Hello ENERGY STAR,

Thank you for advocating for higher performance windows. I think it is really important to focus on windows because windows are a thermal hole in the wall whose performance determines whether it is possible for the building to reach higher levels of actual R-value. I will illustrate what I mean using a few simple scenarios, that utilize a very simple equation, no hiding things behind complex models. The thermodynamic fact is simple, the bulk of heat transfer occurs through the paths of least resistance, it isn't so affected by the paths of greatest resistance.

The $R_{average}$ row in Table 1 below is calculated using the following simple equation area weighted equation that coverts R-values back to U-values, it is really a simple U*A calculation equation.

$$R_{avg} = \frac{1}{\frac{\%\ Area}{R-wall} + \frac{\%\ Area}{R-window}}$$

Despite its simplicity we can learn a lot from this equation from the following scenarios.

Scenario A illustrates the average R-value of a wall if it has a high glazing ratio, 50%, using today's code windows, as shown in Table 1, the average R-value, 5.2, is much closer to the window than it is to the wall. Even if high performance, R-5, windows were employed as shown in scenario D, if the wall has a high glazing ratio, the average R-value, 8, is much closer to the window than it is to the wall. This teaches us that we need to be concerned about glazing ratio because with today's commercially available and affordable glazing technologies, the thermal performance of glass is still way worse than an insulated wall even if we are talking about high performance glazing. Said another way, the performance of a high performance glazing is still very low performance in the world of walls. There is a saying it is not possible to build a highly energy efficient building if the window to wall ratio exceeds 40% (Straube 2008).

When the glazing ratio is brought down to the 15% commonly found in residential homes, the whole wall average R-value improves dramatically as shown in scenarios B and C. While scenarios B and C show the impact of high performance, R-5, windows somewhat, it becomes very evident if we try to achieve a whole wall average R-value that is closer to the 20, the most common cavity insulation level and the level required by code for the last 10 years in climate zones 3, 4, and 5. Why is this relevant? Because we need to be talking about R-values in terms of whole wall R-values instead of the cavity insulation R-value. We don't want consumers to think, I have R-20 insulation in my walls, therefore my house is well insulated. The reality is the whole wall average R-value is closer to R-10 in scenario B, not R-20! Is a whole wall average R-value of R-10, well insulated? I don't think so.

The R-value of the window becomes extremely critical if we want to move to a higher whole wall average R-value. Scenarios E and F show the cavity insulation level that would be required to achieve a whole wall average R-value of 19. An R-value of 19 was selected because to achieve an R-value of 20 with R-3 windows is impossible, even achieving an R-value of 19 clearly illustrates the importance of higher performing windows. As scenario E illustrates, in order to achieve a whole wall average R-value of 19 using R-3 windows, the wall insulation will need to be a comical R-value of 330! A practically impossible feat. However, as scenario F illustrates if the window R-value was increased to R-5, to achieve a whole wall average R-value of 19, the wall insulation will need to be just 37.5 which is an achievable insulation level using many different methods.

Table 1. Impact of Glazing Ratio and Window Performance on Whole Wall Average R-Value

	Scenario A	Scenario B	Scenario C	Scenario D	Scenario E	Scenario F
Window %	50	15	15	50	15	15
Window R-Window	3	3	5	5	3	5
Wall %	50	85	85	50	85	85
Wall R-Wall	20	20	20	20	330	37.5
$R_{average}$	5.2	10.8	13.8	8.0	19.0	19.0

The whole wall average R-values in Table 1 above were calculated using a very simplistic equation that doesn't even consider the thermal bridging at framing members. Thus the actual whole wall average R-values will be a little lower across the board than suggested by Table 1. Even so, the relative impact on the average R-value from the different scenarios is accurate. Additionally for existing windows, the R-value can be much worse than R-3, single pane windows with metal frames have an R-value of 0.86, a double pane window with a metal frame, air filled cavity and no low-e coating has an R-value of 1.3, and a double pane window with a non-metal frame, air filled cavity and no low-e coating has an R-value of 2 (LBNL 2019). Upgrading these windows to high performing windows would improve the energy efficiency and resiliency to extreme temperatures, rot and mold resistance from reduced condensation potential, and creates the opportunity to also select glass that increases its resiliency to other disasters. For double pane windows with non-metal frames that are in good condition it is also possible to upgrade the glass to higher performing IGUs such as thin-triple panes that are gradually becoming widely available on the market (U.S. DOE 2019). This IGU glass replacement path should also be promoted since ¾" thin-triple pane and ¾" double panes with surface 4 low-E are both IGU technologies that are economically available.

Another way to illustrate why windows impact the whole wall average R-value is by Figure 1. R-value is a counterintuitive unit of measure, not all R-values are the same, changes in R-value at the low end of the spectrum results in significant changes in heat loss/gain while even large changes in R-value at the high end of the spectrum nets only small changes in heat loss/gain. This counterintuitive nature of how R-values behave also applies also to the miles per gallon, MPG, unit of measure. We ought to change to talking in units of U-value and gallons per 100 miles but that is a topic for another day. Absent of this change, the important thing to remember is to focus on components that operate in the low end of the R-value spectrum and raise the thermal performance of those components. Windows operate in the R-1 to R-10 range, the area of the curve where even a R-1 improvement makes a BIG difference in energy savings!

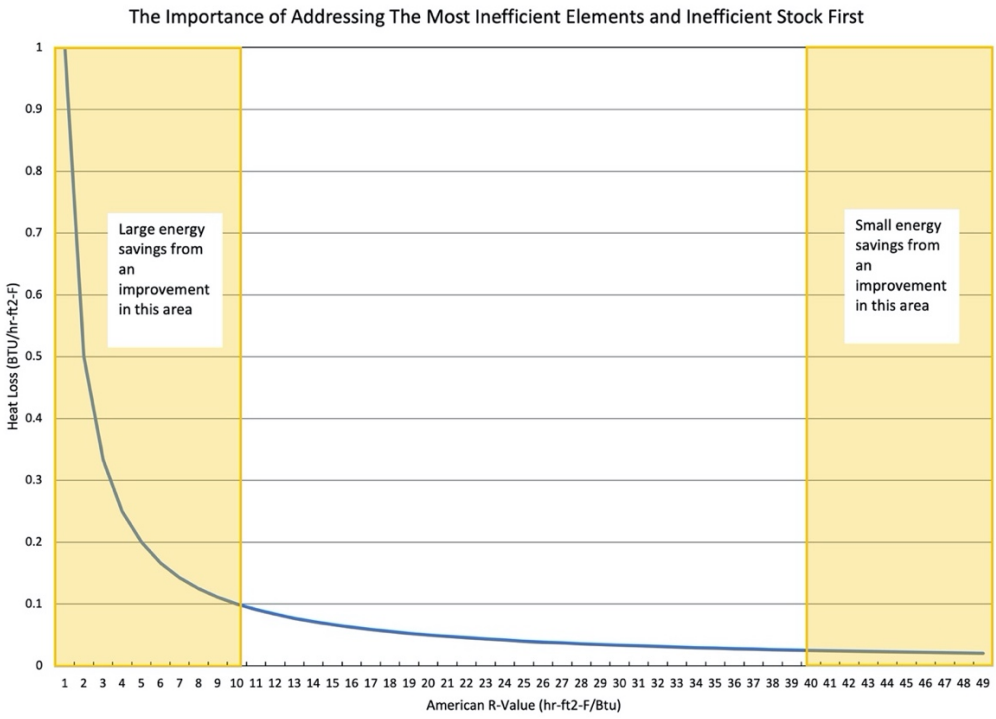

Figure 1. R-value is a counterintuitive unit of measure, not all R-values are the same, changes in R-value at the low end of the spectrum results in significant changes in heat loss/gain while even large changes in R-value at the high end of the spectrum nets only small changes in heat loss/gain. (PNNL 2020).

The thermodynamic argument for advancing that benchmark of a higher performing window has always been true. What has changed recently is the price of high performance windows. Many affordable options exist making it economically viable to make the higher performance a requirement.

Affordable triple pane window are available at lumber yards, and home centers nationwide. BIG consolidated window brands such as Cornerstone Building Brands that own many brand names including ReliaBilt, Atrium, Ply Gem, Great Lakes, Silver Line, American Craftsman, and Simonton, are the most likely to offer an affordable triple pane window near your address. Each brand under the umbrella may only be available at a specific region but each one offers high performance triple pane windows at affordable prices. Ask for options like triple pane, and foam filled insulated frames. Specify a minimum U-value specification in your construction and remodeling requirements so everyone involved in your project knows this is a requirement.

Nationally available home centers like Home Depot and Lowes are one source for affordable triple pane windows, examples below. It is also important to check your more local lumber yards asking for “the most affordable vinyl framed triple pane windows that have a _____ (0.2 or 0.22) U-value or better with _____ operation style”.

- Ply Gem Simonton Madeira with Eco3 Plus or Triple Glaze 2-LowE2 glass Available at Home Depot
- Ply Gem Select Series with HP3-Max Triple glass Available at Home Depot
- ReliaBilt 3900 Series with Triple Pane glass and InsulKor foam filled frame option Available at Lowe’s

It is recommended to search for availability of windows from the nation's top 11 largest window manufacturers in your zip code. For sure there will be at least a few that offer windows in your area. Below are some specification to help one get started:

- Jeld-Wen's V-4500 Series windows with three pane available at Home Depot, Lowe's, and local lumber yards.
- Pella 350 Series Premium Vinyl windows with foam filled frames and triple pane glass options available at local lumber yards.
- Ply Gem (many series and sub brands available but each series has its regional availability), refer to ENERGY STAR Most Efficient Window's Ply Gem listing for details on what to search and ask for, available at Home Depot, Lowe's, and local lumber yards.
- Alside (many series available but each series has its regional availability), refer to Alside's website for details, available from Alside dealers located nationwide.
- Harvey Tribute line of windows with triple pane glass option and foam filled frame option, available from local lumber yards in the Northeastern U.S. ONLY.
- Mi Windows, 1650 Double-Hung, 1685 Double-Slider, 1650 Picture, 1675 Casement, and 1665 Awning with triple pane glass option and foam filled frame option available from local lumber yards.
- Champion Windows Comfort 365 Extreme Energy windows with triple pane glass option. Available from a Champion Window Dealer, many states have a Champion Window Dealer.

Comment about Passive House windows. The testing, THERM modeling, and certification costs associated to get a window approved on the list of Passive House Windows is not a small task. Passive house windows often have a U-value in the 0.15-0.10 range. Getting windows in the 0.15-0.10 range is considerably more expensive and difficult to find than windows in the 0.18-0.22 range. Windows in the 0.15-0.1 U-value range are extremely expensive and extremely heavy. They are for the most part available only in casement, tilt-turn, and fixed/picture window options. It is likely far better value to install a casement window with a 0.18-0.22 U-value in an insulated rough opening such as one insulated with ThermalBuck than it is to invest in windows in the 0.15-0.10 U-value range.

About Casement, Hopper, Awning, Tilt-turn, and Fixed/picture style windows. These styles of windows tend to perform better than single and double hung windows because they can create a more air-tight seal from the first day of operation and throughout its lifetime. They also offer better unobstructed sightlines. When upgrading a window, it is worthwhile to consider whether the location of the window would benefit from or would be possible to upgrade from a single or double hung window to a casement, hopper, awning, tilt-turn, or fixed/picture style window.

Thank you for taking the time to consider my comments. Feel free to reach me at Edward.louie@pnnl.gov or call my cell or office number, Cell: (503) 961-3652, Office: (509) 375-6797.

Sincerely,
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