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PNNL-28809

Double or Triple?

Factors Influencing the Window Purchasing Decisions of High-Performance Home Builders

June 2019

TL Gilbride
SE Selkowitz
OG Dingus
KA Cort, Project Lead

U.S. DEPARTMENT OF ENERGY

Prepared for the U.S. Department of Energy
under Contract DE-AC05-76RL01830

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Summary

As builders become more proficient at building highly insulated walls, spurred on by more aggressive building codes and more effective insulation products, the component most responsible for limiting increases in total wall insulation value is the windows. To address this, the U.S. Department of Energy (DOE) has invested in windows research to improve the performance of residential windows. While big advances were made in the 1980s with the introduction of low-emissivity coatings, significant increases in efficiency have been slow since then. The next logical improvement would be the move to triple-pane windows. Although triple-pane windows have been around for decades, their adoption in the United States has been slow, relative to their more rapid and extensive adoption in other countries.

To better understand why triple-pane windows are so slow to catch on and to inform the development and adoption of a new approach to insulated windows, thin triple-pane windows (or thin triples), Pacific Northwest National Laboratory (PNNL) conducted a market assessment of the window purchasing practices of new home builders in 2018-19. While there are several players who can impact the adoption of new residential window technologies, including manufacturers, retailers, installers, vendors, home owners, and landlords, this report focuses strictly on home builders and the key part they play in new window technology adoption.

PNNL's goal in undertaking this study was to determine what motivates builders to choose or not choose triple-pane windows. A better understanding of the motivations, experiences, and concerns expressed by new home builders regarding window purchases could inform efforts to develop and deliver thin triple-pane windows and lead to their widespread acceptance in the marketplace. For the past several years, the DOE has supported the development of a thin triple-pane window that uses a center pane of thin glass and krypton gas fill to produce an insulated glass unit (IGU) with nearly the same weight and the same thickness as a double-pane IGU but with the performance of the heavier, thicker, standard triple-pane windows available today. This "drop-in" replacement IGU allows the window manufacturer to offer thermally improved windows with ratings equal to conventional triple-pane windows but with no change from the sash and frame design of the double-pane windows more frequently installed by the majority of U.S. home builders. This approach was designed to reduce the risk of new product development for the window companies, while providing a new insulating glass option for builders.

To conduct this study, PNNL interviewed 29 home builders who have participated in the DOE Zero Energy Ready Home (ZERH) program. These builders include many of the most active builders in the DOE ZERH program. Together, they have constructed 2,534 of the 3,417 homes certified through the DOE program as of April 1, 2019. In 2018, they constructed an estimated 1,040 homes and purchased an estimated 17,800 windows. This report summarizes the key findings from these interviews.

Key findings based on these builder interviews are presented in response to the following questions:

- What types of windows do builders pick?
- Why do builders pick the windows they pick?
- Why do builders switch from one window product to another?

- Why do builders choose triple-pane windows?
- Why don't builders choose triple-pane windows?
- What are builders' attitudes and expectations about thin triple-pane windows?
- What do builders know about thin triples?
- What do builders want from thin triples?
- What are builder's concerns about thin triples?
- How much are builders willing to pay for thin triples?

While this is the most extensive survey to date of builders' decision making regarding energy-efficient windows, it is still a small survey. It is illustrative of trends and issues but not definitive; it will be used with other technical and market data to help guide DOE programs. Implications from these findings for important stakeholder groups, including DOE and the technology research community, utility and efficiency program leads, window manufacturers, window retailers, and the codes and rating community are discussed in a separate market assessment and program plan (Cort and Gilbride 2019).

Acronyms and Abbreviations

BeOpt	Building Energy Optimization Tool
DOE	U.S. Department of Energy
HERS	Home Energy Rating System
HIA	Housing Innovation Awards
HOA	home owners' association
HVAC	heating, ventilation, and air-conditioning
IBS	International Builders Show
IECC	International Energy Conservation Code
IGU	insulated glazing unit
LBNL	Lawrence Berkeley National Laboratory
LSG	low solar gain
NFRC	National Fenestration Rating Council
OEM	original equipment manufacturer
PHIUS	Passive House Institute U.S.
PNNL	Pacific Northwest National Laboratory
PV	photovoltaic
R&D	research and development
RESNET	Residential Energy Services Network
SHGC	solar heat gain coefficient
ZERH	U.S. DOE Zero Energy Ready Home program

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1.0 Introduction

As builders become more proficient at building highly insulated walls, spurred on by more aggressive building codes and more effective insulation products, the component most responsible for limiting increases in total wall insulation value is the window. According to Sam Rashkin, Chief Architect for the Building Technologies Office of the U.S. Department of Energy (DOE), "Windows represent a giant thermal hole that disproportionately upsets all the good work you do on the insulated wall assemblies" (Rashkin 2018). To address this deficiency, the DOE has supported on-going windows research. One promising result of DOE-funded research has been the development of a thin triple-pane window ("Thin triple") that uses two standard thickness panes of glass, sandwiching a center pane of thin glass, with krypton gas filling the 1/4-inch gap on each of the center pane and low-E coatings on two surfaces to produce a window with the same weight and thickness as a double-pane insulated glazing unit (IGU) but the thermal performance of a standard-thickness triple-pane window (Selkowitz, Hart, Curcija 2018). Standard glass triple-pane windows have been around for decades, and a form of thin-triples using a low-E coated plastic film as the center layer has been available since the 1980s, but the uptake of both forms of triple-pane windows has been slow. For the plastic film triples, although the performance track record over the last 30 years has been good, the use of a plastic film in the window assembly added production complexity and raised durability concerns so most window companies that initially used it no longer offer that option.

To better understand why triple-pane windows are so slow to catch on and to inform the development and adoption of thin triple-pane windows, Pacific Northwest National Laboratory (PNNL) conducted the market assessment reported here. In 2018-19, PNNL interviewed several zero energy home builders to investigate their window-purchasing practices, experiences, and concerns. The information they provided sheds light on what factors motivate their purchasing decisions regarding triple-pane windows. These findings have implications for DOE-funded thin triple-pane window research, for triple-pane window manufacturers and retailers, for codes and ratings organizations, and for utility and other efficiency program designers interested in the potential of thin triple-pane windows as an energy-efficiency measure. The purpose of this report is to document these builder insights which will inform a separate assessment and planning document that will outline the implications derived from these insights as they relate to key stakeholders.

After this introduction chapter, which includes a brief history of DOE-sponsored window research, a description of the thin triple-pane window technology, and an explanation of the study methodology, the report is organized around the questions PNNL asked of a select group of builders participating in DOE's Zero Energy Ready Home (ZERH) program. The findings are grouped by question in chapters, as follows:

- 2.0 What types of windows do builders pick?
- 3.0 Why do builders pick the windows they pick?
- 4.0 Why do builders switch from one window product to another?
- 5.0 Why do builders choose triple-pane windows?

- 6.0 Why don't builders choose triple-pane windows?
- 7.0 What are builders' attitudes and expectations about thin-triple pane windows including
    - What do builders know about thin triples?
    - What do builders want from thin triples?
    - What are builder's concerns about thin triples?
    - How much are builders willing to pay for thin triples?

Key findings are summarized at the end of each chapter and in a conclusions chapter at the end of this report. These key findings are also presented in a separate market assessment and program plan (Cort and Gilbride 2019), which proposes implications from these findings as they impact important stake holder groups including DOE and the technology research community, utility and efficiency program leads, window manufacturers, window component suppliers, window retailers, and the codes and rating community, as well as builders, contractors, and architects. Cited references can be found in Chapter 9.0. Appendix A lists builders who participated in the interviews. The survey questions for builders are shown in Appendix B. Appendix C lists window brands used by builders surveyed.

1.1 An Overview of Triple-Pane Window Research and Development

While exterior wall insulation levels have increased significantly in the last 30 years, from no insulation to R-11 (MEC 1995) to R-25 for cold climate builders in the 2018 International Energy Conservation Code (IECC), the thermal performance of the typical residential window has not seen similar continued advancement. By comparison, today's ENERGY STAR windows are rated at ~R-3.

Residential windows account for about 2.24 quadrillion Btu (Quads) of U.S. energy consumption or 12% of building energy use. They account for 19% of heating, ventilation, and air conditioning (HVAC) heating loads and 39% of HVAC cooling loads (Selkowitz, Hart, Curcija 2018). Recognizing the importance of windows to the home's thermal envelope, DOE has been supporting the development of better insulated windows for the past three decades.

Significant gains were achieved in windows research between 1980 and 2000, and by the early 2000s, widespread market transformation from clear-glass single-pane windows to double-pane windows consisting of insulated glazing units (IGUs) with low-emissivity coatings and an inert gas fill had been achieved. (See Figure 1.) This was the result of 20 years of public and private investment in technology research and development (R&D), coupled with the launching of the National Fenestration Rating Council (NFRC), an ENERGY STAR windows specification, and tighter codes and standards (Rissman 2013, Geller and Thorne 1999).

The National Fenestration Rating Council (NFRC) is a non-profit organization that was created by the window industry in 1989 to devise a technically sound, impartial way to compare window performance. The NFRC established a rating, labeling, and certification system that employs laboratory tests and computer simulations, backed up by physical testing and factory inspection, to determine a window's basic thermal and optical properties: U-factor, Solar Heat Gain Coefficient, and Visible Transmission. These values are listed on the NFRC labels given to windows that have been rated and certified by the

NFRC. The NFRC also provides education to designers, builders, and consumers on how to read the label and to manufacturers on the requirements for meeting the certification criteria. The organization promotes the label, but does not promote specific ratings or performance values, which are left up to codes and standards organizations, state and local code jurisdictions, utility programs, and others incorporating the label into promotional efforts (Ward, Suozo, and Eto 2000).

In the late 1990s, national programs such as the ENERGY STAR Windows program and the Efficient Windows Collaborative, and regional initiatives in several parts of the country were key players in helping pull the market toward higher-efficiency windows. The DOE/EPA ENERGY STAR windows program was launched in 1997 by DOE and EPA and creates market pull by focusing primarily on the retail market and encouraging consumers to select high-efficiency products based on set performance standards. The Efficient Windows Collaborative was started in 1997 to provide technical marketing information, support, and training materials to manufacturers, suppliers, builders, designers, utilities, trade associations, and others (Ward, Suozo, and Eto 2000).

Increased stringency requirements in building energy efficiency codes was another important factor in driving market uptake for double-pane low-e windows (see Section 1.4). DOE design tools also played a role in encouraging the selection of higher performance windows.

These market push and pull factors helped windows with low-E coatings and argon gas fill to increase market share to the point that they now account for more than 86% of annual sales (Selkowitz, Hart, Curcija 2018). While this transition from the R-1 single-pane to an R-3 double-pane, low-E window represented a remarkable market transition, continued market transformation has slowed, and the next big leap, from double-pane to triple-pane, has yet to occur.

In 2009, DOE launched a Highly Insulating Windows Volume Purchase (WVP) Program to encourage the market adoption of triple-pane windows by reducing the incremental cost of highly insulating windows compared to ENERGY STAR (double pane) windows and raising consumer awareness of highly insulating windows and their benefits. As part of the WVP effort, DOE partnered with the window industry, government laboratories, universities, utilities, and consumer groups to develop voluntary performance and cost specifications and goals. Program activities included executing agreements with manufacturers to meet the specifications and the creation of a WVP website to list window products meeting the cost and performance goals. Sales were tracked over the 2009-2012 program period. Overall, the availability of highly insulating triple-pane windows increased and the incremental cost between double-panes and triple-panes decreased from \$7-10/ft^2 to \$6-7/ft^2 at the conclusion of the program. Figure 1 shows the number of triple-pane double-hung window products that are now registered in the NFRC database. Another key outcome of the program was creation of the ENERGY STAR Most Efficient criteria for primary residential windows, which was adopted based on technical specifications set forth in the WVP program (Parker et al. 2013).

A federal tax credit in place at the start of the WVP, in June 2009 offered 30% of the product price, up to \$1,500, for windows with a U-factor of 0.302 or lower. In January 2011, the tax credit was reduced to 10% of the product price up to \$200. Manufacturers participating in a 2012 WVP meeting identified a return of the \$1,500 tax incentive combined with a higher-tier ENERGY STAR program as the most viable

long-term strategy to significantly move the market for highly insulating windows. They identified the drop in the tax incentive, along with the recession and sluggish housing market, as factors that were contributing to the slowing of the momentum toward higher-performance windows (Parker et al. 2013).

In 2011 ENERGY STAR started a process to update the criteria for windows to a U factor of 0.27 or less for northern climates, from the then current U factor of 0.30. ENERGY STAR eventually adopted a graduated U factor for the northern climate of 0.27 to 0.30 based on SHGC. In 2012 EPA announced a Most Efficient designation for windows of U-0.20 or less. A U factor maximum of 0.22 was proposed for the 2015 International Energy Conservation Code. It was not approved; however, the IECC has seen incremental increases in stringency from U-0.35 in 2009 to U-0.32 in 2012 and 2015, and to U-0.30 in 2018 (see Section 1.4 of this report).

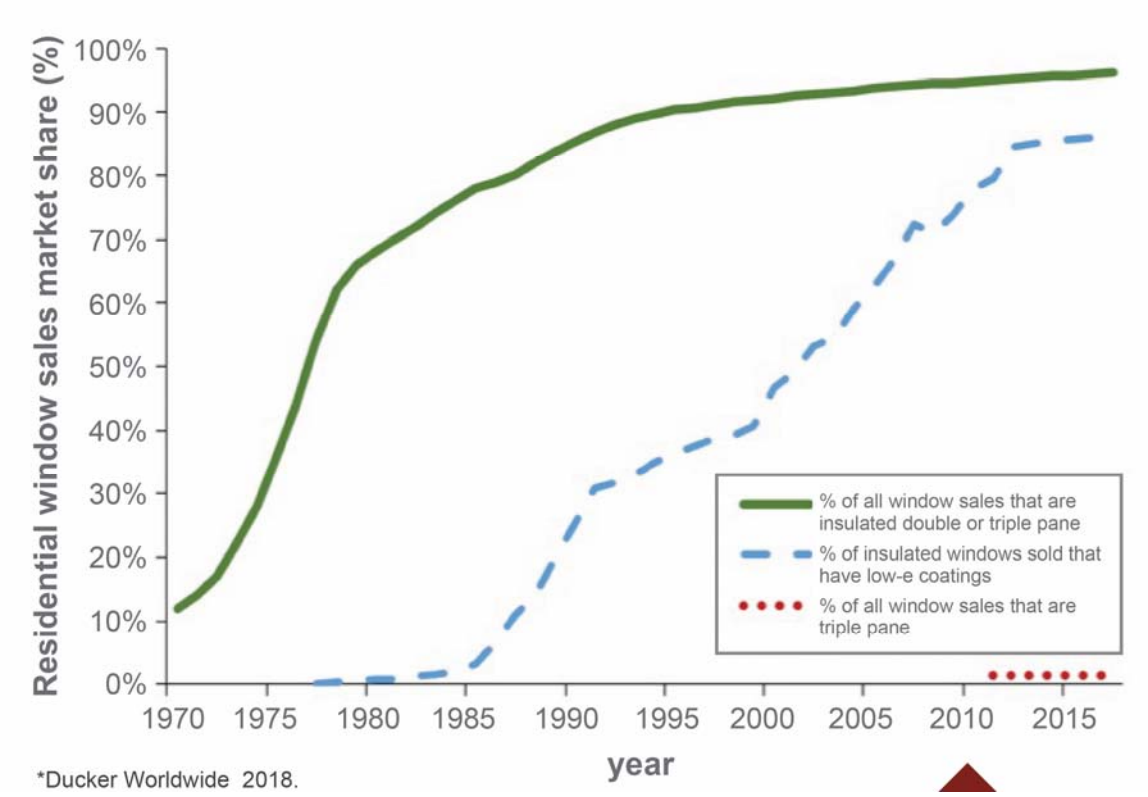


Figure 1. Market push and pull efforts transformed the market for low-emissivity coatings on double-pane windows from 0% in 1980 to nearly 90% in 2010. Can the same happen for triple-pane windows?

1.2 Thin-Triple Window Technology Development

One promising result of DOE-funded research has been the development of a thin triple-pane window. The thin triple-pane window was first proposed by Lawrence Berkeley National Laboratory (LBNL) in 1989 (Arasteh, Selkowitz, and Wolfe 1989), and LBNL received a patent on it in 1991 (Selkowitz, Arasteh, and Hartmann 1991). The goal of thin triple-pane window research is to produce IGUs that are no

thicker or heavier than standard double-pane IGUs, so that the sash and frame design are unchanged from double-pane windows, but the overall window insulating values are equal to or greater than standard triple-pane windows.

The majority of existing IGUs are ¾-inch wide double-pane models with two 1/8-inch layers of glass and a ½-inch gap in between that is filled with argon. To match this ¾ inch thickness, a thin triple-pane IGU would use two ordinary (1/8-inch) layers of glass sandwiching a thin (1/32-inch) layer of glass with a 1/4-inch gap on either side of the thin glass. To improve the R value, the gaps are filled with krypton rather than argon gas and a second low-E coating covers the outer-facing surface of the inner glazing, the #5 surface. For comparison, standard triple-pane windows use three panes of 1/8-inch glass separated by ½ inch gaps that are filled with argon, for an overall IGU thickness that typically measures 1-1/2 inches. Argon performs best at a gap space of ½ inch but does poorly as the space becomes narrower. Krypton, on the other hand, performs well in a gap of ¼ inch.

Typical U-factors for various double, triple, and thin-triple window configurations are shown in Table 1. The U-factor refers to heat transfer—the lower the U-factor, the better the window performs at stopping heat flow. U-factors are the inverse of R-values, which measure a material's insulation effectiveness. For example, if a window has an insulation effectiveness of R-5, take the inverse of 5, which is 1/5; this equals 0.2 so the window's U factor is 0.20. When building standards organizations like ENERGY STAR refer to a window's U-factor, they are typically referring to the overall window U-factor, which is a function of the frame design, frame materials, the spacer design, and IGU characteristics, including the thickness of the IGU, the gas that fills it, and any coatings that might be used. This overall U-factor is the value referenced on the NFRC label. The NFRC also lists the Solar Heat Gain Coefficient (SHGC), the visible transmittance, and the air leakage rating. These values will vary with the overall size of the window; however, the NFRC requires that all U factors for residential windows be reported for a single standard size, 4 feet x 5 feet.

Table 1. Comparison of U Factors for Thin-Triple-, Standard Triple-, and Double-Pane Windows

IGU Description	IGU Width	U, IGU:	U, Fixed window	U, Double Hung
Double-pane low-e IGU, air	.75"	.30	.35	.38
Double-pane low-e IGU, argon	.75	.25	.26	.29
Double-pane low-e IGU, argon, with 2nd low-E on surface #4.	.75	.19	.22	.25
Triple-pane IGU, argon, two-low-E	1.0	.15	.19	.23
Triple-pane IGU, argon, two-low-E	1.25	.13	.18	.21
Thin-triple-pane IGU, argon, two-low-E	.75	.20	.24	.26
Thin-triple-pane IGU, krypton, two-low-E	.75	.13	.18	.21
Notes: For double-pane windows, the low-E coating is on the #2 or #3 surface; for triple-pane two-low-E, the low-E coatings are on the #2 and #5 surfaces. All low-E coatings have an emittance of 0.04. The IGU and window size assumed is the NFRC standard size, 4.0 x 5.0 feet.				

Figure 2 shows the performance of the thin triple (3P) concept in comparison with the center-of-glass performance of various double-pane (2P) options. The graph shows the impact of IGU width on U and R

performance for six IGU options. An IGU width of 0.75 inch is optimal for double-pane with 95% Argon gas fill and one low-emissivity coating (2P-lowe 95% AR) – the most commonly constructed IGU currently on the market. The "2P-surf4" option adds a second low-e coating on the room-facing surface of the double-pane IGU to provide modest additional insulating value. The graph shows that to get a triple-glazed unit that is as thin as 0.75 inches (or thinner) at a U value as good as or better than a double-pane window, the triple-pane unit would have to use Krypton (KR) gas rather than Argon (AR) gas. With Krypton gas, the thin triples can achieve insulating values of R-5 to R-8.

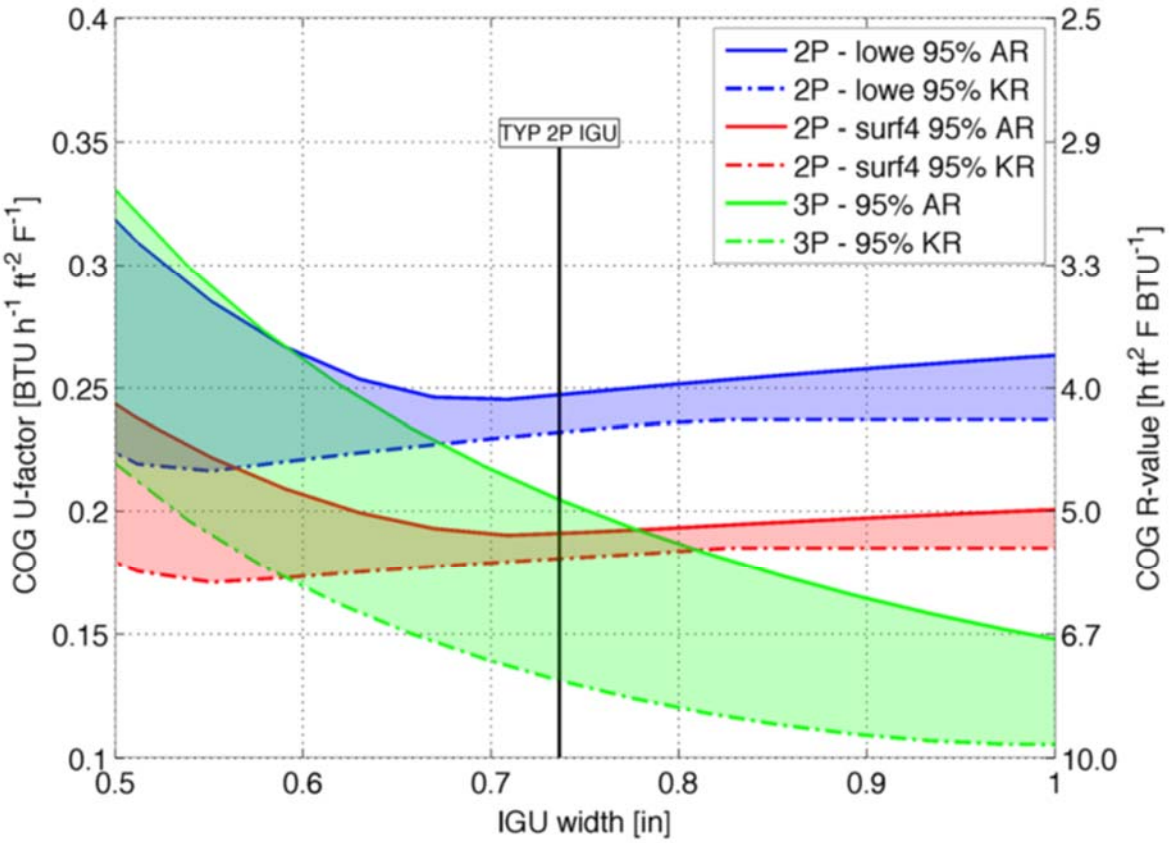


Figure 2. Relationship of U Factor and R-Value to IGU Width for Double- and Triple-Pane Windows with Argon or Krypton Fill and One or Two Layers of Low-E Coatings (Hart and Selkowitz 2018).

Thin-triple IGUs are designed to be interchangeable with double-pane IGUs so they can be installed in any style of frame that will accommodate a double-pane IGU. Installing the IGU in a frame increases the total U-factor (lessens the overall insulation value) because most frame materials are less insulating than a low-e, gas-filled IGU. Frames can be thermally improved, for example the cavities in a hollow vinyl frame can be filled with foam, but these frames are not common. Frame type can affect the overall U value due to air leakage between the sash elements and the frame: fixed windows perform the best, while casement windows with compression seals and good locking hardware are next, and sliders are typically the leakiest window assembly.

Spacer design is one area where the LBNL-designed thin triple-pane windows differ from other standard triple-pane windows on the market. The LBNL design uses a single spacer to separate the first and third panes of glass. The thin middle layer sits or "floats" on this spacer. (See Figure 3.) Standard triple-pane windows and the suspended film windows are usually made with two spacers, one on each side of the center pane or plastic. Not sealing the middle pane can simplify the production process and also allows the krypton gas to transfer from one side of the thin pane to the other, thus balancing pressures between the two gaps. Because there are only two sealant paths, rather than the four found in a conventional design with two spacers, the probability of seal failure should be reduced also. Thin triple-pane windows can also be made with two spacers and with a sealed center pane. In that case a small hole in the middle glass pane allows the gas fill to pass between the two cavities, allowing the gas pressures to balance as the gas on each side expands or contracts due to heating or cooling based on exterior weather and indoor conditions.

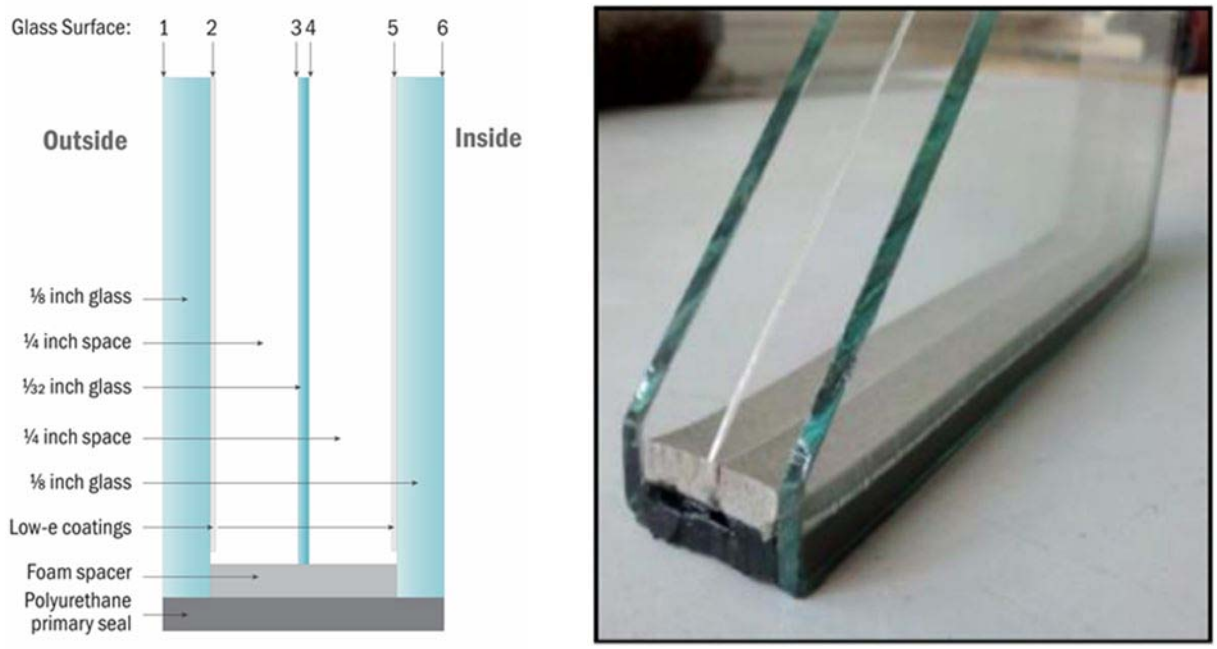


Figure 3. Thin Triple-Pane Window Design showing the Thin Glass Center that Floats on the Spacer and Low-E Coatings on the Second and Fifth Surfaces (Hart and Selkowitz 2018)

1.3 Changes in Materials Costs for Thin-Triple Window Manufacture

While building energy codes and programs such as DOE's Zero Energy Ready Home program and Passive House Institute U.S. (PHIUS) have been drivers for more efficient windows and building envelopes, market forces have also conspired to make thin triples a more realistic possibility from a cost standpoint. When the thin triple concept was first developed in the late 1980s, the thin glass was not commercially available in window sizes. When LBNL re-examined the design 10 years ago, thin glass products were available but at a very high cost. Recently, however, thin glass and krypton, two important components of thin triple-pane windows, have both come down markedly in price (Hart and Selkowitz 2018). Thin glass has become ubiquitous with the advent of flat-screen TVs and monitors, cell phones, and tablets.

Since several manufacturers now produce it in large quantities, the incremental OEM (original equipment manufacturer) cost for thin glass has fallen from $5/ft^2 in 2012 to about $0.60/ft^2 today.

Krypton gas has also come down in price due in part to more available supply. Krypton is used in halogen lights but, with the advent of LEDs, halogen light production has dropped significantly, leaving krypton producers looking for markets. In addition, krypton is a byproduct of xenon production; xenon is used in ion thrusters in satellites so, as more xenon is produced, more krypton is produced. As a result, the price of krypton has also dropped markedly, from $3/ft^2 in 2012 to $0.50/ft^2 today.

The overall incremental manufacturing cost is estimated to be about $2-3/ft^2 for a thin triple-pane window compared to a conventional double low-e IGU (not including supply chain and retailer markups). For comparison, the increased manufacturing cost for a standard triple-pane window is in a similar range if the window manufacturer already makes a window frame that can accommodate the heavier, wider IGU but there's added cost if the window frame has to be redesigned with different profiles and extrusions. An analysis by LBNL showed a simple payback of 5 to 7 years in all U.S. climates for a retrofit when the base case was an older double-glazed clear window and assuming a decision to replace the window was already made so there was no extra labor cost. The paybacks are similar, even in California because, although the savings are less, the energy costs are much higher there. Simple paybacks for thin triple-pane windows, double-pane windows with one low-e coating, double-pane windows with a second low-e coating on surface 4, and standard triple-pane windows are shown in in comparison to double-pane clear glass windows in Figure 4. (Glass surfaces are numbered from outside to inside as shown in Figure 3.)

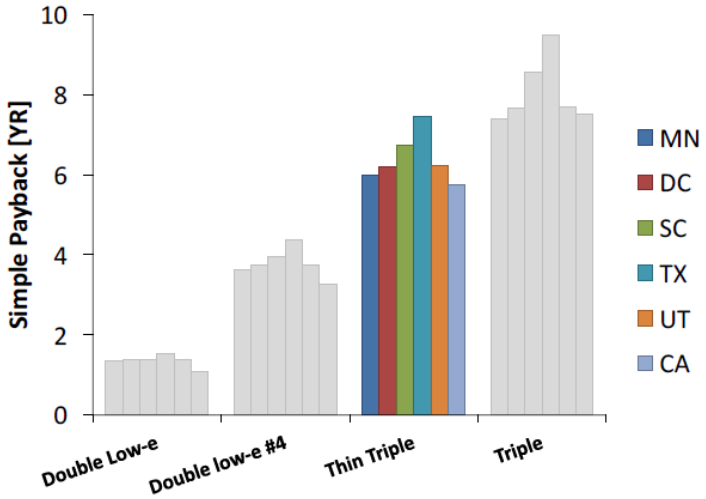


Figure 4. Simple Payback for Thin Triple-Pane Windows, Double-Pane Windows with one Low-E coating, Double-Pane Windows with a second low-e coating on surface 4, and Standard-Thickness Triple-Pane Windows compared to Double-Pane Clear Glass Windows (Hart and Selkowitz 2018).

1.4 Window-Related Codes, Standards, and Specifications in Home Certification Programs

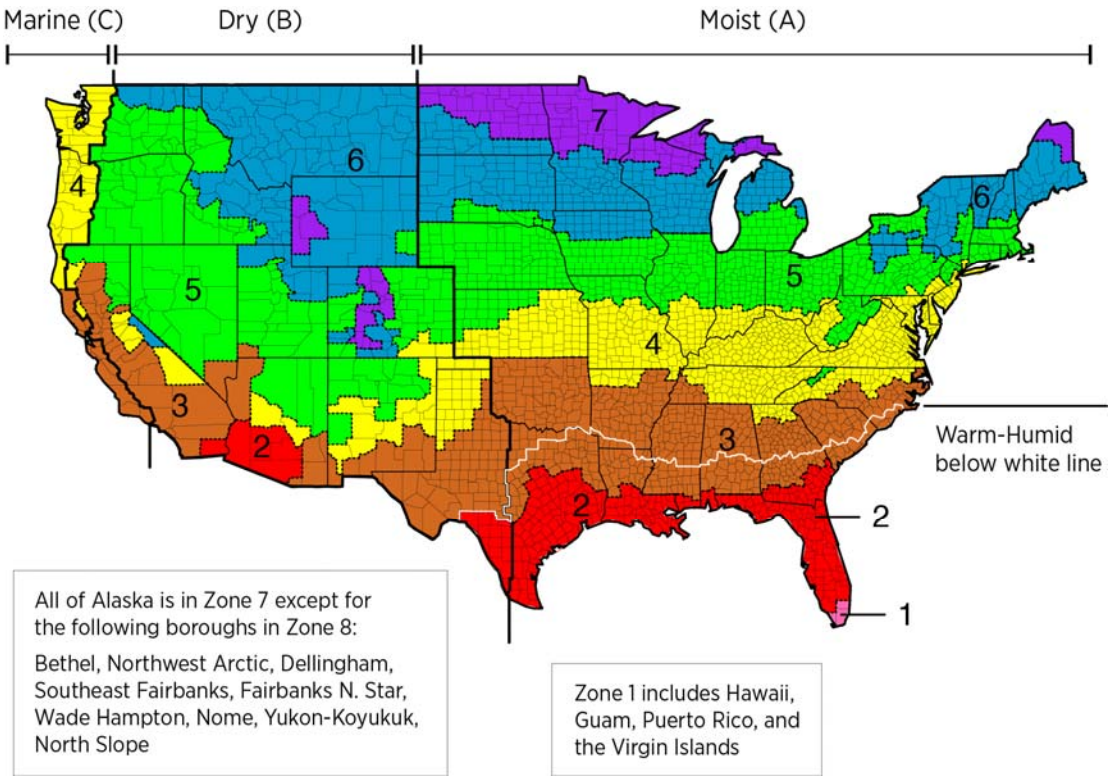
Minimum requirements for window efficiency are specified in building codes and home labeling program criteria. Most U.S. states have adopted building energy codes based on one of the recent versions of the International Energy Conservation Code (IECC), either the 2009, 2012, 2015, or 2018 IECC. The IECC fenestration requirements for these years are shown in Table 2. (These requirements vary based on IECC climate zone, see Figure 5.) ENERGY STAR has its own slightly more stringent fenestration requirements, shown in Figure 6. Figure 6 also shows the ENERGY STAR climate zone designations, which vary slightly from the IECC climate zones shown in Figure 5. Builders participating in the DOE ZERH program must meet a set of mandatory requirements, which includes the requirement that all windows meet or exceed the ENERGY STAR windows criteria.

Table 2. IECC Window Requirements

IECC Climate Zone	2006		2009		2012 and 2015		2018	
	U Factor	SHGC	U Factor	SHGC	U Factor	SHGC	U Factor	SHGC
1	1.20	0.40	1.2	0.30	NR	0.25	NR	0.25
2	0.75	0.40	0.65	0.30	0.40	0.25	0.40	0.25
3	0.65	0.40	0.50	0.30	0.35	0.25	0.32	0.25
4 (except Marine)	0.40	NR	0.35	NR	0.35	0.40	0.32	0.40
5 and Marine 4	0.35	NR	0.35	NR	0.32	NR	0.30	NR
6	0.35	NR	0.35	NR	0.32	NR	0.30	NR
7&8	0.35	NR	0.35	NR	>0.32	NR	0.30	NR
*Can be an area weighted average of fenestration products.								

The DOE ZERH program provides two paths to certification—a prescriptive path, which requires that builders meet a specific set of criteria, in addition to the mandatory requirements, and a performance path, which allows builders to trade off different levels of measures to achieve a target Home Energy Rating System (HERS) score based on a home designed to the prescriptive path requirements. Some builders choose to exceed the ENERGY STAR windows criteria as a trade-off to counter either less insulation in other areas of the home or more glazing (i.e., glass/transparent area). Many DOE ZERH builders also certify their homes through other national or regional home performance programs.

For builders hoping to certify their homes through the ENERGY STAR Certified Homes program, Version 3.0 requires builders to install windows that meet the fenestration criteria of the 2009 IECC but not the more stringent ENERGY STAR windows criteria. However, in 2014, ENERGY STAR Certified Homes issued a national ENERGY STAR Certified Homes Version 3.1, which sets a performance target approximately 15% more efficient than the 2012 IECC (Version 3.0 achieves a whole house efficiency that is roughly 15% more efficient than a home built to the 2009 IECC).



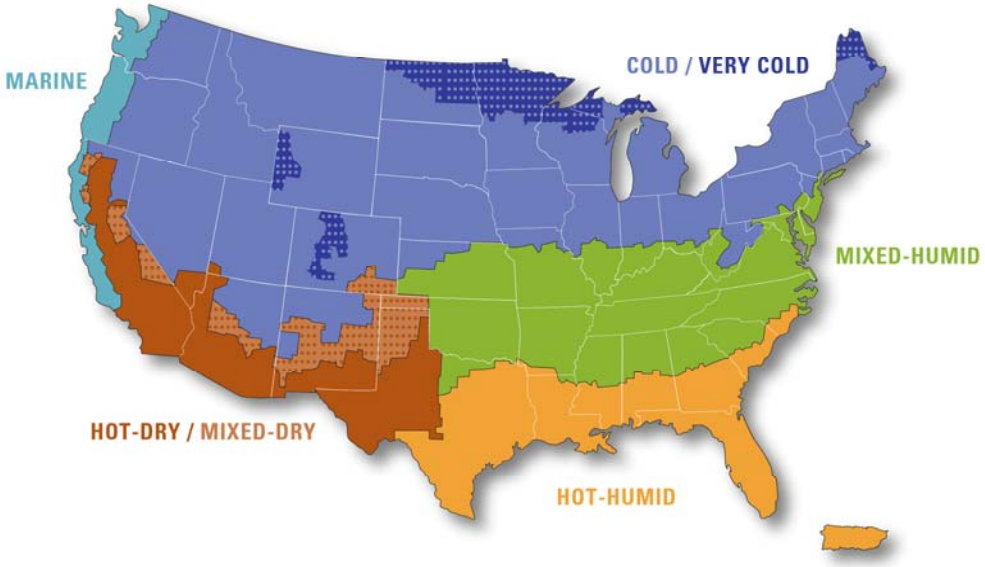


Figure 5. IECC and DOE Building America Climate Zone Designations

WINDOWS			
CLIMATE ZONE	U-FACTOR[1]	SHGC[2]	
Northern	≤0.27	Any	Prescriptive
	=0.28	≥0.32	Equivalent Energy Performance
	=0.29	≥0.37	
	=0.30	≥0.42	
North Central	≤ 0.30	≤ 0.40	
South Central	≤ 0.30	≤ 0.25	
Southern	≤ 0.40	≤ 0.25	

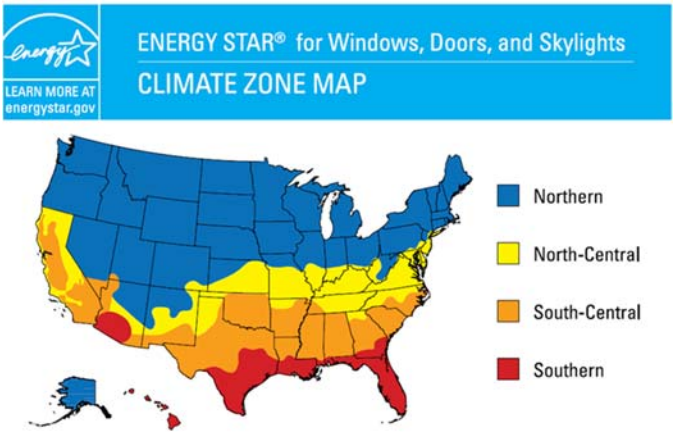


Figure 6. ENERGY STAR Windows Criteria

One way to achieve that target is with better windows, i.e., windows that meet the ENERGY STAR window criteria. These criteria vary by climate zone, with lower SHGC (more sun blocking) in warmer climates and lower U values (i.e., more thermal resistance) in colder climates. In addition to the standard ENERGY STAR criteria, ENERGY STAR has launched a "Most Efficient" program, to promote the highest efficiency products in the market, which would include triple-pane windows. (See https://www.energystar.gov/products/most_efficient for more information.) There is an ENERGY STAR Most Efficient certification for vertical and horizontal sliders, casement style windows, and fixed windows. The ENERGY STAR Most Efficient program specifies the same minimum thermal properties across all climate zones.

Several of the DOE ZERH builders interviewed have also certified at least one home to Passive House Institute U.S. (PHIUS). The PHIUS recommends at least an R-4.5 window, up to R-7 in climates zones 5-7, and R-9 in climate zone 8. (See the IECC climate zone map in Figure 5.)

1.5 Methodology

While there are several players who can impact the adoption of new residential window technologies, including manufacturers, retailers, installers, vendors, home owners, and landlords, this report focuses strictly on home builders and the key part they play in the adoption of new window technologies.

PNNL interviewed participants in DOE's ZERH program, a high-performance home labeling program initiated by DOE's Building Technologies Office in 2013. Zero energy home builders are among those builders most likely to purchase high-performance windows, either to meet the high requirements set by the home labeling and certification programs they participate in or to meet the high personal standards they have set for themselves. PNNL specifically reached out to builders who have participated in DOE's ZERH Housing Innovation Awards and who thus represent the highest performing builders among the DOE ZERH program participants. From December 2018 through March 2019, PNNL attempted to contact all 100 builders who had been recognized through the DOE's ZERH Housing Innovation Awards since 2013. Of the 100 builders PNNL attempted to reach by email and/or phone, PNNL was able to collect in-depth responses from 29 builders.

This group includes builders from across the country who are constructing a variety of types of housing and house sizes. A breakdown of the group by category and by IECC and ENERGY STAR climate zone is shown in Table 3. (See the climate zone maps in Figures 5 and 6.) These 29 builders include some of the most active builders in the program. Together they have constructed 2,534 of the 3,417 homes certified through the DOE ZERH program as of April 1, 2019. In 2018, they constructed an estimated 1,040 homes and purchased an estimated 17,800 windows. The homes built by these builders meet all of the requirements of the DOE Zero Energy Ready Home Program, which include certification to ENERGY STAR Certified Homes, EPA's Indoor airPLUS, the hot water distribution requirements of EPA's WaterSense program, and the insulation requirements of the 2012 International Energy Conservation Code, and the ENERGY STAR window and appliance criteria (DOE 2019). In many instances the builders go beyond these requirements and also add the optional renewables to build homes that achieve a score of 0 or lower on the Home Energy Rating System (HERS) Index (Gilbride and Baechler 2018).

Table 3. Numbers of Builders Interviewed, by IECC Climate Zones, ENERGY STAR Climate Zones, and Builder Category

IECC Climate Zone		ENERGY STAR Climate Zone		Builder Category	
IECC Climate Zone	**Number of Builders***	**ENERGY STAR Climate Zone**	**Number of Builders***	**Category**	**Number of Builders***
1	0	Southern	2	Production	9
2A	1	South Central	11	Affordable	6
2B	2	North Central	3	Multi Family	4
3A	2	Northern	18	Custom Spec	8
3B	1			Custom for Buyer	16
3C	1				
4A	6				
4B	3				
4C	3				
5A	7				
5B	5				
6A	4				
6B	0				

*Some builders build in more than one climate zone or more than one type of home.

Builders were asked about the performance characteristics of the windows they typically purchase, their purchasing practices and motivations, relationships with vendors, reasons for switching vendors and products, primary motivators for choosing or not choosing triple-pane windows including benefits of triple-pane windows and potential design or installation barriers, familiarity with thin triple-pane windows, and concerns if any regarding thin triple-pane windows. The findings are documented in Chapters 2.0 through 7.0. For a full list of the questions asked, see Appendix B.

Throughout this report quotes from builders are included, especially where these quotes reflect a consensus of opinion among many respondents. Some quotes are also included because they reflect a unique but important perspective on a topic. The most significant findings are listed at the end of each chapter.

This report summarizes the key findings from these interviews. While this is the most extensive survey to date of builders' decision making regarding energy-efficient windows, it is still a small survey. It is illustrative of trends and issues; however, it is not definitive. Some of the concerns and perceptions voiced by builders may not have technical solutions that could be addressed by R&D efforts; however, these opinions affect the reputation of these high-performance technologies and, thus, pose market barriers that should be recognized as part of any DOE market-pull strategy related to high-performance windows. Findings from this market assessment will be used with other technical and market data to help guide DOE programs. Implications of these findings for important stakeholder groups, including DOE and the technology research community, utility and efficiency program leads, window manufacturers, window retailers, and the codes and rating community, will be discussed in a separate market assessment and program plan report (Cort and Gilbride 2019).

PNNL did not interview homeowners for this report. Window replacements make up roughly 60% of total residential window sales. This builder survey does not capture all of the factors driving these window replacement decisions, which could be an important source of triple-pane window sales. There is evidence of increasing awareness of the value of high-r (including triple-pane) windows by consumers. For example, a 2019 National Association of Home Builders Survey[1] of home buyers found that 77% of the respondents identified triple-pane windows as either an essential or desirable feature when buying a home (note, no price points were provided as part of the survey). In the interviews described in this report, 17 of the builders (over 50%) construct custom homes for buyers as part or all of their inventory of projects and 14 of those 17 builders use triple-pane windows for some or all of their homes. Window selection is an option that custom home buyers are more likely to influence than other building envelope components.

[1] Information presented by Rose Quint at NAHB's Sustainability and Green subcommittee meeting, April 2019.

2.0 What Type of Window do Builders Pick?

Builders were asked questions about the basic characteristics of the windows they typically install, including U-factor (insulation value), solar heat gain coefficient (SHGC), frame style, and frame material.

2.1 U-Factor and SHGC Value

While DOE ZERH builders must install windows that meet the ENERGY STAR window criteria as a mandatory requirement for certifying their homes to DOE ZERH, many go beyond ENERGY STAR levels. The windows they specify may vary in U-factor from project to project; however, many builders identified a typical U-factor they aim for. These typical values are shown individually for each builder in Figure 7. (Note, builders who build in more than one ENERGY STAR climate zone are represented by more than one data point. For builders who reported using both double- and triple-pane windows, the graph depicts a weighted average of their typical U values.) U values of 0.22 or lower on the graph are all representing triple-pane windows. A U-factor of U=0.20 is equivalent to an R-5; 14 of 29 builders are currently installing a window rated at R-5 or better (U=≤ 0.20), and 8 of the 17 builders in the ENERGY STAR northern climate are meeting or beating an R-5.

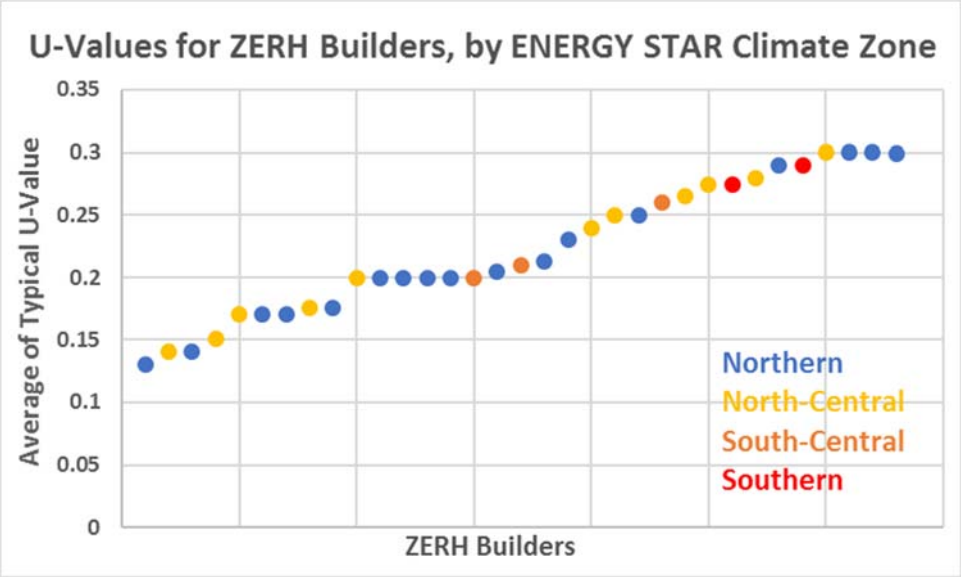


Figure 7. Typical U Values for Windows Used by each DOE ZERH Builder Interviewed (Dot color indicates ENERGY STAR climate zone)

Builders may vary or "tune" the U factor and solar heat gain coefficient (SHGC) of individual windows within a home to increase performance. For example, in northern climates, a builder might use a lower U-factor window on the north-facing side of the house to increase the insulation value on the colder north side. The same builder might choose a lower SHGC for windows on the west side of the house to reduce glare and heat gain from the afternoon summer sun, but he might choose a higher SHGC for windows on the south side of the home if beneficial heat gain is desired from the low winter sun. We asked the DOE ZERH builders if they do any tuning of windows, and more than one-third indicated they have employed window tuning on at least some of their homes (see Figure 8). Of those who did not tune

the windows, one of the most common reasons given was that they had little control over the SHGC for windows that met their U-factor target in their price point. Many builders also cited a desire to simplify things for their installation contractors.

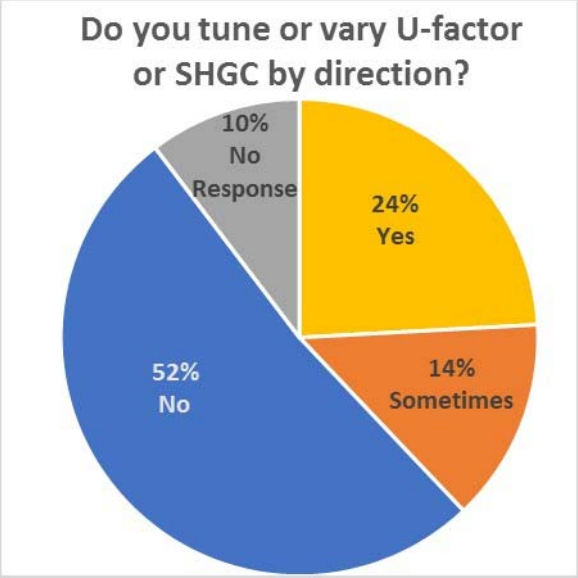


Figure 8. Do You Tune or Vary the U Factor or SHGC Based on the Orientation of the Window in Relation to the Sun?

2.2 Frame Style and Frame Material

In addition to U-factor and SHGC, there are several other variables to consider regarding the windows themselves that can affect the cost and/or performance of the windows. The frame type of the window can affect performance. Fixed windows provide the best performance, because they have the least amount of leakage and least amount of frame to glass. We asked builders which type of window they used and noted all answers; many builders use more than one type. (See Figure 9.) Casement windows, which have gasket-like seals that can compress around all four edges of the window, are the second highest performing from an air leakage standpoint (after fixed) and were the most popular frame type among our builders. These results diverge from national averages of all windows sold where double-hung windows are the most common type, followed by sliders. Sliders typically have the most air leakage and were among the styles least chosen by the builders we interviewed.

Builders were well aware of the impact frame type can have on overall thermal performance. One builder noted that switching from a double-hung to a casement window improved the U factor by 0.01. A production builder who builds in the hot-dry and mixed dry climates noted his company is transitioning from a frame mix of about 40% fixed glass, 40% slider, and 20% single hung to 60% fixed and 40% casement due to the casement's better locking and sealing mechanisms. Another builder pointed out that casements make good egress windows because "you can go with half the size if the whole window opens." The chief drawback to casements is price, although one Habitat for Humanity builder who uses single-hung triple-pane windows that are installed by volunteers also noted "casements have to be hung perfectly square; single-hung are a little more forgiving." Some builders

also noted problems with hardware breakage on triple-pane casement windows. Several builders said they use fixed (non-opening) windows wherever possible. Said one builder, “Most of our windows are not openable; with HRVs [heat recovery ventilators] in the house, people are unlikely to open the windows because the air quality is so high.”

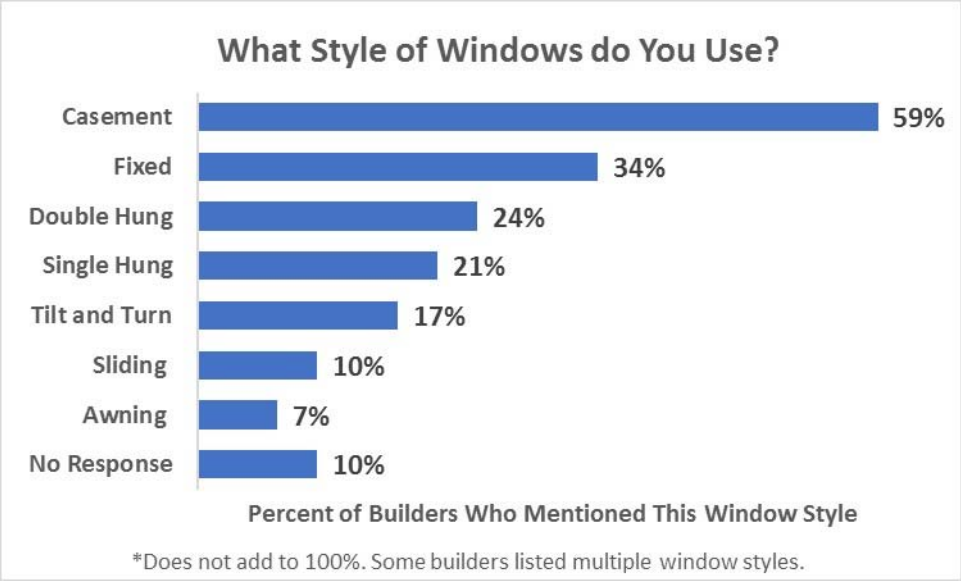


Figure 9. What Frame Style Are Most of Your Windows?

The material the framing is made of can also have an impact on the window’s energy performance. Frame materials include wood, wood interior clad on the exterior face with vinyl or aluminum, composite (made of ground wood and plastic), vinyl (polyvinyl chloride or PVC), uPVC (a more rigid vinyl), metal, fiberglass, and hybrid (wood on the inside and a different material on the outside). Wood frames perform fairly well, with frame U-factors in the range of 0.3 to 0.5 Btu/hr-ft^2-°F (Efficient Windows Collaborative 2019). Molded frames like vinyl, uPVC, fiberglass, and metal can be improved thermally by filling the hollow frame with insulation or separating the hollow cavity into multiple chambers, thus trapping air and breaking up convective loops, which can transfer heat. The majority of the DOE ZERH builders chose vinyl-framed windows for their high performance and low cost (Figure 10).

In addition to framing material, gas fill in the glazing cavities is another variable in the overall window assembly. Choices include air, argon, and krypton, in order of cost. Air is the least insulating of the three. Argon has about a 34% lower conductivity than air; Krypton has a 63% lower conductivity than air (Wilson 2012) although the improvements in a specific window will also depend on the width of the cavity. Nearly all of the builders we interviewed installed argon-filled windows; only one used krypton-filled windows. One Colorado builder used air-filled windows, citing high altitude as a concern with gas-filled windows.

Low-emissivity coatings are very thin, transparent, multilayer silver-based coatings applied to one or more glass surfaces of a double- or triple-pane window to reduce radiant heat transfer through the glazing assembly. In addition to their primary original function to reduce the U factor, they have also been engineered to provide excellent solar control by lowering the SHGC value over a wide range, while

maintaining transparency. Different versions of the coatings can thus serve multiple functions: they can block out summer solar heat gain and ultraviolet rays while letting in visible light and they can reflect winter heat back into the house. Some IGU makers produce IGUs that have low-emissivity coatings on two surfaces for multiple benefits. For example, for a heating-dominated climate, a double-pane window could have a low-e coating to minimize summer heat gain and an additional low-e coating on surface 4 (the surface facing inside the house) to reflect heat back into the room. This second low-E surface alone can reduce the overall U factor of the window by 0.03 to 0.05.

All of the windows used by our builders had low-e coatings. About 90% of all windows sold nationally use low-E coatings.

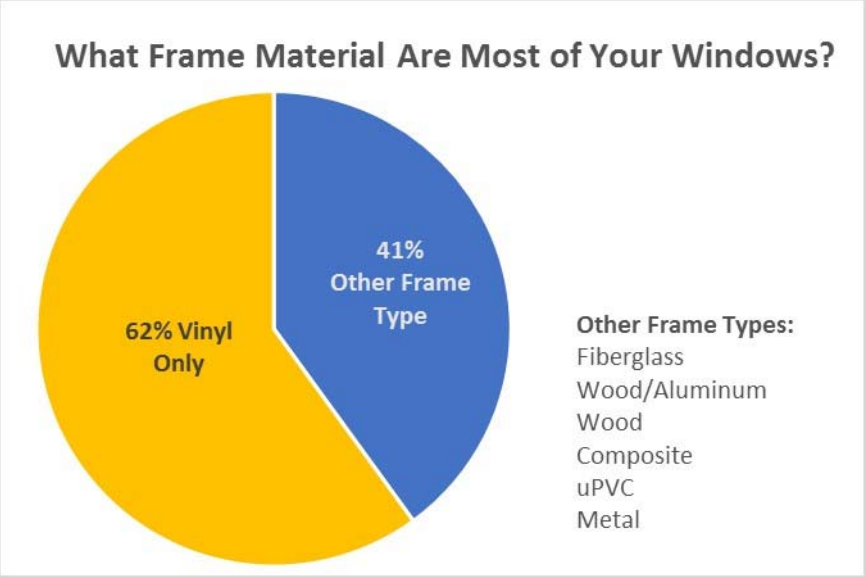


Figure 10. What Frame Material are Most of your Windows?

2.3 Key Findings

Findings related to the characteristics of the windows the builders choose to use are as follows:

- Two-thirds of the ENERGY STAR northern climate builders interviewed are already installing an R-5 (triple-pane) window.
- More builders would tune the SHGC of their windows (vary SHGC by the direction the window is facing) if they had more options for SHGC in lower priced windows.
- Some builders don't tune (vary SHGC by window orientation) in order to keep installations simpler for their installers.
- Builders seeking high performance know casements are the highest performing openable frame types.
- Only one of these high-performance builders uses krypton-filled windows.

3.0 Why do Builders Pick the Windows they Pick?

While one might suspect price would be the primary reason for picking one window over another, among the DOE ZERH builders interviewed, performance was given as the primary reason three times as often as price, regardless of whether they were using mostly double- or mostly triple-pane windows. (See Figure 11.) Price was the most common secondary reason for picking a particular window. (See Figure 12.)

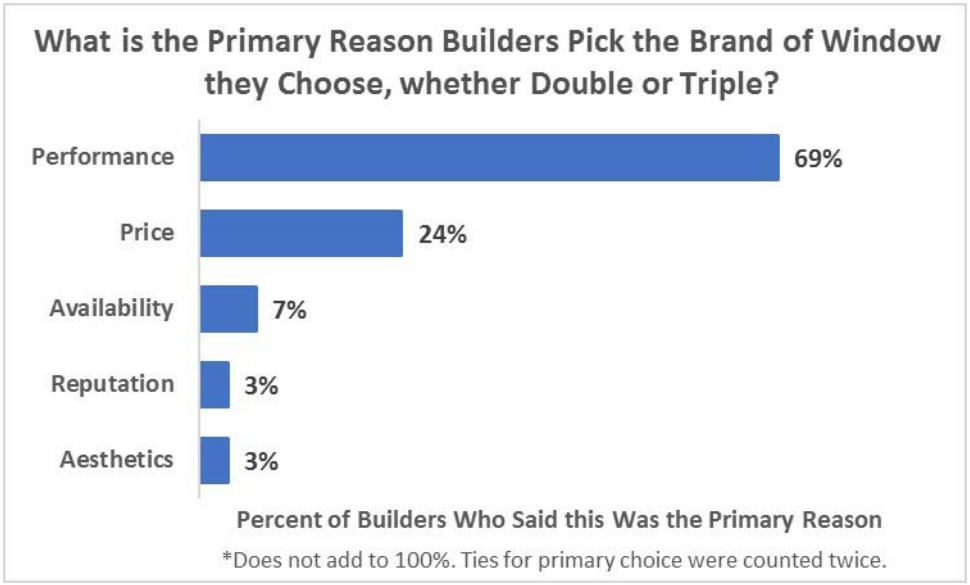


Figure 11. What is the Primary Reason Builders Purchase a Specific Window (double or triple)?

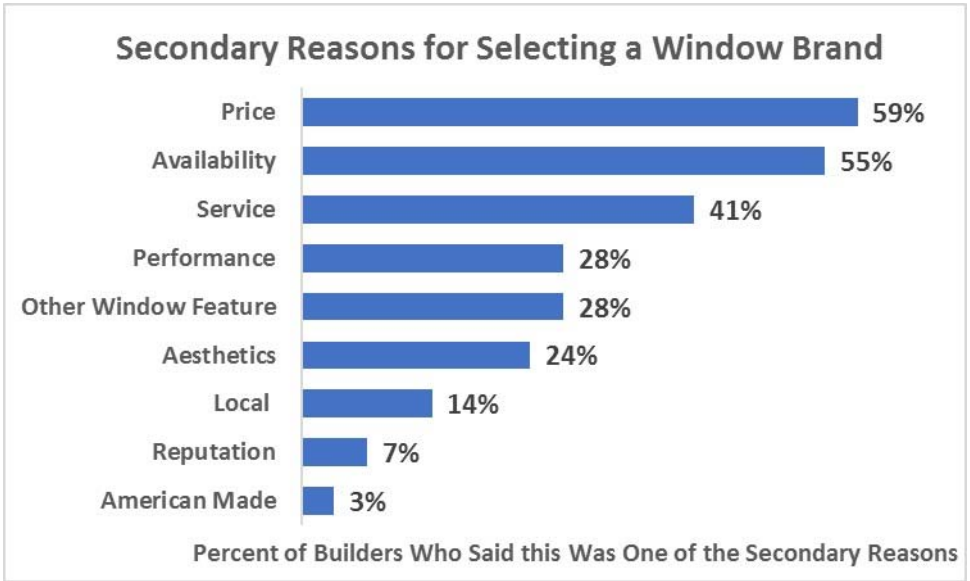


Figure 12. What are the Secondary Reasons Builders Purchase a Specific Window (double or triple)?

3.1 Performance

The DOE ZERH builders pay especially close attention to the performance characteristics of their windows because window performance is one of the items they can trade off when seeking to achieve a lower (i.e., better energy saving) HERS score. As explained above, participants in the DOE ZERH program determine a target HERS score for their home and then must meet or beat that score; many builders are seeking a true net zero home with a HERS score of 10 or lower. The ratings are done by third-party raters who are certified through the Residential Energy Services Network (RESNET). These raters evaluate the home, conduct blower door and duct blaster tests, and determine the HERS score with the use of a software such as REMRATE, Ekotrope, or EnergyGauge that enables the rater and builder to clearly see how adjustments in window performance can affect the HERS score. The HERS rater may also serve as an energy performance consultant on a project, and several builders noted that their rater made recommendations on windows that would help them meet their performance goals.

Said one builder, “My rater recommended these windows. I ask him every month what I can do to get a better HERS score, and he suggested triple-pane windows to me. This change dropped our HERS score by a point.” This builder noted “I’m looking for anything to trim my score without breaking the budget.”

An east coast production builder sticks with his window company because “we’ve had trouble getting that glass package (U value, SHGC, and visual transmittance) from any other maker. We’ve tried looking at other manufacturers, and they couldn’t match this package without getting us a window that looks tinted.”

While performance can refer to the items reported on the NFRC label, especially the U value of the glass package, it is clear that other factors play into builders’ concept of performance, including durable construction, and sturdiness of the frame. Although builders see the heavy weight of many standard triple-pane windows as a detriment, builders still want a solid, sturdy frame.

One builder said, “I look for energy efficiency and construction of the window, one that performs as advertised and doesn't fall apart.” A builder in upstate New York praised his brand for the airtightness of the frames. One builder focuses on manufacturer attention to detail on frame joints, gaskets, and finish.

A Maryland builder expressed a concern about “making sure the frame is sturdy enough. We haven’t had issues but we’ve heard of other brands where the middle part of the window was weak and it could buckle a little bit so that is something we look for.”

Another builder tried a cheaper brand then returned to his more expensive brand because it had a sturdy frame and “very few product defects.” This builder rejected a well-known brand because he didn’t like their quality, fit, and finish. “We have used them on some smaller, cheaper projects but we had to come back to (our other manufacturer) and fine-tune the project after the fact because the product wasn’t sturdy enough and flexed during construction.”

One builder in New England did equate weight with quality, i.e., a heavier window is a higher quality window. He praised his European triple-pane window makers for their “very solid, very heavy, technically sophisticated products.”

While performance was critical, it did not always mean a triple-pane window. In fact, 40% of the builders who picked performance as their primary reason still use a double-pane window. This is likely driven by price as nearly all of these are production or affordable home builders.

3.2 Price

Price was the second most common primary reason and the most common secondary reason for picking a window brand (see Figure 12.) and builders, especially production builders, admitted that they were always weighing one in relation to the other.

It's always "price versus performance and overall reputation" said a Midwest builder. Although builders were asked to rank their reasons for picking the windows they chose, five builders, felt price and performance were so equal they ranked both number one. Another production builder who ranked performance number one said he works with his vendor to find the U value he needs at a price he can afford. An Arizona production builder said "price was the ultimate reason" he picked the vendor he uses; "the biggest factor is cost." A Utah production builder said price was his number one reason for picking both the brand and the trade partners he uses.

Price sensitivity is *the* limiting factor for many builders. "I'd love to have a 0.1 or 0.2 (U factor window) in every house but it's price," said a production builder from Pennsylvania. A Virginia production builder was one of several who voiced the sentiment that, even though performance is important, windows cannot be overpriced in comparison to other home features "The window has to fit into the whole package of costs." Even those builders who don't bid out every job will price check occasionally to make sure they are still getting a good deal.

Builders mentioned several tricks to keep the prices down – ordering standard sizes or in 6-inch increments and limiting unusual window styles (round or arch top) or extra large sizes to an optional upgrade or higher end house model, choosing vinyl over other frame materials, and forgoing any say in SHGC as long as they get the U value they want. One builder mentioned getting home designs "down to only four styles and sizes of windows; that is a way to save money." Some builders choose windows from a high-quality brand's lower priced line which might offer fewer frame styles and color choices but lower prices. One builder mentioned that he looks up window prices on line and the lumber supply store where he buys his windows will match or beat the price.

3.3 Availability

The second most common secondary reason for picking a brand was availability (Figure 12). Where builders buy their windows can impact and limit their purchasing decisions. Builders in our survey identified four sources: from a building supply company, from a window vendor or installer, from a sales representative who represents many brands, or from a sales rep who works directly for a window manufacturer and represents one brand. (See Figure 13.) Builders who buy from window representatives have access through them to multiple window brands. Builders who buy from manufacturer representatives who represent one brand are likely researching to find the manufacturer they want to buy from, then contacting one of that company's representatives. Many of the DOE ZERH builders get their windows from the same local building supply company where they buy most of their

lumber and construction supplies. More than one-fourth of the builders surveyed buy from a local window retailer; most of these vendors offer installation although some builders choose to install their own for greater quality control.

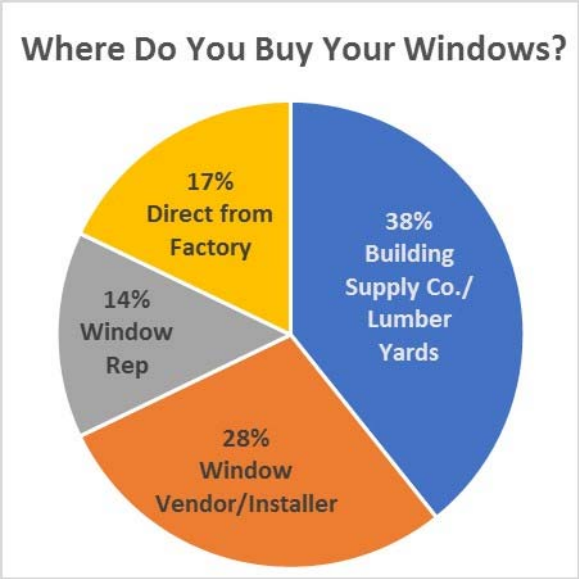


Figure 13. Where Do You Buy Your Windows?

Depending on the size of the building supplier and whether they are located in a rural or urban area, building supply stores might have access to many window brands.

For window vendors, pricing and availability of window products can be based on a complex relationship with the window manufacturers. Several builders, especially production builders, commented that their local distributor only carried one or two brands, often because by just carrying a few brands, the vendor can meet certain sales volume thresholds that earn the local distributor discounts and special pricing from the manufacturer, which incentivizes them to carry and promote only that brand. Because production builders are more likely to use a vendor who also installs windows, they may be more dependent on the local vendors.

One large production builder who said availability was their primary reason for picking a window brand noted that their window vendor, who is also their window installer, only carries one brand because they are able to command discounts and rebates by committing to sell a certain volume of that manufacturer's product. "They may talk to us about other brands, but they will be clear that they won't get the same price. Some installers have loyalty to a product not to a builder, so they will refuse to work with you if you want to try a different product. The loyalty comes from discounts on products and good relationships and support. It's hard to push them away from that without a good reason. So when we ask about a new product, some installers say 'sure we've got a good relationship with that company and we will install their product.' Sometimes they'll say 'we have no relationship with them so we will not install their product.' I think it's based on manufacturer rebates. If the vendor gets good rebates, they are incentivized to carry specific brands. They sometimes pass on those rebates to the builder, not 100% of the time but it may factor in to them providing a more competitive bid."

On the other hand, several custom builders, who often use their framers or in-house staff to install, said availability was not an issue; they would seek out the windows that meet their performance criteria regardless of where they had to go to find them, even to Europe.

Three of the builders we interviewed have actually become window reps for high-performance window companies because they couldn't find a local distributor of a product that met their specifications. One builder in Washington state, who also sells zero energy home plans to other builders, was specifying a triple-pane window that buyers of his home plans could not find. He referred so many people to the Vancouver BC triple-pane window maker he uses that the company asked him to become a representative.

3.4 Customer Service, Vendor Relationships, and Buying Local

Regardless of what window source they are using, if the builder finds a sales person they can trust to be knowledgeable about the many glass and frame options available from the product lines they are representing and to provide good customer service with accurate ordering and fair pricing, this sales person could engender a surprising degree of loyalty, enough loyalty that the builder would not bother to get bids every time. One-third of our builders have not changed their supplier or brand in at least five years and over half do not get bids on every home.

Customer service was noted by several builders as a key reason for picking a brand. One builder stated "the most important thing is the reputation of the company's customer service." Another builder noted he chose his brand based on "reliability, quality, materials, and performance." Another builder who tried a different brand then returned to his favorite brand despite their higher prices, said "they handle warranty issues right away."

Said one builder in Seattle "We work with a local person who represents several window brands. She knows windows very well. We tell her what we need for the project and she helps identify a product that meets our specs at a decent price. We trust her and her expertise to find us the right product."

A Habitat builder in Florida said, "I've been here 11 years and we've used (our distributor) the whole time. We have developed a relationship with them over the years. They offer us a great price too. We stay with tried and true."

A custom home builder in Colorado said he buys his Wisconsin-made windows through a local window store and he's stayed with that vendor for 12 years because the vendor "is so knowledgeable about all the details."

Notes a production builder in the southwest, "It's all about relationship and quality of service. Do they do good rough estimates? Are they good at pricing out a job?"

A production builder in Utah who employs two vendor/installers said, "We have long-standing relationships with our trade partners. We stick with our relationships, we don't necessarily get bids for every project."

Having a good relationship with a window vendor and then losing them is a significant source of frustration for builders. One Chicago area production builder's experience underscores the complexity of the relationship. "We like to find and continue with a trade partner. We want one window vendor that we can trust to give us the product, performance, and price we need. We had a great relationship with our past window rep; we liked the brand he represented. But, the manufacturer's local distributor was a building supply company that went out of business, and they haven't gotten another (local distributor). We spent $300,000 on windows this year; we would love to work with (that manufacturer's) factory directly, but they only work through distributors and they have no local distributor."

Although some DOE ZERH builders buy windows made by large nationally known manufacturers, many of our builders buy their windows from smaller regional manufacturers. In fact 21 of the 32 brands mentioned were only mentioned by one builder. Table 4 shows the number of different brands represented in each company size category.

Some builders commented that they liked buying from local window manufacturers from a low carbon footprint standpoint, and one builder noted that it was important to him to buy American made. Said one Arizona builder, "Our windows are made right here in Prescott Valley. They are trucked only 20 miles from the factory to where they are used." One Minnesota builder said, "I have found windows need to be made locally – in the same state or in a surrounding area that understands the cold climate."

A production builder in Virginia who buys from a local manufacturer commented, "I've been using (our window maker) for 20 years. He's watched me evolve from affordable, to middle income, to high tech. He can make what I need. I've never bought from anyone else. It's a great relationship."

Table 4. Window Brands Used, by Size of Manufacturer

Number of Builders who Chose a Brand this Size	Size in Annual Sales
11	Over $1 Billion
	$500 - $1 Billion
4	$300 - $500 Million
	$200 - $300 Million
5	$100 - $200 Million
2	$50 - $100 Million
	$30 - $50 Million
1	$15 - $30 Million
	Less than $15 Million
16	Less than $10 Million*
*estimate. Source: Window&Door, Top 100 Manufacturers 2018 Report. Accessed May 16, 2018.	

3.5 Aesthetics

Aesthetics was identified as a reason for choosing a window more often as a secondary reason than as a primary reason. Custom home buyers often request a specific frame style, frame material, or color, even if they don't specify a brand name. Some homes are built in historic neighborhoods that have requirements for specific window styles and colors on street-facing facades. One builder said he's built in neighborhoods where the developer or the Home Owners Association specified a specific brand of window.

3.6 Brand Reputation

Very few builders selected brand reputation as a primary or secondary reason for choosing a brand. Brand reputation was sometimes a driver for the builder, often based on a company's reputation for good service, but several custom builders indicated brand preference came from the home buyer, who could have considerable influence on window selection in custom home purchases.

However, several builders felt that their buyers didn't know or care about window brands. One production builder in Colorado said, "Most homebuyers don't know window manufacturers by name, except a few of the largest, and those brands are for luxury homes typically."

3.7 Key Findings

Findings related to why builders pick the window brands or vendors they pick are as follows:

Performance

- The majority of builders ranked performance as the number one reason for choosing the windows they use on a project.
- Builders consider performance aspects of the whole window, including operating performance and functionality, in addition to the energy performance of the glass and frame.
- Builders want a solid, sturdy window. One builder equated the heavy weight of European triples with a higher quality.
- Builders have had trouble getting the glass package performance they need (U factor, SHGC, and visual transmittance) in a window that doesn't look tinted.
- High-performance builders are concerned about the HERS score and will choose a window specifically to lower their HERS score.

Price

- Price was the most common secondary reason for picking a window.

Availability

- Production builders who use vendor installers are often limited by vendor-manufacturer relationships in what windows they can order.

Vendor Relationships/Buying Local

- One-third of the builders we interviewed have not changed their supplier or brand in at least five years. For these builders, “it’s all about relationship.”

- Over half of the builder interviewed do not get bids on every home but instead rely on relationships with a trusted window supplier to give them a good price, good product, and good customer service.

- More than half of the brand selections by builders were for small regional manufacturers. 21 of the 32 brands mentioned were only mentioned by one builder.

Aesthetics

- Aesthetics was listed as among the least important reasons identified for picking a window.

Brand Reputation

- Brand identity seemed to be a low priority.

4.0 Why do Builders Switch Window Products?

Builders who have switched brands or vendors in the last five years identified several reasons for switching brands. (See Figure 14.) Nearly two-thirds of builders interviewed have switched brands or vendors recently.

4.1 Performance

We noted performance was the primary reason for picking a window brand. It was also the primary reason for switching brands. In some cases, the builder was seeking a window with a lower U value. In many instances, performance referred to product quality. For example, a Habitat builder in Michigan mentioned when they switched from one company's double-pane windows to a triple-pane model, the new product had issues with the frame twisting and bending and they had a lot of leakage problems forcing them to look for a different brand. A Colorado builder said he had switched to a cheaper product based on price then switched back to his old brand because the cheaper product wasn't sturdy enough and flexed during construction.

4.2 Price

Only four builders mentioned switching due to price. In one case, it was because the window manufacturer raised prices several times but the builder was also having quality issues with the company's product. In another case involving a custom builder who installs triple-pane windows, the builder has a preferred vendor but is willing to switch to a lower cost brand if the customer can't afford that brand. However, he noted "every time I order from someone else, we have to rerun the math to see what happens. We have cases where we've run the numbers and we were going to have to add a second heat pump to match the performance of (my preferred brand) so it ended up being cheaper overall to go with (my preferred brand's) triples." The third and fourth cases involved custom builders who spec windows based on the wishes of their client, although both have brands they recommend based on performance.

4.3 Customer Service

Another reason for switching brands and vendors was poor customer service (for example, mixed up orders or delays resolving warranty issues). For example, one builder in Georgia was using a window vendor, but he switched to ordering from his lumber supply store because of customer service, not window quality; he is still using the same national brand. "There were planning issues. The vendor didn't seem to understand the goals of the project, they forgot to list some of the windows. I focused on the performance side and assumed they were counting correctly. I also had issues on the delivery and installation. They did not do a good job on the installation."

4.4 Quality

A few builders changed brands because of quality issues and high callbacks. One production builder in Delaware was experiencing "a lot of maintenance and warranty issues. We were getting home owner complaints – broken seals was a big one, hardware not locking, windows tough to open and close, etc."

4.5 Other

Other issues cited by builders for switching window brands or vendors include vendors or distributors who went out of business or stopped carrying their preferred brand, long lead times (this was from two builders regarding windows coming from Europe), weight (the builder found a lighter weight triple-pane window), and changing to a brand specified by the Home Owners Association (HOA). For custom builders, each project is unique, and client requests can lead to changes in vendor or brand. One builder noted he recently switched brands to find a triple-pane manufacturer who could provide him with windows and matching doors that are American with Disabilities Act (ADA) compliant.

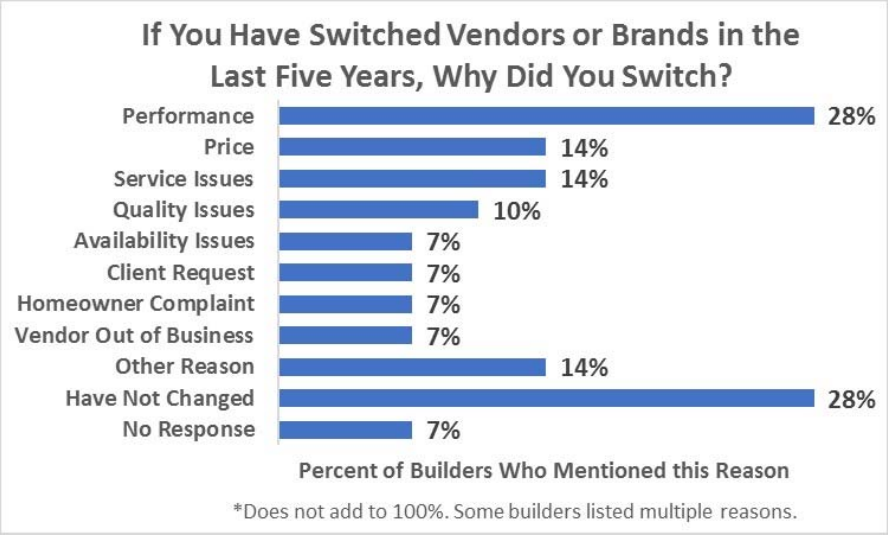


Figure 14. If You Have Switched Vendors or Brands in the Last 5 Years, Why Did You Switch?

4.6 Key Findings

Findings related to why builders switch window brands or vendors are as follows:

- Builders will "vote with their feet." Several left a vendor due to poor customer service or product quality issues.
- Builders want a vendor partner who understands the builder's high performance goals.
- Builders are price sensitive but performance is even more important.

5.0 Why do Builders Choose Triple-Pane Windows?

Of the DOE ZERH builders surveyed for this study, 41% use all triple-pane windows and another 28% install triple-pane windows in most or some of their homes. (See Figure 15.) This corresponds to data for all DOE ZERH Housing Innovation Award[1] participants (100 builders), where 39% of builders reported using triple-pane windows. All of the production builders we interviewed are using a double-pane window. Two custom builders who also do some production homes use 100% triple-pane windows. Three of the four affordable home builders we interviewed use 100% triple-pane windows. DOE's Zero Energy Ready Home program defines a production builder as one who has certified at least 15 DOE ZERH since the previous June. An affordable home is "a home built to an affordable price point that includes income-eligibility requirements for owners and/or occupants."

Builders participating in the windows study who have installed triple-pane windows in their homes were asked if the triple-pane windows are standard or an optional upgrade. (See Figure 16.) For most of these builders, they are standard; for 40% triple-pane windows are an optional upgrade. All of the builders who offer them as an optional upgrade are custom home builders.

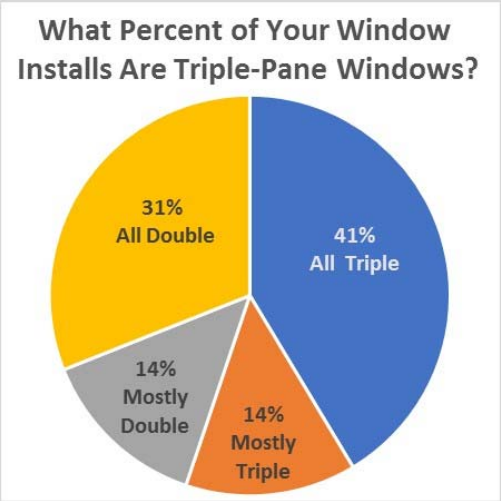


Figure 15. What Percent of Your Window Installs are Triple-Pane Windows?

[1] See https://www.energy.gov/eere/buildings/housing-innovation-awards for more information.

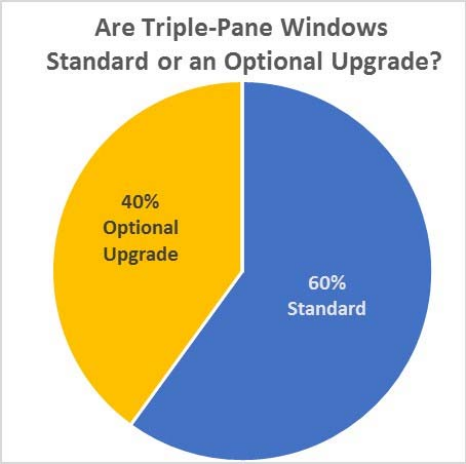


Figure 16. Are Triple-Pane Windows Standard or an Optional Upgrade?

5.1 Performance

For builders who choose to install triple-pane windows, the overwhelming majority said performance was the primary reason. (See Figure 17.) Their detailed answers provided additional nuances to their motivations.

One builder in the Chicago area said he uses triples for "performance and to distinguish us in the market. We are the only builder in our market using triple-pane windows."

Two builders specifically mentioned HERS score. One custom builder said he uses triples to boost his "HERS score. We are trying to move into higher performance homes. We are going to triple pane for that reason. I want to make something I'm happy about." A New York builder said, "My goal is to have the lowest HERS score possible before solar."

A Seattle builder said installing triple-pane windows is "the right thing to do" and it helps him get to the 5-Star Built Green program requirement of being 30% better than local code.

A Long Island builder of homes for nonprofit agencies said, "The life cycle cost and sustainable savings is more important than immediate first cost. The simple payback doesn't make sense. If I forecast the savings over 30 years, it makes sense. The math works for us more because we have such high utility rates. Our electricity is 18 to 21 cents/kWh."

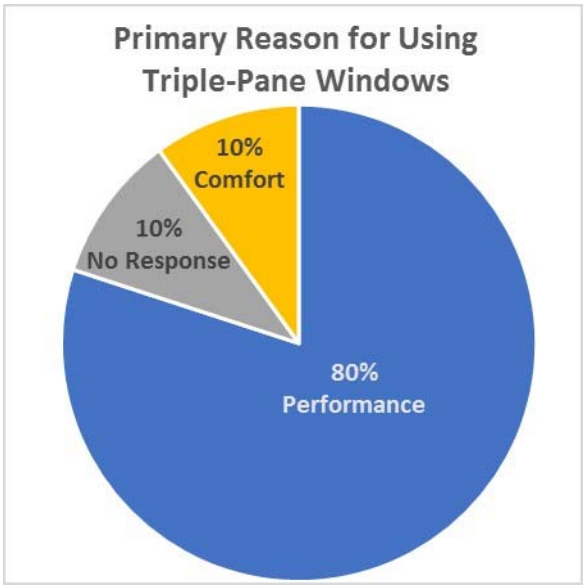


Figure 17. What is Your Primary Reason for Using Triple-Pane Windows?

5.2 Noise Reduction

The most mentioned secondary reason that builders gave for using triple-pane windows was noise reduction. (See Figure 18.) Only one builder specifically mentioned energy efficiency, although it is implied in performance.

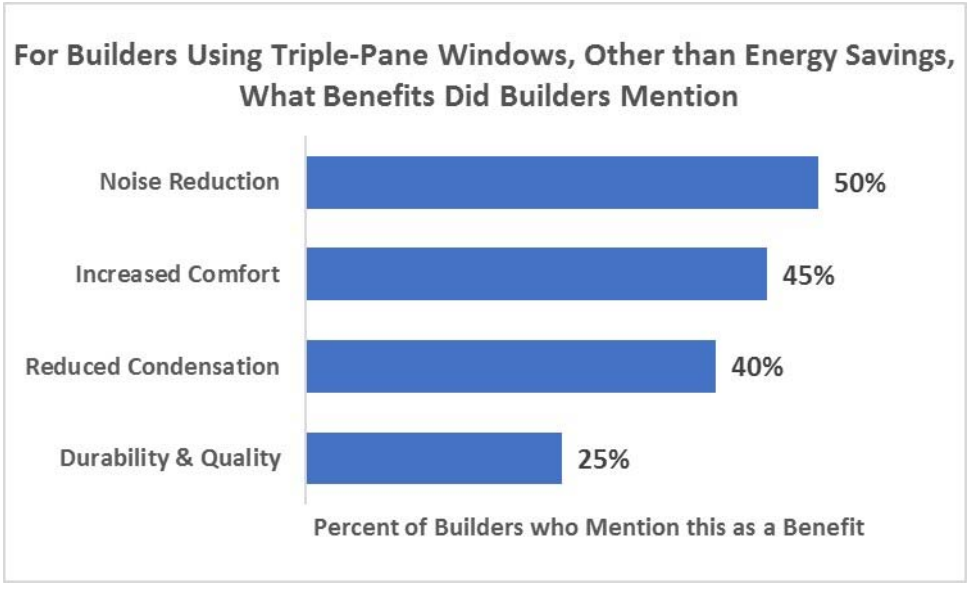


Figure 18. Benefits Builders Mention for Triple-Pane Windows

A builder who constructs urban infill homes in Seattle promotes triple-pane windows as part of the highly insulated envelope that makes his homes so quiet. “When someone comes into the house and you shut the door, it’s like getting into a Mercedes or BMW. It’s so solid and quiet. We are building homes next to Boeing Field airport in Seattle. Planes are flying right overhead so close you can clearly see them from the houses, and it is so quiet inside you can’t hear them.”

Another builder in eastern Washington also mentioned the sound-dampening effects. “A house with triple-pane windows is incredibly quiet. People always comment on how quiet my homes are. That cannot be accomplished without a U value below a U=0.2. My standard for a window is U=0.18 and doors are U=0.24 because of that.” He went on to say “Researchers are now finding health benefits (physical and psychological) to quieting the home. It was a big topic at the 2019 International Builders Show (IBS). Joe Lstiburek (a well-known building scientist) mentioned it in his IBS talk. You can stand outside a triple-pane window and yell, and you won’t hear it in the house. It’s amazing how many people are sound sensitive. I had a builder in Cle Elum who just built a home for a couple in Seattle, and they asked him to build specifically for sound attenuation.”

5.3 Increased Comfort

Several cold-climate builders mentioned comfort as a benefit. An upper Midwest builder said, “We are in the 20s and 30s here in the winter. You can stand in front of these windows and not feel any difference in temperature from the center of the house.” “The comfort level is really noticeable,” said a Colorado builder. “You can stand next to a triple-pane window on a 1-degree day in a t-shirt. It’s too cold for that with a double-pane window.” Another builder commented that with triple-pane windows the comfort level is consistent across the room and close to the window.

A Midwest builder noted that triple-pane windows are a part of their marketing effort to position themselves as unique in the market. “We advertise that all of our homes have triple-pane windows for greater comfort, durability, and air quality.” This builder said his home owners have noticed the “the pure comfort of sitting next to a triple-pane window.”

5.4 Decreased Condensation

Reduced condensation was the third most common secondary reason for choosing triple-pane windows. A builder on Long Island noted that the double-pane windows he used in the past had condensation and mold on the window sills. “People don’t like water puddling up.”

One custom builder in Connecticut said, “We point out when you get windows with U values that are low, even with very cold outdoor temps you are very unlikely to get condensation. Ten years ago we did a very expensive house, very elegant, with lots of windows. I suggested triple-pane windows; they went with double-pane. Last winter it got really cold and they got all this condensation. They called me asking about replacing all the windows.” He noted the irony that putting in double-pane windows to “save money” actually ended up costing much more, due to the cost of two sets of windows and the labor to remove the double-pane and install new triple-pane windows.

One Habitat for Humanity builder in the Midwest said performance and condensation were the reasons his affiliate switched from double- to triple-pane windows. “Water destroys structures. We used to use double-pane windows but we would get so much condensation, we would literally see rotting of the wood sills and the drywall around the windows, as well as frost on the inside face of the windows and mold on the walls. It’s a real durability and health issue. Six years ago, we switched to triple-pane windows. Since we started installing them, there is zero condensation on the windows, even when it’s zero degrees outside and high humidity inside.” The builder noted their homes usually go to families with children and inside humidity can sometimes get up to 80% due to cooking, bathing, and laundering, even with continuous ventilation. “And still we’re not seeing condensation issues. In my own home, with double-pane windows, I’m seeing ice on the windows inside the house in the winter.”

5.5 HVAC Impacts

While high-performance home programs like the DOE ZERH program require that HVAC systems be sized according to the Air Conditioning Contractors of America (ACCA) Manual J sizing calculations, “rules of thumb” for HVAC system sizing abound in an industry eager to avoid customer callbacks for not providing enough cooling or heating. Rules of thumb may recommend 1 ton (12,000 BTUs of equipment capacity) for every 600, 500, or even 400 ft^2 of living space. Manual J calculations will nearly always recommend smaller “right-sized” systems. High performance home construction that includes high levels of insulation and highly efficient windows can allow builders to reduce HVAC equipment sizes even more while still providing adequate heating and cooling.

Builders were asked what impact, if any, triple-pane windows had on their HVAC systems. (See Figure 19.) Half said it allowed them to reduce the size of their HVAC system. Over one-fourth reported that they can use mini-split heat pumps and that, even with ductless heat pumps, temperatures are even throughout the home, including along exterior walls with windows.

A Connecticut builder said, “Window performance is absolutely going to make a difference in HVAC sizing. You could go crazy with your walls and roof, and if you have poor windows, it will seriously undermine that. Your loads are a sum total of your exterior surfaces.”

A custom home builder in California noted that using triple panes “simplifies duct design and permits the use of mini-splits in some applications.” He added “room loads are more even.”

A builder in Ohio who uses ducted and ductless mini-splits said, “I can do shorter duct runs when I have better windows. The registers don’t have to be blowing directly on the windows.”

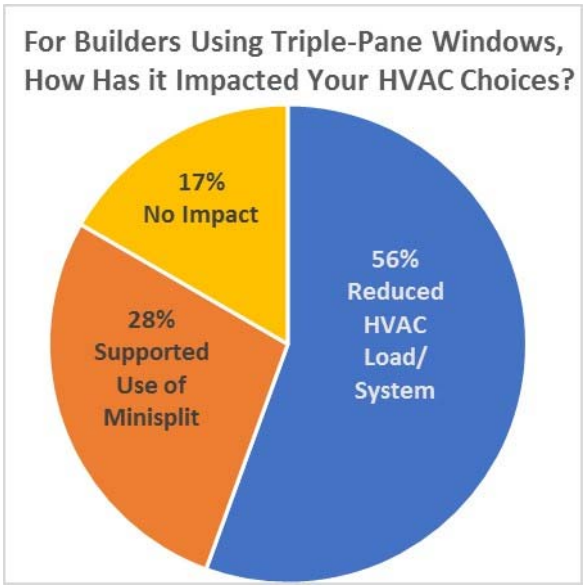


Figure 19. How Have Triple-Pane Windows Impacted HVAC Equipment Selections?

A builder in Bellingham, Washington, noted that his loads "typically are in the 9,000 to 12,000 BTU/hr range (.75 to 1-ton range). Bigger homes could be 14,000 to 17,000 BTU/hr (1.16 to 1.41 ton). For bigger homes, we use a ductless air-to-water heat pump rated at 22,000 BTU (1.83 ton). It ramps down for lower load times. For smaller homes, we use an air-to-air mini-split heat pump that is rated at 9,000 BTU. It also ramps down for lower loads." These HVAC capacities are about one-fourth the size of the central heat pumps or air conditioners that would typically be recommended for a 2,000 to 3,000-ft^2 home using HVAC industry rule of thumb sizing estimates.

A Seattle builder was able to downsize the HVAC for his three-story, 3,000 to 4,000-ft^2 urban infill homes, "and it's comfortable everywhere, no cold spots."

An upstate New York builder said the whole load for the homes he builds is "18,000 to 22,000 BTUs for a 3,000 to 4,000-ft^2 house." This builder noted "I definitely see it in the HERS modeling. If I were to switch to a regular ENERGY STAR double-pane window, it would probably increase my HERS score by 10%-20%." This builder notes that if he were to install U=0.27 double-pane ENERGY STAR windows, instead of the U=0.18 triple-pane windows he now installs, he would have to increase the size of his HVAC system by 13% to 15% for his typical 3,000-ft^2 home with 18% to 20% glazing. This would increase his HVAC system costs by about 15% as well. "I don't need registers near outside walls because the triple-pane windows and ICF walls perform so well I don't get cold walls." This builder noted if he did use double-pane windows instead of triple-pane windows, he likely would install his supply registers near outside walls, which with his compact three-story house designs would add about 30 feet of duct and about $300 to $400 to the duct installation cost.

A Long Island builder noted that "windows had a bigger impact on our cooling load than on the heating load in Manual J. We see much less summer heat gain if we use better windows. On the winter heating side, we have less condensation and dripping." Another builder in the Midwest noted, "there is a big cooling difference from the low-e coatings."

For one builder the high-performance of triple-pane windows is actually too good. This builder and zero energy home designer from Washington state said, “I have actually used double-pane in some small homes because if we make the house too efficient, the home owner will drop plans for the heat pump and go to electric resistance heat instead. The smallest heat pump unit out there now is 9,000 BTUs. When someone makes a 5,000 BTU ductless heat pump, we’ll be there, but for now my homeowners on some very small homes are choosing resistance heat, which drives energy use back up.”

A Habitat builder from Michigan who installs triple-pane windows in all his homes, said that “having better windows has allowed us to have center throws for the HVAC ducts and we do not notice it being cold near the windows.” He also explained that the insulating triple-pane windows and highly insulated walls he uses have allowed him to go to a small, high-efficiency furnace. The furnaces we get are 15,000 Btus with a modulating burner and modulating fan and 2.5-inch ducts. The fan motor can modulate down to 5,000 Btus.”

This Michigan builder asked his HERS rater to provide us with numbers showing what the heating load is in the Habitat affiliate’s homes with triple-pane windows and what the heating load would be for those same homes if they installed double-pane instead of triple-pane windows. The HERS rater ran RemRate for four recently constructed homes.

Table 5 shows the impact that using double-pane instead of triple-pane windows would have on the space heating design load, which dictates HVAC sizing, for these four homes designated M1 through M4. The HERS rater noted that the design load differences would have been even larger if the homes had been bigger, market-rate homes, but choices in home design made by this Habitat builder (including small size, fewer windows, large overhangs, and basic rectangle design) kept the heating and cooling loads small regardless of window U values. The HERS rater noted that the energy cost savings were slightly higher than the HVAC heating load reductions, so for example for the MI 1 house the cost savings were a little over 6%.

The rater also noted that the MI-4 house design was built several times. The first time it was actually built for sale as a market-rate house with double-pane U=0.44 windows installed. In subsequent constructions of this design, the windows were changed to U=0.21. Other improvements in envelope insulation were also made but, according to the rater, the better U value alone allowed the builder to use a 15,000 Btu furnace rather than a 30,000 Btu furnace, which yielded a $200 up-front savings. It also allowed them to do interior supply register throws instead of installing supply registers along exterior walls, cutting the amount of duct installed in half, for a material savings of another $500. It also cut the cooling design load from 1.4 tons (17,000 Btu) to 1 ton (12,000 Btu) yielding a 29% cooling design load reduction and bumping the SEER rating from 21 to 25. According to the rater, switching to higher performing windows yielded a total drop in installed HVAC costs of 9.5%.

A Seattle area builder who uses triple-pane windows also asked his HERS rater to give us RemRate results for five recent homes showing space heating design loads for the homes with triple-pane windows and with double-pane windows. These homes are included in Table 5 as well and are designated WA 1 through WA 5. Window-to-wall ratios for these homes ranged from 17% for WA 3 to 23% for WA 5. As shown, the change to triple panes alone yielded HVAC reductions of 10% to 13%-

Table 5. Examples of Space Heating Design Load Reductions Due to Triple-Pane Instead of Double-Pane Windows in Several Homes from Two Builders

House	Double Pane		Triple Pane		HVAC Heating Load Reduction
	U-Value	Btu Design Space Heating Load	U-Value	Btu Design Space Heating Load	
MI 1 (Springmont), 900 ft^2	0.31	15,937	0.21	14,942	6%
MI 2 (Denner/Trimble), 1,100 ft^2	0.32	13,191	0.21	12,309	6%
MI 3 (Cedar), 1,200 ft^2	0.32	13,401	0.21	12,435	7%
MI 4 (Gateway), 1,000 ft^2	0.44 & SHGC 0.51	22,209	0.21 & SHGC 0.29	18,357	17%
WA 1 (16th Ave) 2,730 ft^2	0.27 & SHCG 0.30	16,600	0.20 & SHGC 0.30	14,400	13%
WA 2 (MLK) 1,057 ft^2	0.27 & SHCG 0.30	9,100	0.20 & SHGC 0.30	8,200	10%
WA 3 (33rd Ave) 2,635 ft^2	0.27 & SHCG 0.30	17,700	0.20 & SHGC 0.30	15,900	10%
WA 4 (42nd Ave) 2,595 ft^2	0.27 & SHCG 0.30	13,800	0.20 & SHGC 0.30	12,200	12%
WA 5 (Flora Ave) 2,646 ft^2	0.27 & SHCG 0.30	21,600	0.20 & SHGC 0.30	18,800	13%

5.6 Key Findings

Findings related to why builders choose triple-pane windows are as follows:

- Performance trumps all other reasons as the primary reason for using triple-pane windows.
- Noise reduction is seen by some as a health benefit.
- Noise reduction was the most mentioned secondary reason for using triple-pane windows.
- Increased comfort is noticed by home owners.
- Condensation affects more than visibility; it is a health and durability issue as well.
- Half of the builders interviewed acknowledged that triple-pane windows allowed them to reduce their HVAC size.
- Many said with triple-pane windows they could do interior throws rather than installing supply duct registers along exterior walls.
- Many builders felt that triple-pane windows “enabled” them to install mini-split ductless heat pumps.
- Data from two builders showed that switching from double to triple pane windows reduced HVAC heating loads from 6% to 17% in smaller homes and from 10% to 13% in larger homes.

6.0 Why Don't Builders Choose Triple-Pane Windows?

Builders who don't use triple-pane windows were asked about why they do not install triple-pane windows and were given a list of reasons to choose from, which included cost, availability, not enough energy savings, no consumer demand, installation issues, and design issues. Primary and secondary reasons for not installing triple-pane windows are shown in Figure 20.

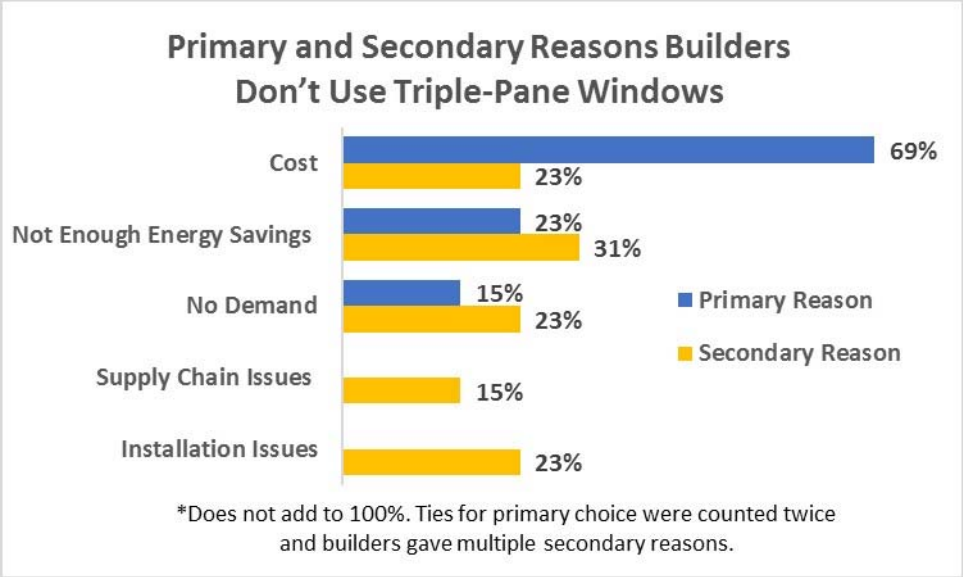


Figure 20. Primary and Secondary Reasons Builders Don't Use Triple-Pane Windows

6.1 Cost

For the 31% of the DOE ZERH builders who don't install triple-pane windows, and the 14% who sometimes install triple-pane windows, price was by far the biggest reason for not installing triple-pane windows.

As one custom builder who installs triple-pane windows in about 30% of his homes noted, "Cost is the only reason I would not use triple. There is no other reason."

A production builder in Virginia said, "I'd prefer to have a triple pane. I've used them in the past, but I'm looking for something for production homes in the $400,000 price range. The window has to fit into the whole package of costs."

A Pennsylvania builder who does production and custom homes said, "If the price came down, I'd do it in a second. I've looked at the cost trade off. For example, 'If I do better windows, can I decrease my PV and still hit net zero?' So far it doesn't pencil out. I'd love to have a U=0.1 or U=0.2 window in every house but … I can't justify the added cost."

A production builder in Arizona said, "The biggest factor is cost. If I were building my own home, it'd have an 8-inch wall and triple-pane windows. But, we are a production builder, so we have to be cost

sensitive. I can't go so high end in one area that it will cause issues in other areas. We constantly ask ourselves 'Will anything I'm putting into this house cause an objection for the home owner?' We are already $1 to 1.50 more per square foot than the ENERGY STAR builder down the street. But, our sales staff can justify that cost with a whole list of improvements – better windows, better air sealing, slab edge insulation, an ERV. If I'm selling a $300,000 house, and I want to bump up the cost $30,000 just to put in a high-end window package, our home buyers won't buy it."

One Ohio custom builder said triple-panes can cost twice as much as good double-pane windows. When he got two quotes for a very large home with 70 windows, the double-pane quote was $65,000, the triple-pane quote was $120,000.

A custom home builder in Georgia said, "My only triple-pane house was $24,000 for [an upscale U.S. brand of] windows, I could have done good double-panes on that house for $6,000. I spec'd a 4,500-ft^2 home with European triple-pane windows and doors for $62,000. U.S. double-pane windows were $25,000."

Note that these are direct quotes from the builders and reflect their personal experiences and perceptions. This feedback shows that there is tremendous variability in the cost of windows. In some cases, increased cost is based on extra costly features and expensive frame options but in other cases it is the result of the complex market dynamics of the building and window industry. As with automobiles and appliances, there can be a 3:1 difference in price for nominally similar functionality in products as seem from some of these reported cost quotes. It is possible that, in some cases, they may be comparing a lower end line of double-pane windows in one brand to a higher end line of triple-pane windows in another brand. One study used to assess potential changes in the 2019 California building standards used a figure of $32/ft^2 as the average cost for a standard triple-pane, vinyl-framed double-hung window as compared to $25/ft^2 for conventional double pane low-E vinyl windows (Cort and Gilbride 2019). A typical 2,000-ft^2 home with 18 average sized double-hung vinyl-framed windows totaling 20% of the floor area would thus have an installed cost for double-pane windows of $10,000 while the same number and area of triple-pane windows would cost $12,800. While the prices in the quotes above are quite a bit higher than that, they reflect the perceptions of builders, and notably of high-performance builders, who while disposed toward a preference for high-performance products, are still leery of triple-pane windows because of a presumption that triple-pane windows will be exorbitantly expensive.

6.2 Not Enough Energy Savings

Many builders felt the savings were not high enough to justify the initial cost of triple-pane windows and several mentioned the long payback.

Said a production home builder in Utah, "We'd have to see a significant energy savings, i.e., HERS drop." Like several builders, this builder mentioned the trade-offs they would consider as they weigh their options. "We would compare adding triple-pane versus adding 1 inch of rigid foam on the outside, which we don't do now but are considering upgrading to. We are at the point of saying 'what can we do to

improve our envelope - maybe rigid foam or better windows?' Both will do it, which one is more cost effective?"

A production builder in Arizona said, "If the performance gains were high enough to save me money elsewhere, like in HVAC, than yes I could do it. If I could drop a half ton off HVAC, then yes."

A Fort Collins, Colorado, production builder said "Our rater ran BeOPT. The BeOPT results are in reference to the price of solar. (To reach the HERS net zero goal) it was cheaper to put more solar PV on the house than to do triple-pane windows."

A Pennsylvania builder who does production and custom homes explained why he uses double-pane R-4 windows instead of triple-pane R-5 windows. "An R-30 wall minus the R-4 windows may drop the total wall value from R-30 to an R-24. I know it's a detriment to not use triple pane, but I can't justify the added cost."

A Habitat builder in Florida said, "We don't have as dramatic a temperature swing as the northern climates, so the energy savings aren't big enough to justify triple panes."

A Denver production and multi-family home builder said, "Going from U=0.22 to U=0.20 (high performing double-pane to triple-pane) is hard to justify. If it was $2,000 more per home to go to triple pane, that makes sense. When the added cost is $7 to $10,000 per home, that gets tough to justify."

"The simple payback doesn't make sense," said a Long Island builder of nonprofit housing who said he uses triple-pane windows anyway because he felt the life cycle costs do justify the expense.

For products like windows with expected lifetimes of 30 to 40 years, the longer term cost/benefit perspective will almost always provide significant life cycle savings. First cost affordability may be a barrier but innovative financing could help and if the cost of the added cost of better windows is embodied in a 30-year mortgage the homeowner may see net monthly benefits beginning with the first mortgage payment. An eastern Washington custom and production builder said "U=0.24 is the magic number and you can do that with a [specific IGU brand] 366-i89 coated double-pane window. So it's not worth it to add a thin third layer if you don't get the performance boost. It has to be at least U=0.16 or 0.18." This builder, who also sells windows, noted the long payback: "If you do the modeling on a standard window, the payback on a triple pane is never there and many people cannot be convinced (to buy them)." He said he installs triple-pane windows in the homes he builds anyway because "I made a decision to only use triple-pane windows because of the 'high-performance home' message I'm promoting."

6.3 No Demand

Some builders mentioned the lack of consumer awareness or demand for higher-R windows. Others mentioned that their raters and energy modeling software could get them to the overall home performance target they were seeking with good double-pane windows.

An Arizona production builder told us “We did offer a triple-pane package on some of our homes. In the 700-plus homes sold since I’ve worked for (this company), only one home owner has bought it.”

A custom and production home builder in New York uses triple-pane windows for their performance, but he said, “People don’t ask for them. The education level of the people is low. They (home owners) don’t care about the windows.”

One custom home builder in Georgia listed “no consumer demand” as the number one reason he doesn’t install triple-pane windows, with not enough energy savings second, and price third.

“Double pane is all we do now, based on climate zone and RemRate modeling,” a production builder in Arizona told us.

Said a production builder in Delaware, “We are looking at our windows and saying ‘these are very good windows.’ We are already paying more and installing a better window than our rivals. Will the customer really agree that a triple-pane is $2,000 better? I think it would be overkill to go that route.”

A Fort Collins, Colorado, production and multifamily builder said, “Our energy modeling software said double-pane is all we needed for our climate zone.” According to the software, she could meet her performance targets less expensively with more PV than with triple-pane windows. When asked if she would offer triple-pane as an optional upgrade, this builder replied, “It’s all or nothing. It’s too tricky in a production home environment to offer both.”

6.4 Supply Chain Issues

Supply chain issues include limitations on what is available locally, concerns about long lead times, and difficulty getting replacement parts. No builder we interviewed ordered extra windows and stored them for upcoming jobs. As one builder noted, “storing windows is like warehousing eggshells.” All builders we spoke with ordered their windows per house, or per project for multifamily projects, and planned for just-in-time delivery so that windows would not sit on the ground at the site. All of the builders were sensitive about long lead times and expressed a desire to avoid unexpected delays in delivery that could hold up the production schedule.

Lead times for the builders interviewed (the amount of time from placing the order to receiving the windows) varied dramatically, from 1 week to 4 months, and not surprisingly there was a strong correlation between length of lead time and location of window source, with windows from Europe and Canada requiring the longest lead times. (See Figure 21).

Although some DOE ZERH builders used windows from large nationally known brands, many of our builders buy their windows from smaller regional manufacturers. In fact 21 of the 32 brands mentioned were only mentioned by one builder. See Appendix C for window brands.

Builders may buy locally because they feel they are getting a good price, have a good relationship with the local vendor, desire locally produced products to reduce carbon footprint, or are buying from a vendor who is also their installer. However this relationship can limit what choices are available to the

builder. As mentioned in Section 3.3, some window vendors only want to sell products from manufacturers with whom they have volume pricing arrangements. Some builders mentioned their window vendors steer them toward certain brands. Three production builders, in Arizona, Delaware, and Pennsylvania mentioned their window vendor has never offered them triple-pane windows as an option.

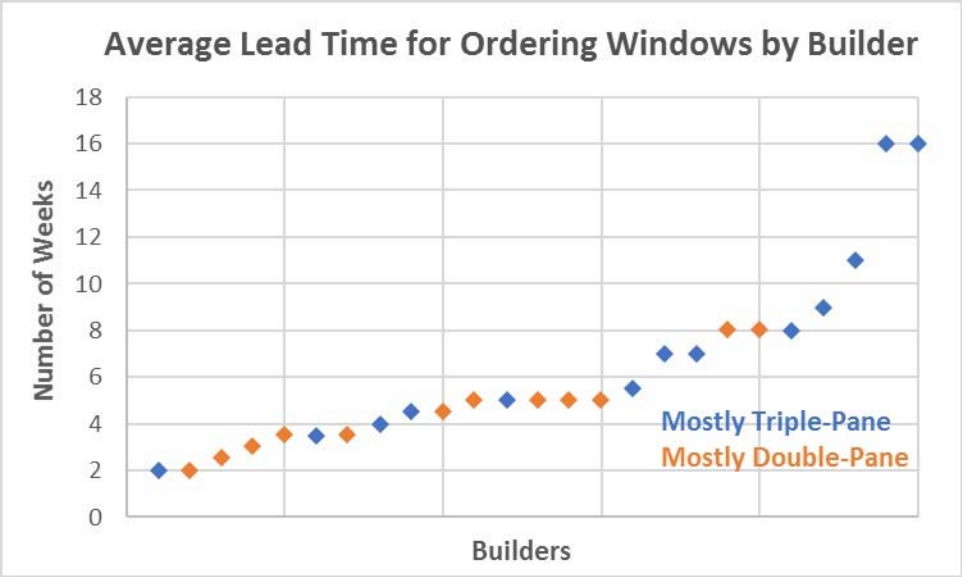


Figure 21. Lead Time for Ordering Windows, by builder

While some builders said they would be willing to go beyond a local vendor if they could find a better priced window that met their performance criteria, several expressed a concern about shipping delays and longer lead times.

A production builder in New Mexico and Arizona said, “It’s taking longer to get building materials. This is an industry issue. It used to take 2 weeks from order time to delivery for windows; now it often takes 8 weeks. Once the home buyers’ loan is approved, for us it’s 5 days for permitting; we are pouring the foundation within 10 days; and walls are up within 2 weeks. We’d like to install windows as soon as framing and sheathing are done.” He also expressed concerns about getting replacement windows. “Now, if I have a window that pops with customers living in the house, and we verify the window shouldn’t have popped, we need to replace it. Our customers don’t want to wait 3 to 6 weeks for a replacement window so that would be a concern with triple-pane windows. Can we get replacements fast?” All of the builders interviewed said they do not keep an inventory of windows on hand, due to lack of storage space and concerns about breakage, so if a window breaks, a replacement has to be ordered.

A production builder from Virginia, who buys most of his double-pane windows locally, said, “If I do a one-off home with an R-5 window from a different vendor, that’s fine. But when I put windows into a production environment, I’ve got to be able to fill the order. And, I’ve got to be able to get replacements in quick if something breaks.”

Concerns about delays were heightened when builders mentioned the possibility of buying triple-pane windows from Europe. Five builders mentioned using European windows on at least one project. However, only two used European windows for most of their projects, and both of those are custom builders in the northeastern United States where there appear to be more product representatives and distributors for European brands.

Many builders expressed serious concerns about purchasing windows from Europe, due to the long lead times and potential difficulty of getting replacement windows or parts if windows were to arrive damaged. In Figure 21, the two lead times at four months were for European distributors.

“I love the [European-manufactured] windows. We just can’t deal with the supply chain issues. We can’t handle an order being late or damaged in shipping,” said a production builder who buys his double-pane windows from a local manufacturer whose factory is less than 20 miles away. “It’s easy and quick to get replacement windows if we need them. We can just run over to the factory to pick up another one.”

“We were using [a brand from Europe], based on performance, but issues with lead time and service caused us to look domestically, and we ended up with [a U.S. company],” said a builder from New England.

“We used [a European brand of] windows that we bought through a local vendor. They were a logistical nightmare. It took months to get them,” said a Seattle area builder. Another eastern Washington builder, who used the same vendor, said he waited over 6 months for his windows. Although he buys from Canada, he stated emphatically that he would “never, ever buy windows from Europe again.”

While these two examples are outliers that may not accurately reflect the shipping times to be expected for window orders from Europe, they do reflect a perception that we heard voiced by several builders of concerns about long wait times.

Two Canadian companies were among the 32 brands mentioned and four builders have used Canadian brands. Lead times were longer than for some U.S. brands but were not described as problematic.

6.5 Installation Issues

Installation issues could relate to the size and weight of the triple-pane windows and problems with incorporating them into the builder’s standard design or problems with physically installing them. While no builder cited installation issues as a primary reason for not installing triple-pane windows, nearly 40% cited it as a secondary reason. Builders reported that it takes more crew more time to install triple-pane windows than to install double-pane windows, especially for larger windows, where special equipment might need to be brought in. This equates to higher installation costs, which adds to the overall costs for triple-pane windows.

In interviews, it was clear that builders take the window installation process seriously, with over one-third of builders reporting they personally install their own windows or use in-house staff. (See Figure 22.) As one custom builder from Ohio noted “Windows are probably one of the most important installations in the house. I personally do the flashing. It’s got to be right.” Another production and

custom builder from New York echoed that. “I have my own crews install the windows. I do my own flashing. I want to make sure it’s done right. Windows are the great equalizer if you do it wrong. That’s why you’ve got to get it right.”

A third of the builders interviewed said their framing crews install the windows, although that is usually after training and “with a lot of babysitting from someone on my staff” as one production builder put it. One-tenth use a contractor who specializes in window installations and 14% use the vendor they buy their windows from, although several builders mentioned they bought from a window vendor or building supplier who installed windows but they preferred to install their own.

Windows are typically installed after framing and sheathing is up and the roof is on. The windows are sometimes installed before and sometimes after house wrap and rigid foam are installed; either way, great care must be taken to keep the air and water boundaries continuous

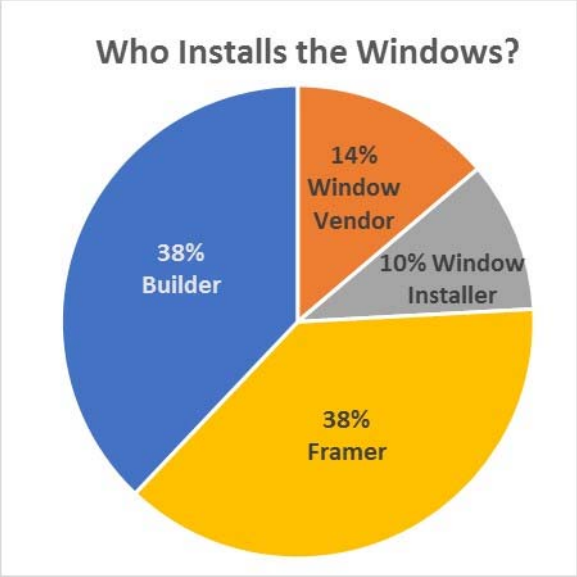


Figure 22. Who Installs the Windows?

6.5.1 More Weight Means More Crew, Rented Equipment, and Higher Costs

Triple-pane windows can be 25%-50% heavier than similar sized double-pane windows. Glass weighs about 1.6 lb/ft^2 for 1/8-inch glass so, for a small 6-ft^2 bathroom window, adding the third pane would add about 10 pounds for the glass only. For a large 5 x 8 (40-ft^2) picture window, it would add 60+ pounds to the window for the third pane of glass alone. The extra spacer and wider, heavier frame would add to the weight increase depending on the frame materials and design details, so for this 5x8 example, the total added weight for going from a double-pane window to a triple-pane window might be about 100 pounds (for the glass and the wider frame).

For builders installing double-pane windows, most estimate “one guy and one hour per window,” including the time it takes to pull the window off the truck and carry it to the install location. However,

installation time estimates went as low as one installer at 10 minutes per window. A production builder in Delaware who uses a window vendor to install the windows said it takes three guys 2 hours to install 15 to 18 double-pane windows in one of his homes, including unloading from the truck and installing the pan flashing, caulking, and tape flashing before and after.

For builders installing triple-pane windows, most estimate at least two installers per window. A builder in North Carolina who uses triple-pane windows noted an average-sized triple-pane window takes two guys typically 30 minutes to install, but large windows can require four guys and a lift. A production builder said a good rule of thumb is a triple-pane window that is 4x6-feet or less will take two guys. Anything larger will take three or more guys.

A Colorado production builder confirmed this as his reason for using double-pane windows: “Heavier windows will take more time and effort to install and thus cost more.”

A Chicago area builder said an unplanned forklift rental added $4,000 to the cost of an install because the triple-pane windows were too heavy for his crew to lift.

A nonprofit builder on Long Island said, “Standard triple-pane windows are too heavy for my installers. They can’t carry it up the ladder by themselves. So it takes them longer. If you force contractors to do something they don’t want to do, they move slower from the get go, just getting out of the truck. It takes them longer to walk it up, instead of 1 hour per window, it’s more like 2 hours. With the heavy triples you need two guys instead of one, so that doubles the cost. If they are very heavy, we’d need a lift truck.”

A Seattle-area builder who uses triple-pane windows describes the process. “We carry the windows up through the house for second-floor windows. We hold them with suction cups. It takes three to five guys, with at least two inside and one outside.” This builder limits the size of his second-story windows so he doesn’t have to rent a lift truck.

On the other hand, one custom home builder made the point that weight was not the issue for him. “I don’t care about the weight of the windows. I don’t care if they are 100 pounds heavier. We only have to move them once.” However, this builder typically installs double- not triple-pane windows due to cost, and builder experiences has shown that heavier windows do cost more to install from a labor standpoint.

6.5.2 Construction Sequence

Construction sequencing issues can impact window selection. For example, a nonprofit builder on Long Island said, “With our construction sequence, windows go in before the internal staircases are installed so we can’t take second-story windows up the inside stairs, they have to go up a ladder.” This builder has sought out lighter weight triple-pane windows for two-story homes for that reason.

6.5.3 Need for Structural Reinforcements

If the windows are exceptionally heavy a builder may have to add reinforcements to his walls to accommodate the added weight. For example, one Seattle area builder had problems with heavy windows on one project. He said, “The European Passive House-certified windows were way too heavy. We had a south-facing wall with four big 6x8 windows on it. We got them installed and saw that our wood headers were bending and we were getting water intrusion. We had to uninstall and re-install the windows after putting in a steel cross bar to support the framing. We needed a boom and four guys to get them in place.” They have since switched to a different brand of lighter weight triple-pane windows.

6.5.4 Size and Design Limits

Several builders have noted design issues with the weight and thickness of standard triple-pane windows. One production builder in the southwest explained that one reason his company does not use triple-pane windows is the frame thickness. “We have design issues. Triple panes are a much heavier, larger, thicker window. On some of our homes we’re doing a 2x4 wall so the triple-pane window is too thick. If it’s not plug and play, it’s not going to work.”

One Seattle area builder who does use triples noted “We don’t have a cherry picker or crane on site, so we have a maximum size limit. We don’t install windows larger than 25 ft^2 above the first floor. Buildability is an issue, we have to design what we can build affordably.”

A nonprofit builder on Long Island noted that, in addition to requiring more guys, the heavier triple-pane windows also require different fasteners; they use screws instead of nails. A Chicago builder acknowledged, “The weight of the triple panes also has been a problem for us. We’ve had manufacturers tell us they could only make limited sizes on triples in casement and awning style windows because their hardware would only support so much weight.” Some manufacturers use stronger hardware to handle the added weight but that adds to the cost of the windows.

A custom builder in Colorado who often uses large picture windows for the views said, “Our brand’s largest triple window is 7x9 feet and weighs about 400 pounds. We use suction cups on it and five guys. We do have to think about what’s feasible when designing window sizes for the second floors.”

6.5.5 Risk of Dropping and Damage

The weight of standard triples adds to concerns about damage from handling or dropping the windows. “Aside from cost, the other trouble with triples,” said a production builder in Washington, “is because they are extremely heavy, they require so much more handling, so there is more likelihood of damage. And the subcontractors [complain] and moan.”

6.5.6 Concerns about Safety for Installers

Some builders expressed concern for the safety of their crews when lifting and carrying very heavy windows. A nonprofit builder on Long Island noted “There are safety concerns too, getting these things up a ladder.” This builder said with double-pane windows, one guy can carry the window up a ladder by himself. With heavy triple-pane windows, it takes several guys and longer to work out the logistics of

lifting the window into place. This builder switched from standard triple-pane windows to a thin triple with a plastic film center layer and reported that the thin triple was more like installing a double-pane window.

A custom builder in Ohio said, “You’ve got to keep things simple and weight adds complexity. I have stayed away from the monster triple panes from Europe because they are massively heavy. It takes too many people to lift them. They have fantastic performance but they are too heavy. With very heavy weight, you are subjecting your installers to danger. And there is more potential for damage to the building.”

6.5.7 Concerns about Weight for Home Owners

Some builders expressed real or anticipated concerns with weight causing problems for home owners. One production builder said weight could be an issue for home owners and from a warranty stand point. “People have to be able to lift the windows up and down. If the frame bows in and makes it hard to lift them, will that be an extra warranty cost you’ll have to deal with?”

A Chicago-area custom and production builder mentioned a brand of heavy triple-pane double-hung windows they were using that had a problem with the top sash dropping whenever the home owner unlocked the window. “Our houses have 9-foot ceilings and the home owners were having to stand on a stool to close them. The windows were too heavy for some of the home owners to get them back into place to lock them.” The builder had to go into seven homes and pin the top windows permanently shut because the manufacturer didn’t have a fix for them. The builder has not had similar problems with other brands.

6.6 Key Findings

Findings related to why builders don’t choose triple-pane windows are as follows:

- Price is by far the biggest reason for not using triple-pane windows – 69% of builders said it was the primary reason.
- Builders believe triple-pane window packages could cost two to three times as much as a double-pane package for the same house, although a bottoms up analysis of the additional materials costs suggest that these increases are based on current market dynamics, and not the fundamental cost differential of a triple compared to a double.
- The performance improvement has to be noticeable, for example a big enough performance gain that the builder can downsize the HVAC by half a ton or a 1 or 2 point drop in the HERS score, for builders to consider upgrading to triple pane.
- Builders can get to U=0.22 with a double pane in some window designs, so they don’t think the third pane is worth the extra cost if the gain is only going to move the thermal performance to a U=0.22 or U=0.20. Achieving U values this low requires adding a surface 4 low-E to the double-

pane window, which makes it more expensive than a conventional double low-E ENERGY STAR window.

- Customers don't ask for triple-pane windows.
- Some builders say energy modeling is not showing a need for triples for the builder to achieve their performance targets in some climates.
- Three production builders said their window vendor has never offered them triple-pane windows as an option.
- Builders expressed concerns about long lead times and difficulty getting replacement parts.
- No builder cited installation issues (like weight) as a primary reason for not installing triple-pane windows, but nearly 40% cited it as a secondary reason.
- Builders gave examples of several secondary reasons for not wanting to use triples: the cost of renting special equipment to lift heavy windows, construction sequencing issues, the need to reinforce wall structures or limit sizes to limit weight when specifying triple-pane windows, the greater risk of dropping and damaging the windows, and the safety of their crews when carrying the heavier windows.
- The installation of triple-pane windows typically at least doubles the number of workers needed to install the windows (2 to 5 workers per window instead of 1 to 2).
- A production builder said heavier, larger, thicker triple windows don't work on their 2x4 walls – "if it's not plug and play, it's not going to work for us."
- One builder said weight could be an issue for home owners. "If the frame bows in and makes it hard to lift them, will that be an extra warranty cost you'll have to deal with?"

7.0 What are Builders' Attitudes and Expectations Regarding Thin-Triple Pane Windows?

During the interviews we explained to the builders that DOE has been involved in research to develop thin triple-pane windows – windows that are as thin and light-weight as double-pane windows but incorporate a thin center layer of glass and a krypton gas fill that enables them to have performance equal to or greater than standard triple-pane windows. We noted that these differ from the "thinner" triple-pane windows currently available from two manufacturers that use a stretched plastic film with a low-e coating as the center layer instead of a glass center pane. It had to be heat shrunk to stay taut; it sometimes wrinkled and stress from the film would sometimes cause premature failure. These quality control issues would not be experienced by a thin triple window using a center pane of glass. Several manufacturers offered this product when it first came out in the 1980s. Although the performance record has been good, the production process added complexity and cost so currently only two manufacturers offer it. This product will be referred to in discussions below as a "plastic-film triple" window.

We asked several questions to gauge builders' knowledge of, use of, and concerns about thin triple-pane windows. (See Figure 23.) We also asked if they would consider switching to thin triple-pane windows if they were available and if they could foresee any installation issues with them. Their answers regarding what they perceive to be the benefits of thin triple-pane windows and what they want from thin triple-pane windows are summarized in Section 7.1. What issues they have heard of or anticipate with thin triple-pane windows are described in Section 7.2. Note that any issues they have had or heard of regarding current or past builder experiences with thin triples would likely be referring to experiences with the plastic film triple windows described above. We also asked questions about costs including how much more would builders be willing to pay for thin triples. Cost information is provided in Section 7.3.

About half of the builders we interviewed had heard of thin triple-pane windows (likely the plastic film triple windows) and 10% had actually used the plastic film triple windows. (See Figure 23.) About 21% said they had heard of problems with thin triples; again, this would be referring to the plastic film triple windows.

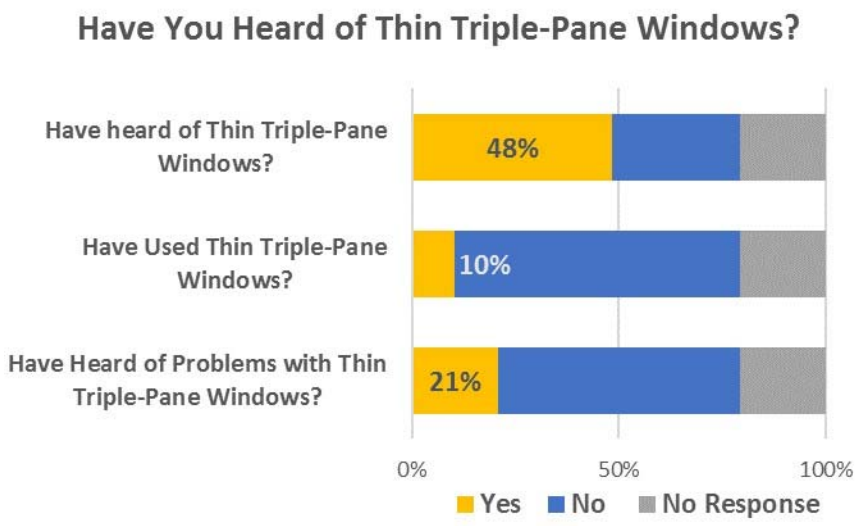


Figure 23. Have You Heard of, Used, or Know of any Issues with Thin Triple-Pane Windows?

7.1 What do Builders Want from Thin Triple-Pane Windows?

Builders were asked "If you had access to windows that were thin triple pane rather than standard triple pane, would you switch to them? (i.e., thin triples that are the same thickness and weight as double-pane windows and the same or better U value compared to a standard triple). Their responses show what they would be looking for in a thin-triple pane window and what they see as the benefits.

7.1.1 Better Performance, Same Price

Several builders interviewed said they would be willing to try thin triple-pane windows if the performance were shown to be the same as or better than standard triple-pane windows and especially if the price were the same. Many were willing to pay more than they currently pay for windows to obtain thin triples if the performance improvement is significant enough (see Section 7.3).

Several builders who install standard triple-pane windows said they would consider trying thin triple-pane windows if they could match the performance and cost of what they are already using. A custom home builder in Minnesota said he is "always looking for better products where price versus performance makes sense." A builder in Seattle said, "Absolutely, I'd consider them, if you can give me the same performance and price." A custom home builder in California said, "Yes, we would evaluate and switch if performance was equal." Said a production and custom home builder in upstate New York, "Yes, I'd consider them if the performance was there. It all depends on that. If much better, maybe."

Production home builders, most of whom are currently using double-pane windows, expressed more cautious interest. A production home builder in Virginia said, "If there was a cost savings and high R value, at the same price, yes." Said a production builder in Colorado, "If they were the same price? Absolutely. Unless we have issues with glass breaking or supply chain issues."

A production builder who builds in three climate zones in Arizona said, “In my case, windows have a big impact on envelope performance. Some of our homes have 20% or higher window-to-wall ratio - lots of sliding glass doors, lots of indoor-outdoor living. So a .05 U value improvement is a big impact on our shell. If I could get these great technologies in a normal frame, then I could offer a better experience to our home owners. I’d like to offer a window product where the home owner won’t feel cold radiating at them from the window. Thin triple-panes hold a lot of promise. Thin triple technology has the ability to bring affordability to a higher performing window, which is always of interest to us.”

A builder who builds production homes in New Mexico and Arizona said he was definitely interested in thin triples, because he wants to increase the window area in his homes, although he said it would have to be better performing than the double-pane windows he uses now. “Everyone here wants windows, lots of windows. Everyone wants indoor-outdoor living. I’d look at it up to a cost of 15% more.”

A production and custom home builder who already uses triple-pane windows acknowledged that triples don’t price out on energy efficiency alone but said they are still worth it for a higher quality home. “It works for sound mitigation for health and for comfort when sitting next to the window. I want my homes to last for 100 years so I’m future proofing my homes with excellent windows and window seals.”

7.1.2 Lighter Weight

Many builders expressed an appreciation for lighter weight windows, citing the labor challenges mentioned in Section 6.5 for installing standard heavy triple-pane windows.

A production builder in the southwest noted that switching from doubles to standard triple-pane windows would make the labor component of his window installation quotes go up 20% just for the sliding doors, because of the labor associated with the weight. Many builders estimate two to five times the number of installers for triple-pane as for double-pane windows.

A Seattle-area builder acknowledged that lighter windows would definitely be easier to install. This builder uses triple-pane windows now, but the weight has forced him to limit the size of second story windows to a maximum of 25 ft^2 (approximately 4x6) because he doesn’t feel his crew could safely install anything bigger without a crane or lift truck.

Two builders have already begun installing triple-pane windows using the stretched plastic center layer. Said one builder, “Less weight is what I consider one of (their) bigger selling points - triple-pane performance at double-pane weight.” The other builder, who constructs affordable housing in New York said of his brand, “Because their thin plastic triples are lighter, there is less bellyaching from the contractors about the weight.” This builder said he can now estimate one guy per hour per window to install, instead of two or three guys per hour per window.

A custom builder in Ohio said, “I’m very encouraged by the research you are doing. We need this product desperately. I wish they were here today. I would adopt if they really were lightweight.”

7.1.3 Sliding Doors

One topic that several builders mentioned was the need for light-weight triple-pane sliding doors. In line with the trend for indoor-outdoor living, many homes today are built with one, two, three, or more sliding doors and those sliders may be two, three, or more panels wide. These glass doors can constitute a significant amount of wall area and thus represent a substantial energy penalty if the doors are of suboptimal thermal performance.

As one Arizona production builder who now uses double-pane windows said, “Even if I didn’t use thin triples anywhere else, I’d be interested in them for sliding glass doors. We use big sliders, 9 feet up to 16 feet across. We’d be very interested in a thin triple slider.”

A custom home builder in Arizona who uses triple-pane windows, acknowledged that sliders are sometimes an issue because of the weight. A home builder in eastern Washington who uses triple-pane windows expressed the need to find one company that will make good high-R, low-weight triple-pane sliding doors and matching windows and French doors for his high-end custom and production homes. After trying several manufacturers who make triple-pane windows, he settled on one company in large part because they make doors that match the aesthetics of their triple-pane windows.

To get some idea of the prevalence of sliding doors in new homes, PNNL reviewed floorplans for all 199 projects in the DOE ZER Housing Innovation Award files and found that about half of the homes have sliding doors; many homes have more than one sliding door. Builders who already use triple-pane windows were about as likely to use sliding doors as builders who install double-pane windows, with nearly half of all homes having at least one sliding door, and one-fourth having two or more. (See Figures 24 and 25.)

A comparison of sliding door use by home type revealed that sliders were popular among production and multi-family home builders, with some production builders including four or more sliders. (See Figure 26.) Almost half of the multifamily builders and 60% of production builders installed sliding doors, which is significant as these builders are likely to be responsible for many more homes over a given year than custom and affordable home builders.

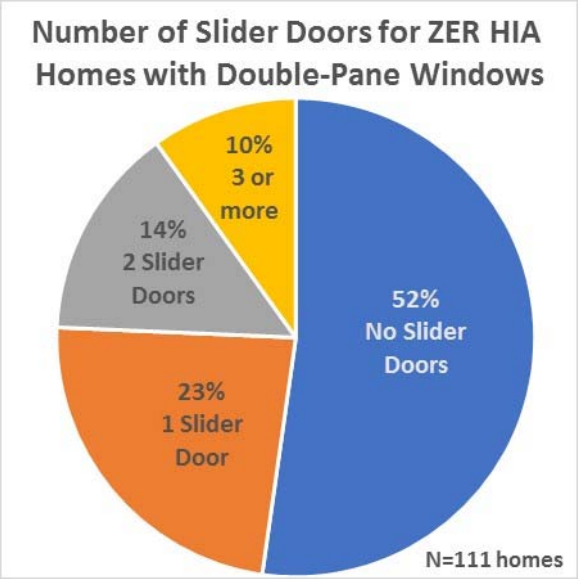


Figure 24. Number of Sliding Doors per Home for DOE ZER HIA Homes with Double-Pane Windows

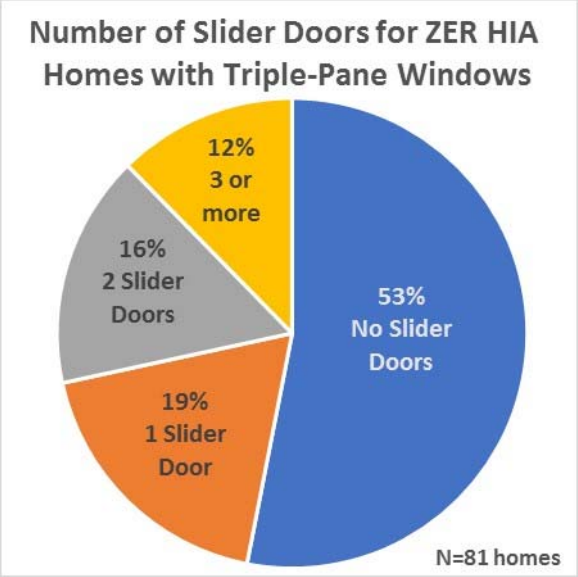


Figure 25. Number of Sliding Doors per Home for DOE ZER HIA Homes with Triple-Pane Windows

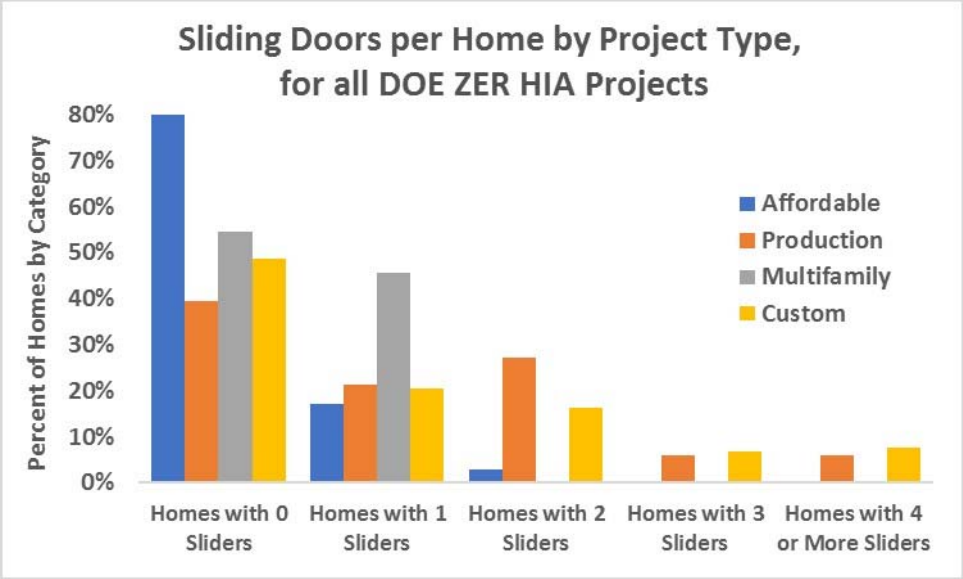


Figure 26. Number of Sliding Doors per Home for DOE ZER HIA Homes, by project type.

7.1.4 Key Findings

Findings related to what builders want from thin triple-pane windows are as follows:

- About half of the builders interviewed have heard of thin triple panes that use a plastic stretched film as the center pane and about one-fourth have heard of problems with these plastic film triple-pane windows.
- Builders are willing to pay on average 10% to 15% more for thin triples, if the performance gain is significant, i.e., gets them better than R-5.
- Builders are interested in something that allows them more glazing, especially southwest builders.
- Triple-pane windows offer health and comfort even if they don't pencil out. "I'm future proofing my homes with excellent windows and window seals."
- Builders who already use thin stretched film triples said the switch to lighter triples cut labor from three installers per window to one installer on most windows and eliminated lift trucks and cranes.
- There is a great need for lightweight triple-pane sliding doors. Half the builders install at least one sliding door, one-fourth install two or more.

7.2 What are Builders' Concerns about Thin Triple-Pane Windows?

PNNL asked the builders if they had heard of or experienced any technical or performance issues related to thin plastic triple windows, if they had any concerns about their use, or if they thought there would

be any installation issues related to thin-triple pane windows. Their answers are grouped by topic below. Where builders describe experiences of poor performance with thin triple-pane windows they are referring to the thin plastic triples described above and as noted below. Some builders who currently use double-pane windows responded with concerns related to switching from double to either thin or standard triple-pane windows, and their responses are included here where relevant.

7.2.1 Energy Performance versus Cost

Many builders expressed concern that the increase in energy performance would not be enough to justify the extra cost.

Said a production builder in eastern Washington, “The U-value would have to get down to at least U=0.16 or U=0.18.”

A New York builder who already uses triple-pane windows said he’d consider thin triples “if the performance was there. It all depends on that. If much better, maybe.”

A production builder in Virginia also said he would consider thin triples if there was a high enough R value gain. He said he can already get an R-4.5 with a double-pane argon-filled casement window. “Just going to an R-5 triple-pane doesn’t make enough of a difference in RemRate.”

A production and custom builder in Pennsylvania saw the savings in relation to the photovoltaic systems he installs. “If I could drop a kW from the PV and get the same HERS, I’d consider thin triples. And, that would have to be no more than $50-$70 (extra cost) per window because my houses have about 20 to 30 windows.” (The national average cost for solar PV installation was $3,050 per kW of panels in 2018 so under this scenario if triple-pane windows could be purchased for $1,000 to $2,100. One kW of PV panels will produce about 4 kWh per day of electricity on average.)

A multi-family builder in Colorado said, “It would come down to the energy modeling. If energy modeling shows triple is beneficial, we’d do it.” This builder notes that her energy modeling software currently showed it was more cost-effective to add more photovoltaic panels than to go from double- to triple-pane windows.

7.2.2 Price

Many builders mentioned price as the impediment that would prevent them from purchasing thin triple-pane windows, but they often spoke of it in the context of a cost-benefit ratio, i.e., if the benefit was substantial enough, they would be willing to spend more for the windows. In fact, four-fifths would be willing to spend more than they currently pay for windows. (See Section 7.3.)

A production builder in Arizona who uses double-pane windows said, “The biggest factor for us is cost. If we could find cost-competitive triple panes, we’d buy them. If the performance gains are high enough to save me money elsewhere, like in HVAC, than yes I could do it. If I could drop a half ton off HVAC, then yes. Anything more than a 10% increase in cost, I’d have to really justify what the benefit is to get to triple.”

"I'd love to have a U=0.1 or U=0.2 in every house but it's price. I know it's a detriment to not use triple pane, but I can't justify the added cost. If the price came down, I'd do it in a second," said a production builder in Pennsylvania.

A production builder in Utah noted, to consider thin triples the "price would have to be consistent (with what we now pay for doubles) and we'd have to see a significant energy savings (i.e., HERS drop)."

A production builder in Delaware said, "We are already paying more and installing a better window than our rivals. We are already above everyone with our HERS. Not sure why we would want to be that much better. We'd rather be a little bit better in everything. We can't afford to be a 10 in one area and a 3 in everything else. If it costs $100 more per window, $1,800 more per house, is the customer going to see the value, are they going to appreciate it? 15% would probably be the tops we'd spend [over what we are now spending on windows] in terms of going to triple."

7.2.3 Thin Triples are Already Available

A few builders mentioned that they were using American-made triple-pane windows that they felt were already pretty light-weight and easy to handle compared to the thick, heavy Passive House-qualifying European triples. Note, these builders were not using the thin triples with the center layer of stretched plastic but triples with three standard thickness panes set close together in a lighter weight frame. One builder in Seattle said, "The triple-pane windows we are using are no more difficult to install than a double pane, not much bigger than a double. We don't have to do anything exceptional. A lot of time it's one guy holding the window and one guy nailing it."

7.2.4 Too Thin

Some builders expressed concern some current brands of American triple-pane windows that use three standard-thickness panes are not of good quality because the panes are too close together and the frames are too lightweight and not sturdy enough. Two builders who use triple-pane windows felt these thinner American triple-pane windows were inferior products compared to the thicker European triple-pane windows and both expressed concerns about their performance.

A custom builder in Virginia explained ". We don't use American triple-pane units since the glazing space is sub-optimal. They fit three panes of glass into the same thickness as a double-pane glazing unit. Performance is diminished by their standard frame / IGU thickness. I have yet to see any data supporting this statement [that thin triples could equal standard triples]. The thinner units do not match the performance of the Canadian and European triple-pane IGUs."

A custom and production builder from eastern Washington who also is a representative for several triple-pane window manufacturers said, "Most American window manufacturers of triple panes have an inch for their IGU: three pieces of 1/8-inch glass plus 5/8-inch of spacing (two 3/16-inch gaps). They don't get enough insulation (due to the narrowness of the spacing) to offset the thermal problems so the performance is U=0.232 or 0.24 even with a triple pane." (Note both the narrowness of the gaps and the use of argon instead of krypton fill contribute to the poor thermal performance with these designs.

When krypton is used, a ¼ inch space filled with krypton is similar in performance to a ½ inch space filled with argon.)

This builder also expressed concerns about shipping saying that thin triple-pane windows could break during shipping because, if the center pane of glass vibrates much during shipping, there would not be enough space to keep the panes from touching and it could shatter the inner layer. He had not seen this happen but he was warned about this by some factory reps who told him this could occur with larger dimensioned windows. “That is why some companies will steer builders to two 6 x 6 or 5x6 triple-pane windows rather than one large window. This other brand say theirs won’t shatter because they won’t go over a certain dimension. If you have a gap of at least 3/8-inch to ½-inch it won’t shatter, but less than that it could. I have had two regional window manufacturers tell me that the largest glazing unit they make is 30 square feet.”

This builder went on to say “Many of the low end window manufacturers that utilize a standard 7/8-inch glazing unit try to accommodate a triple-glazed pane by adding a third layer of glass. This practice is rather futile because the middle pane does not add much more than U=0.04 to the assembly but it does add substantial cost. Many reputable window manufacturers have made adjustments but the practice does exist in the industry. When I spec a vinyl window, I often use because they specifically make a frame that accommodates a 1 3/8-inch triple-pane IGU. The ½-inch between the panes with i89 and 366 glass and argon gas fill creates optimal performance, albeit expensive. It is one of the Cadillac versions of a triple pane. They will build a glazing unit up to 60 square feet and ship it long distances. This would not be possible with normal shipping procedures for windows if the panes only had 3/16-inch between the panes. I want to be clear that this procedure is not a common practice but it has been used by some manufacturers, who I will not name, to allow them to play in the triple-pane world without the added expense of modifying their frames to build a truly efficient triple-pane glazing unit.”

7.2.5 Window Design / Product Flaws

Several builders commented on issues they’d heard of or anticipated. A few had actually experienced issues with them.

One custom builder mentioned hearing about and personally experiencing issues with early versions of the thin plastic triples.

A Chicago builder who uses standard triple-pane windows, said he’d consider thin triples. However, he said, “If it’s suspended film windows, I’d have to really look at it because the thin film has bowed, degraded, or warped in our market.” He heard of these and other issues from other builders and said he saw these issues himself on another builder’s project. “They (thin triples) would have to be the same cost (as the standard triples they currently use), and maybe less than I pay now to make sure it works because I have a risk of adoption.”

A custom builder in Ohio was one of several who mentioned using flange-attached windows. Builders told us that Passive House certified windows don’t have flanges but most of the builders we interviewed have crews trained to install and flash windows that do have flanges. Windows that don’t have them could be problematic. For example one custom home builder in Minnesota said he had no concerns

about switching to thin triples as long as the windows had nailing fins (flanges). Another production builder said, “I’d be willing to switch to a different vendor to buy triple-pane windows if the manufacturer could get us a flanged window. Passive House doesn’t like a flanged window. But it’s the easiest from a water management standpoint and gets the best results likely for our installers.”

A production builder in Delaware said his concerns would be “making sure the frame is sturdy enough. We haven’t had issues but we’ve heard of other brands where the middle part of the window was weak and it could buckle a little bit so that is something we look for. The (triple-pane) glass package could be too heavy.” Another concern he had is “getting a high-performance window that doesn’t look tinted.” He’s personally ordered and sent back several double-pane windows trying to get a combination with the right performance without appearing overly tinted.

7.2.6 Climate and Altitude

Some builders expressed concerns about high altitudes both for installation and transport of gas-filled windows. These issues are common to all gas-filled windows, double or triple, and most window companies have learned how to install breather tubes or other components to handle altitude changes during shipping. Issues and solutions should be similar whether transporting argon or krypton filled windows.

7.2.7 Air Tightness

Several builders told us they had had trouble with air leakage through triple-pane windows in the past and that was one reason for switching brands. A builder in Seattle said that builders going for Passive House certification would want “more than good U and SHGC values. They also want multi-point locking mechanisms because air leakage is really an issue for them.”

7.2.8 Availability for Warranty Issues

Two production builders who said they would be interested in thin triple-pane windows if the price was right also raised concerns about warranty and supply chain issues. Said one builder, “I would imagine that warranty and customer service on broken or failed glass assemblies might be more difficult if there isn't a thin glass producer near our location.” Another remarked they would be interested “unless we have issues with glass breaking or supply chain issues.” Both builders currently use locally produced windows.

7.2.9 Adoption Risk

More than one builder mentioned the risk of early adoption. As one builder said, “I’m not going to risk my livelihood on what might fail.” A Chicago area production and custom builder said, “They would have to be the same cost, and maybe less than I pay now (for my standard triples) to make sure it works because I have a risk of adoption. We give a 10-year envelope warranty. If there is any failure in the envelope we are responsible because we warranty the installation and materials. Most of our suppliers for envelope products give us at least a 10-year product warranty and we stand behind our installation.” (Cardinal offers a 20-year warranty on its IGUs.)

A production builder in Delaware who said he is already installing “a very good (double-pane) window,” voiced uncertainty about the benefits and perceived value of upgrading to offering triple-pane or thin triple windows. “If it costs $100 more per window, $1,800 more per house, is the customer going to see the value, are they going to appreciate it? I think it would be overkill…so we probably would not switch any time soon. I don’t know how it would benefit us.”

7.2.10 ENERGY STAR

Only one builder mentioned ENERGY STAR but it was not as a motivator. This production builder from Colorado, who was referring to the possibility of ENERGY STAR increasing its specification to require triple-pane windows in the northern climate, said, “Would ENERGY STAR be a motivator to switch to triple pane? No, it would be a reason for us to call and complain. It’s such a cost increase.”

7.2.11 Key Findings

Findings related to builders’ concerns about thin triple-pane windows are as follows:

- Performance is the most mentioned concern regarding upgrading to thin-triple pane windows, with many builders expressing concern about them.
- One-fifth of builders have heard of problems with thin triple-pane windows that use a polymer film for the center layer.
- Some builders think that the American-made triples are too thin, i.e., the gaps are too narrow to provide adequate thermal performance. One builder found an American brand of triple-pane window that seemed to be thin already and to provide adequate performance.
- Some builders who like European triples equate thin triples with poor performance (not enough R value).
- One builder said if the IGU is too thin, the glass will break during shipping.
- Builders want windows with flanges for easier installation and flashing.
- Some builders have had experiences with frames that were not sturdy enough.
- Builders expressed concerns about low-e glass looking tinted.
- Builders have experienced air leakage in some brands of triple pane windows. One builder said this would be a big concern for builders seeking Passive House certification.
- Builders want a warranty. For builders concerned about adopting a new technology this may help.

7.3 How Much Would Builders be Willing to Pay for Thin Triple-Pane Windows?

We asked builders how much more they would be willing to pay for thin triple-pane windows compared to the double- or triple-pane windows they are currently using. Their answers are summarized in Figure 27. Most DOE ZERH builders said they were willing to pay 10% to 15% more for thin triple-pane windows than they are currently paying for double- or triple-pane windows. This included all of the production home builders who responded to this question.

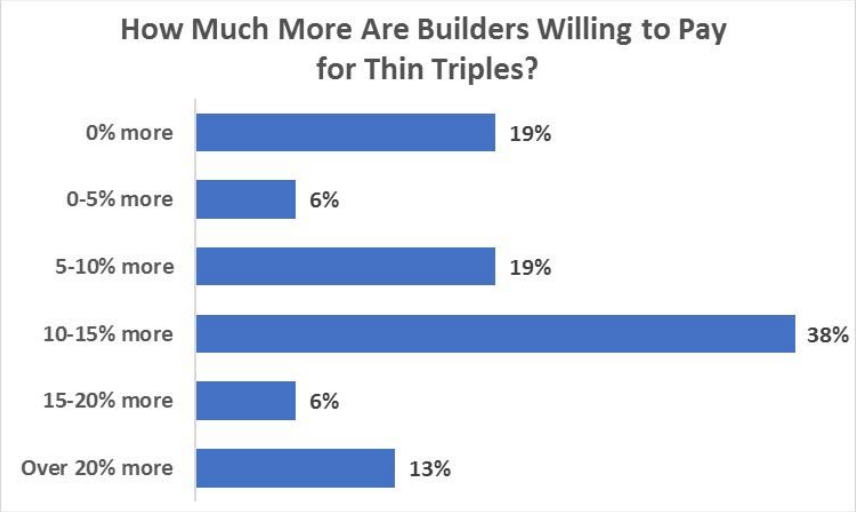


Figure 27. How Much More are Builders Willing to Pay for Thin Triple-Pane Windows.

Some cost information was collected from builders. In some cases this data was pulled from actual pricing estimate sheets or invoices the builder provided. In some cases, this was the builder's guesstimate of costs for one or more recent projects. These numbers are therefore provided as a snapshot of costs from the field. It should be noted that window costs are a factor of both the IGU or glass package and the frame. Some frame materials are much more expensive than others.

Table 6. Average Window Costs per House, for Builders Interviewed

	Window Package Cost, Average	Window Package Cost, Range
Double-Pane Houses	$11,400	$4,500 - $24,000
Triple-Pane Houses	$19,000	$4,000 - $60,000

7.3.1 Key Findings

Findings related to builders' attitudes about the price of thin triple-pane windows are as follows:

- Most DOE ZERH builders said they were willing to pay 10% to 15% more for thin triple-pane windows then they are currently paying for double- or triple-pane windows. This included all of the production home builders who responded to this question.

- Window prices vary greatly depending on brand, frame, glass package, style, and size. Overall, the price variance for triple panes is estimated to be much larger than for double panes. Builders, even high performance builders, are buying and expecting to buy across a broad range of prices.

8.0 Conclusions

Key findings from PNNL's interviews with zero energy ready home builders regarding their window selection choices are summarized below. These findings will be used together with other technical and market data to help guide DOE programs. Implications of these findings for important stakeholder groups, including DOE and the technology research community, utility and efficiency program leads, window manufacturers, window retailers, and the codes and rating community, will be discussed in a separate market assessment and program plan report (Cort and Gilbride 2019).

8.1 Key Findings regarding the Types of Windows Interviewed Builders are Currently Installing

- Two-thirds of the ENERGY STAR northern climate builders interviewed are already installing an R-5 (triple-pane) window.
- More builders would tune the SHGC of their windows (vary SHGC by the direction the window is facing) if they had more options for SHGC in lower priced windows.
- Some builders don't tune (vary SHGC by window orientation) in order to keep installations simpler for their installers.
- Builders seeking high performance know casements are the highest performing openable frame types-.
- Only one of these high-performance builders uses krypton-filled windows.

8.2 Key Findings Regarding Why Builders Pick the Windows they Pick?

Performance

- The majority of builders ranked performance as the number one reason for choosing the windows they used on a project.
- Builders consider performance aspects of the whole window, including operating performance and functionality, in addition to energy performance of the glass and frame.
- Builders want a solid, sturdy window. One builder equated the heavy weight of European triples with a higher quality.
- Builders have had trouble getting the glass package performance they need (U factor, SHGC, and visual transmittance) in a window that doesn't look tinted.
- High-performance builders are concerned about the HERS score and will choose a window specifically to lower their HERS score.

Price

- Price was the most common secondary reason for picking a window.

Availability

- Production builders who use vendor installers are often limited by vendor-manufacturer relationships in what windows they can order.

Vendor Relationships/Buying Local

- One-third of the builders we interviewed have not changed their supplier or brand in at least five years. For these builders, “it’s all about relationship.”
- Over half of the builder interviewed do not get bids on every home but instead rely on relationships with a trusted window supplier to give them a good price, good product, and good customer service.
- More than half of the brand selections by builders were for small regional manufacturers. 21 of the 32 brands mentioned were only mentioned by one builder.

Aesthetics

- Aesthetics was listed as among the least important reasons identified for picking a window.

Brand Reputation

- Brand identity seemed to be a low priority.

8.3 Key Findings regarding Why Builders Switch Brands or Vendors

- Builders will “vote with their feet.” Several left a vendor due to poor customer service or product quality issues.
- Builders want a vendor partner who understands the builder’s high performance goals.
- Builders are price sensitive but performance is even more important.

8.4 Key Findings Regarding Why Builders Choose Triple-Pane Windows

- Performance trumps all other reasons as the primary reason for using triple-pane windows.
- Noise reduction is seen by some as a health benefit.

- Noise reduction was the most mentioned secondary reason for using triple-pane windows.
- Increased comfort is noticed by home owners.
- Condensation affects more than visibility; it is a health and durability issue as well.
- Half of the builders interviewed acknowledged that triple-pane windows allowed them to reduce their HVAC size.
- Many said with triple-pane windows they could do interior throws rather than installing supply duct registers along exterior walls.
- Many builders felt that triple-pane windows "enabled" them to install mini-split ductless heat pumps.

8.5 Key Findings regarding Why Builders Don't Choose Triple-Pane Windows

- Price is by far the biggest reason for not using triple-pane windows – 69% of builders said it was the primary reason.
- Builders believe triple-pane window packages could cost two to three times as much as a double-pane package for the same house, although a bottoms up analysis of the additional materials costs suggest that these increases are based on current market dynamics, and not the fundamental cost differential of a triple compared to a double.
- The performance improvement has to be noticeable, for example a big enough performance gain that the builder can downsize the HVAC by half a ton or a 1 or 2 point drop in the HERS score, for builders to consider upgrading to triple pane.
- Builders can get to U=0.22 with a double pane in some window designs, so they don't think the third pane is worth the extra cost if the gain is only going to move the thermal performance to a U=0.22 or U=0.20. Achieving U values this low requires adding a surface 4 low-E to the double-pane window, which makes it more expensive than a conventional double low-E ENERGY STAR window.
- Customers don't ask for triple-pane windows.
- Some builders say energy modeling is not showing a need for triples for the builder to achieve their performance targets in some climates.
- Three production builders said their window vendor has never offered them triple-pane windows as an option.
- Builders expressed concerns about long lead times and difficulty getting replacement parts.

- No builder cited installation issues (like weight) as a primary reason for not installing triple-pane windows, but nearly 40% cited it as a secondary reason.

- Builders gave examples of several secondary reasons for not wanting to use triples: the cost of renting special equipment to lift heavy windows, construction sequencing issues, the need to reinforce wall structures or limit sizes to limit weight when specifying triple-pane windows, the greater risk of dropping and damaging the windows, and the safety of their crews when carrying the heavier windows.

- Triple installs typically double or greater the number of workers needed to install the windows (2 to 5 workers per window instead of 1 to 2).

- A production builder said heavier, larger, thicker triple windows don't work on their 2x4 walls – "if it's not plug and play, it's not going to work for us."

- One builder said weight could be an issue for home owners. "If the frame bows in and makes it hard to lift them, will that be an extra warranty cost you'll have to deal with?"

8.6 Key Findings Regarding What Builders Want from Thin Triple Windows

- About half of the builders interviewed have heard of thin triple panes that use a plastic stretched film as the center pane and about one-fourth have heard of problems with plastic film triple-pane windows.

- Builders are willing to pay on average 10% to 15% more for thin triples, if the performance gain is significant, i.e., gets them better than R-5.

- Builders are interested in something that allows them more glazing, especially southwest builders.

- Triple-pane windows offer health and comfort even if they don't pencil out. "I'm future proofing my homes with excellent windows and window seals."

- Builders who already use thin stretched-film triples said the switch to lighter triples cut labor from three installers per window to one installer on most windows and eliminated lift trucks and cranes.

- There is a great need for lightweight triple-pane sliding doors. Half the builders install at least one sliding door, one-fourth install two or more.

8.7 Key Findings regarding Builders' Concerns about Thin Triple Windows

- Performance is the most mentioned concern regarding upgrading to thin-triple pane windows, with many builders expressing concern about them.
- One-fifth of builders have heard of problems with thin triple-pane windows that use a polymer film for the center layer.
- Some builders think that the American-made triples are too thin, i.e., the gaps are too narrow to provide adequate thermal performance. One builder found an American brand of triple-pane window that seemed to be thin already and to provide adequate performance.
- Some builders who like European triples equate thin triples with poor performance (not enough R value).
- One builder said if the IGU is too thin, the glass will break during shipping.
- Builders want windows with flanges for easier installation and flashing.
- Some builders have had experiences with frames that were not sturdy enough.
- Builders expressed concerns about low-e glass looking tinted.
- Builders have experienced air leakage in some brands of triple pane windows. One builder said this would be a big concern for builders seeking Passive House certification.
- Builders want a warranty. For builders concerned about adopting a new technology this may help.

8.8 Key Findings Regarding What Builders are Willing to Pay for Thin Triple Windows

- Most DOE ZERH builders said they were willing to pay 10% to 15% more for thin triple-pane windows then they are currently paying for double- or triple-pane windows. This included all of the production home builders who responded to this question.
- Window prices vary greatly depending on brand, frame, glass package, style, and size. Overall, the price variance for triple panes is estimated to be much larger than for double panes. Builders, even high performance builders, are buying and expecting to buy across a broad range of prices.

8.9 Conclusions

These key findings are also presented in a separate market assessment and program plan (Cort and Gilbride 2019), which proposes implications from these findings as they impact important stake holder groups – window researchers, efficiency program leads, window manufacturers, window retailers and vendors, and the codes and rating community, as well as builders, installers, and architects.

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Appendix A – DOE ZERH Builders Interviewed

Builder	URL	City, State	Climate Zone	Category
Amaris Homes	https://minnesotagreenhomebuilder.com/	Maplewood, MN	6A Cold	Custom
AquaZephyr	http://ecovillageithaca.org/	Ithaca, NY	6A Cold	Production, Multifamily, Affordable, Custom
BPC Green Builders	https://www.bpcgreenbuilders.com/	Wilton, CT	5A Cold	Custom
BrightLeaf Homes	https://www.mybrightleafhome.com/	Hinsdale, IL	5A Cold	Custom
C and B Construction	http://candbhomes.com/	Cottonwood, AZ	3B/4B Mixed-Dry	Custom
Carl Franklin Homes	http://www.carlfranklinhomes.com/	Lewisville, TX	3A Hot-Humid	Affordable
Clifton View Homes	http://www.cliftonviewhomes.com/	Whidbey Island, WA	4C Marine	Custom, Affordable
Dwell Development	http://www.dwelldevelopment.com/	Seattle, WA	4C Marine	Custom
Garbett Homes	https://www.garbetthomes.com/	Salt Lake City, Utah	5B Cold	Production, Multifamily
Greenhill Contracting	http://www.greenhillcontracting.com/	Esopus, NY	5A Cold	Custom, Production
Kalamazoo Valley Habitat for Humanity	https://habitatkalamazoo.org/	Kalamazoo, MI	5A Cold	Affordable
Habitat for Humanity, South Sarasota County	http://www.habitatsouthsarasota.org/	Venice, FL	2A Hot-Humid	Affordable
Health-E Community Enterprises of Virginia	http://www.vrlhomes.com/	Williamsburg, VA	4A Mixed-Humid	Production, Custom
High Performance Homes	https://www.hphpa.com/	Gettsyburg, PA	4A Mixed-Humid	Custom, Production
Imery Group	https://imerygroup.com/	Athens, GA	3A Mixed-Humid	Custom, Production
Insight Homes	https://www.itsjustabetterhouse.com/	Bridgeville, DE	4A Mixed-Humid	Production

Leading Force Contracting Services	http://www.leadingforceedc.com/	Selah, WA	5B Cold	Custom
United Way of Long Island	http://www.unitedwayli.org/	Long Island, NY	4A Mixed-Humid	Affordable
Mandalay Homes	http://www.mandalayhomes.com/	Prescott & Phoenix, AZ	4B Mixed-Dry,2B Hot-Dry	Production
Mantell-Hecathorn Builders	https://www.m-hbuilders.com/	Durango, Colorado	5B Cold	Custom
One Sky Homes	http://www.oneskyhomes.com/	San Jose, CA	3C Marine	Custom
Palo Duro Homes	http://palodurohomes.com/	Farmington, NM	2B Hot-Dry, 4B Mixed-Dry	Production
Promethean Homes	http://www.prometheanhomes.com/	Steeles Tavern, VA	4A Mixed-Humid	Custom
Revive Properties	http://www.revivefc.com/	Fort Collins, CO	5B Cold	Multifamily
S. D. Jessup Construction Inc.	http://www.sdjessup.com/	Pilot Mountain, NC	4A Mixed-Humid	Custom
Sareth Builders	https://www.sarethbuilders.com/	Westlake, Ohio	5A/6A Cold	Custom
TC Legend Homes	http://www.tclegendhomes.com/	Bellingham, WA	4C Marine	Custom, Affordable
Thrive Home Builders	https://www.thrivehomebuilders.com/	Denver, CO	5B Cold	Production, Multifamily, Affordable
Unity Homes	https://unityhomes.com/	Walpole, NH	5A/6A Cold	Custom

Appendix B – Survey Questions

What category/type of homes do you build?	
How many per year?	
Where and what climate zone?	
Double __ or triple__ Or some % of each__	
What frame material? Vinyl? Wood? Aluminum? Fiberglass? Other? Mix?	
What U value?	U=
What SHGC value?	SHGC=
What design? (fixed, casement, double-hung, single-hung, tilt and turn, hopper	
How many low e coatings?	
What fill is in the windows? Argon? Air? Krypton?	
Do you vary the U or SHGC by orientation? __	
Are your windows ENERGY STAR rated?	
What is the ESTAR minimum in your climate zone? [find ES window specs for all climates at the following, scroll to last page for colored charts of specs. https://www.energystar.gov/sites/default/files/ES_Final_V6_Residential_WDS_Spec.pdf]	
Are your windows above the ENERGY STAR minimum?	
What brand and model of windows do you use?	
*Do you order standard sizes or custom sizes?	
How did you pick the brand? How did you pick this vendor?	
What made you choose that brand? (if more than one reason, rank order of following) Price___ Availability, What your building supplier offered___ NFRC rating/Performance ___ Other features___ Service of supplier ___ Other ___	
*What does quality in a window mean to you?	
Who do you buy your windows from?	
Is it the same vendor you buy other building products from?	
*Do you get bids for every job?	
Have you changed windows or vendors recently? N/Y If so why?	
What windows and suppliers have you used in the past?	
Do you order windows per house, or do you bulk purchase?	
What is the lead time for new windows? For replacement or parts?	
Does your vendor charge you per window or per house?	
How much would a whole house typically cost?	
What is your window cost per square foot?	
Who installs your windows? A window vendor or your own crews?	
How many guys does it usually take to install a window?	
How much do you pay either your own crew or vendor to install them?	
If you use Triple Pane,	
What are your main reasons for using triple, instead of double pane?	
Other benefits of Triple pane	
Have you always used triple pane?	
If you switched, or use both, what do you have to do differently in terms of design or wall construction to accommodate triple-pane vs double pane?	
How and when do you do the installation?	
Anything different in terms of installation technique?	

Any other differences in purchasing triple versus double pane windows?	
Are there any plusses to you as the builder for installing triple-pane instead of double-pane windows?	
Are there any trade-off benefits to using triple-pane instead of double-pane?	
In HERS modeling software? i.e., Does it allow you to downsize the HVAC or the insulation amounts or to increase glazing?	
Do you have a ducted heating/cooling system?	
Has triple-pane windows had any impact on your HVAC equipment?	
Has it allowed you to go to a compact duct design with interior throws?	
Or a ductless heating system?	
If you have a ducted HVAC system, where are the ducts located?	
Has triple-pane windows affected any other design or equipment choices, for good or for bad? Which ones?	
Do you mention the triple-pane windows in your marketing? y/n If yes, how do you describe them?	
Are they standard features or an optional upgrade?	
Are there any benefits besides the energy savings that you point out to the home owner?	
If you had access to windows that were thin triple pane rather than standard triple pane, would you switch to them? (thin triples that are same thickness and weight as double-pane and the same or better Uvalue as standard triple).	
Have you ever heard of thin triple-pane windows?	
Have you ever used thin triple pane windows? Have you had any performance problems with them or heard of anyone having problems with them?	
If you were to switch from standard triple to thin triple pane windows, can you see any way in which that might add to your design/construction/installation costs (not counting the material cost of the window itself)?	
What complaints if any do you get from home buyers regarding the windows?	
Have you had any window-related callbacks?	
Have you or would you consider other high-performance type windows	
Other Technical Issues	
If you don't use Triple Pane windows,	
What are the reasons why not? - Pick order: Cost___ Availability___ Supply chain issues (such as _____) Not enough energy savings___ No consumer demand___ Installation issues___ (such as___) Design issues _____ (such as_____)	
Has your supplier ever offered you triple-pane windows?	
Would you be willing to switch to a different vendor or window supplier to buy triple-pane windows?	
Could you see switching to triple-pane windows in the future?	
Do you think there would there be any installation issues?	
What would be the driver for that?	
What would it take for you to switch to triple-pane windows?	
*Have you ever heard of thin triple-pane windows?	
*Have you heard of any performance issues with thin-triple pane windows?	
If you had access to windows that were thin triple pane rather than standard triple pane, would you be more willing to switch to them? (thin triples that are same thickness and weight as double-pane and same NFRC rating as standard triple).	
If they were the same price?	
If they were more expensive?	
*How much more would you be willing to pay for triple over double pane windows?	
What complaints, if any, do you get from home buyers regarding windows?	
Have you had any window-related callbacks?	

Appendix C – Window Manufacturers' Products Used

Window Brand	Headquarters Location	No. builders who used this brand*	Manufacturer Size**
Accurate Dorwin	Canada (MN))	1	Not in top 100 Manufacturers
Alliance	NJ	1	Not in top 100 Manufacturers
Alpen	CO	4	Not in top 100 Manufacturers
Alpine Windows	WA	1	Not in top 100 Manufacturers
AluProf	Poland	1	Not in top 100 Manufacturers
Amsco Windows	UT	2	$50 Million to $100 Million
Andersen Windows & Doors	MN	10	Over $1 Billion
Atrium Windows & Doors/Atrium Corp.	TX	3	$300 Million to $500 Million
Avanti Industries LLC	AZ	1	$30 Million to $50 Million
B.F. Rich Windows and Doors	DE	1	Not in top 100 Manufacturers
Cascade Windows	WA	2	$100 Million to $200 Million
Cascadia Windows	Canada (BC)	1	Not in top 100 Manufacturers
Coeur D'Alene Window Co.	WA	1	Not in top 100 Manufacturers
Custom Vinyl Products LLC	VA	1	Not in top 100 Manufacturers
DAKO	Poland	1	Not in top 100 Manufacturers
EuroClime Windows	WA	2	Not in top 100 Manufacturers
EuroLine Windows Inc.	Canada (BC)	1	Not in top 100 Manufacturers
Front Range Window & Door	CO	1	Not in top 100 Manufacturers
Jeld-Wen	NC	6	Over $1 Billion
Kensington HPP Inc.	PA	2	$15 Million to $30 Million
Klearwall	NY	1	Not in top 100 Manufacturers
Karr Windows	Poland	1	Not in top 100 Manufacturers
Kolbe & Kolbe Millwork Co.	WS	5	$100 Million to $200 Million
Interstate Windows	PA	1	Not in top 100 Manufacturers
Intus Windows	VA	4	Not in top 100 Manufacturers
Mathews Brothers Co.	ME	1	$15 Million to $30 Million
Marvin Windows & Doors	MN	6	Over $1 Billion
MI Windows and Doors	AZ	1	$300 Million to $500 Million
Milgard Windows & Doors	WA	3	$500 Million to $1 Billion
Okna Windows Manufacturing	PA	1	$30 Million to $50 Million
Pella Corp.	IA	8	Over $1 Billion
PGT Innovations	FL	1	$500 Million to $1 Billion
Ply Gem	OH	7	Over $1 Billion
Prime Window Systems	WA	1	Not in top 100 Manufacturers
SchüCo	Germany	1	Not in top 100 Manufacturers
Sierra Pacific Windows	CA	3	$200 Million to $300 Million
Simonton Windows & Doors	WV	2	Not in top 100 Manufacturers
Unilux Windows and Doors	Germany	1	Not in top 100 Manufacturers
United Window & Door Mfg.	NJ	1	$50 Million to $100 Million
Ventana Windows & Doors	Canada (ON)	1	Not in top 100 Manufacturers
Vinyltek	Canada (BC)	3	Not in top 100 Manufacturers
Wasco Windows	WI	1	Not in top 100 Manufacturers
Windsor Windows & Doors	IA	1	Not in top 100 Manufacturers
Zola Windows	Poland	3	Not in top 100 Manufacturers

* Many builders have used more than one brand currently and in the past.
** Top 100 Manufacturers 2018 Report, only includes manufacturers in North America, https://windowanddoor.com/article/may-2018/top-100-manufacturers-2018-report?page=0%2C0

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