BNL-24637

GLAZING AND THE TROMBE WALL*

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ABSTRACT

Single, double and triple glazing are examined for use in passive solar Trombe walls and south facing windows. Net gains and losses are calculated employing regional weather data and annual contribution to heating load reduction is evaluated. The study concentrates on the reflectivity of each glass pane, including the dependence of relectivity on the angle of incidence of the radiation, and resulting heat gains and losses. This facet of passive design heretofore has been inadequately treated and is shown to be significant. The marginal value of each additional pane is investigated with regard to heat gain, energy savings and total costs. Additionally, attention is given to the effects of Trombe wall energy storage.

I. INTRODUCTION

Passive techniques for solar energy collection are receiving increasing attention in both new housing construction and retrofit applications. The use of such techniques has great appeal which can be attributed to their low cost, simplicity, and applicability to heating and cooling in a diversity of climates. Passive solar design covers a wide range of concepts, from proper building orientation to elaborate collection and storage devices. The energy-conscious homeowner can significantly reduce heating and cooling demand by employing combinations of these techniques. This paper considers the use of south-facing glass windows for collection of solar energy and its concomitant storage in a massive concrete Trombe wall. More precisely, we focus on the comparative value of single, double and triple glazing in fenestration, considering both reflective losses and increases in insulation value. We concentrate on a climate akin to that of Boston, although the techniques may be readily applied to any region. The decrease in window efficiency caused by the presence of a Trombe wall is also discussed. We note that the Swedish government now requires triple glazing in all new construction and provides loans for retrofits. In this paper, we offer a preliminary and partial answer to the question, "What is the marginal value of a third additional pane of glass in the United States?"

*This work was supported by the Applications Analysis Branch of the Division of Energy Storage of the U.S. Dept. of Energy.

II. THE ROLE OF REFLECTIVITY

The key element in passive solar design is a large south-facing window area. Greater southern exposure yields a higher gain of direct radiant energy. It becomes important here to account for the factors that determine net energy gain. These are: type of glazing, coefficients of heat transmission, solar insolation, weather patterns and reflectivity and absorption losses. While U values and solar and weather data are well documented, the work performed on the effects of multipaned glazing of active solar collectors (1,2) does not seem to have been carried over to studies of the values of additional glazings in the design of windows and other passive systems such as the Trombe wall (3,4,5,6,7). This evaluation is essential if we are to compare the increasing reflectivity losses and better insulation values that accompany additional panes of glass.

To evaluate reflectivity losses, we must know the angle of incidence of radiant energy striking the exterior glass surface. For a vertical glass surface facing south, the angle of incidence of beam solar radiation, θ_1 is given as:

$$\cos\theta_1 = -\sin\delta\cos\phi + \cos\delta\cos\omega\sin\phi \qquad (1)$$

where:

δ = the solar declination angle.

$= 23.45 \sin \frac{360+n}{365}$, where n is the day of the year

ϕ = latitude (north positive)

ω = solar hour angle, each hour equalling 15° of longitude (mornings positive, afternoons negative) and solar noon is zero (e.g., ω = +15 at 11 a.m., and -30 at 2 p.m.

The angle of incidence may then be calculated hourly for each day in a given year. Given these data, it is then possible to determine reflectivity, in single, double, and triple glazing. For a single air-glass interface, the angle of refraction, θ_2, is calculated first, using Snell's law:

$$\sin\theta_2 = \frac{n_1}{n_2}\sin\theta_1 \qquad (2)$$

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Next the fraction of reflected incident insolation at an air-glass interface is (2):

$$\rho = \frac{I_r}{I_o} = 1/2 \left[\frac{\sin^2\left(\theta_2-\theta_1\right)}{\sin^2\left(\theta_2\ \theta_1\right)} + \frac{\tan^2\left(\theta_2-\theta_1\right)}{\tan^2\left(\theta_2-\theta_1\right)}\right] \quad (3)$$

where:

I_o = incident energy

I_r = reflected energy

ρ = fraction of incident energy reflected

For each type of glazing, we are interested in the fraction of incident energy transmitted by 2n surfaces, T_n, where n is the number of panes (2):

$$T_n = \frac{1-\rho}{1+(2n-1)\rho} \quad (4)$$

In this paper, we will ignore the small losses due to absorption of incoming solar insolation in the glass (which in a more detailed model would also serve to lessen heat transmission losses to the outside) and assume that all transmitted energy is absorbed by the room or by a Trombe wall if one is present. Thus the total power being absorbed at any given time per unit area is

$$I_n = I_t \cos\theta_1 T_n, \quad (5)$$

where I_t is the incident radiant energy. Attenuation of the solar radiation by the long atmospheric path early and late in the day is ignored since almost all such radiation is lost to reflections.

III. HEAT LOSS

A large south-facing window area will lose significant quantities of heat during the heating season. Increasing the number of window panes will reduce this loss by decreasing U, the coefficient of transmission. In general, the heat loss per unit area, L, during heating season, L, is given by

L = U x DD x 24 hr/day

where:

U = coefficient of heat transmission (J/hr-m^2-°C)

DD = degree days (°C)

The above data are regionally specific and readily available. For U values, we use (8,9):

Single glazing, U = 2.3 x 10^4 J/hr-m^2-°C

Double glazing, U = 1.1 x 10^4 J/hr-m^2-°C
(5/8 inch air space)

Triple glazing, U = .74 x 10^4 J/hr-m^2-°C
(1/2 inch air space)

The air spaces are optimal; wider spacings do not decrease U, due to increased convection.

In the interest of brevity, several factors and possibilities are ignored in this analysis. For example, the engineering approximation that the heat losses can be adequately described by a single "U" value should be refined by the separation of the convective and radiative components of heat loss (10). Then the possible benefits of various convection-inhibiting devices located between the glazings (11) could be evaluated. These refinements will be taken up in later studies. We also specifically exclude from present considerations "active" devices such as insulated shutters or "beadwalls" which, if implemented, would clearly reduce the value of the third layer of glazing.

IV. AN EXAMPLE

The above methodology for solar gain and heat loss was applied to solar and weather data for the vicinity of Boston, Massachusetts (12). Latitude =42.5° was used in equations 1-3 to calculate the single surface reflectivity, ρ. This was inserted in equation 4 to calculate the total transmitted energy based on insolation data from reference (2), for each sunlit hour of one day of each week in the heating season, for single, double and triple glazing. The index of refraction, n_2, was taken as n_2=1.526, typical of window glass (2). These results were then scaled up by a factor of seven to obtain the total seasonal gain, and multiplied by .55 to account for cloud cover occurring about 45% of the time during the heating season. The heat gain from insolation is summarized in Table 1. Heat losses are calculated using the given U-values and approximately 5600 degree days for Boston. Losses are summarized in Table 1 and the net gain for a south facing window is given in column 3 for each glazing type. These calculations will be repeated with more accurate information and weather data, such as that on the SOLMET tapes (13). Until this is done, the results below must be regarded as tentative.

V. NET GAIN WITH STORAGE IN A TROMBE WALL

We note here the effect on energy gain of using a Trombe wall for thermal storage. Specific Trombe wall design parameters may be found in References 3,4,5, 6 and 7. The advantage of employing this massive concrete storage wall directly behind the window include prevention of overheating and accompanying uncomfortable drastic room temperature changes and storage of heat with slow release for evening heating requirements.

It is important to note, however, that net gain will decrease from that through an unobstructed window by approximately 10% with the use of concrete wall storage situated directly behind the south-facing glazing (see Table 1, column 4). The air temperature midway between exit and entry vents of the Trombe wall, averaged over the heating season will be about 1.4° C above room temperature (14). This temperature rise will increase the heat transmission resulting in the indicated decrease in net heat gain.

VI. ANALYSIS OF NET GAIN

Table 1 gives net gain for south-facing windows backed by a Trombe wall during the heating season. Addition of a second glass pane with 5/8" air space results in a 210% increase in net energy gain. Adding a third pane with 1/2" air space to the double glazing yields a net gain increase, of 11%. The dollar value per square foot of additional glazing may be evaluated using representative fuel prices for the Boston area. Space heating fuel in the region is predominantly #2 oil, with many new multifamily structures having electric resistance space heat. Representative prices are \$ .50/gallon for oil and \$ .048/KWh for electricity. Considering an oil furnace efficiency of .67,(which is perhaps optimistic, but one hopes people will optimize furnace operation before turning to solar energy) these translate to \$5.10/GJ and \$13.30/GJ respectively. Marginal savings by fuel type are summarized below in Table 2, where the annual fuel savings have been converted to the corresponding capital costs under the assumption of a 15% capital recovery factor, taken to include the presumably small O&M charges.

VII. CONCLUSIONS

A survey of suppliers on Long Island indicates that one eighth inch glass, strong enough to be the central of three glazings, can be obtained for about \$7.50/ square meter, while plastics, such as Kalwall, Tedlar or Teflon, are available for about \$4.30 per square meter. If these are taken as lower bounds to the marginal cost of the third glazing, to which assembly costs would have to be added, it is clear that extremely low assembly costs would have to be realized to make a third pane of glass attractive, even if it were saving energy produced through electric resistance heating. In cases such as the Trombe wall, where visual acuity is not important, a third glazing of plastic material would appear to be worthwhile, but again only in the case of electric backup. In the likely event of continued fuel price increases, these options will become more clearly worthwhile, and a third glazing of plastic could well become economically attractive even if it is displacing heat produced from fuel oil.

Table 1

Heat Flow Through Various Glazings

(GJ/m^2 - heating season)

	Net Insolation	Heat Transmission	Net Gain	Net Gain With Trombe Wall
Single	2.04	1.74	.30	.27
Double	1.79	.83	.96	.87
Triple	1.61	.55	1.06	.96

Table 2

Marginal Savings for the Trombe Wall Configuration

	Increase in Net Gain Due to Last Pane		Marginal Value of Last Pane ($\$/m^2$)	
	Percent	Gj/m^2-Heating Season	Oil at \$5.10/GJ	Electric at \$13.30/GJ
Double Pane	220%	.60	20.00	53.00
Triple Pane	10%	.09	3.10	8.00

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