THERMAL INSULATION OF WINDOW GLASS

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November 1973

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Thermal Insulation of Window Glass*

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Abstract

The thermal insulation of window glass can be increased by a factor of two with a simple spray-on semiconductive coating.

A traditional style dwelling with about 10% of its wall area devoted to single pane windows loses from 30 to 50% of its heat energy through these windows during a cold spell. With properly fitted storm windows the heat loss is reduced to about 10 to 15% of the total. Double glazing (two panes of glass separated by a small air space and mounted in the same frame) would reduce the heat loss to the 15 to 25% range but as a modern style house has almost twice the window area of a traditional house the percentage heat loss remains quite large. Infrared radiation plays a major role in accounting for these losses. We show that a commercial spray-on semiconductive coating, SnO_2 ,¹ which is transparent in the visible decreases the infrared emissivity of glass. This lower emissivity significantly decreases the heat loss through single panes, double glazed and storm windows. For special coatings of $\text{SnO}_2:\text{Sb}$ ² or $\text{In}_2\text{O}_3:\text{Sn}$,³ which are not yet commercially available, the heat transmission is decreased by at least a factor of two for all three window geometries.

The power radiated by a body depends on its temperature and its emissivity as given by the Stefan-Boltzmann law

$$W = \epsilon \sigma T^4 \quad (1)$$

where ϵ is the emissivity of the surface and varies from 0 for a perfect reflector to 1 for a perfect absorber (black body).

$$\text{In Eq. 1, } \sigma = 0.17 \times 10^{-8} \frac{\text{BTU}}{\text{ft}^2 \text{hr} (\text{°R})^4} = 5.67 \times 10^{-8} \frac{\text{watt}}{\text{m}^2 (\text{°K})^4}.$$

The spectral distribution of the radiation is given by the Planck radiation law. For our purposes it is sufficient to identify a few characteristic wavelengths associated with the distribution.

Only two percent of the energy is found below a wavelength, $\lambda_{\min}$, given by

$$\lambda_{\min} T = 1600 \text{ micron } \text{°K},$$

fifty percent of the energy is found below a wavelength, $\lambda_{\frac{1}{2}}$, given by

$$\lambda_{\frac{1}{2}} T = 4100 \text{ micron } \text{°K}$$

and ninety-eight percent of the energy is found below a wavelength $\lambda_{\max}$ given by

$$\lambda_{\max} T = 18000 \text{ micron } \text{°K}$$

For a room temperature radiator the value of the emissivity in the far infrared region of the electromagnetic spectrum between $\lambda_{\min} = 5.3 \text{ micron}$ and $\lambda_{\max} = 60 \text{ micron}$ determines the radiated power.

To estimate the relative importance of heat transport by radiation we calculate the net radiative transfer of heat between two glass surfaces separated by a small air space and compare it to the conductive transport. The small spacing insures that convective heat transport is suppressed.

Area A_1 of emissivity and absorptivity ϵ_1 at T_1 is opposite area $A_2 = A_1$ of emissivity and absorptivity ϵ_2 at T_2 . The net radiative transfer with $A_1 = A_2 = A$ is⁴

$$W_{\text{Net}} = \frac{A\sigma}{\left(\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1\right)} (T_1^4 - T_2^4) \quad (2)$$

or for small temperature differences the power transmitted per unit area per degree temperature difference is

$$R = \frac{W_{\text{net}}}{A \Delta T} = \frac{4\sigma T^3}{\frac{1}{\epsilon_1} + \frac{1}{\epsilon_2} - 1} \quad (3)$$

In the infrared between 5 and 60 micron wavelength glass has a very large absorptivity so we set $\epsilon_1 = \epsilon_2 \cong 1$. From Equation 3 we note that

$$R = 6.1 \left(\frac{\text{Watts}}{\text{m}^2 \text{ } ^\circ\text{C}} \right) = 1.1 \left(\frac{\text{BTU}}{\text{hr f}^2 \text{ } ^\circ\text{F}} \right) .$$

With the two panes of glass separated by $\sim 1''$, convection is suppressed and the heat transmission due to conduction alone is

$$C = 0.9 \frac{\text{Watts}}{\text{m}^2 \text{ } ^\circ\text{C}}$$

so

$$\frac{R}{C} \approx 6.5.$$

Apparently even at room temperature far infrared radiation is the dominant heat transfer mechanism for the storm window

geometry. Consequently, the emissivity of glass in the far infrared plays a major role in the thermal insulation of windows.

Tin oxide in the form of a thin film on glass has been used for a number of years as a transparent electrode or as a transparent heater. These films are usually applied by spraying a mixture of SnCl_4 with ethanol onto a glass substrate which has been heated to 400°C . The SnCl_4 is transformed into the wide band gap ^{semiconductor} SnO_2 at the glass surface.

In the wavelength region from 5 to 30 microns the SnO_2 coating is observed to reduce the infrared emissivity of window glass by about 10%.⁵ This change is associated with the free charge carriers in the semiconducting SnO_2 . As the carrier concentration is small the plasma frequency ($\omega_p = \sqrt{\frac{4\pi Ne^2}{\epsilon_0 m}}$) associated with the free carriers occurs below the frequency region of interest. Recently, carrier concentrations $N \approx 10^{20} \text{ cm}^{-3}$ have been achieved by adding some SbCl_3 or HF to the SnCl_4 solution before spraying.⁶ In this case the plasma resonance occurs at smaller wavelengths ($\approx 2\mu$) and the emissivity of the coated glass is reduced to $\epsilon = 0.2$ between 5 and 60 microns. An even smaller emissivity, $\epsilon = 0.1$, has been observed for a $\text{In}_2\text{O}_3:\text{Sn}^3$ coating in this wavelength region.

We have estimated the power transmitted per unit area per degree temperature for a single pane of glass, for double

glazed glass ($\frac{1}{4}$ " spacing) and for storm windows (1" spacing). These results are summarized in Table 1. An $\epsilon = 0.9$ is assumed for the uncoated glass and an $\epsilon = 0.1$ for the coated glass. Natural convection plus radiation heat transfer is taken into account for the two exposed glass surfaces. In all three cases we have assumed that the temperature difference between the air and the glass is less than 20°F .

From the literature the coefficient for heat transmittance in $\frac{\text{BTU}}{\text{hr f}^2 ^{\circ}\text{F}}$ (U-no.) for a single glass pane is $U = 1.1$ and for a storm window $U = 0.5$.⁷ The corresponding calculated values in Table 1 for $\epsilon = 0.9$ compare reasonably well with these experimental U-nos.

It is evident from the $\epsilon = 0.1$ column of Table 1 that a factor of two decrease in heat transmission can be expected for all three geometries. It should also be mentioned that these coatings which have a thickness which is smaller than the wavelength of visible light actually toughen the glass surface. Because of the incipient national fuel shortage, glass companies may find simple coatings such as these worthy of further development for the home construction industry.

Acknowledgements

I would like to thank Dr. R. Kaplow for calling references 3 and 6 to my attention.

References

- * This research was conducted under the auspices of the Advanced Research Projects Agency of the Department of Defense under Contract No. DAHCl5-71-C-0253 with the University of Michigan. Additional support was received from the U. S. Atomic Energy Commission under Contract No. AT(11-1)-3151, Technical Report #COO-3151-32.
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TABLE 1

Power transmitted $\left(\frac{W}{m^2 \cdot ^\circ C}\right)$ for different window geometries.
 (The corresponding U-nos. in $\frac{BTU}{ft^2 \cdot hr \cdot ^\circ F}$ are given in parentheses.)

	<u>$\epsilon = 0.9$</u>	<u>$\epsilon = 0.1$</u>
Single Pane	≥ 8 (1.4)	≥ 4 (0.7)
Double Glazed ($\frac{1}{4}$ " spacing)	4.4 (0.8)	2.2 (0.4)
Storm Window (1" spacing)	3.8 (0.67)	1.5 (0.27)