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Reducing solar effect on the glazing material based on using non-linear patterns

Shiang-Jiun Lin*, Hao-Hu Li

Department of Mold and Die Engineering, National Kaohsiung University of Applied Sciences, No. 415 Chien-Kung Rd., Kaohsiung 807, Taiwan

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ABSTRACT

Glazing energy resulting from solar radiation can be a primary source to vary the thermal field inside of a building. As the glass material is loaded by excessive solar radiation, the drastic increase in the glazing energy yields the greater solar heat transferring indoors and thereby raises the interior temperature. Reducing the glazing energy or temperature resulting from solar radiation can be a solution to decrease the solar effect on the interior thermal field and subsequently advantageous to reduce energy demands. Therefore, this paper provides non-linearly patterned glass technology which incorporates non-linear patterns throughout the exterior surface of glass to reduce the solar effect on the glass material. Based on theoretical and experimental analyses provided in this paper, incorporating non-linear patterns over the glass surface is able to yield the increase in the incident angle as well as the decrease in the solar energy acting on the glass. Therefore, the temperature reduction of the solar-loaded glass material can be acquired as the non-linear pattern is applied. However, the thermal performance of non-linearly patterned glass is dependent on the pattern design. Reducing the dimension of the pattern spacing and/or the radius of curvature of the non-linearly pattern member helps decrease the surface temperature of glass under solar radiation.

1. Introduction

Increasing the glazing energy and the surface temperature of the glass material resulting from solar radiation can give the increase in the transmitted solar energy as well as the interior temperature. Therefore, in order to reduce the solar effect on the window glass, this paper provides non-linearly patterned glass technology which incorporates non-linear patterns over the exterior surface of glass to decrease the intensive solar energy getting into the glass material.

Past studies related to the patterned glass technology were lately introduced by Lin et al. [1,2]. However, Lin et al.'s works concentrated on analyzing interior solar heat dissipations due to linearly but the proposed non-linearly patterned glass. Based on employing CFD (Computational Fluid Dynamics) modeling simulations, Lin et al. [1] found that as the linear patterns are incorporated throughout the external surface of roof glass under solar radiation at noon, the increase in the incident angle resulting from the surface patterns yields the reduction of radiation heat flux on the inner face of the window glass as well as the decrease in temperatures distributed in the interiors. Experimental measurements for analyzing thermal responses of solar-loaded linearly patterned glass were conducted by Lin et al. [2]. Lin et al. utilized IR and thermocouple instruments to record temperatures on the interior surface of linearly trapezoidal patterned glass. Based on Lin et al.'s measured results, as the linearly patterned glass is applied on the window opening, the temperature of patterned glass due to solar energy is indeed lower than that of the traditional flat glass. Moreover, the linearly patterned glass design is able to influence the thermal response of the glass material under solar loaded. Reducing the non-sloped areas as many as possible appearing on the pattern body enables to effectively decrease the solar heat existing in the interiors [2].

In addition to the linearly patterned glass technology, many solutions, associated with the reduction of the solar effect on the interior thermal field, had also been provided in literatures. Hassan et al. [3] applied free convection to dissipate interior solar heat. According to Hassan et al.'s study, the single-sided ventilation is independent of the location of the two adjacent openings; however, as the two window openings are placed apart, especially one opening is located far left and the other one is located far right, the interior ventilation due to the window openings will be greatly improved. The size of windows can be related to the interior temperatures in summer season. Persson et al. [4] gave

* Corresponding author.
E-mail address: kathysjlin@kuas.edu.tw (S.-J. Lin).

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that smaller-sized windows facing to south helps reduce energy demands for cooling. Glass double façade is often utilized in commercial buildings to reduce the solar energy transmittance to the interior. In order to enhance the reduction of transmitted radiant energy, Manz [5,6] optimized the glass double façade by analyzing the effect of glazing layer sequence and ventilation properties on the thermal behavior of glass, using a spectral optical and CFD model. Etzion and Erell [7] developed a glazing mechanism, which consists of a transparent glazing and absorptive glass with the low shading coefficient, to decrease the solar radiant energy transmitting windows. Etzion and Erell's mechanical system gives a rotatable frame to flexibly place the absorptive glazing facing to either exterior or interior of the building as the solar energy changes. PV ventilated technology provides the opportunity to decrease the energy consumption in warm climates. Chow et al. [8] first introduced an energy model of a PV ventilated window system and reported that the transmittance of a solar cell obtained in the range of 0.45–0.55 can give the best energy savings based on analyzing a small office room in Hong Kong. Glass with coatings can vary the solar heat load transferred into indoors. Blue and green glasses help filter some infrared radiation and thereby can be used as an outer pane of a double-glazed unit in warm climates [9]. Multilayer thin film coated on the glass enables the reduction of solar heat existing in the interiors [10]. Genaro et al. [11] applied copper-based thin coating on the glass surface to reduce the solar heat gain. Based on analytical results, an 18% decrease in energy consumption can be attained by using Genaro et al.'s technique. Feuermann et al. [12] attenuated the solar heat gain, using a double glazed tinted window. Glass rotation is able to alter the solar energy entering the building. Saleh et al. [13] controlled the solar heat gain of glazing by horizontally rotating the window pane to achieve the energy conservation for the air-conditioning system. According to Saleh et al.'s study, two optimum rotation angles could be acquired. One optimum rotation angle of a window pane can result in the decrease in the air-conditioning size and the other rotation angle will help reduce the energy consumption. Due to the importance of analyzing the interior thermal field associated with the energy consumption of a building, Sujoy et al. [14] measured the optical properties of the window glazing to determine the percentage absorption of incident solar radiation. Nielsen et al. [15] provided the diagrams, which give the net energy gain, to evaluate the energy performance of different windows, based on analyzing the glazing orientation, tilt, U-value and g-value.

As mentioned previously, while many solutions provided in the literatures can give the decrease in the solar effect on the interior temperature, most of them could be complex, costing and/or elaborative. Besides, even though the patterned glass technology was lately developed, related studies only emphasize on linearly patterned glass. Therefore, in order to understand the effect of non-linear pattern on the thermal response of the solar-loaded glass, this paper analyzes the non-linearly patterned glass, using theoretical and experimental techniques.

2. Theoretical analysis for non-linearly patterned glass

Glazing energy of the solar-loaded glass material can be theoretically determined as follows [16].

$$q = E_{\mathrm{DN}} \cos\theta \,\mathrm{SHGC}(\theta) \tag{1}$$

where E_{DN} is the direct normal solar irradiation, θ is incident angle and SHGC is the glazing solar heat gain coefficient. The solar heat gain coefficient (SHGC) obtained in Eq. (1) can be expressed by [16].

$$\mathrm{SHGC}(\theta) = T^f(\theta) + NA^f(\theta); \quad N = \frac{U}{h}. \tag{2}$$

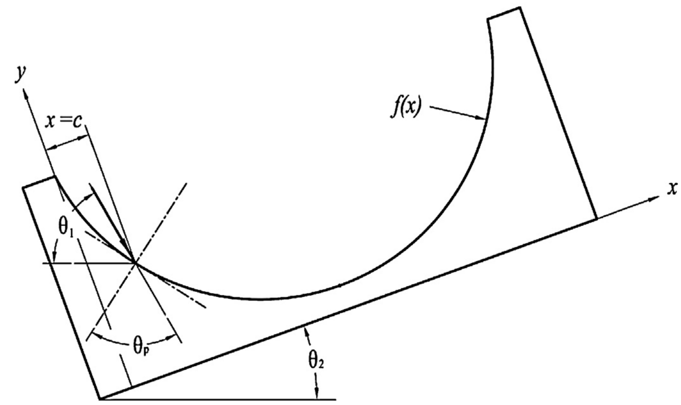

Fig. 1. The schematic diagram of incident angle on the left side of non-linearly patterned glass.

where $T^f(\theta)$ is the front transmittance of the glass, $A^f(\theta)$ is the absorptance of glazing, N is the inward-flowing fraction, U is the U-factor of glazing and h is the heat transfer coefficient between exterior ambience and glass. As indicated in Eq. (1), when the incident angle and/or solar heat gain coefficient of glass varies, the glazing energy will change. Moreover, Eq. (1) gives that the SHGC is dependent on the incident angle; however, it can be slightly affected by the incident angle based on the same glass material. For instance, when the incident angle of the solar-loaded traditionally/conventionally clear-single glazing are 0°, 40° and 50°, the SHGC of the glass material equal 0.81, 0.80 and 0.78, respectively [16]. Since the theoretical expression of glazing energy indicates that the glazing energy of the solar-loaded glass material is the cosine function of the incident angle, varying the incident angle could help reduce the solar energy getting into the glass material. This paper incorporates non-linear patterns throughout the exterior surface of glass to alter the glazing energy induced in the glass under solar radiation and achieves the temperature reduction on the glazing surface.

Fig. 1 plots the incident angle θ_{p} at $x = c$ on the left side of the non-linearly patterned glass under solar radiation and whose theoretical expression is written in Table 1, where θ_1 is the direction of incoming solar ray clockwisely measured from horizon, θ_2 is the tilted angle of the patterned glass, $f(x)$ is the geometric equation of the non-linear pattern and c is the distance measured from the reference origin $x = 0$. As written in Table 1, if the surface non-linear pattern satisfies $\tan^{-1}[-f'(x)|_{x=c}] > \theta_2$, the incident angle on the left side of the patterned glass at $x = c$ equals $\pi/2$ as solar radiation aligned with $\tan^{-1}[-f'(x)|_{x=c}] - \theta_2$ or $\pi - \theta_2 + \tan^{-1}[-f'(x)|_{x=c}]$. Due to the glazing energy related to cosine function of the incident angle, the incident angle equal to $\pi/2$ yields zero glazing energy induced in the patterned glass. However, when the incoming solar ray is coincident with $\pi/2 + \tan^{-1}[-f'(x)|_{x=c}] - \theta_2$, the incident angle on the left side of the non-linearly patterned glass at $x = c$ becomes zero which will allow the maximum solar energy transmitting into the glass material. On the other hand, if the surface non-linear pattern design gives $\tan^{-1}[-f'(x)|_{x=c}] < \theta_2$, the non-linearly patterned glass loaded by solar energy, which is aligned with $\pi/2 - \theta_2 + \tan^{-1}[-f'(x)|_{x=c}]$, will result in zero incident angle on the left-sided area at $x = c$; however, the incident angle at the same location will become $\pi/2$ as the direction of solar radiation is coincident with $\pi - \theta_2 + \tan^{-1}[-f'(x)|_{x=c}]$, as shown in Table 1. Fig. 2 illustrates the incident angle on the right side of the non-linearly patterned glass under solar radiation. Theoretical expressions of incident angles of Fig. 2 are written in Table 2. As indicated in Table 2, when the design of surface pattern yields $\theta_2 + \tan^{-1}[f'(x)|_{x=c}] < \pi/2$, the glazing energy induced in the non-linearly patterned glass on the