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A smart window for angular selective filtering solar radiation

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Abstract

A novel optical filter with the angular selective light transmission for using in a double glazed smart window is proposed. The angular selectivity is provided by the relative position of the grating layers on two surfaces of the window panes. The surface gratings are formed by absorptive, reflective or scattering strips alternating with directionally transmissive strips. A graphic-analytical method for calculating the angular characteristic of light transmittance, an algorithm to optimize the solar radiation filtering according to the orientation of the window to the cardinal and an algorithm to calculate the geometric parameters of the filter with pre-specified characteristic of the transmittance are presented. The angular selective filtering of the solar radiation preadapted to the known trajectory of the sun relative to the specified window is provided without using the Venetian blinds or other daylight-redirecting devices.

Keywords: Smart window; Directional light transmission; Optical filter; Gratings with alternating strips; Angular selective characteristic; Solar radiation

1. Introduction

Angular selective regulation of the directional light transmission of a window is of great practical importance for optimal daylighting and indoor insolation. The challenge is to control short and long wave solar radiation passing through the window to avoid discomfort from direct sunlight and glare as well as temperature increase. The incidence angle of sunlight varies depending on the time of a day and a season. Due to the angular dependence of the reflectance, a part of the direct normal irradiance (Blanc et al., 2014) falling on the window permanently changes.

Smart glasses currently used in the windows regulate the temperature and illumination level indoors depending on the change of the environmental parameters or due to the electric current passing through an active layer of the laminated glass. Some types of smart glasses and chromogenic materials listed in Table 1.

The above mentioned smart glasses (some types of chromism are not used in the windows so far) though providing control over the intensity and spectrum of the transmitted solar radiation, cannot achieve the selective regulation on the ranges of incidence angles. Such a regulation requires the use of additional devices, especially blinds, to dynamically adapt to the position of the sun. Light transmission properties of the windows with Venetian blinds are characterized by ray-tracing calculations based on a bi-directional transmission distribution function (Andersen et al., 2005). Smart window integrated with water-cooled solar cells, illuminated by two-axis tracking solar concentrators can (i) generate electricity, (ii) block direct sunlight, (iii) transmit diffuse sunlight and (iv) provide domestic hot water (Sabry et al., 2014).

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Nomenclature

Θ	incidence angle	h	width of directional light transmission (mm)
Θ_n	refraction angle	l	offset of beam (mm)
Θ_c	characteristic angle of filter	l_c	offset of beam for characteristic angle of filter (mm)
n	refractive index	H	elevation of the sun
s	distance between two panes or thickness of filter glass (mm)	A	azimuth of the sun
t_i	width of strip (mm)	A_0	azimuth of orientation of window to the cardinal
k	multiplicity of steps	A	azimuthal incidence angle
τ	transmittance	B	refraction angle corresponding to the azimuthal incidence angle
α	natural absorptance of glass		
ρ	reflectance of glass surfaces		

Angular selective regulation of the directional light transmission of a window is possible without the use of additional daylight-redirecting devices. Such a function can be provided by application of a novel optical filter (Zakirullin, 2012, 2013a, 2013b) in the window system. The filter is created by a method described in the Application PCT/RU2010/000234 (Zakirullin, R.S. Expedient of regulation of the directional gear transmission of light; fil. 11.05.10; publ. 19.05.11, WO 2011/059360). RU Patent 2509324 was issued on the basis of this application. The US Patent is pending. Unlike conventional thin film optical filters (Macleod, 2012), this filter consists of a sheet glass substrate with grating layers on both surfaces. The surface gratings are formed by absorptive, reflective or scattering strips alternating with directionally transmissive strips. The angular selectivity of light transmission is provided by the relative positioning of transmissive strips on the input and output surfaces – as the incidence angle changes, the proportion of radiation that passes through both gratings of the filter also changes. Thus, the light transmission of such smart window with optical filter continuously changes in real time mode depending on the incidence angle of sunlight.

In Section 2, the peculiarities of using the grating optical filter in a window system and calculation of the angular characteristics of the light transmission are described. Section 3 presents the algorithms of optimizing filtering solar radiation and calculating parameters of the filter with pre-specified characteristics of the light transmission. Section 4 provides the conclusions.

2. Smart window as an optical filter with angular selective light transmission

2.1. Design of a smart window with grating optical filter

A grating optical filter with angular selective light transmission (Zakirullin, 2013a, 2013b) based on a sheet of glass is applicable to a window with single glazing. The input and output gratings of such window are located on both

Table 1
Types of glass or chromism, mechanism of action and references.

Type of glass/chromism	Mechanism of action	Reference
Low-emissivity	Visible spectrum transmission and IR reflection	Berning (1983) and Horowitz et al. (2011)
Photochromism	Transmission varies with intensity of incident shortwave UV or visible light	Ferrari and Perciante (2008)
Ionochromism and acidichromism	Color change with addition of ions	Yokoyama et al. (1991)
Thermochromism	Control of amount of solar heat with changes in ambient temperature	Gao et al. (2012)
Thermotropism	Temperature dependent change of light scattering	Seeboth et al. (2010)
Chemochromism	Optical properties depend on reaction with hydrogen	Benson et al. (1999)
Gasochromism	Change in transmittance by interaction with diluted hydrogen gas	Opara Krasovec et al. (2000)
Halochromism	Color change due to change in pH of solution	De Meyer et al. (2012)
Solvatochromism	Color change with change in charge transfer mechanism	Reichardt (1994)
Hygrochromism	Color change with infiltration or displacement of liquid compounds inside porous structure	Deparis et al. (2014)
Mechanochromism	Color change in response to mechanical perturbation	Morris et al. (2015)
Piezochromism	Pressure dependent shift of selective reflection wavelength via the entire visible range	Seeboth et al. (2011)
Tribochromism	Photoemission turns on upon gentle grinding of the samples and sensitivity to pH in fluid solution	Lee and Eisenberg (2003)
Electrochromism	Change in transparency and color on passing electric current	Niklasson and Granqvist (2007)