Solar Energy 158 (2017) 440–447

Contents lists available at ScienceDirect

Solar Energy

journal homepage: www.elsevier.com/locate/solener

Experimental characterization of glazing with glass prisms

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A R T I C L E I N F O

Keywords:
Glass
Raster
Prism
Transmittance

A B S T R A C T

The principles of design for two types of prismatic elements have been studied. The theoretical approach has been used for design of the glass prisms to optimize their function for given application and geographic location. The two manufactured prismatic glass elements have been applied in triple glazed window samples with a low emissivity coating and experimentally tested to determine the realistic angular selective optical properties. A specific test stand for glass prism transmittance measurement has been developed and applied. The results have been compared with conventional triple glazing with clear glass panes and triple glazing with solar control pane applied, both alternatives with the identical low emissivity coating. Significant advantages of transmittance selectivity (low transmittance for high solar altitude – summer condition, high transmittance for low solar altitude – winter condition) have been proved especially for triple glazing with reverse symmetrical prism. The results open the possible application of the prismatic structures in modern façade envelopes, e.g. curtain walling facades or greenhouse walls as low-cost alternative to other types of shading devices.

1. Introduction

In order to achieve the nearly-zero energy buildings goal, solar heat gains should be managed effectively while visual discomfort and glare minimized (Konis, 2013; Leslie, 2003; Rodriguez-Ubinas et al., 2014). Solar radiation influences the energy consumption in different ways in different seasons. In summer, excessive solar heat gains result in higher energy consumption due to the increased cooling load requirement; in winter, solar radiation entering through the openings in the facade can provide passive solar heating; in all seasons of the year the solar radiation improves the daylight quality. Well-designed solar control devices can significantly reduce the energy demand of the buildings and enhance the natural daylight utilization in the indoor environment. Many principles exist. Most of the systems must be specifically designed to window orientation, room configuration and latitude (Fontenelle and Bastos, 2014; Ochoa et al., 2012; Valladares-Rendón et al., 2017). Overhangs and other static devices affect the architectural and structural design of a building and must be considered at the start of the design phase as they require a defined geometry significantly associated with the building architectural design. External dynamic shading devices such as sun-blinds and shutters can be utilized to block the solar radiation before it reaches the interior environment (Kuhn et al., 2001). Number of studies proved that manual control by occupants could result finally in thermal and visual discomfort (Gago et al., 2015). The solution to this problem is application of automated blinds (Shen and Tzempelikos, 2013). They are relatively complex and expensive because of their moveable parts. Moreover, automated external shading devices can negatively affect natural daylighting and finally increase the electric demand for lighting if not equipped with complex predictive control and sensors (Mahdavi and Dervishi, 2011; Liu et al., 2015).

An alternative approach to control the solar heat gains is the use of prismatic structures instead of simple glazing. Prismatic panes are structured transparent devices made of clear glass or acrylic material that are used to redirect or refract sun rays. The possibility of controlling the direct solar radiation with prismatic pane systems has been described by many authors in the past. In order to eliminate the direct component of solar radiation Senzo (1968) patented a light transmitting panel which consists of pair of transparent plates each provided with a plurality of adjacent prisms and capable of redirecting the solar radiation incident in a predetermined range. Koster (1984) described a glazing unit which uses horizontal, specular profile bars in the intermediate space between the two panes of a glazing system in order to reject the direct solar radiation during summer and to transmit it into the room during winter. Yonah (1985) in 1985 patented a one layer panel, comprising a plurality of adjacent triangular prisms, which transmits sun rays incident at a specific range of incidence angles while reflecting sun rays incident out of given range. Critten (1988 showed that prismatic glass could be used to enhance winter sunlight in greenhouses, further Kurata (1991) demonstrated the effects of a Fresnel prism in a greenhouse cover, concluding that the transmission of light in winter was increased while in summer it decreased. Edmonds

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http://dx.doi.org/10.1016/j.solener.2017.08.087
Received 7 February 2017; Received in revised form 22 August 2017; Accepted 31 August 2017
0038-092X/

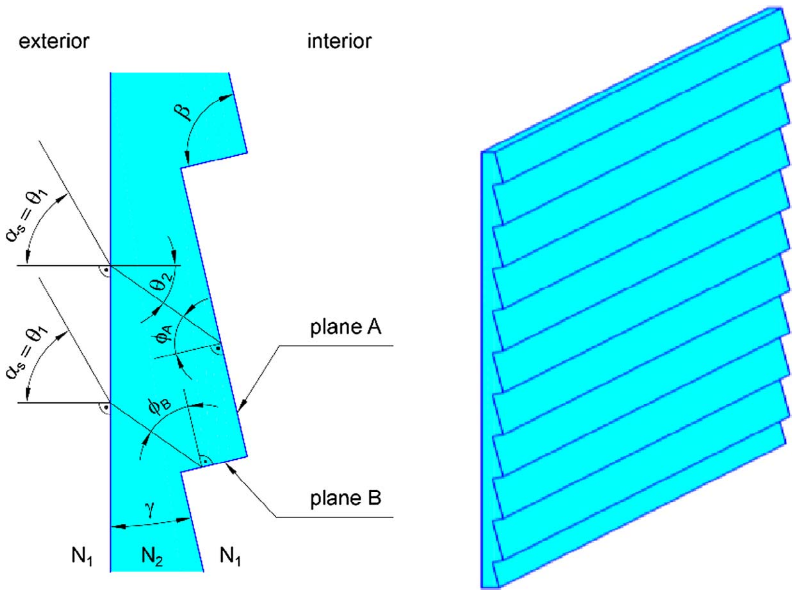

Fig. 1. Geometry of frontal asymmetrical prism.

(1993) analyzed a glazing unit in which the optically effective part consist of horizontal ribs vertically positioned one above another. Christoffers (1996) investigated a prismatic pane with two refracting surfaces and had reported a reduction of direct radiation by 90% in July and only by 10% in January. Advantages of prismatic glazing unit in comparison to double glazing unit and solar control glazing unit had been reported by Lorenz (1998, 2001). Korecko et al. (2010) studied the utilization of passive prismatic glazing for reduction of the greenhouse energy consumption. Use of asymmetric prism combined with low concentration PV in the façades has been investigated by Sabry (2016). Last decade has brought studies of micro-structured daylight systems. Microstructured prismatic structures have been combined with different kinds of functional coatings and investigated (Walze et al., 2005; Nitz and Hartwig, 2005). Microstructured light redirecting devices based on polymeric materials have been investigated (Klammt et al., 2012; Mashaly et al., 2017; McNeil et al., 2017) and resulted in similar illumination performance as established daylighting systems with less expensive production technology. Shehabi et al. (2013) showed a potential of the dynamic prismatic window coating that can continuously readjust incoming light to maximize the performance and energy savings available from daylighting controls.

Another method how to control solar heat gains is utilizing static angular selective films and coatings, which admit the daylight within a specific range of incident solar altitude angles. Mbise et al. (1997) carried out an experiment, comparing experimentally the efficiency of singular-selective metal-containing films of various types based on Cr, Al, Ti and W. The highest angular selectivity was obtained with evaporated Cr. Zakirullin and Letuta (2015) developed a novel optical filter with the angular selective light transmission for application in single or double glazed smart window. The angular selectivity of solar radiation transmission is provided by relative positioning of transmissive strips on the front and back surfaces – as the incidence angle changes, the proportion of radiation that passes through both gratings of the filter also changes.

The presented study shows the experimental characterization of two different prismatic glass structures designed and manufactured to be integrated into triple glazing. Results are compared with conventional clear triple glazing and solar control triple glazing which are still the only wide spread competitive solution in the building practise today.

2. Design of the prismatic structures for angular selective reflection

Prism function for solar heat gains control is based on total internal reflection of propagating sun rays on the interface between transparent material (glass, polymethylmethacrylate, polycarbonate, etc.) and air at given incidence angle. Proper geometry of the prismatic structure can be designed by application of Snell's law and geometric relationships for Sun path (solar altitude angle, solar azimuth angle) for any part of the year at given geographical location.

Subjects of presented investigation are two different types of prismatic glass structures originally developed for double glazing application in the greenhouses (Korecko et al., 2010). Considerable advantage of the glass prismatic structures lies in a cheap production method of continuous casting where the price for the prisms is similar to usual float glass panes. Moreover, use of the glass prismatic components for angular selective reflection of solar radiation in buildings results in application of passive devices without moving parts, excessive control equipment and auxiliary energy consumption, but with practically unlimited lifetime. Compared to this, polymeric materials suitable for prism manufacturing show long-term degradation of the transmittance due to exposition to UV radiation or dust (Blaga, 1978; Mastekbayeva and Kumar, 2000; Köhl et al., 2005).

3. Frontal asymmetrical prism

First type of investigated optical structure applies the modification of asymmetrical rectangular prism with a flat interface facing to incoming solar radiation and the horizontal prism structure facing to interior environment, so called frontal asymmetrical prism. This kind of prismatic structure was originally developed for application in double glazing as outer layer. The internal glazing panes have to be always made of tempered glass for safety reasons while low cost glass prism cannot undergo the tempering process and outer position was thus the only possibility in double glazed window. Geometry of the frontal asymmetrical prism is presented in Fig. 1. In the principle, the rays incident at angle θ_1 at flat interface air-glass are refracted at angle θ_2 in the glass according to Snell's law

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{N_2}{N_1} \tag{1}$$

where is N_1 index of refraction for air ($N_1 = 1$), N_2 index of refraction for glass ($N_2 = 1.52$).