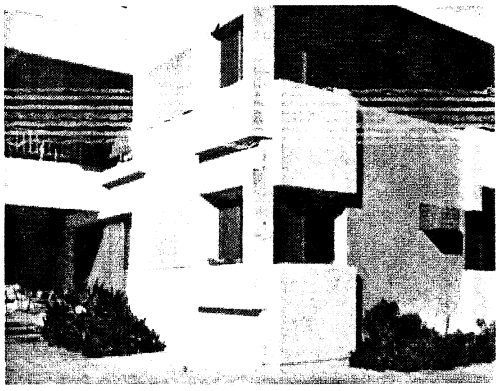
Reducing Heat Loss Through



Window Retrofitting

Substantial amounts of recoverable energy are lost through windows. The authors conclude that simple, well-sealed panels can reduce heat loss through steel-sash windows by a 4-factor when infiltration is not present and by an 8- factor when it is.

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TREATMENT of window area in industrial, commercial, and institutional buildings represents a vast opportunity to reduce heating costs and energy consumption. As detailed in Table 1, annual heat loss through windows accounts for about 5% of the U.S. energy consumption or about one and one-half times the energy derived from oil transported by the Alaskan pipeline. Americans pay over $30 billion annually to compensate for this loss.

A relatively simple window treatment to eliminate a substantial portion of this loss involves tightly sealed, interior-applied insulating panels. The purpose of this paper is to show how the performance of several such systems was predicted and verified by using standard test methods.

WINDOW AND PANELS

The prime window studied here was a 3.8 × 6.8-ft (1.2 × 2.1 m) steel-sash architectural projected window commonly used in schools, industry, and monumental buildings. The total crack length around the two operable ventilators was 22.7 ft (6.9 m). The window was glazed with single-strength glass and putty. No weatherstripping or weep holes were present. Cam-type locks were used to secure the ventilators.

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Insulating panels were mounted in the same opening as the window, as shown in Fig. 1; the panels were spaced 2.75 in. (70 mm) from the indoor surface of the window. Panels were mounted by a combination of aluminum-framing members and plastic-retaining strips which effected an apparently tight seal between adjoining panels and between the panels and opening.

The three types of panels investigated had physical and geometric properties as described in Table 2.

HEAT TRANSFER

In accordance with standard texts, the rate of transfer of heat through a window system in the absence of air infiltration is calculated from the equation

$$Q = UA\Delta T \qquad (1)$$

where

Q = rate of heat transfer Btuh
U = overall "air-to-air" coefficient of heat transfer (Btu/h · ft^2 · F)
A = area (ft^2)

and

ΔT = indoor-outdoor temperature difference (F).

For the composite system of layers comprising the window system sketched in Fig. 1, the overall heat-transfer coefficient is obtained 1 om the equation

Table 1
Magnitude of Energy Loss Through Windows (July 1979 data)

Item	Quantity	References
U.S. National Energy Consumption (N.E.C.)	80 × 10^{15} Btu/yr	4,5
Energy used for space heating in U.S. (20% of N.E.C.)	16 × 10^{15} Btu/yr	6,7
Energy lost through windows (25% of space heating loss = 5% of N.E.C.)	4.0 × 10^{15} Btu/yr	6
Energy content of barrel of crude oil	5.8 × 10^6 Btu/bbl	8
Crude oil equivalent of energy lost through windows in U.S.	690 × 10^6 bbl/yr	calculated from above
Current crude oil delivery rate by Alaskan pipeline (approx.)	420 × 10^6 bbl/yr	9
Annual cost of energy lost through windows in U.S. (@ $7.65/$10^6$ Btu)*	30.7 × 10^9 US $/yr	calculated from above

*Based on use of heating oil costing 75¢/gal., containing 140,000 Btu/gal., and burned at 70% efficiency. In most of the U.S. energy costs less with gas and more with electricity.

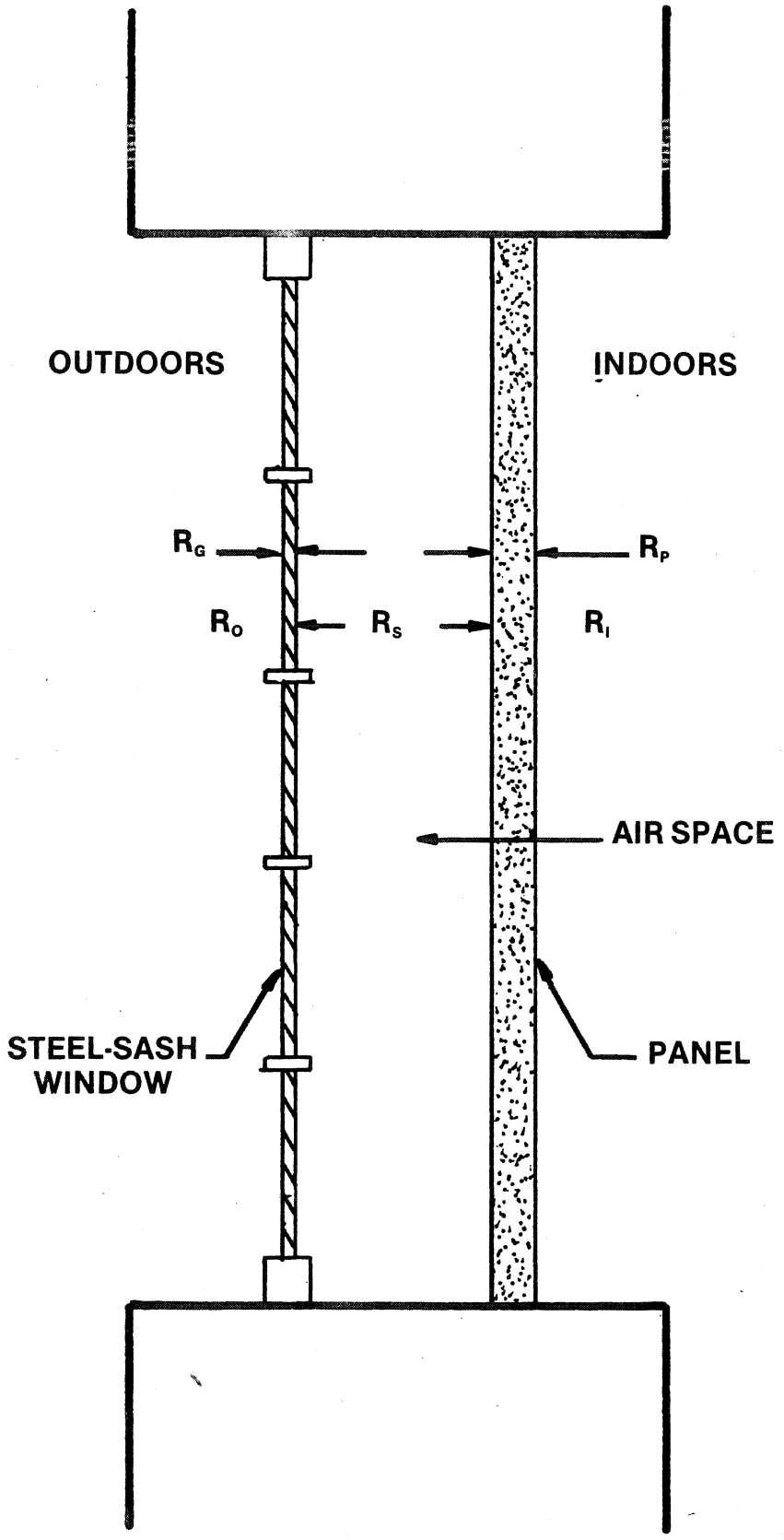

Fig. 1. Schematic view of window with panel installed (not drawn to scale).

$$U = 1/R_O + R_G + R_S + R_P + R_I) \quad (2)$$

where the R values are unit-area thermal resistances of the respective layers in h · ft² · F/Btu; as indicated in Fig. 1, the subscripts O, G, S, P, and I designate, respectively, the outdoor air film, the glass, the air space between the glass and the panel, the panel, and the indoor air film.

If one also includes infiltration effects, the total rate of heat flow Q_T is calculated from the equation

$$Q_T = UA\Delta T + \pi c Q_A \Delta T \quad (3)$$

where

π = density of air (lb/ft³)
c = specific heat of air (Btu/lb · F)
Q_A = rate of air infiltration (ft³/h)
and other symbols are defined as before.

If Eq 3 is rewritten in the form

$$Q_T = (U + \pi c Q_A/A)A\Delta T \quad (4)$$

it is noted that the equation has the same form as Eq 1, except that the overall heat-transfer coefficient U is now replaced by the quantity $U + \pi c Q_A/A$. The latter quantity serves as an effective overall coefficient U_E, which includes both the usual coefficient U an additional infiltration component U_I. This relationship is expressed by the equation

$$U_E = U + U_I, \quad (5)$$

where the infiltration component is given by the equation

$$U_I = \pi c Q_A/A \quad (6)$$

OVERALL COEFFICIENT

According to handbook data, when indoor and outdoor temperatures are, respectively, 70 F (21°C) and 0 F (−18°C), and when outdoor wind velocity is 15 mph, the unit-area thermal resistance R_I for the air film inside the window is 0.68 h · ft² · F/Btu, and values for R_S, R_G, and R_O are, respectively, about 1.00, 0.02, and 0.17 h · ft² · F/Btu.[1] Substitution into Eq 2 gives the following result.

$$U = 1/(1.87 + R_P) \quad (7)$$

Values for R_P taken from Table 2 are substituted into Eq 7 to obtain theoretical U-values for each of the three panel types. The theoretical results are compared in Table 3 with experimental results obtained for the same panel types as described elsewhere.[2]

INFILTRATION COMPONENT

Air-flow rates through the window were measured with a static-pressure difference of 0.112 in. H_2O between opposite sides of the window.[3] The measurements were then repeated for each of the three panel types in place as in Fig. 1. Results are shown in Table 4. By inserting the tabulated values of Q_A into Eq 6, the infiltration component U_I is calculated; results are shown in the last column of the table.

Table 2
Description of Sample Panels

Designation	Substrate	Interior Face†	Apparent Density (lb/ft³)	Composite Thickness (in.)	Thermal Conductance* (Btu/h · ft² · F)	R_P Unit-Area Thermal Resistance# (h · ft² · F/Btu)
Type I	High-density mineral-wool board	8-mm vinyl	23.0	0.585	0.763	1.31
Type II	High-density mineral-wool board	8-mm vinyl; 4.7% of area consisted of holes punched for acoustical-absorption purposes	21.7	0.586	0.725	1.38
Type III	Medium-density mineral-wool board; 6% of area consisted of holes punched for acoustical-absorption purposes	0.105-in. needle-punched acrylic fabric; approximate density 9.5 lb/ft³	16.0	0.721	0.508	1.97

†Opposite surface on all panel types spray-coated with flat-white paint.
*Measured by ASTM C 518, thermal-transmission measurement method, at 70 F (21 °C). #Commonly called "R-value."

Table 3
Overall Heat-Transfer Coefficients for Steel-Sash Window Insulated with Various Panel Types (infiltration not included)

Panel Type	R_P (h · ft² · F/Btu)	U(Btu/h · ft² · F) Theory	U(Btu/h · ft² · F) Experiment*
I	1.31	0.315	0.34
II	1.38	0.308	0.33
III	1.97	0.260	0.27

*Performed in accordance with ASTM C 236 with warm-side temperature = 70 F (21°C), cold side temperature = 0 F (– 18°C), static-pressure difference across the test window = 0.0 in. H_2O (no air infiltration), and 15-mph dynamic wind at cold side.[2]

Table 4
Calculation of Infiltration Component from Static-Pressure Tests for Steel-Sash Window Insulated with Various Panel Types

Panel Type	Q_A† (ft³/h)	U_I* Btu/h · ft² · F)
None	2730#	1.90
I	213	0.148
II	379	0.264
III	130	0.091

†Performed in accordance with ASTM E 283, with static-pressure difference across the test window = 0.112 in. H_2O corresponding to a wind velocity of 15 mph.[3]
*U_I calculated from Eq 6, using $\pi = 0.075$ lb/ft³, c = 0.240 Btu/lb · F, and A = 25.8 ft², so $U_I = 0.000697\ Q_A$.
#Test value of 110 ft³/hr · ft given in 1960 *ASHRAE Guide*, p. 151, for same type of window; with present crack length = 22.7 ft, $Q_A = 22.7 \times 110 = 2500$ ft³/h.

Table 5
Effective Overall Heat-Transfer Coefficient of Steel-Sash Window With and Without Panel Insulation; Theory Compared with Experiment

Panel Type	U_I (Btu/h · ft² · F)	U (Btu/h · ft² · F)	U_E (Btu/h · ft² · F) Theory	U_E (Btu/h · ft² · F) Experiment*
None	1.90	1.15†	3.05	(—)#
I	0.148	0.315	0.463	0.49
II	0.264	0.308	0.572	0.51
III	0.091	0.260	0.351	0.34

†Calculated from Eq 2, taking R_S and R_P = 0; this value agrees with the handbook value for U in absence of infiltration.[1]
*Performed in accordance with ASTM C 236 with warm-side temperature = 70 F, cold-side temperature = 0 F, and static-pressure difference across test window = 0.112 in. H_2O, corresponding to 15-mph dynamic wind conditions.[2]
#Value could not be obtained for 0.112-in.-H_2O pressure difference because test-chamber equipment could not handle excessive infiltration; value obtained for 0.03-in.-H_2O pressure difference was 2.41 Btu/h · ft² · F.

OVERALL COEFFICIENT

A theoretical value for the effective coefficient U_E is obtained by adding the theoretical U-value from Table 3 to the calculated value for U_I from Table 4. This is done in tabular form in Table 5 to obtain the theoretical values shown in the next-to-last column.

The last column in Table 5 shows results obtained by direct experiment in a guarded hot-box apparatus with outdoor wind velocity and indoor-outdoor pressure difference corresponding to those assumed in obtaining the calculated results.[2]

REFERENCES

1. American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc., *ASHRAE Handbook of Fundamentals*, New York, NY (1972).
2. "Thermal Transmittance Test Report for Armstrong Cork Company," Architectural Testing, Inc., Report ATI-465, (January 16, 1979).
3. "Air Infiltration Test Report for Armstrong Cork Company," Report ATI-463, (December 27, 1978).
4. Federal Energy Administration, "1976 Executive Summary, National Energy Outlook," U.S. Government Printing Office, (1976), p. 4.
5. Lincoln, G.A. *Science*, Vol. 80, (April 13, 1973) p. 156.
6. Berman, S.M., and S. D. Silverstein, "Energy Conservation and Window Systems," U.S. Department of Commerce, National Technical Information Service, PB-243-117, (January 1975).
7. Stanford Research Institute, "Patterns of Energy Consumption in the United States," Menlo Park CA (November 1971).
8. "Energy Management in the Federal Government, Annual Report to the President of the United States, Fiscal Year 1977," U.S. Department of Energy, (August 1978), p. vii.
9. *Journal of Commerce*, (April 17, 1978) p. 32.