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Study of High-Performance Windows Incremental Manufacturing Cost

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Executive Summary

The following report summarizes the findings of a project to explore manufacturing cost differentials of windows with enhanced thermal properties to meet the new ENERGY STAR® V7-compliant target. The Northwest Energy Efficiency Alliance (NEEA) commissioned Stephen Selkowitz Consultants to conduct this research. The objective of this study is to quantify the incremental manufacturing cost of upgrading window thermal properties so that NEEA can explore new programmatic and financial actions to help rapidly transform window markets in the Pacific Northwest to meet the latest update to the ENERGY STAR window performance criteria.

Approximately 80% of windows sold today in the Pacific Northwest are ENERGY STAR V6-compliant[1] windows with a U-factor of 0.27; however, less than 5% of current sales would meet the newly announced ENERGY STAR V7-compliant[2] window criteria with a U-factor of 0.22 in ENERGY STAR's Northern Climate Zone.[3] The new voluntary U-factor criteria will become effective in October 2023, so window manufacturers have less than a year to determine how to upgrade their product lines to meet the new criteria. They may choose not to upgrade to V7 if they believe that much higher product costs will reduce their market share.

The analysis described in this report shows that the incremental costs to comply with the new performance targets are modest. Understanding these manufacturing cost options will allow NEEA to assess the value and design of potential market intervention programs to accelerate the shift to V7.

This report explores several technical pathways to make the required thermal improvements, and concludes that an upgrade to a thermally enhanced double-glazed window or a shift to a triple-glazed window can be achieved at an incremental manufacturing cost of ~$1.80–$2.10/sf with volume production. Other studies suggest that this should result in a consumer price increase for the upgrade in the median range of $4.00–$7.00/sf. As market acceptance increases to the point where this new performance level becomes the dominant product for new and retrofit markets, incremental costs could drop even further.

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1 V6 = ENERGY STAR Residential Windows, Doors, and Skylight Specification Version 6.0

2 V7 = ENERGY STAR Residential Windows, Doors, and Skylight Specification Version 7.0

3 https://www.energystar.gov/sites/default/files/Windows_Doors_and_Skylights_Program_Requirements%20v6.pdf

1 Introduction

Window energy performance is primarily influenced by the thermal properties of the window; it is also influenced by the interaction of many other factors, such as climate, orientation, building operating characteristics and associated shading. The primary window thermal properties of interest to regulatory and code bodies, ENERGY STAR®, the National Fenestration Rating Council (NFRC) and utility rebate programs are thermal conductance (U-factor), solar heat gain coefficient (SHGC) and air leakage.

1.1 Background

In northern states of interest to the Northwest Energy Efficiency Alliance (NEEA), where heating loads typically dominate overall annual energy use in homes, the U-factor is normally the property of greatest interest in controlling the overall annual energy impact of a window. Modifying the design of the window to reduce the U-factor is thus a key NEEA goal that contributes to annual energy savings, reductions in HVAC sizing and cost, and improved occupant comfort. Improving window properties without significant increases to product costs is the key to enlisting market forces to transform existing window markets to a new performance goal that meets regional energy savings needs.

NEEA has programs to support builders and homeowners in reducing the energy impacts of their new and existing homes to meet emerging mandatory and voluntary energy targets. Furthermore, the Environmental Protection Agency's (EPA's) ENERGY STAR windows program has recently released its new performance requirements for Residential Windows, Doors, and Skylight Specification Version 7.0 (V7), which will require a significant improvement in window thermal properties beginning in October 2023. Compliance with V7 will require changes to most window designs sold today, either to squeeze higher levels of performance out of modified double glazing or by a shift to triple-glazed products. In either case, additional components and more manufacturing steps will raise both the production cost and market price of these new products. This study is intended to identify and clarify for NEEA the likely range of increase in cost to manufacture these new products. The focus here is on the manufacturing cost required to achieve these new performance levels; the final market price at which they are offered to consumers for purchase is further influenced by many other business factors, as discussed in Section 2, below.

1.2 Scope and Objectives

The focus of this report is on new window designs with lower U-factors. As noted above, the SHGC also influences overall annual energy performance, as reinforced by the existing and new ENERGY STAR compliance options with tradeoffs between U and SHGC. But whereas U is a complex function of many window physical design parameters, as discussed in Section 3, the SHGC of almost all windows can be "tweaked" higher or lower by making relatively simple glass or glass coating substitutions that generally do not involve window design changes and generally have modest, well-defined manufacturing cost differentials.

Furthermore, the new 2023 ENERGY STAR requirements for SHGC include no significant proposed changes from prior versions. In addition, many codes already specify relatively low SHGC values, e.g., 0.3, that cannot be physically reduced much further without creating a darker view through lower light transmission glass—a choice that would be unacceptable to most homeowners. As a result, the authors do not expect to see significant design changes that increase window costs in order to change SHGC.

The scope of this study is limited to exploring cost differentials of windows with enhanced thermal properties to meet the new ENERGY STAR target. In addition to energy savings, these new designs may provide other quantitative and qualitative benefits to homeowners. They will reduce the likelihood of condensation on windows, which could otherwise lead to mold growth and deterioration of building components. They will improve thermal comfort in a room, potentially allowing lower thermostat setpoints that will further increase energy savings. They may allow reduced expense for HVAC systems, both heating sources and thermal distribution systems. They could increase the resale value of the home. Each of these benefits offers potential market and economic value to homeowners and could favorably impact market transformation efforts. None of these potential benefits are assessed in this analysis.

2 Manufacturing Cost vs. Market Price

EPA has finalized the requirements for the new ENERGY STAR Residential Windows, Doors, and Skylight Specification Version 7.0 (V7)[4] program, which will become effective in October 2023. Compliance with the V7 program will require significant product changes in ENERGY STAR's Northern Climate Zone[5] (including NEEA program areas) from the ENERGY STAR Residential Windows, Doors, and Skylight Specification Version 6.0 (V6)[6] program that represents about 80% of window sales in 2022. While some products on the market today can meet the new V7 criteria, most will have to be redesigned, thus adding cost to the current product design. This review focuses on the incremental manufacturing cost of the key window elements that will be needed to meet the new ENERGY STAR V7 values.

To purchase new ENERGY STAR-compliant windows, the consumer will pay more than this incremental manufacturing cost. The market price paid by a homeowner or homebuilder will increase, but over a much wider range than the manufacturing cost. Many significant differences exist between the underlying manufacturing cost of a product and the price at which that product is sold to the end user. This report focuses on quantifying the incremental direct manufacturing cost of the new window products, which can be divided into two broad categories: 1) Materials, e.g., extra layer of glass, additional coatings, new gas fill and/or thermally improved spacers; and 2) Assembly cost—labor and amortized cost of equipment used for assembly, e.g., automated insulating glass unit (IGU) lines. Understanding the magnitude of these costs gives a basis on which to understand the range of ultimate market prices paid by consumers.

To move from manufacturing cost of the window to the market price paid by a homeowner, two other factors are in play:

First, manufacturers incur other direct and indirect costs that are added to the manufacturing cost of all their products—e.g., the cost of owning and operating their buildings, R&D costs, warranty cost, marketing costs and a range of other administrative and legal costs.

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[4] Draft is available at https://www.energystar.gov/sites/default/files/asset/document/ES_Residential_WDS_Draft%201_V7_Spec.pdf
[5] https://www.energystar.gov/sites/default/files/Windows_Doors_and_Skylights_Program_Requirements%20v6.pdf
[6] https://www.energystar.gov/products/spec/residential_windows_doors_and_skylight_specification_version_6_0_pdf

Second, while some products may be sold directly from the manufacturer to the end user (adding transportation and delivery costs), most find their way to an installation via a more circuitous route—via a distributor or a big box retailer, and via an installer or contractor, each of whom adds a markup to the final purchase price. These supply chains and their downstream costs exhibit wide variability and flexibility, which explains the substantial variations in final market price paid by the consumer. Appendices C through E describe additional estimates of consumer market prices.

3 Thermal Properties of Windows and IGUs: Focus on Insulating Glass Unit (IGU)

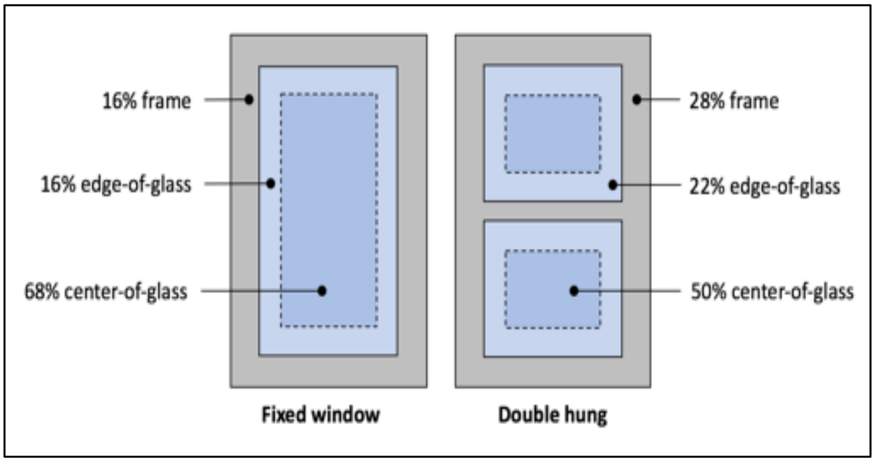
Windows are complex assemblies of many parts, all of which contribute to the overall NFRC-rated U-factor, which is the rating NEEA, code bodies and ENERGY STAR all reference in their respective programs. The overall window U-factor is composed of three distinct elements: Center of glass, edge of glass and frame/sash. The overall window product U-factor is the area-weighted average of the three and is defined by NFRC as:

U_{window} total =

$(U_{frame} \times Area_{frame} + U_{edge\text{-}of\text{-}glass} \times Area_{edge\text{-}of\text{-}glass} + U_{center\text{-}of\text{-}glass} \times Area_{center\text{-}of\text{-}glass})$/Total Window Area

Confusion often arises in thermal performance claims between the "glass properties" and the "whole window properties." In most modern windows the center-of-glass element is the best thermal performer, so a lower overall U is favored by window designs with the highest center-of-glass fraction. The ratio between the center of glass area and overall window area is partly a function of the "design" of the windows and of their size. European windows historically have wide sashes/frames and American windows historically have much thinner sashes/frames. However, an equally important factor with any window is the "operator type," which defines the ability of the window to open to provide fresh air or to allow egress, often a code requirement. At one extreme, a fixed picture window has the least amount of sash/frame and thus the highest glass/frame ratio; a pivoting window such as an awning, hopper or casement window is next, with one element of operable sash in the frame; and the horizontal or vertical sliding windows (single-/double-hung) have the smallest glass/frame ratio due to the multiple sash elements in each window. Figure 1 shows the relative area of each of these elements for a typical fixed window vs. a typical double-hung window for a standard NFRC residential window size, 3 ft x 5 ft.

Figure 1. Relative Importance of Various U-factor Components for Fixed and Sliding Windows



Note: Source—Lawrence Berkeley National Laboratory (LBNL). Based on NFRC standard window size of 3 ft x 5 ft

The size of the window unit and the operator type will impact U-factor and other thermal properties with any given selection of frame, glazing, coatings, gas fill and spacers. NFRC has standardized its residential ratings on a 3 ft x 5 ft window (15 sf) which is used throughout this analysis. As Figure 1 shows, the center of glass comprises 68% of the area of the fixed window but 50% of the area of the double-hung window. Thus, it will generally be more challenging to achieve lower U with a double-hung unit than with a fixed or casement window. For this reason, EPA does most of its ENERGY STAR analysis using the "worst case" double-hung window design, which means that if this design is viable, virtually all other window designs will be equal or better in thermal properties. While these issues may seem "administrative," they can be critical for a manufacturer who would prefer that all product lines employ the same coated glass, edge seals or gas fills.

Frame selection is also a key determinant of U-factor. The two dominant framing material choices are vinyl and wood; several others have growing (fiberglass) or shrinking (aluminum) market shares. Recent market share of each framing material is shown in Table 1.

Table 1. 2019 US Residential Market Share by Framing Material

Framing Material	Million Window Units	Market %
Wood and Wood Clad	7.2	14%
Vinyl	36.4	72%
Aluminum	4.1	8%
Other (e.g., fiberglass)	3.1	6%
Total	**50.8**	**100%**

Note: Source—Fenestration and Glazing Industry Alliance (FGIA)

Differences exist across these primary framing materials, and usage is increasing of hybrid designs or composite frames made of two or more materials, e.g., a low-maintenance vinyl or aluminum outer layer bonded to a wood inner layer seen by the homeowner. Window companies are unlikely to shift frame design materials just to meet new thermal requirements; therefore, this report, as well as ENERGY STAR analyses, focuses on the dominant market leader: vinyl frames fabricated from vinyl extrusions. However, even within this submarket, a wide range of vinyl extrusion cross-sections exists, with some variation in thermal properties based on features such as frame thickness and extrusion geometry, and the use of insulating inserts within the vinyl extrusions. These extrusions are designed to hold IGUs of different thicknesses. The most common current frame design holds a 0.75”–0.88”-wide IGU to accommodate today’s dominant double glazing, typical of about 80% of all current windows. However, many manufacturers also offer frame sections that will accommodate a wider 1” or 1.25” IGU; these can more easily be adapted to hold a wider triple-glazed IGU.

3.1 Focus on the Insulating Glass Unit

Most window companies offer one or more distinct product lines that differ in quality, features, and thus cost, independent of thermal properties. These distinctions might include different hardware, more choices for color or finish, different gaskets and weatherstripping, more options for screens and grills, sensors and electronics for security, and so forth. All of these impact manufacturing costs and market price, but most have minimal effect on thermal properties. Furthermore, if a manufacturer is facing the challenge of improving the U-factor of its product with speed and minimal cost, it is likely to first focus on improving the IGU element rather than making a more radical change to the type or design of the frame it utilizes. Note that in some cases, some existing frame types can be thermally improved without major design changes, e.g., simply by adding foam or other insulating inserts in the frame cavities—some of these cases are noted in the sections that follow.

In order to better define the changes needed in the IGU, and thus their impacts on manufacturing costs, the research team had to first define a base case and then the desired target performance values. This report defines four performance levels and focuses on the two with the most near-term relevance. The four levels are:

1. Current and projected building code requirements
2. Current ENERGY STAR V6 requirements (2022)
3. New ENERGY STAR V7 requirements (beginning October 2023)
4. Projected future “2025/2030” targets to support net zero energy/carbon goals

3.2 Current and Projected Building Codes

Typical building code window U-factors in the Pacific Northwest can be higher or lower than the International Energy Conservation Code (IECC) target values. As Table 2 shows, IECC target values in Climate Zones 4c and 5, as well as in Zone 6, will decrease from 0.30 to 0.28 between 2021 and 2024. Note that current 2022 Oregon code already exceeds the proposed 2024 IECC targets.

Table 2. Current and Projected Window Properties to Meet Building Codes

Climate Zones 4c & 5	Maximum U-Factor Required for New Homes Built in 20XX (Prescriptive Code Compliance Path)			
State	2021	2022	2023	2024
WA	0.30	0.30	0.28	0.28
OR	0.27	0.27	0.27	0.27
ID	0.32	0.32	0.32	0.32

Climate Zone 6	Maximum U-Factor Required for New Homes Built in 20XX (Prescriptive Code Compliance Path)			
State	2021	2022	2023	2024
MT	0.30	0.30	0.30	0.30
ID	0.30	0.30	0.30	0.30

Notes:
Source—NEEA Codes & Standards team internal projections
Orange cells = 2021 projected IECC U-values (0.30)
Yellow cells = 2024 projected IECC U-values (0.28)

3.3 Current ENERGY STAR Residential Windows, Doors, and Skylight Specification Version 6.0 (V6)

ENERGY STAR V6 has been in place since 2017 and requires U<= 0.27. EPA reports that 84% of windows sold in the Northern Zone meet or exceed the requirement. Notably, code in Oregon (and in other locations) is already at, or approaching, this ENERGY STAR V6 level, which was one of the motivations for tightening the specification in the newly adopted V7. This V6 spec is typically met today with a double-glazed, low-E, argon-filled IGU.

3.4 Newly Adopted ENERGY STAR Residential Windows, Doors, and Skylight Specification Version 7.0 (V7)

The newly adopted ENERGY STAR V7 (effective October 2023) will reduce the Northern Zone value to U <= 0.22, although a higher U-factor is permitted with tradeoffs for a higher SHGC:

U <= 0.22 with any SHGC (>0.17)
U <= 0.23, with SHGC >= 0.35
U <= 0.24, with SHGC >= 0.35
U <= 0.25, with SHGC >= 0.40
U <= 0.26, with SHGC >= 0.40

A similar tradeoff table exists for the current V6 requirement. Tradeoffs between U and SHGC are based on the fact that higher SHGC allows some additional useful passive solar gain in winter to offset heat losses. The Canadian building code has had a similar ER rating with a solar gain tradeoff for years. These tradeoffs provide some flexibility in meeting V7 with a higher U-factor, but the tradeoff introduces some potential challenges. While helpful in winter, the selection of a higher SHGC can lead to higher summer cooling bills, more discomfort with summer heat waves, and larger chiller/HVAC size/cost in new construction. It can also create challenges for the window manufacturer trying to track and manage inventory, since each window might now have to be available with three different glass packages rather than a single U/SHGC combination. (Note: Some windows are now manufactured with different IGU glass thicknesses due to different size/wind load structural factors, safety requirements, etc.). Consequently, this report focuses on the manufacturer's ability to achieve a 0.22 U-factor and the associated "worst-case" manufacturing costs. The cost to build an IGU for a 0.23–0.26 U-factor window will always be lower than for a 0.22 unit. ENERGY STAR also has a "Most Efficient" window product category, requiring U <= 0.20 in all climates. Though EPA lists more that 50 window companies offering thousands of different windows meeting this value, this remains a niche market, never having attracted a national market share of greater than 2%–3%.

3.5 Projected “2025/2030” Targets

Canada has set aggressive future window aspirational performance targets of U ~0.14–0.18 as it progresses to 2025 and 2030; however, these targets are too distant in terms of timing to drive mainstream product design today. These very low future U-factor targets are noted here, however, because whereas the new ENERGY STAR targets might be met with aggressive incremental changes to double glazing, the only way to achieve these projected 2025 or 2030 values over time will be to shift the IGU to a triple-glazed design or to a vacuum-insulated glass (VIG) unit. (The VIG achieves its very low U-factor using a low-E coating and by evacuating all the air between the two layers of glass and separating them with tiny 0.3mm spacers so the panes of glass do not touch.) While the potential thermal performance is very good, the costs today are high. The window sash must also be redesigned to properly hold the VIG and there are currently no VIG manufacturers making product in North America. Creating that manufacturing infrastructure will take time.

Given that about 80% of all window sales meet or exceed current ENERGY STAR V6 requirements, these performance values, rather than the less strict code values, are used in this report to define the “current base product” design and cost. Also, given the speculative nature of the 2025/2030 targets proposed in Canada, the authors don’t believe they will drive product redesign in the short term; this report therefore focuses instead on meeting the “near-term” ENERGY STAR V7 U-factor target of 0.22 in 2023.

4 Cost to Meet New Performance Requirements: Shifting U-factor from 0.27 to 0.22

Window designs evolve over time; however, any given performance level will always have a wide range of market prices based on different business/sales models, and many design factors beyond the thermal performance. As noted earlier, this report focuses on the manufacturing costs associated with thermal improvements needed to meet the 0.22 U-factor.

If the thermal performance of an existing window is to be improved, the fastest and lowest-cost approach for a window manufacturer is to focus on improving the IGU, which is the largest contributor to overall window thermal properties (see Figure 1) and is normally least disruptive to the window manufacturing process. Thermal improvements in the IGU can be made via design changes, such as changing the width of the IGU pocket, and/or by component or materials substitution, such as changing from a metal spacer to a warm edge spacer, changing the low-E coating or changing the gas fill. The manufacturing costs of each of these options can be estimated.

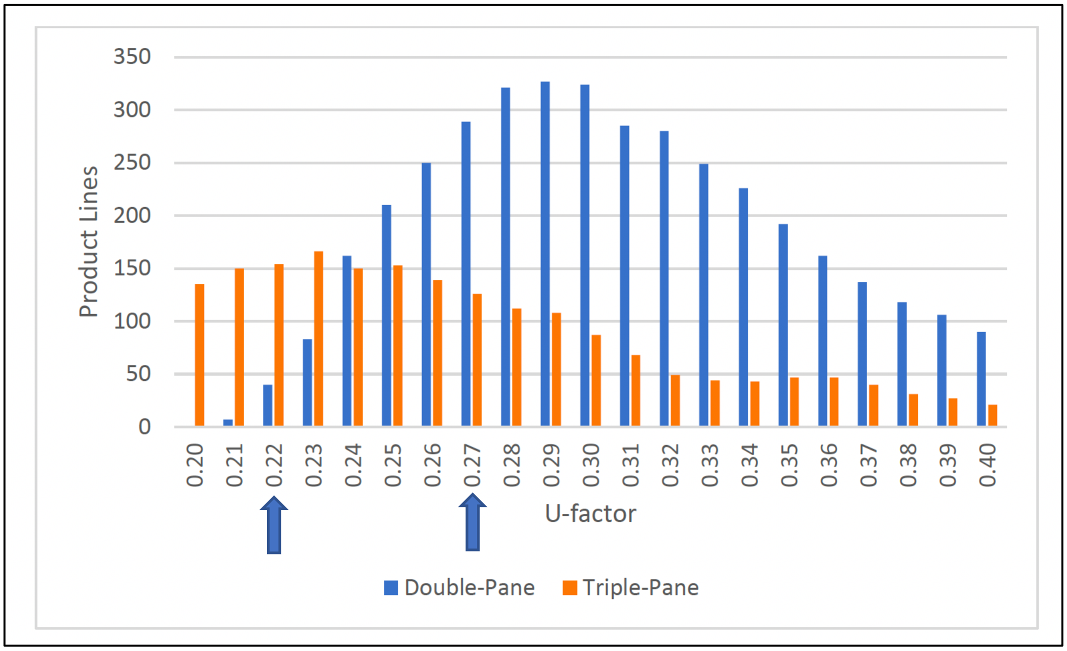
Innovation in product design to improve performance often initially results in higher costs, but these can decline over time. Assembly and/or manufacturing process changes needed to accommodate new or modified materials may also result in higher start-up costs.

These initial costs will likely decrease over time due to a learning curve, to continuous improvement practices, to economies of scale as production volume increases and by selection of new components that deliver enhanced performance at lower cost points. However, some countervailing market pressures increase costs, with no change in design, such as the conditions in 2022 with impacts from COVID-19 and general inflation. These impacts are likely applicable to all costs, not just the incremental costs of thermal improvements, but should be considered on a case-by-case basis.

4.1 Thermal Design and Cost Scenarios for Thermally Improved IGU: Moving from ENERGY STAR V6 to V7

Using the vinyl vertical slider (double-hung) window as a test case, the project team examined costs of two alternate pathways to transition from a U-factor of 0.27 to 0.22. The starting point in both cases is a double-glazed, low-E, argon-filled IGU, which is the current standard design for meeting 0.27. The NFRC Certified Product Directory (CPD) gives certified product data for a wide range of double- and triple-glazed products by U-factor and number of glazing layers, as shown below in Figure 2. (Note that the number of products listed in the NFRC CPD does not correlate to actual production and market sales).

Figure 2. Number of Product Lines in NFRC CPD for Vertical Vinyl Sliders—Double Pane and Triple Pane IGU Options



Notes: Target U-factors of 0.22 and 0.27 indicated by arrows
Source—EPA, ENERGY STAR for Windows, Doors and Skylights V7 Draft 1 Stakeholder Webinar, July 27, 2021

Two trends are clear. First, the 0.27 U-factor can be easily met with the double pane designs, but reaching the 0.22 target is not easily achieved with current double pane products. Second, the triple-glazed product can easily meet the 0.22 target and below, but perhaps surprisingly, many variants perform no better than doubles; this is because some of these triple-glazed designs omit a second low-E coating or omit argon gas fill to reduce costs. It is only when one gets to 0.24 and below that the advantage of the basic triple IGU design becomes clearer.

The following sections describe the manufacturing costs of incremental thermal improvements from 0.27 to 0.22 with each pathway, starting with the 0.27 double-glazed window as a base case to meet the current ENERGY STAR V6.

4.2 Base Case ENERGY STAR V6

Most ES V6 double pane units will start with a low-E coating (surface-2, double or triple silver coating to meet SHGC) and argon gas fill, and may use an improved spacer; about a quarter of the CPD products specify a surface 4 low-E coating as well.

> ***Note on glass surface terminology:***
>
> Low-E coatings are transparent multilayer coatings deposited on glass that are used to improve thermal and optical performance and can be placed on different glass surfaces. The IGU glass surfaces are numbered from the outside to the inside; each glass layer has two surfaces; in a double-glazed IGU, surface-1 is the outer-facing surface of the outer layer of glass; surface-2 and surface-3 face the cavity between the glazings, and surface-4 on the inner glazing faces the room. For a triple-glazed unit, surface-6 on the third glass layer faces the room.

Beginning with the earlier-described common IGU design that meets the V6 ENERGY STAR criteria, the project team estimates the incremental cost for two design scenarios to meet the new 0.22 target in the next sections.

4.2.1 Scenario 1: Keeping the Double-Glazed Configuration

Reducing the U-factor to 0.22 while maintaining a double-glazed configuration requires a surface-4 low-E, a thermally improved spacer and perhaps enhancement of the frame with foam inserts. The base IGU would already have a low-E coating on surface-2 and an argon gas fill. To summarize:

- Add surface-4 low-E
- Switch to a warm edge spacer
- Possibly improve frame thermal properties

Table 3. Incremental Costs for Scenario 1

Scenario 1 Incremental Cost	($/sf)
Surface-4 low-E	$0.75–$1.00
Warm edge spacer	$0.30
Foam/Frame	$0.75
Total Added Cost/sf	**$1.80–$2.05**

4.2.2 Scenario 2: Transitioning to a Triple-Glazed Unit

The second scenario is built around a transition to a triple-glazed unit. In this case, minimum incremental requirements are:

- Add a second low-E coating (assume from the base case a triple silver coating on surface-2), so add a high solar gain coating on surface-5
- Add a spacer/likely warm edge
- Add a third middle glass layer, conventional glass or thin glass
- Include argon gas fill in the second cavity
- Use a wider frame to accommodate triple slot width
- Include additional IGU assembly cost

This analysis assumes the IGU pocket is ~1" or wider to accommodate the extra glass and gas cavity using an argon gas fill. Spacing of 3/4" to 7/8" may require additional thermal improvements such as krypton gas and/or surface-6 low-E. The marginal cost of moving to a wider frame to use argon would normally be cheaper than these alternatives so that lower-cost option is modeled here; this assumes an additional two lbs of vinyl, per EPA, for the wider frame. This analysis assumes the IGU is made on an automated IGU line and that extra cost is added to assemble the third glass layer.

Table 4. Incremental Costs for Scenario 2

Scenario 2 Incremental Cost	($/sf)
Single silver low-E (surface-5)	$0.20–$0.30
Warm edge spacer (second cavity)	$0.60
Third piece of glass (2.5mm)	$0.20–$0.30
Argon—second cavity	$0.05–$0.20
Wider frame	$0.20
IGU Assembly	$0.50
Total Added Cost/sf	**$1.75–$2.10**

5 Summary and Conclusions

A window manufacturer can choose among multiple pathways to update product lines to meet the newly approved EPA ENERGY STAR Northern Zone V7 criteria for the window U-factor of 0.22, starting with today's double-glazed V6-compliant product with a U-factor of 0.27. These technology upgrade pathways are described earlier in this report and incremental manufacturing costs are estimated in Section 4.2 for the two most likely pathways to reach the new thermal performance levels. The primary focus here is on improving the IGU, although some modest frame changes are addressed in each scenario.

The first technology pathway (Scenario 1) focuses on an upgrade to existing double-glazed windows and the second pathway (Scenario 2) transitions to a triple-glazed window. The two scenarios have similar overall incremental manufacturing costs of ~$2/sf, largely due to the high cost of the surface-4 low-E most commonly used in Scenario 1 and the fact that a cheaper high solar gain low-E can be used in Scenario 2 as the second low-E coating in the triple-glazed unit. Various thin glass options could be substituted in place of the standard single strength third glass layer assumed here. Although they are more expensive than the default glass (current incremental costs: 1.6mm glass (+$0.35–$0.45/sf) or 0.7mm glass (+$0.90–$1.00/sf)), each results in a lighter-weight window that might be easier to handle and install. A small "manufacturing process" cost is added to Scenario 2 to assemble the third glass layer; however, the costs between the two scenarios would be similar if the IGUs are made on a high volume, automated IGU line.

The incremental manufacturing cost estimates of ~$2/sf to upgrade from a U-factor of 0.27 to 0.22 are consistent with prior market data that suggested these 0.22 U-factor windows can be sold to the end user for incremental market prices of $4–$7/sf. As noted previously, a wide range of business and market factors impact how the incremental manufacturing cost is translated into incremental market prices paid by homeowners.

Can these "bottoms-up" cost studies be verified by real market data? Several studies have assessed the existing or projected market prices of 0.22 U-factor windows. The EPA market analysis for the V7 update collected retail window sales data for double- and triple-glazed windows. The market price premium for the triple pane windows within a product line showed a wide overall 10:1 price range across all 15 window suppliers (Appendix C). However, the middle third of the 15 products evaluated have incremental market prices ranging from ~$55 to ~$80 for a 15 sf window, or $3.70–$5.30/sf. These median incremental market prices are a factor of roughly two to three times higher than the estimated incremental manufacturing costs in Section 4.2, which is typical for markups across the supply chain for window products, These incremental market price data points are reinforced by two other recent studies in the Pacific Northwest:

- A 2020 study from the Regional Technical Forum showing incremental market prices of $4.92/sf, dropping to $4.00/sf as volume further increases (Appendix D); and
- A 2019 study that updated the Standard Information Workbook used by the Regional Technical Forum showed an incremental market price range of $3–$6/sf when changing from a U-factor of 0.30 to 0.22 (Appendix E).

The wide variation in market prices for windows with similar performance properties reinforces the notion that market price is not always tightly coupled to a narrow definition of manufacturing cost. For example, if market acceptance increases to the point at which this new ENERGY STAR V7 performance level (U-factor of 0.22) becomes the dominant product for new and retrofit markets, several market forces are likely to come into play. Window companies may purchase key component materials from suppliers at lower prices due to higher volume. New investments in automation, justified by increasing production volume, can decrease costs. In addition, the ordering and customer fulfillment process for a non-standard, limited-volume product is almost always higher than for mainstream products; if the new high-performance product reaches a dominant market share, the overall fulfillment cost to supply a poorer-performing legacy product might exceed the cost of the newer higher-performance window.

These market trends provide some optimism, although no certainty, that the relative costs of the new high performance windows can become even more cost competitive vis-à-vis their legacy ENERGY STAR products as their V7 market share increases beginning in 2023.

Appendix A: Cost Data from EPA V7 ENERGY STAR Analysis

Table 5. Incremental Cost of Glazing and Coating Options

Component Item	Estimated Cost Range ($/ft²)	Notes
Standard 2.5mm clear glass (single-strength annealed)	$0.20–0.30	For residential IGU fabrication
Standard 3mm clear glass (double-strength annealed)	$0.25–0.35	For residential IGU fabrication
Standard 3.2mm clear glass (tempered)	$0.35–0.50 for stock products $0.50–$1.00 for special order	For residential IGU fabrication
Thin clear third layer of glass (1.6mm)	$0.35–0.45	For a thin triple residential IGU fabrication
Single silver sputtered (coating only)	$0.20–0.40	For surface 3 dual-glazed IGU
Double silver sputtered (coating only)	$0.20–0.40	For surface 2 dual-glazed IGU
Triple silver sputtered (coating only)	$0.35–0.75	For surface 2 dual-glazed IGU
Low-E high gain pyrolytic (coating only)	$0.20–0.40	For surface 2 or 3 dual-glazed IGU
Fourth surface pyrolytic (coating only)	$0.20–0.40	For fourth (or sixth) surface IGU
Fourth surface indium tin oxide (ITO) sputtered (coating only)	$0.75–1.00	For fourth (or sixth) surface IGU

Note: Source—EPA ENERGY STAR Windows, Response to Comments (Part 1) on Version 7.0
https://www.energystar.gov/sites/default/files/asset/document/Response%20to%20Comments%20%28Part%201%29%20on%20Version%207.0%20Specification%20Discussion%20Guide%20-%20September%202020.pdf

Table 6. Incremental Cost Data for Gas Fill and Spacers, Frames

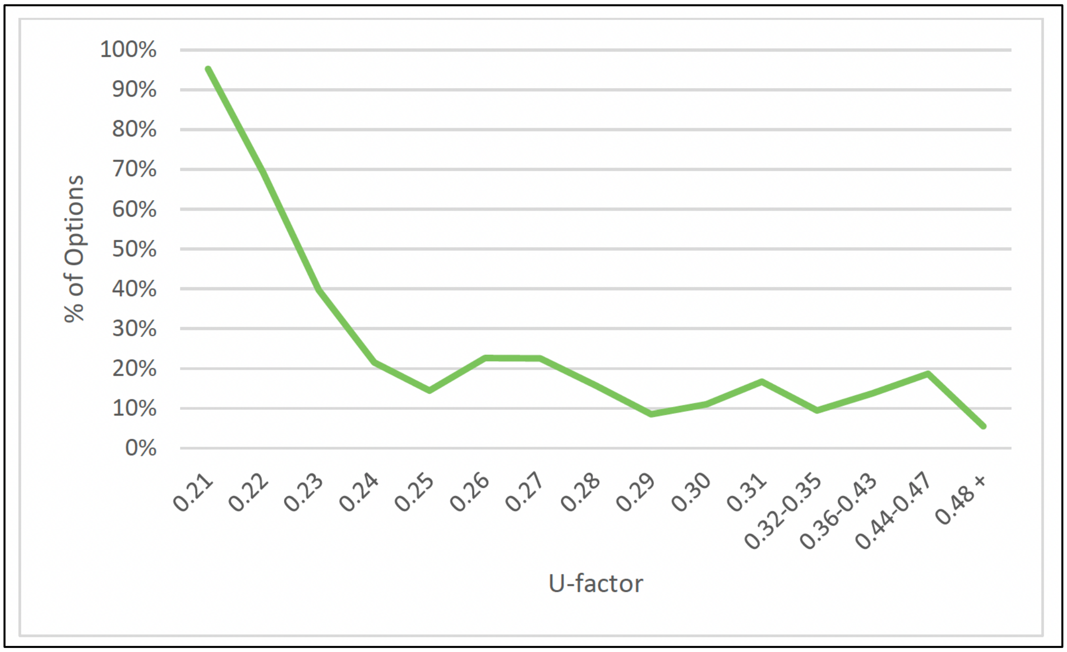
Component Item	Estimated Cost Range	Notes
Air	$0	
Argon gas	$0.05–0.20/ft²	Including overfill (injection fill or chamber fill)
Krypton gas	$0.70–1.10/ft²	Including overfill
Standard aluminum spacer	$0.10–0.15/ft	Box or U-shape
Standard tin-plated steel spacer	$0.10–0.15/ft	U-shape
Warm edge spacer (stainless steel)	$0.20–0.30/ft	Box or U-shape (range of options)
Foam spacer	$0.25–0.35/ft	Silicone foam
High-performance spacer	$0.30–0.40/ft	Top performer – Nonmetal spacer element
Total spacer cost with automation	$0.35–0.50/ft	Automation costs more but has reduced labor costs.
Expanded polystyrene foam insert for frame	$8–$12/window	Cut foam, manually inserted
Spray foam into frame	$8–$12/window	Two-part foam (polyiso), manually inserted
Advanced vinyl frame with vinyl foam	≈ $20/window	Foam added when frame is extruded; there is no labor cost.
Advanced vinyl frame (more chambers)	Additional cost by vinyl weight	Extrude more chambers when fabricating. Performance impact varies by design.
Vinyl commodity price	$1.40–$1.60/lb	
3'x5' – Vertical slider – 7/8" slot	18–20 lbs	Dual glaze
3'x5' – Vertical slider – 1-1/8" slot	19–22 lbs	Dual or triple glaze, PG50
3'x5' – Vertical slider – 1-3/8" slot	24–26 lbs	Triple glaze, PG80

Note: Source—EPA ENERGY STAR Windows, Response to Comments (Part 1) on Version 7.0
https://www.energystar.gov/sites/default/files/asset/document/Response%20to%20Comments%20%28Part%201%29%20on%20Version%207.0%20Specification%20Discussion%20Guide%20-%20September%202020.pdf

Appendix B: Percentage of Double Pane, Vinyl, Vertical Sliders with Foamed Frames

In order to achieve U-factor <= 0.22 using a double-glazed window, most window products in the NFRC CPD must utilize foamed frames.

Figure 3. Percentage of Double Pane, Vinyl, Vertical Sliders with Foamed Frames

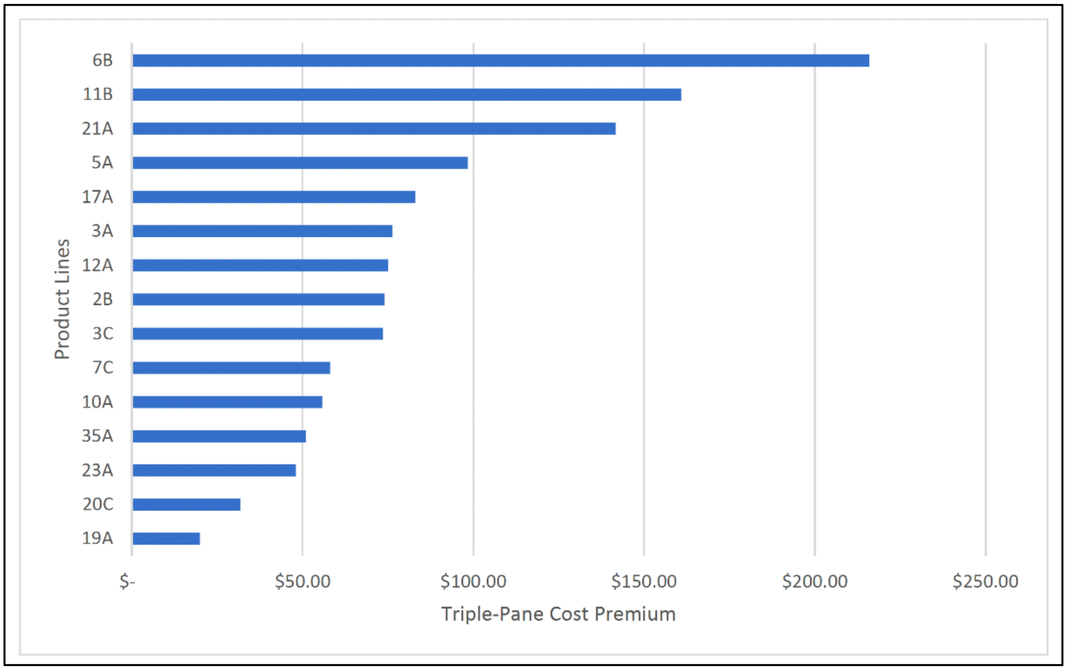


Note: Source—Figure 2 from ENERGY STAR Windows, Doors and Skylights Version 7.0 Criteria Analysis Report, July 2021

Appendix C: Incremental Consumer Price Premium for Triple-Glazed Windows

Note the ~10:1 difference in market price premium in the figure below, from the lowest to highest. The middle third of the 15 products have costs ranging from ~$55 to ~$80 for a 15 sf window, or $3.70–$5.30/sf.

Figure 4. Market Price Premium for Adding Triple Pane to a 15 sf Window within a Product Line



Note: Source—Figure 12 from EPA ENERGY STAR Windows, Doors and Skylights Version 7.0 Criteria Analysis Report, July 2021 https://www.energystar.gov/sites/default/files/asset/document/V7_Stakeholder%20Meeting_7-27-2021_final.pdf

Appendix D: Window Market Cost Data

(Note: Excerpt from Regional Technical Forum Standard Information Workbook. This is a study of market costs as experienced by window purchasers. Energy 350 June 2020 memo from O'Neil to C. Steinhoff; New Homes Cost Assumptions)

Window components have historically been the hardest to determine cost, based on both the proprietary nature of the industry as well as the wide range of cost options in the market. However, as part of a large envelope measure update in 2018,[7] the RTF relied on a significant dataset of utility program information from around the region to determine average window costs for single family homes. Costs were determined using extrapolated data from utility program findings and found to be in line with current market prices at big box stores as well as cost data from ASHRAE and PNNL.

Results from this analysis pointed to a much lower incremental cost than was previously estimated. Due to market forces and diminishing costs for thin film technology, incremental window costs are estimated to be $4.92/sqft from a code baseline U-0.30 to a U-0.20 window. Future costs for windows are expected to decrease slightly over time as thin film becomes standard market practice and costs continue to diminish. Based on this assumption future costs are expected to decrease slightly to $4.00/sqft. This cost/sqft is in line with established triple pane windows overseas and was used as a threshold for a mature triple pane window market.

Based on the sources outlined above, we updated costs for windows, walls, and infiltration in the CERF model to reflect these recent cost findings for use in the New Homes Cost-effectiveness tests. A summary of the component end state and original, current, and estimated future costs are given in the table below.

Components (End-state)	Original Cost/sf	Current Cost/sf	Future Cost/sf
Walls (R21+5)	$ 1.53	$ 0.73	$ 0.46
Windows (U-0.20)	$ 30.00	$4.92	$ 4.00
Infiltration (3 ACH50)	$ 0.40	$ 0.46	$ 0.07

[7] March, 2019 Regional Technical Forum Presentation: *Standard Information Workbook Updates* https://nwcouncil.app.box.com/v/20190319SIWPres

Appendix E: Window Cost Data Updates for Use in Standard Information Workbook

The following data on current and proposed window costs come from a March 19, 2019 Regional Technical Forum presentation entitled *Standard Information Workbook Updates.*[8] The slide presentation outlines a centralized data resource for regionally representative costs for 13 efficiency measures; slides 23 and 24 shown below summarize current and proposed window cost data.

WINDOW COSTS (from Slide 23 in RTF presentation)

- Current costs
  - Data source: 2011–2012 Energy Trust of Oregon (ETO) and Tacoma program data; Pacific Northwest National Laboratory (PNNL); Lowes.com
  - Data coverage: Single family, multi-family
  - Methodology:
    - Single family: lower quartile method used to adjust for non-EE window features
    - Multi-family: smaller dataset, so median cost used rather than lower quartile
- Proposed costs
  - Data source:
    - Single family and multi-family: 2017–2018 Bonneville Power Administration, Puget Sound Energy (PSE), Energy Trust of Oregon, Idaho Power Company (IPC), and Tacoma program data
    - Manufactured homes: 2017–2018 Bonneville Power Administration data
  - Data coverage: Single family, multi-family, manufactured homes
  - Methodology:
    - Installed cost of U30 window (U-factor = 0.30) estimated using lower quartile method with all utility data
    - All other window costs estimated using incremental cost from U30, calculated two different ways:
      - from direct numeric comparison of similar-sized jobs in BPA data, and
      - extrapolation from all utility data
    - U30 window costs use housing type-specific data, but multi-family and manufactured housing use per-square-foot incremental costs to extrapolate to other U-values

[8] https://nwcouncil.app.box.com/v/20190319SIWPres

Window Costs, $/sf (from Slide 24 in RTF presentation)