Title

TRANSPARENT HEAT MIRRORS FOR WINDOWS: THERMAL PERFORMANCE

Permalink

Authors

Rubin, M.
Creswick, R.
Selkowitz, S.

Publication Date

1980-08-01

Lawrence Berkeley Laboratory
UNIVERSITY OF CALIFORNIA

ENERGY & ENVIRONMENT DIVISION

To be presented at the Fifth National Passive Solar Conference, University of Massachusetts, Amherst, MA, October 19-26, 1980

TRANSPARENT HEAT MIRRORS FOR WINDOWS: THERMAL PERFORMANCE

Michael Rubin, Richard Creswick, and Stephen Selkowitz

August 1980

Prepared for the U.S. Department of Energy under Contract W-7405-ENG-48

DISCLAIMER

TRANSPARENT HEAT MIRRORS FOR WINDOWS: THERMAL PERFORMANCE

Michael Rubin   Richard Creswick   Stephen Selkowitz
Lawrence Berkeley Laboratory
University of California
Berkeley, CA 94720

ABSTRACT

The thermal performance of a window system can be improved by the application of a transparent heat mirror coating. This paper discusses the ways in which optimum thermal performance can be achieved for a variety of conventional and advanced window designs. Residential applications are emphasized.

1. INTRODUCTION

A transparent heat mirror is a thin-film coating whose purpose is to improve the energy efficiency of an architectural window or a solar collector. The coating is applied to the glazing material, which may be either glass or plastic. Thermal radiation heat transfer is suppressed due to the high infrared reflectance of the heat mirror thereby improving the insulating properties of the window. Solar transmittance is decreased at the same time, which is detrimental to the net energy performance of the window in the winter heating season.

The intrinsic materials properties which are usually taken as figures of merit are the normal transmittance to solar radiation, T, and the infrared emittance, ϵ. Once T and ϵ have been determined, the thermal performance will still depend on the placement of the coating on the window and other physical characteristics of the window system.

This paper addresses questions relating to the proper use of heat-mirror coatings for architectural windows. Both factory built and retrofit designs are considered. Overall heat transfer coefficients or U-values are calculated for a standard set of conditions. These numbers allow some fundemental comparisons to be made and will assist in determining the optimum application of transparent heat mirrors in window systems.

Seasonal heating energy requirements which include the effects of solar gain, in addition to thermal losses or gains are examined. Some long term energy calculation of this type is necessary to make meaningful comparisons between window designs based on net energy performance.

2. HEAT TRANSFER RATES

The thermal losses through the window are determined by solving the steady-state energy balance equation at each layer in the window. The algorithm is general enough to be applied to windows composed of an arbitrary number of parallel layers, including plastics which may be partially transmitting to IR radiation and gases other than air. Any solid layer may have a thin film coating. Frame and sash areas are not included in these calculations. Results have been confirmed with laboratory testing using a calibrated hot box.

As the emissivity of the heat-mirror approaches zero, the radiative component of heat transfer to adjacent surfaces at different temperatures also goes to zero. The convective/conductive component will be unaffected except for a small perturbation caused by a change in the temperature distribution across the window due to the presence of the heat-mirror.

The reduction in overall thermal conductance (U-value) due to the presence of a heat-mirror will be greatest when the coating is placed so that it acts to reduce radiation transfer in a section of the window where convective heat transfer is already relatively small. In a multiple glazed window with 1/2 inch air spaces the convective heat transfer coefficient is lowest in the air spaces and highest at the outside surface of the window where windy conditions may raise the conductance by an order of magnitude.

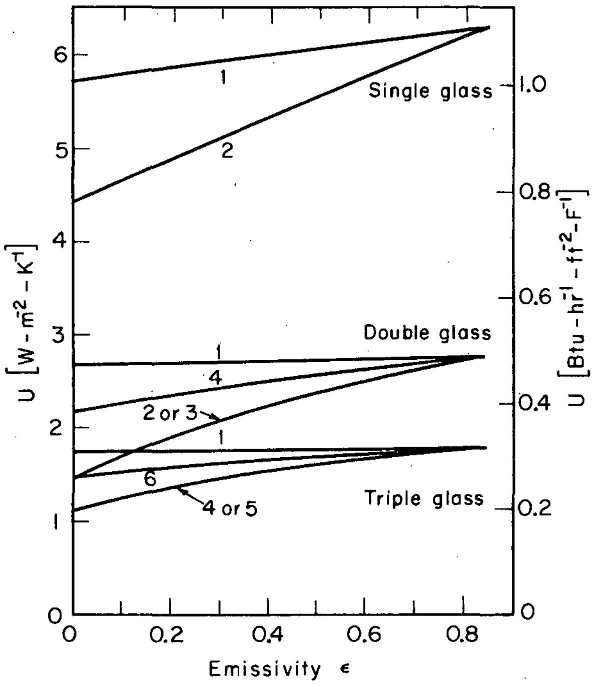

Fig. 1. U-value under ASHRAE standard winter conditions (1) vs. ϵ for single, double and triple-glazed windows incorporating heat-mirrors. The surfaces on which the heat-mirror appears are given consecutive numbers starting from the outside surface labeled 1.

Figure 1 confirms that the U-value is lowest in each type of window when the heat-mirror appears on an enclosed surface rather than an inside or outside surface. U never goes to zero even at $\epsilon=0$ because convective heat transfer is still present. When the heat-mirror is on an outside surface (no. 1) U is almost independent of ϵ. Also, an enclosed gap is the location which is best protected from wind, sun, rain, air-borne particles, cleaning chemicals, etc. Based on poor performance and stringent requirements on durability, the outside surface heat-mirror should be removed from consideration.

To a lesser degree, the same arguments hold for an inside surface coating. In some retrofit situations, however, the inside surface will be the only available location for the heat-mirror.

At night, when there is no solar intensity on the window, the heat transfer rate is identical for a heat-mirror placed on either side of the same air gap in a multiple glazed window. This is only true provided the two panes forming the gap are opaque to infrared radiation, which is essentially the case for glass. The symmetry will be broken if there is sunlight or if one or both of the panes is semi-transparent to radiation in the far infrared spectrum.

Windows with multiple air gaps such as triple glazing should have the heat-mirror in the gap closest to the room. In the winter the temperature rises as one moves toward the inside. Then the magnitude of the radiative transfer, which is proportional to t^4, is largest in the inner gap and the heat-mirror will be most beneficial there. This will be at most a 3% effect, but consideration of solar gains will show that there are additional benefits with this configuration.

Ideally, a heat-mirror is perfectly transmitting in the solar spectrum. For a real heat-mirror some sunlight will be absorbed and reflected. In order to maximize solar heat gain the coating should be placed on the inner pane of the window. This will allow more of the solar radiation absorbed in the coating to be transferred inwards as useful heat. Previously, it was shown that thermal performance is best on either surface of the closest air gap to the room. Consideration of potential solar gain now dictates that the coating be on the room side of that enclosure.

Installation of one or two uncoated plastic films in the air gap of a double glazed window is a way of producing effective triple or quadruple glazing (2). Table 1. shows that these configurations are actually a little worse than the corresponding all glass varieties due to the partial infrared transparency of the plastic. Heat mirror coatings deposited on these plastic films can reduce the rate of heat transfer tremendously. For double glazing with an insert consisting of two 4 mil polyester baffles (or a continuous plastic film coated on one side and wrapped around a spacer) the lowest U-value shown in Table 1. is .74 $W\text{-}m^{-2}\text{-}K^{-1}$.

Table 1. U-values for Windows Incorporating Heat Mirrors

Window Type	Gap (in.)	Coated* Surfaces	U-value**,1
single glass	-	-	6.28
	-	2	4.55 - 4.91
single glass + inside baffle	1/2	-	2.94
	1/2	3	1.57 - 1.88
double glass	1/2	-	2.76
	1/2	3	1.59 - 1.90
	1/2	4	2.21 - 2.43
double glass + 1 baffle	1/2	-	1.93
	1/2	4	1.16 - 1.34
	1/2	3,4	.89 - 1.11
	1/4	-	2.28
	1/4	4	1.68 - 1.80
	1/4	3,4	1.42 - 1.60
triple glass	1/2	-	1.79
	1/2	5	1.18 - 1.36
double glass + 2 baffles	1/2	-	1.49
	1/2	3,6	.74 - .89
	1/6	-	2.05
	1/6	3,6	1.16 - 1.61

*A blank entry in this column means that all surfaces are uncoated. The range of U-values given for coated surfaces are for values of ϵ between 0.05 and 0.2.

**Units are in $W/m^2\text{-}K$. To convert to $Btu/hr\text{-}ft^2\text{-}F$, multiply by .176.

Comparing the triple glazing to the double plus one polyester baffle with heat-mirror on surface 4 now shows that the all glass window fares slightly worse. With a heat-mirror coating the infrared transparancy of the polyester is now an advantage because the reflectivity of the coating affects the adjacent gap. If the polyester was made thinner or if a polymer with higher IR transmittance was used a further reduction in U-value is possible. Using 1 mil thick polyester, which has an IR transmittance, T_{ir}, of about 0.5 compared with $T_{ir}=0.25$ for 4 mil polyester, reduces the rate of heat transfer by 5%. A film with a theoretical maximum T_{ir} of .8 would reduce the heat transfer rate by 15%.

The very low U-value of .74 mentioned above is achieved for 1/2 inch air gaps throughout. If standard frame sizes for double-glazed windows fix the overall gap at 1/2 inch, then the individual gaps are constrained to 1/4 inch and 1/6 inch for one and two plastic inserts, respectively. These small gaps increase convective heat transfer and negate some of the benefit of the heat-mirrors. The U-value in Table 1 for double glass plus two coated polyester baffles with 1/6 inch gaps, are no better than for one plastic insert with a heat-mirror on surface 4 and 1/2 inch gaps. The reduction in solar gain caused by the additional baffle and its added cost will make the two baffle system less attractive than the single baffle system under the constraint of 1/2 inch total spacing. The addition of a low conductance gas offers a more effective strategy for further reductions in U-value if the overall gap size is limited.

The U-value for double glazing with heat-mirror in position no. 3 is actually better than for a single plastic insert with heat-mirror in position no. 4 when constrained to 1/2 inch total gap. Since the heat-mirror coating is most effective when the convective heat transfer in the gap is low we might benefit by spacing the coated layers asymmetrically to give the heat-mirrored gap a smaller convective component. The minimum U-value occurs for a heat-mirror gap of 0.4 inch giving about a 9% improvement over equal spacing (two 1/4 inch gaps) but only a 4% improvement over double glazing without an insert. For larger total gap spacing there will be a less pronounced improvement in U-value using this technique because the convective component of heat transfer in the enclosure is in a regime where it is a more slowly varying function of gap width.

Another means of minimizing convection in tandem with the radiation surpressing effects of the heat-mirror is to include a low conductance gas-fill in a sealed insulating unit. Argon gas with an $\epsilon = .05$ heat-mirror can decrease the U-value over that of the heat-mirror alone by 30%. With an $\epsilon = .2$ heat-mirror the reduction in U-value is 25%.

3. SEASONAL PERFORMANCE

We have been able to draw some qualitative conclusions by comparing U-values alone. In general, a more rigorous demonstration of the relative energy benefit between two windows is necessary. When there is a significant reduction in solar heat gain due to an improvement in thermal insulation we must make a seasonal or annual net energy calculation.

The performance of a given window system in the heating season is determined by computing the "useful solar gain" and thermal losses hour by hour for a typical day in each month, and then integrating the sum of these two components over the entire day.

The instantaneous solar gain is determined using the Liu-Jordan method as modified by Kusuda and Ishii (3). The solar gain is then calculated from the intensity, the angle of incidence of sunlight on the window surface and the angular dependent solar optical properties of the window. The results in this section are for a south facing window in Madison, Wisconsin. The heating energy requirement for orientations other than south show a weaker dependence on solar transmittance.

The "useful solar gain" differs from the instantaneous transmitted solar flux in two respects. First, the thermal mass of the room is approximated by spreading the instaneous solar gain over several hours after it is absorbed. We call this the "available solar gain". Second, only those available solar gains which go to off-set thermal losses are counted; if the available solar gains exceed the total thermal losses, the excess solar gain is rejected as "overheating". This truncated solar gain is what we define to be the "useful solar gain". The total thermal losses are composed of losses through the window and the building envelope. A U-value of 0.5 $W-m^{-2}-K^{-1}$ is taken for the envelope.

The inside temperature is fixed at 18°C (65 °F) and the outside air temperature at each hour of the day is determined by a sinusoidal function fit to the average high and low temperature for each month.

There is no general relationship between the solar and far infrared radiation properties for heat-mirror coatings. A functional relation could be found for a particular class of heat-mirror coatings but, ultimately, the properties would be determined by the details of the deposition process and the particular system of materials being used. Therefore, T and ε will be treated as independent parameters. T is chosen to have a range of 0.5 to 0.8, and ε varies from 0.05 to 0.3. However, some of the high T, low ε combinations may never be attainable at low cost. Once the heat-mirror properties have been selected the seasonal performance of various window designs can be calculated. The results are shown in Fig. 2.

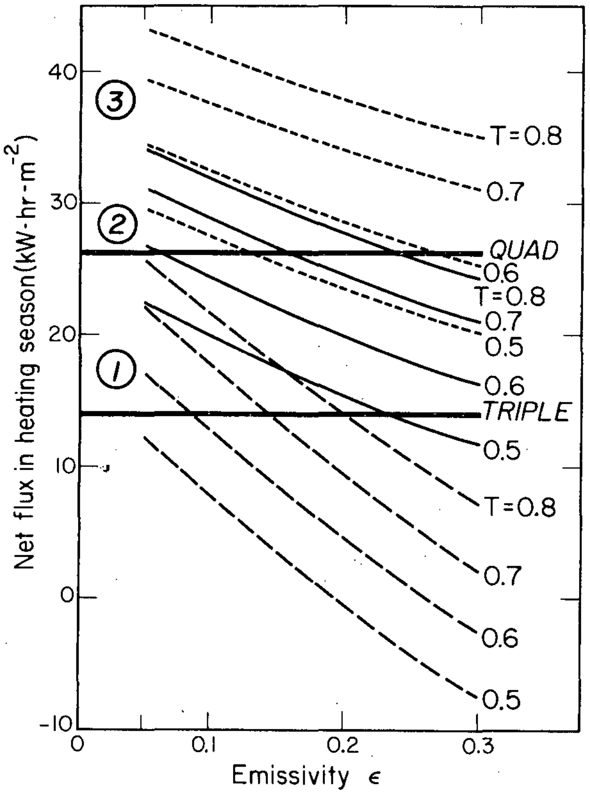

Fig. 2. The net energy flux attributable to $1m^2$ of window in the heating season vs. emissivity of the heat-mirror surfaces for (1) __ __ __double glass with a surface 3 heat-mirror, (2) ____double glass with one 4 mil. polyester baffle, heat-mirror on surface 4 and (3) ---double glass with 2 baffles, heat-mirrors on surfaces 3 and 6. Solar transmittance of the coating/substrate composite is the parameter. Total transmittance for the window wll be lower.

A double glazed window with T=.6 requires an emissivity of .08 to be equivalent to triple glazing. If the transmittance is increased to 0.8, the requirement for equivalence to triple glazing is relaxed to ε=.2. For T=.8 and ε=.05 the double glazed unit with mirror is as good a quadruple glazing.

Double glazing with a heat-mirror coated plastic baffle equals quadruple glazing for the following combinations of properties for the insert: T=.8, ϵ=.06; T=.7, ϵ=.15; and T=.8, ϵ=.25. A double glazed window with two plastic baffles with heat-mirror coatings has a very low U-value (table 1). However, if the transmittance is low the reduction in solar gain begins to outweigh the good thermal insulation. A double baffle window with T=.6 is no better than a single baffle with T=.8.

The figures are calculated for an "energy conserving" house, that is, one with unusually good wall insulation and thermal mass. If a more ordinary house is modeled, then the effects of solar gain are less amplified, so that the family of curves for each window type will be clustered more tightly together. Also, all the curves wll be shifted downwards since some of the beneficial solar gains will be lost. For low T, the requirements on ϵ to achieve the same net flux as triple or quad glazing are less stringent than for the energy conserving house. Double glazing with a T=.6, ϵ=.15 coated pane equals triple glazing. Double glazing with a polyester baffle equals quadruple glazing when the baffle has T=.6 and ϵ=.15.

4. CONCLUSIONS

(1) If possible, a heat-mirror coating should be placed on the room side of the air space nearest to the room to maximize solar heat gain and minimize thermal losses.

(2) For retrofit applications where the choice of location of the heat-mirror coating is limited to either the inside or outside surface, the coating should be on the inside surface. However, it is recommended that the heat-mirror be applied to the enclosed side of one of the add-a-pane type retrofit devices. This will not only improve the insulating properties with an additional air gap, but also will improve the contribution of the heat-mirror coating.

(3) Use of a heat-mirror coated plastic film inserted in the air space of a double glazed window can decrease heat transfer by 30% over double glazing with heat-mirror in position 3. Asymmetric gap spacing can lower the U-value over equal spacing by 5%. A highly IR transparent plastic substrate can cause a further reduction of as much as 15%. More research is needed to develop suitable substrates.

(4) Low conductance gas-fills used in sealed units with a heat-mirror coating can reduce the U-value by as much as 30% compared to air-filled windows.

(5) If a heat-mirror-coated substrate has a solar transmittance $\geq$ 0.6 and an emissivity $\leq$ 0.15, then a window incorporating this coating is competitive, on the basis of heating energy performance, with a window that has an additional pane. This conclusion is valid only for a south facing window in a cold climate.

5. ACKNOWLEDGEMENT

The work described in this paper was funded by the Office of Buildings and Community Systems, Assistant Secretary for Conservation and Solar Applications of the U.S. Department of Energy under contract No. W-7405-ENG-48.

6. REFERENCES

(1) Standard ASHRAE winter conditions: Outside air temperature, t_{out} = -18 ^{o}C (0 ^{o}F), inside air temperature, t_{in} = +18 ^{o}C (65 ^{o}F), wind speed = 24 km/hr (15 mph).

(2) S.E. Selkowitz, "Thermal Performance of Insulating Window Systems", ASHRAE Transactions, vol. 85, part 2 (1979) pp. 669-685.

(3) T. Kusuda and K. Ishii, Hourly Solar Radiation Data for Vertical and Horizontal Surfaces on Average Days in the United States and Canada, Nat. Bur. Stand., Bldg. Sci. Ser. 96 (Apr. 1977).

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720