocks direct light. However, it continues to transmit diffused sky light and light reflected from the surface of the earth and from opposing buildings (which is ultimately also diffused). This allows, in contrast to conventional smart windows, using diffused daylight to achieve comfortable lighting conditions without glare and excessively bright indoor surfaces. When the chromogenic strips are inactive (at a low temperature and the intensity of solar radiation), the light transmission of the smart window is slightly lower than the light transmission of conventional windows.

3. Principles of a building typology with optimal daylighting

Figure 2 shows an example of dividing the building's facade into shading and lighting zones, taking into account two opposing buildings. All three buildings are located in parallel, the paths of solar beams are shown for the time of maximum solar radiation at the selected calculating date (usually this is the middle of the hottest period of the year or the day of maximum solar radiation). At this time, the illuminated part of the facade of the building needs maximum sun protection, that is, the light transmission of smart windows with activated chromogenic strips should be minimal, and for the shaded part of the facade it is possible to use smart windows with a relatively large light transmission (in extreme cases, in this area you can apply conventional windows).

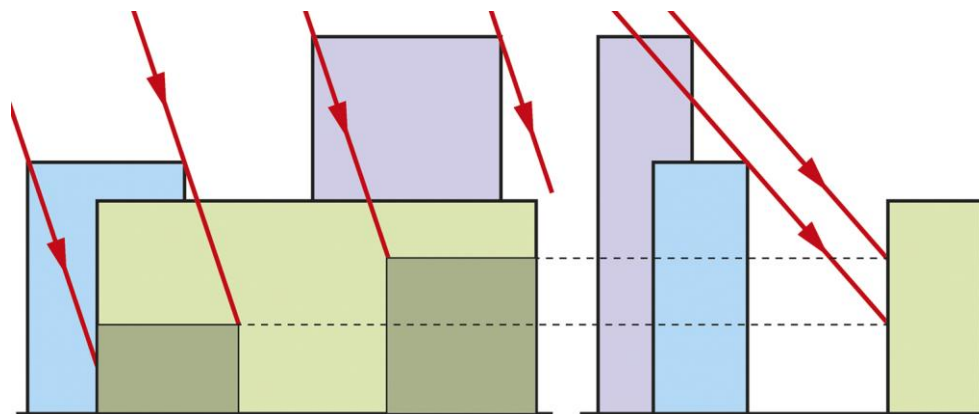


Figure 2. Determining façade areas of the building for the selection of options of the smart window taking into account the opposing buildings.

Thus, in this case, for the considered facade of the building, it is advisable to use smart windows of two types that differ from each other in the level of light transmission. The slope angles of the gratings of both types must be the same, since they are designed for the same facade. The characteristic angles

of the filters must also be the same due to the same incidence angles of the solar beams. However, the ratio of the widths of the transmissive and chromogenic strips will be different. The widths c of the directionally transmissive strips of the output gratings are calculated (for single and double/triple glazed windows, respectively) by [8, 9]:

$$c = 2s \sin \Theta_c / \sqrt{n^2 - \sin^2 \Theta_c} - 2s \sin \Theta_{av} / \sqrt{n^2 - \sin^2 \Theta_{av}} \quad (1)$$

$$c = 2s \tan \Theta_c - 2s \tan \Theta_{av} \quad (2)$$

where s is the distance between gratings, Θ_c is the characteristic angle of the filter, n is the refractive index of the glass, Θ_{av} is the specified average angle ($\Theta_{av} < \Theta_c$) corresponding to the average value of the preset real (required) light transmittance of the filter.

The numerical simulation [9] shows that for the same value of the width of the strip c , in order to increase the light transmission of the filter, it is necessary to reduce the period of the gratings. Similarly, taking into account the surrounding buildings, smart windows are calculated for all the facades of the building, with the exception of the northern sector, where sun protection is not required. The dimensions of the windows of all the facades will be the same, and the thin-film coatings of the filters will not violate the aesthetic appearance. In addition, the absence of blinds and other devices will even improve the aesthetic properties of windows, especially panoramic ones. Ergonomic properties will also improve (there is no need to constantly adjust the position of the blinds lamels, since a smart window with an optical filter self-adapts to the position of the sun), as well as environmental factors (lack of window construction elements, for example, blinds requiring replacement with subsequent disposal). Smart windows with optical filters will cost more than conventional windows, but they also perform additional functions of angular regulation of light transmission and save money on the purchase of light redistribution devices, their installation and operation.

During seasonal and daily movement of shaded and illuminated sections of the facade, smart windows of two corresponding types will function in a less optimal mode, since their parameters are calculated for the time with the most required sun protection, when the intensity of solar radiation is maximum.

4. Conclusion

A novel approach for the use of optical filters in smart windows to achieve comfortable conditions of natural lighting and insolation indoors is presented. Two gratings formed with thin-film chromogenic parallel strips on two surfaces of pane(s) of the window provide the angular-selective light transmission without using light redistribution devices. The design and principle of operation of the smart window and methods for calculating filter parameters have been briefly described. The principles of using smart windows with optical filters are demonstrated.

The proposed building typology is best suited for a complex of buildings in which people are mostly in the daytime, that is, for public buildings such as offices, classrooms, libraries, mega malls, etc. The considered approach is applicable not only for newly designing buildings, but also for reconstructing old buildings with replacing windows.

References

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