

Tests and Analysis of Solar-optical Properties of Building Glass

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Abstract : Shading coefficient of building glasses is very important to evaluate their energy consumption. It can be calculated out by following ISO 9050 and GB/T 2680-94. This paper describes the experiments and analysis of the solar-optical properties of clear glass, LOW-E glass and PVB laminated glass. These different kinds of building glasses with different thickness are tested by the spectrophotometer. As a result, the values of their reflectance and transmittance in the spectrum range from 300nm to 2500nm are obtained. The solar factors, including total solar energy transmittance and solar direct transmittance, are figured out. Meanwhile, the visible light (380nm~780nm) transmittance and reflectance are considered as their optical property. These values are compared with each other in order to find out the most suitable one to use in hot-summer-warm-winter areas of China. Based on careful analysis, it can be concluded that PVB laminated glass possesses obvious abilities of insulation which would lead to better energy efficiency in practice.

Key words : building glass; solar-optical properties; solar energy transmittance; shading coefficient

1. INTRODUCTION

Building glass, like other kinds of transparent building constructions, are more and more widely utilized in modern society. It is reported that^[1] in the year of 2001, around 7,500,000 square meters of glass curtain wall are produced (used) in china, approximately 2/3 of the total production in the world. Until the end of 2001, 42,000,000 square meters of glass curtain wall are set up in our country. The style of these glass has developed from simpleness in the past days to variety nowadays, LOW-E glasses, PVB laminated glasses, double or triple-glazing insulated units and other kinds of glasses came out one after another. As a result, this kind of transparent construction makes an increasingly notable effect on the energy consumption of the whole building. It is considered to be a most emergent task to control the quality of energy usage, based on the experiments on optical and thermal properties of these glasses.

2. EVALUATION STANDARDS OF SOLAR-OPTICAL PROPERTIES

The main request to solar property, as the same meaning as thermal property, of building glass are shown as following: a. Ability to control solar radiation, that is, based on the demand of people indoor, to decrease or increase the amount of solar radiant heat passed into the room. b. Heat preservation capability, that is, the ability to keep indoor thermal comfort under the difference in temperature between the inner and the outer space. In winter or some cold areas, it is demanded that the solar radiation in the spectrum of 0.3~2.5 μm is able to 100% transmit through, while

all of the infrared radiation with wavelength over 2.5 μm can be reflected back to inside. As a result, the heating load can be reduced. In summer or hot areas, visible light in the spectrum of 0.38~0.78 μm should have high or moderate transmittance, around 50%~60%, while the reflectance of the other lights in the spectrum should be also high, so that the solar radiation coming indoor is largely decreased and the air-conditioning load becomes much less without holding the sky light back.

When satisfying the demands of thermal performance by controlling the solar radiation of glazing or glazing units, day-lighting should also be taken into account: gain as much sky lights as possible to increase indoor illumination, at the same time of preventing glare.

The following indices are usually used to evaluate the solar-optical properties of glass in buildings:

2.1 Solar radiation control

Total solar energy transmittance g

Constituted by solar direct transmittance τ_d and Secondary heat transfer factor q_s , it indicates the ratio of the total solar radiation on glass to the ones which gets into the room. According to the standard^[2], solar direct transmittance τ_d can be calculated by using the following formula:

$$\tau_d = \frac{\int_{300}^{2500} S_\lambda \cdot \tau(\lambda) \cdot d\lambda}{\int_{300}^{2500} S_\lambda \cdot d\lambda} \approx \frac{\sum_{350}^{1800} S_\lambda \cdot \tau(\lambda) \cdot \Delta\lambda}{\sum_{350}^{1800} S_\lambda \cdot \Delta\lambda} \quad (1)$$

where, $\tau(\lambda)$ is the solar spectral transmittance of the glazing, S_λ is the spectral distribution of the solar

radiation, $\Delta\lambda$ is the spectral bandwidth. The value of $S_\lambda \cdot \Delta\lambda$ can be found in standards [2,3].

Shading coefficient S_g

It is defined as the ratio of the total solar energy transmittance g of glass or glazing units with coatings and other hi-tech improvements to g of 3mm normal flat glazing. It shows the change of solar energy after transmitting these constructions. The total solar energy transmittance of 3mm flat glass is prescribed as 88.9% [2].

2.2 Optical performances

2.2.1 Visible light transmittance τ_v

It indicates the transmittance capability of glass, coating and other kinds of transparent constructions in the spectrum 380nm ~ 780nm (visible light). According to [2,3], τ_v can be calculated using the following formula:

$$\tau_v = \frac{\int_{380}^{780} D_\lambda \cdot \tau(\lambda) \cdot V(\lambda) \cdot d_\lambda}{\int_{380}^{780} D_\lambda \cdot V(\lambda) \cdot d_\lambda} \approx \frac{\sum_{380}^{780} D_\lambda \cdot \tau(\lambda) \cdot V(\lambda) \cdot \Delta\lambda}{\sum_{380}^{780} D_\lambda \cdot V(\lambda) \cdot \Delta\lambda} \quad (2)$$

where, $\tau(\lambda)$ is the spectral visible light transmittance, D_λ is the relative spectral power distribution of illuminant D_{65} , $V(\lambda)$ is the photopic luminous efficiency function defining the standard observer for photometry, $\Delta\lambda$ is the spectral bandwidth.

2.2.2 Visible light reflectance $\rho(\lambda)$

It shows the reflectance capability of transparent constructions in the spectrum 380nm ~ 780nm (visible light). It can be calculated using the same formula to (2), but the value of $\tau(\lambda)$ needs to change to $\rho(\lambda)$.

2.3 Thermal performance

2.3.1 Hemispherical emissivity ε_i

It shows the ability of transparent constructions to send out radiative heat. The value depends on the surface physical performance. The less ε_i is, the

fewer heat the surface sends out. The ε_i value of ordinary flat glasses is 0.837, while to some LOW-E coatings, the value can be 0.05 to 0.15.

2.3.2 Thermal conductance K

It is composed of the heat transfer coefficients towards the inside and outside respectively and the heat transfer coefficient in the construction itself. In the case that the position of glazing is vertical, $\varepsilon_i = 0.83$ and the wind velocity of outside surface is approximately 4m/s, the value of h_o and h_i is 23W/(m² K) and 8 W/(m² K) [3] respectively.

To single glazing units, there is no difference between the value of thermal conductance of units and the one of constructions. But to the transparent constructions with 2 or more glazings, such as sealed insulating glass units and so on, the thermal conductance should be divided into 2 parts—thermal conductance of glazing units h_g , and the one of air

interlayers G . G can be calculated using the following formula [4]:

$$G = \left[\frac{4\sigma T^3}{1/\varepsilon_1 + 1/\varepsilon_2 - 1} + N_u \cdot \frac{\lambda}{s} \right]^{-1} \quad (3)$$

where, $\varepsilon_1, \varepsilon_2$ are the hemispherical emissivity of the glazings next to air interlayer. σ is Stefan-Boltzmann value, equals to $5.67 \times 10^{-8} \text{W}/(\text{M}^2 \text{K}^4)$. T is the average temperature in the interlayer. S is the thickness of air interlayer, λ is the thermal conductance of air.

2.3.3 Thermal resistance R

It shows the ability of constructions to prevent the heat transferring because of difference in temperature. It is reciprocal of thermal resistance.

3. METHOD

Several kinds of building glass, namely clear glass, LOWE-coated glass and PVB laminated glass, are tested, according to the method in standards [2,3], by spectrophotometer and emissometer (Model AE).

3.1 Equipments

All the optical data in this paper are tested by spectrophotometer. Spectrophotometer is a special equipment used to measure optical transparent materials such as glass, lens and prism. It includes a high-sensitivity integrating sphere and a sample compartment, with the capacity of measuring spectral transmittance, reflectance and absorbance in different range of spectrum. It also enables color analysis and film thickness calculation. The integrating sphere ensures highly accurate measurement from 175~2600nm, while the sample compartment enables the machine to test large samples (max. 430 × 430mm) in a nondestructive way. Meanwhile, computers can control the process of data gathering and data output, that is, export data in a certain bandwidth. The accessory software can make mathematical analysis and numerical calculation.

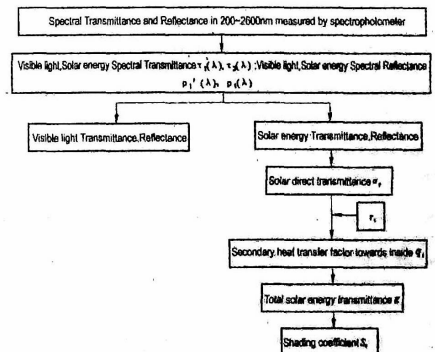


Fig. 1 Test method

Emissometer Model AE is a special-purposed instrument for making emittance measurements. Its output of voltage is linear with emittance of the sample. So the hemisphere emissivity can be obtained.

3.2 Test method

Under the direction of international standard [3] and the Chinese national code [2], all the necessary values are measured. In accordance with these data, the principal parameters ε_v and g are calculated. The procedure are wholly showed in the figure 1.

4. TEST SAMPLES

Different kinds of glass in building, with different thickness or coatings, are taken in. The test samples include: 6mm glass with LOWE coating, 11mm and 7mm PVB laminated glass, while 12mm and 8mm clear glass are taken as a comparison to these samples. PVB laminated glass in the test, especially mentioned, is a kind of anti-bandit glass, which is produced by bonding two layers of clear glass together with a plastic interlayer of polyvinyl butyral sheet. The PVB resin is more versatile as it allows for the manufacture of curved laminates or the incorporation of patterned glasses. The detailed structure of PVB laminated glass is showed in figure 2.

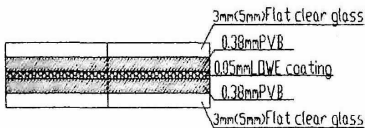


Fig. 2 Structure of PVB Laminated Glass

5. RESULTS AND ANALYSIS

The figures (Fig. 3,4) listed below show the curves of spectral transmittance and reflectance of the samples in the range of 200–2600nm.

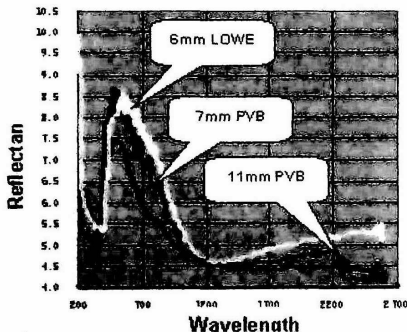


Fig.3 Curves of Spectral Reflectance

In figure 3, it is obviously exhibited that the values of reflectance of the three samples are close to each other. However, in the area of visible-light spectrum (380–780nm), more lights would be reflected for 11mm PVB laminated glass. In the whole tested spectrum, 6mm glass with LOWE coating reflects most lights, 7mm PVB laminated glass reflects less to it, while 11 mm PVB laminated glass does the least.

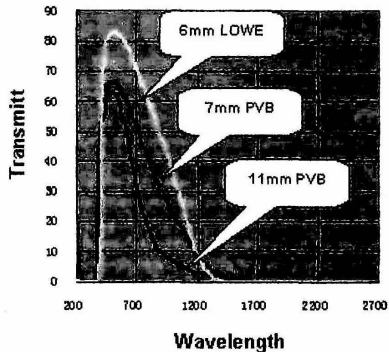


Fig.4 Curves of Spectral Transmittance

Figure 4 displays that in the near infrared region above 1500 nm, the values of transmittance of all the samples are almost equal to zero. As a result, they could keep redundant solar radiations out of windows. Therefore, in hot summer days, indoor air temperature can be notably reduced, while saving energy of air conditioning. The performances of insulation of these samples will play an important role in hot-summer-warm-winter zone, where energy for indoor air-conditioning takes greatest percentage of the building consumption. Besides their wonderful property against solar heat transmitting, the values of visible light transmittance are relatively low, meaning that the requirements of indoor illumination may not be satisfied, especially for the rooms using 11mm PVB laminated glass. In this case, manual lighting, instead of depending on day lighting solely, should be taken into account.

Based on the measurement results, the values of visible light transmittance and reflectance, total solar energy transmittance and shading coefficient can be calculated by following notes in standards. As is revealed above, this procedure requires so much integral that it would be rather complicated by finishing it manually. So, a series of EXCEL sheets are developed to cover all the calculations. The results are exhibited in Table 1.

Table 1 Calculation Results

Items	12mm Clear Glass	8mm Clear Glass	6mm LOWE Glass	7mm PVB laminated Glass	11mm PVB laminated Glass
Hemispherical Emissivity	0.89	0.89	0.43	0.84	0.84
Visible Light Transmittance τ_V (%)	85.97	88.65	81.18	64.12	57.89
Visible Light Reflectance ρ_V (%)	8.35	8.87	8.26	8.08	7.12
Solar Direct Transmittance τ_e (%)	72.93	80.22	53.80	41.87	30.34
Solar Direct Reflectance ρ_e (%)	7.38	8.06	6.85	6.56	5.95
Solar Direct Absorptance α_e (%)	19.69	11.72	39.35	51.57	63.71
Total Solar energy Transmittance g (%)	78.01	83.24	61.92	52.52	43.50
Shading Coefficient Sc	0.88	0.94	0.70	0.59	0.49

From the table above, the differences in total solar energy transmittance and shading coefficient between clear glass, LOWE-coated glass and PVB laminated glass can be obviously detected. Both LOWE coated glass and PVB laminated glass have the ability of insulation. Their g and Sc values are much less than the ones of clear glass. However, what civil engineers and designers should paid special attention to is that their absorptance values are far larger than the ones of clear glass. As a result, when these kinds of glasses are utilized in large-scale glass curtain walls, thermal stress among blocks of glazing units would engendered. When this kind of stress comes to a certain value, the glazing units would be broken.

6. CONCLUSIONS

The PVB glasses, as well as LOWE-coated glass measured, have apparently small values of shading coefficient, besides their safety characteristics. They can keep almost 50% of the total solar radiation out of the room, directly decreasing the air-conditioning energy consumption in summer. If they are wildly used in hot-summer-warm-winter zone where heating in winter is nearly not necessary, the thermal

performances of envelopes can be significantly improved, thus building energy would be more efficient.

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