Glass window coatings for sunlight heat reflection and co-utilization

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Buildings that simultaneously provide natural illumination and thermal comfort for all seasons have met with increasing demand as conventional resource limitations are realized. In this context, organic and metal–dielectric coatings are tested, and a simple, coated double-glazed window with solar blinds is conceived that includes passive infrared (IR) reflection, active illumination control, and integration to the building envelope. As a result, a proper spectrally selective coating is applied to produce a low-emissivity solar window with climate-adaptive co-utilization of the reflected IR. © 2011 Optical Society of America

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1. Introduction

Double glazings have been increasingly used in contemporary buildings because they provide thermal insulation (U value) with small losses of natural illumination. However, in summer, air conditioning may be needed to maintain interior comfort, with consequent financial and environmental costs.

A spectrally selective, heat mirror coating can be added to keep out the nonilluminating infrared (IR) [1], but then solar energy is wasted that could be useful for heating in wintertime. This is achievable with a Trombe wall [2], but at the expense of natural illumination.

On the other hand, shade building accessories have been used by humanity for centuries. Fixed or trellised overhangs can account for seasonal changes, but not for daily fluctuations. These needs are met by adjustable overhangs or awnings, but with additional hardware that implies external construction and maintenance costs (which are also presently prohibitive for electro- or photochromic glasses in large areas). Internal curtains or venetian blinds are much cheaper and readily available, but they are inefficient in keeping the heat out of a sunny window in summer.

In this context, conception of a simple double-glazed solar window that combines a passive heat mirror coating on glass with active control of the natural illumination is presented, as well as co-utilization of sunlight by means of the reflected IR for either cooling or guided heating of buildings.

2. Experimental Tests and Design Considerations

A double-glazed window is illustrated in Fig. 1, where the heat mirror coating is indicated in the inner side of one glazing.

Between the two panes of glass, as in the profile illustrated in Fig. 2, we show solar blinds—absorptive on one side and reflective on the other.

For heat reflection, two coatings of a different nature were considered: one based on polymer layers (P70) and another on a metal–dielectric multilayer (LX70). Both were tested by a series of measurements with a Cary 5000 spectrophotometer. As claimed by the manufacturers and as shown in Fig. 3, both present around 70% visible transmittance with very similar decay toward zero in the near IR.

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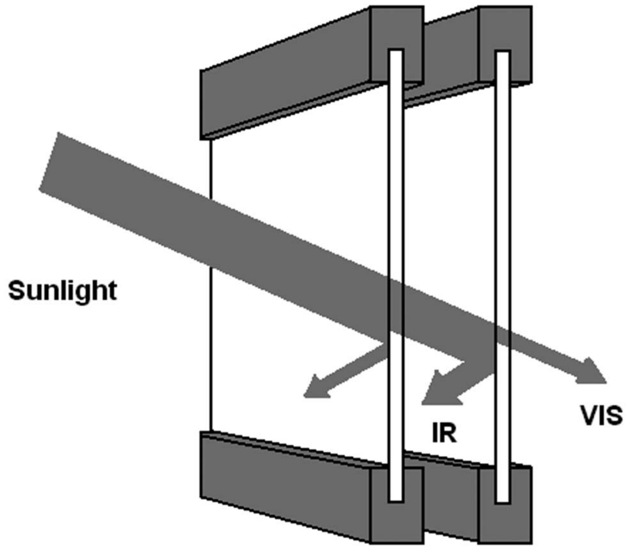

Fig. 1. Double glazing: the main IR reflection is shown.

However, their reflectance behavior is quite dissimilar, as can be seen in Fig. 4. The P70 on glass is absorptive and thus highly emissive in the IR (see [3], for instance).

In contrast, the LX70 metal–dielectric multilayer is truly IR reflecting, and thus was chosen as a low-ε coating in the IR. In a basic configuration, its performance can be achieved by starting from a three-layer design, which consists of a single metal layer surrounded by two high-index dielectric matching layers [4]:

$$\text{air/dielectric/metal/dielectric/glass},$$

where the metal layer has a high IR reflectance and a metal oxide can be used for the high-index dielectric.

Furthermore, the reflected IR, in association with the solar blinds within the double glazing, can produce a natural "heat pump" for either heating along the envelope of the building, especially its shady side,

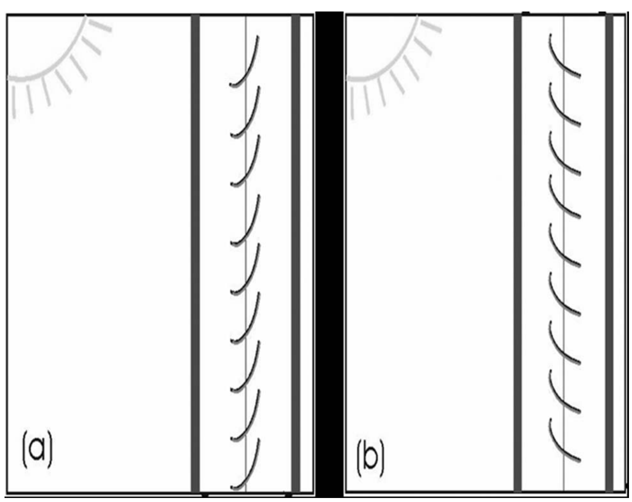

Fig. 2. Inner solar blinds: (a) absorption mode and (b) reflection mode.

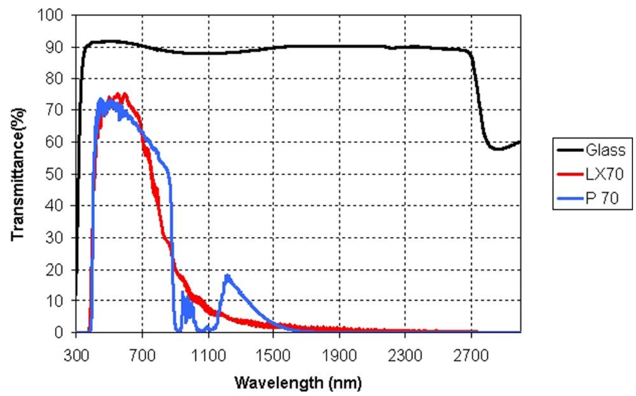

Fig. 3. (Color online) Spectral transmittance curves of polymer (P70) and metal–dielectric (LX70) films on glass (also shown for reference).

or for bringing cool air from this area when warmer gases are exhausted through a clerestory, as shown in Fig. 5 [5,6].

With regard to viability of the concept, at first, from a simplistic point of view consider that the sun approximately corresponds to a blackbody at 5760 K, with 51% emission energy in the IR and 37% in the visible [3]. In the IR below 2.5 μm, around 90% is transmitted by the first glazing and 75% reflected by the second, coated glazing (see Fig. 4), which means that the inner air space with solar blinds can absorb, in a first approximation (no multiple reflections considered), between 90% and 65% of the incoming radiation. Similarly, in the visible spectrum, around 90% is transmitted by the first glazing and 15% is reflected by the coated glazing (see Fig. 4), corresponding to between 90% (if directly absorbed by the solar blinds) and 13% (if only backreflected) of the incoming radiation available for heating the air space. Therefore, from the solar constant of 1353 $\mathrm{W\,m^{-1}}$, a rounded average of 60% (about 40% in the IR plus 20% in the visible) of the emitted energy could be made available for co-utilization. This corresponds to 60% of 1.94 $\mathrm{cal/cm^2}$ per minute, or about 550 $\mathrm{cal/cm^2}$ per day of eight sunny hours at normal incidence and an air mass of zero.

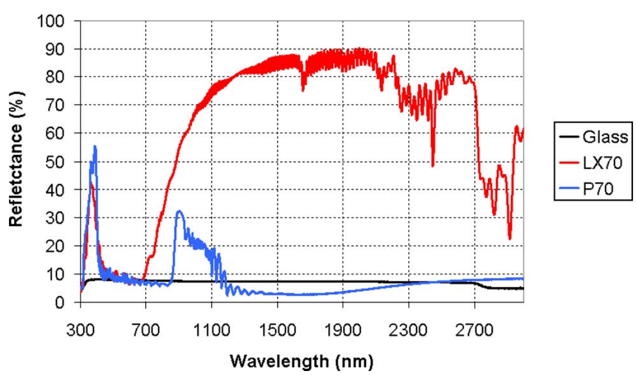

Fig. 4. (Color online) Spectral reflectance curves of polymer (P70) and metal–dielectric (LX70) films on glass (also shown for reference).

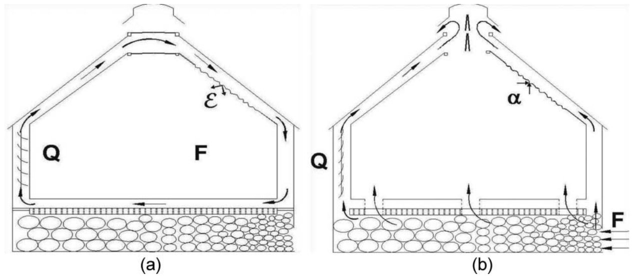

Fig. 5. Simplified operation scheme of the envelope system in Casa e for (a) winter and (b) summer. **Q** and **F** represent the heat (sunny side) and cold sources, respectively. On the shady side, a textured metallic surface is employed to intensify the heat exchange (from [5]).

More realistically with atmospheric losses, and taking into account daily means of measured total solar radiation (direct and diffuse) incident on a horizontal surface in winter, with correction for a vertical surface [7], that final amount per day becomes 180 cal/cm^2 in Madison, Minnesota (45° N latitude) and 300 cal/cm^2 in Porto Alegre, Brazil (30° S latitude).

In Madison, 9 m^2 of double-glazed solar window could then produce 12 Mcal daily. For a well-insulated space, where the glazing area is up to 30% of the floor area and typical heat loss is 6.4 Btu/day/sq ft/ °F ($\pm$15%) [8], that solar window could increase the temperature of a room with 30 m^2 of floor area by around 13 °C. For that room during winter in Porto Alegre, the same solar window under more solar radiation could increase the temperature by 22 °C. This rough estimate indicates that auxiliary heating would be required in a cold winter at high latitudes, whereas the double-glazed solar window could provide enough space heat during most sunny days in a milder winter, at 30° or lower latitudes.

3. Conclusions

Analysis and application were presented of an IR mirror coating to a solar window device that allows simultaneous passive heat processing and active control of natural illumination. The integrated system acts as a Trombe wall for winter heating and summer cooling, with further capabilities of visible transparency, easy installation/support of the solar blinds, and heat storage, when needed, in the building masonry itself.

Co-utilization of sunlight as a natural heat pump by use of the reflected IR, for heating or cooling, is made possible by a combination of the coated double glazing with inner solar blinds. For more sophisticated applications, these could be motorized and automated, or the concept extended to electro- or photochromic windows, if affordable. Monitoring of the system is presently underway at "Casa e" [9], an experimental house devoted to renewable energy sources, for yearly tests of performance.

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References

1. C. G. Granqvist, *Spectrally Selective Surfaces for Heating and Cooling Applications* (SPIE, 1989).
2. D. Wright and D. A. Andrejko, *Passive Solar Architecture: Logic and Beauty* (Van Nostrand Reinhold, 1982), Chaps. 3–5.
3. S. Wieder, *An Introduction to Solar Energy for Scientists and Engineers* (Wiley, 1982), Chap. 1.
4. H. A. Macleod, *Thin Film Optical Filters*, 2nd ed. (Macmillan, 1986), Chap. 12.
5. F. Horowitz, G. B. de Azambuja, A. F. Michels, and R. S. Ribeiro, "Strategies for thermal comfort with envelope house solar harnessing in the humid (sub)tropics," in *Proceedings of the II Brazilian Congress on Solar Energy and III ISES Latin American Regional Conference* (Universidade Federal de Santa Catarina, 2008), on CD-ROM.
6. F. Horowitz, M. B. Pereira, and G. B. de Azambuja, "Sunlight heat reflection and co-utilization from glass windows coatings," in *Optical Interference Coatings*, OSA Technical Digest (Optical Society of America, 2010), paper MC10.
7. J. A. Duffie and W. A. Beckman, *Solar Engineering of Thermal Processes* (Wiley, 1980), Chap. 2.
8. E. Mazria, *The Passive Solar Energy Book* (Rodale, 1979), Chap. 5.
9. J. A. Strauss, R. S. Ribeiro, G. B. de Azambuja, and F. Horowitz, "Casa e," http://www.if.ufrgs.br/casae/.