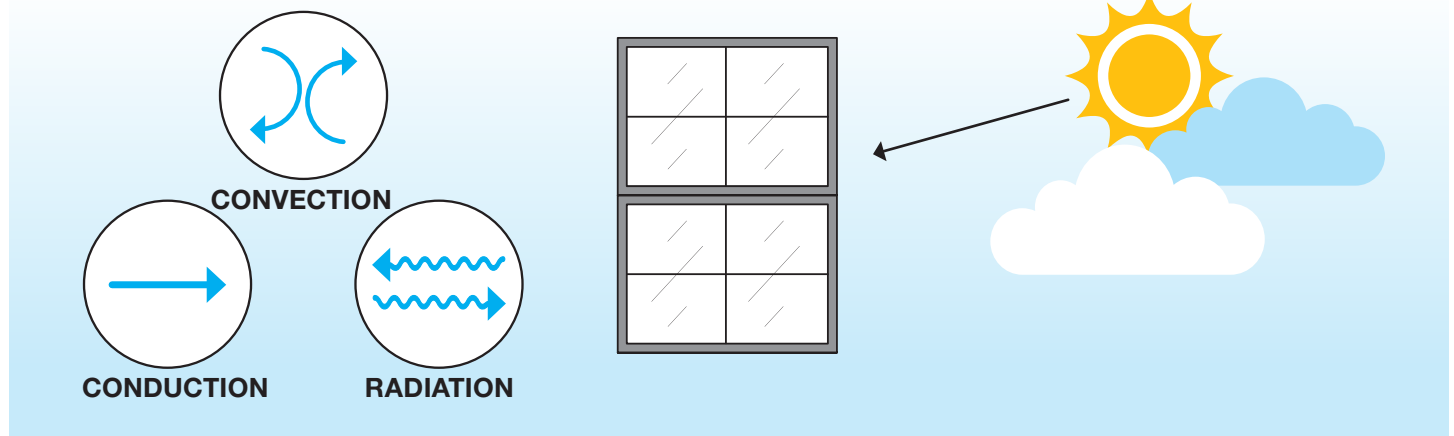


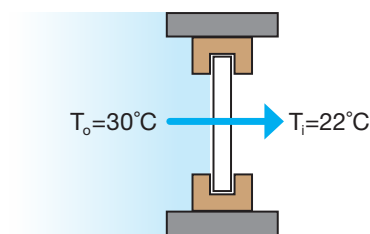
Factors that Affect Energy Efficiency in Windows

1 Temperature-Driven Heat Flow

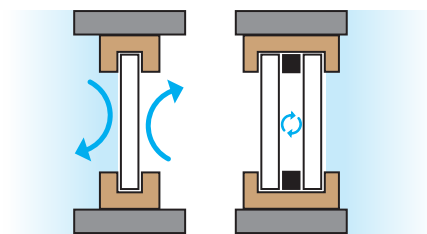


2 Solar Radiation

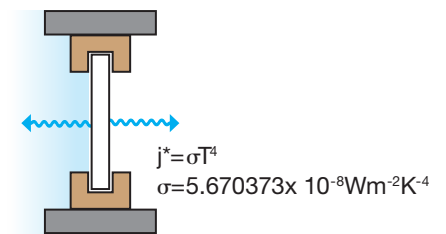
There are three modes of heat flow relevant to window heat transfer:



CONDUCTION occurs when heat flows through solid material from a warmer area to a cooler area.

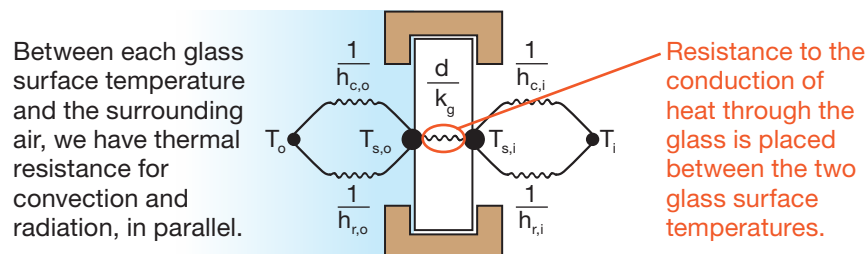


CONVECTION occurs when heat is transferred due to the movement of fluids — such as between the bulk of the air and one of the window surfaces or in the space between two glass layers in a double-pane window



Glass surfaces emit and receive long-wave infrared **RADIATION** according to the Stefan-Boltzmann Law (*bodies radiate energy proportionally to their temperature to the fourth power*).

Resistance Network Model: The heat flow through a window can be represented by a resistance network.



$$h_{c,o} \begin{cases} 15.0 \text{ (winter)} \\ 26.0 \text{ (summer)} \end{cases} \quad k_g = 1 \text{ Wm}^{-1} \text{ K}^{-1} \quad h_{c,i} = 8.28 \text{ Wm}^{-2} \text{ K}^{-1}$$

Learn more about windows at windows.lbl.gov/outreach

Total Heat Flow: This equation models the total heat flow through a window due to these three forms of heat transfer, defining heat transfer per unit area.

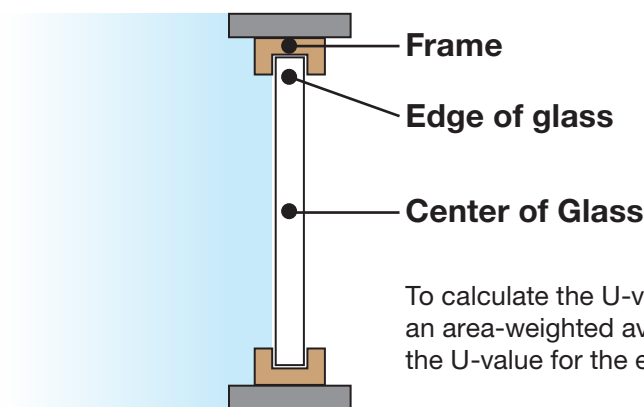
This factor represents **CONDUCTION** where “d” is the thickness of the window glass and “k_g” is the conductivity of glass.

The **CONVECTION** coefficients h_{c,i} and h_{c,o}, are standard, and defined in units of watt per meter squared per Kelvin.

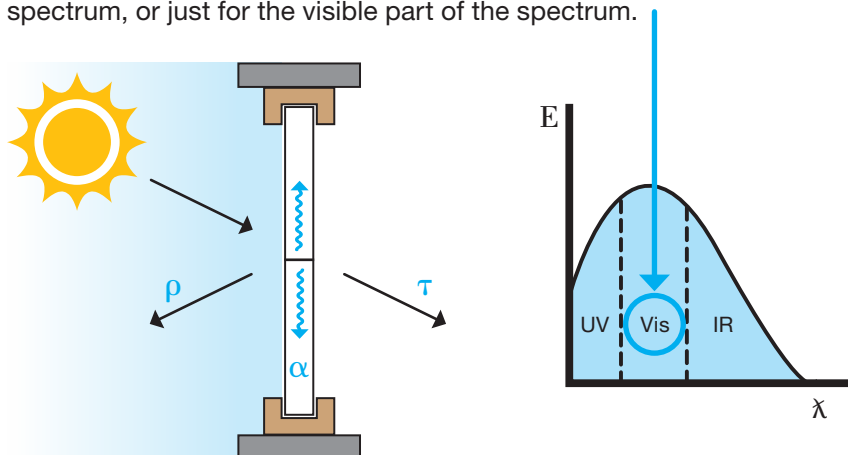
The **U-VALUE** of the window, which characterizes heat flow due to temperature differences, is obtained by solving for the resistance network.

Using this approximation, we can use similar coefficients for **RADIATIVE** heat transfer. Because radiative heat transfer is not linear with respect to temperature difference, this mode of heat transfer will become more dominant as the temperature difference increases. (This formula is a common approximation used to keep the main equation linear.)

Whole Window U-value: Thus far we’ve characterized heat flow for a section called the “center of glass” which is far away from the frame. But heat transfer conditions closer to the frame, and at the frame itself, are different.



Solar Radiation: When solar radiation hits a window, it can be transmitted, reflected, or absorbed. These results can be quantified as fractions of incident radiation – transmittance (τ), reflectance (ρ), and absorptance (α) – and can be defined across the whole solar radiation spectrum, or just for the visible part of the spectrum.



Solar Heat Gain Coefficient:

Returning to the main equation, we can add this term, representing the energy transmitted through the glass when solar radiation hits it.

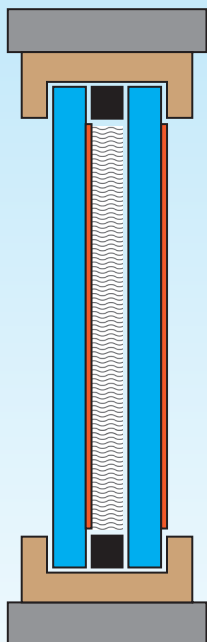
To account for energy that is re-radiated to both the interior and exterior of the window, we add the coefficient n, or the inward flowing fraction – representing the fraction of the absorbed energy that ends up inside the space.

Solar Heat Gain Coefficient

$$\frac{Q}{A} = U(T_o - T_i) + I(\tau_{sol} + n\alpha_{sol})$$

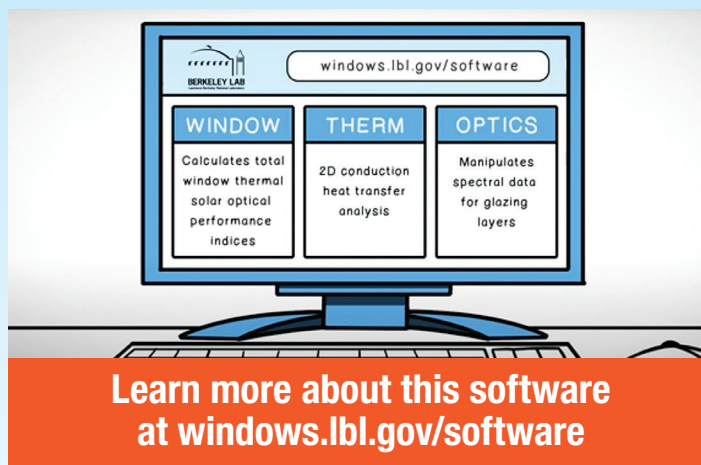
$$\frac{1}{U} = \frac{1}{h_{c,o} + h_{r,o}} + \frac{d}{k_g} + \frac{1}{h_{c,i} + h_{r,i}}$$

For most practical purposes, the **U-VALUE** and the **SOLAR HEAT GAIN COEFFICIENT** help to characterize a window’s energy efficiency, and the comfort it might add to a room.



While this information sheet focused on a single pane window, many windows are more complex – with additional panes, coatings, or other variables.

At Berkeley Lab, we've developed software applications called WINDOW, THERM, and OPTICS, to help you perform these calculations on any window.



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