Cold Climate Housing Research Center

CCHRC

Whole Wall R-Values

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Due to the recent emphasis on home retrofits and weatherization, many people have become accustomed to new terms, such as “insulation R-value” or “low-e windows.” These terms are beneficial for understanding and comparing building products, but it is easy to oversimplify the potential benefits of those products when they are not viewed holistically. The following discussion will explain the components of a wall system and how the individual R-values combine to create a whole wall R-value. Typically the importance windows play in determining the overall thermal resistance of walls is underestimated by considering walls and windows as separate components. This is appropriate for many purposes, such as a home energy audit, but can be misleading when focusing on one component to the exclusion of the other. Understanding whole wall R-value will help you make effective decisions about retrofitting walls and windows.

R-Values in Brief

R-values describe the ability of a material, such as insulation, to slow the transfer of heat. Ignoring other differences between insulation types, this simple rule prevails: the higher the R-value, the better the insulation.

R-values are often stated in terms of assumed installation thicknesses, such as a R-19 fiberglass batt made to fit in a 2x6 wall stud cavity. R-values are also commonly expressed in values per inch of thickness, such as R-3.85 per inch for Type I expanded polystyrene (EPS), or “white board” foam insulation. For either of these examples, the R-values are for that product alone, not the finished wall assembly.

Windows are a little different. Thanks to the National Fenestration Rating Council (NFRC) certification program, certified windows have published U-factors that take into account all the various components of the window (glass, frame, hardware, gas fills between panes, etc.). In other words, the U-factor is the sum of all component R-values in a defined system. Don’t be misled by a “center of glass R-value” for a window, as that can exaggerate the thermal performance of the window as a whole. Because of the way the window component R-values add up, the U-factor is stated as the inverse of the total window R-value:

$$\text{U-Factor} = \frac{1}{R_{\text{value}}}$$

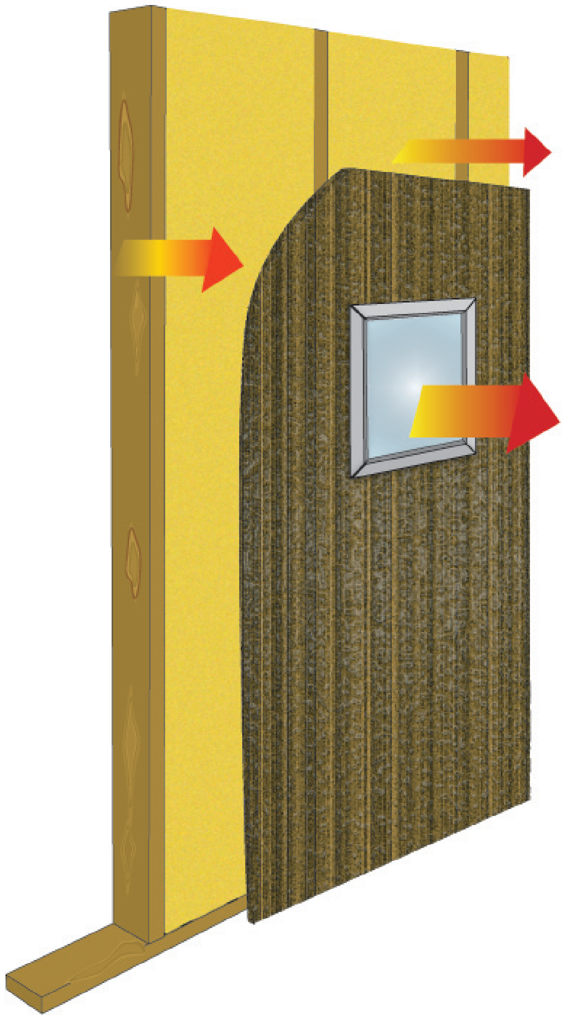
Whereas a higher R-value means a better insulator, lower U-factors signify better insulators. For example, a window with a U-factor of 0.5 is equivalent to a total R-value of 2, and insulation with a R-value of 10 will have a U-factor of 0.1.

Of course the walls of our homes are made up of many products. Considering a typical residential wall section in Alaska, as depicted in Figure 1, we see there are three primary paths for heat to escape from your warm home into the cold winter air. These include through the:

- insulated portion of the wall,
- structural framing of the wall,
- and the windows and doors.

How all those different R-values sum up depends on how those components are put together. Examining the wall section shown in Figure 1 and envisioning heat flowing perpendicular to the wall, heat from inside a house will flow through the wall components through a few paths.

Figure 1 – Depiction of wall section with three main heat flow paths (insulation, framing, windows)



One of those paths can be described, from inside to outside, by the equation below for the insulated portion of the wall:

$$R_{insulation} = R_{drywall} + R_{fiberglass} + R_{sheathing}$$

We also have to consider that the fiberglass batts are placed between the wall studs, so the same equation modified to describe the heat flow through the studs is as follows:

$$R_{stud} = R_{drywall} + R_{stud} + R_{sheathing}$$

Just as water and electricity seek the path of least resistance, heat preferentially flows through the weakest thermal component of the wall assembly. The studs have a lower R-value than the insulation, so it's the preferred path for heat flow. Using commonly accepted R-values for each component (see the appendix for details), and including the contribution of air films on the inside and outside wall faces, we see that:

$$R_{insulation} = 21.1 \frac{hr \cdot ft^2 \cdot F°}{BTU}$$

$$R_{stud} = 8.8 \frac{hr \cdot ft^2 \cdot F°}{BTU}$$

But how do we account for these two parallel paths where the heat can preferentially choose the least resistive path? This calculation is done by adding the reciprocal of each path while accounting for the fraction of area that each path represents. Therefore we need to know the percentage of wall area that is taken up with structural framing, or the "framing factor", which is 11% for 24-inch on center 2x6 construction. Using the parallel-path flow method described in the ASHRAE Fundamentals (2009):

$$U_{wall} = \frac{1}{R_{wall}} = \frac{89\%}{R_{insulation}} + \frac{11\%}{R_{stud}} = \frac{.89}{21.1} + \frac{0.11}{8.8} \frac{BTU}{hr \cdot ft^2 \cdot F°}$$

$$R_{wallt} = 18.3 \frac{hr \cdot ft^2 \cdot F°}{BTU}$$

Some authors have pointed out that real framing factors are substantially higher, around 25% nationwide (Kośny et al., 2001), which would lower the whole wall R-value further to approximately 15.7. However, there is a more significant factor to consider without getting lost in this debate. Windows are yet a weaker component in terms of thermal performance, so their contribution to the whole wall R-value needs consideration as well. For an older double-pane window, it is reasonable to expect relatively low thermal performance:

$$R_{window} = \frac{1}{U\text{-factor}} = \frac{1}{0.5} = 2.0 \frac{BTU}{hr \cdot ft^2 \cdot F°}$$

The percentage of wall taken up by windows will vary between homes, and even between the different walls of a home. Considering the case where 11% of the wall area is taken up by these windows, the whole wall R-value will decline significantly. A window-to-wall ratio of 11% is approximately the average for Alaska homes (ARIS citation). Continuing with methods outlined in ASHRAE (2009):

$$\frac{1}{R_{total}} = \frac{78\%}{R_{insulation}} + \frac{11\%}{R_{stud}} + \frac{11\%}{R_{window}} = \frac{0.78}{21.1} + \frac{0.11}{8.8} + \frac{0.11}{2} \quad \frac{BTU}{hr \cdot ft^2 \cdot F°}$$

$$R_{total} = 9.6 \ \frac{BTU}{hr \cdot ft^2 \cdot F°}$$

It is common practice to refer to a wall's R-value by referencing simply the sum of the insulating layers, such as calling a 2x6 fiberglass insulated wall a "R-19 wall." If an additional R-10 layer of insulation was added, it would then be called an "R-29 wall." This rule of thumb remains approximately valid when considering the losses from the wall framing, as shown above where a "R-19 wall" was reduced to a "R-18.3 wall." However, the example above shows this is a gross overestimation of a wall's performance when the losses from windows are integrated into the whole wall R-value.

Effectiveness of Retrofit Options

Getting back to the idea of improving the energy efficiency of a home, what does this mean when considering retrofitting options for walls? The two main methods for reducing heat loss are by upgrading the wall insulation or buying better windows. Which is going to give you a better improvement in total wall R-value? The answer depends on the wall considered, so let's set up a common scenario.

Scenario One

Expanding on the previous discussion, consider a house wall with 2x6 wood-frame construction insulated by fiberglass batt insulation with double-pane windows. We'll call this set-up our "pre-retrofit scenario," as depicted in Figure 1. We see the vast majority of the wall area is occupied by insulation (78%), whereas the areas taken up by windows (11%) and wood framing (11%) are much lower. At first this seems to indicate that the biggest gains would result from improving the insulation, however the opposite is often the case.

Looking at Table 1, which summarizes whole wall R-values for different retrofit choices, we see that there is substantially more benefit by upgrading the windows than adding insulation alone. This is because windows have by far the lowest thermal resistance in the wall section. By upgrading old double-pane windows to modern triple-pane units, the resulting improvement in whole wall R-value is 59%. By contrast, if our retrofit is to add two inches of EPS insulation to the outside of the wall, the improvement in whole wall R-value is only 15%. **This demonstrates the importance of improving the weakest thermal component of the wall.** It also illustrates that R-values in complex systems do not always match our intuition, so in reality a R-3 improvement in windows can sometimes trump a R-9 or even a R-17 improvement in insulation.

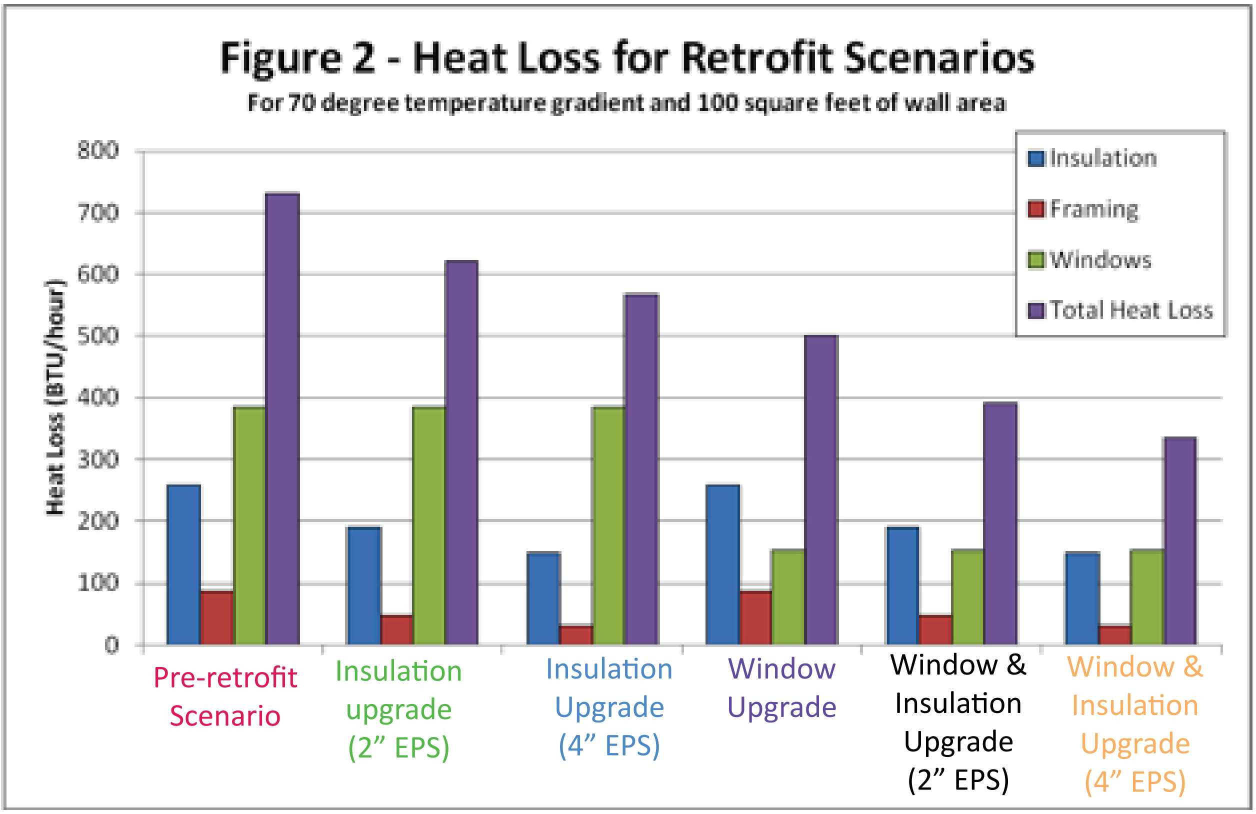


Figure 2 - Heat Loss for Retrofit Scenarios

For 70 degree temperature gradient and 100 square feet of wall area

To probe the possibilities for retrofits a little further, let's also examine how multiple retrofits help in improving the wall performance (Table 1 and Figure 2 below). When a window upgrade is combined with the addition of two inches of EPS insulation, we see that the combination provides a 100% improvement over the pre-retrofit scenario. This is a remarkable improvement that far exceeds the individual upgrades alone. Of course there are limitations, as adding another two inches of EPS for a total of four inches would improve the whole wall R-value by 128% over the pre-retrofit condition. Simply put, the additional two inches of insulation has less return that the first two inches. But there are other reasons why it would be important to add more insulation, as we'll discuss below.

Table 1. Whole Wall R-Values Including Windows

	Pre-Retrofit Scenario	Insulation Upgrade (2" EPS)	Insulation Upgrade (4" EPS)	Window Upgrade	Window & Insulation Upgrade (2" EPS)	Window & Insulation Upgrade (4" EPS)
Whole Wall R-value	9.6	11.3	12.4	14.0	17.9	20.9
Difference in R-value over baseline	---	1.7	2.8	4.4	8.4	11.3
Improvement over base-line (% change)	---	18%	29%	46%	87%	118%

Scenario 2

Windows need special attention in the case of highly insulated walls. Walls with exterior insulation have numerous benefits, one of which is that they minimize the heat loss through framing members by providing a thick layer of continuous exterior insulation. When six inches of rigid foam insulation is added to our pre-retrofit scenario, the quality of the windows will largely control the whole wall R-value. As shown in Table 2, with relatively low-performance windows left in place, the whole wall R-value is approximately half of a retrofit that includes an upgrade to high-performance windows. Targeting even higher wall insulation values would have a negligible effect on the total wall R-value, further highlighting the importance of high-quality windows in home retrofits.

It is important not to overextend this analysis, as there are other factors to consider in a wall retrofit. For example, the placement of a vapor-impermeable insulation is crucial to bear in mind on a more local scale. While it may be tempting to place less than six inches of rigid foam on the outside of the wall to save money on material costs, this could be a mistake. The majority of the insulation R-value needs to be kept on the "cold side" of the vapor barrier (and exterior foam insulation can act like a vapor barrier) to avoid condensation of water vapor within the wall assembly. Replacing windows avoids this concern. This is the case whether your whole wall R-value is large or small.

Table 2. Retrofit Wall Whole Wall R-Values Including Windows

	Old windows (R-2)	New windows (R-5)
	Retrofit with 6" EPS	Retrofit with 6" EPS
Combined Insulation R-Value	44.2	44.2
Total Wall R-Value	13.1	23.2

Conclusions

This paper has focused on the role of windows in determining whole wall R-values. Windows are sometimes overlooked since they are a small fraction of the total wall area for most homes and fairly expensive to replace, but to do so neglects that the disproportionally large role windows play in determining the overall thermal resistance of a wall. Simply put, it does little good to add more wall insulation if more heat is leaving through your windows. While it is not necessary or common to include the contribution of windows in the determination of a wall's overall R-value, doing so provides a more realistic representation of a wall's thermal resistance. This can be useful for approximate evaluation of retrofits or new construction designs.

There are of course many components in a home's envelope that are critical in determining the energy efficiency and comfort of a home. Additionally, numerous systems within the home are equally as important to evaluate, such as heating and ventilation systems, hot water heating and storage, and electrical appliances, to name a few. Therefore it is important to get an energy audit before undertaking the time and expense of retrofitting your home. An energy auditor can take into account all the various factors relating to improving the energy efficiency and comfort of a home.

Glossary

Framing factor
The percentage of wall taken up with structural components that displace insulation, such as studs, plates, and headers.

Low-E
Short for "low emissivity." This refers to the coatings placed on interior panes of glass that help block the transfer of heat by infrared radiation, while still allowing most visible light to pass through the glass.

R-value
The thermal resistance of a material, and the inverse of thermal conductance. A good thermal conductor (metal) is a poor resistor, while a good thermal resistor (insulation) is a poor conductor.

Triple-pane window
"Triple" refers to the number of glass or plastic film panes in the window frame or sash. A common trick to determine the number of panes in a window is to hold a flashlight or lighter near the window. The number of visible reflections will show you the number of panes.

U-factor
The thermal transmittance for a whole window assembly. While thermal conductance is for a single material, the U-factor integrates all the thermal properties of an assembly into a single value.

References

ASHRAE Handbook: Fundamentals (2005) Chapter 25, *Thermal and Water Vapor Transmission Data*.

Jan Kośny, David Yarbrough, Phillip Childs, and Syed Azam Mohiuddin (2001) *Couple Secrets about How Framing is Effecting the Thermal Performance of Wood and Steel-Framed Walls*. Oak Ridge National Lab, http://www.ornl.gov/sci/roofs+walls/research/detailed_papers/thermal_frame

Other Publications or Resources of Interest:

“Thermal Properties of Walls”, UAF Cooperative Extension Service

“REMOTE, A Manual”, Cold Climate Housing Research Center

The Efficient Windows Collaborative’s Window Selection Tools: www.efficientwindows.org/selection.cfm

Appendix

	R-value per inch	Thickness (inches)	R-Value (ft² · F° · hr)
Inside air film	–	–	0.68
Gypsum drywall	–	0.5	0.45
Fiberglass batt	–	5.5	19
Plywood sheathing	–	0.5	0.79
Hem/fir 2x6 stud	1.22	5.5	6.71
2” EPS	3.85	2	7.70
4” EPS	3.85	4	15.40
6” EPS	3.85	6	23.10
Outside air film	–	–	0.17