Analysis of Window, Door, and Skylight Standard

Re: SB 24-214 and HB 23-1161

March 11, 2025

SB 24-214 amended CRS 6-7.5-105, 5(j), providing the Colorado Department of Public Health and Environment (CDPHE) and Colorado Energy Office (CEO) the opportunity to evaluate the window, door, and skylight standard codified in CRS 6-7.5-105, 5(j)(I). The statute allows the standard to be evaluated for two primary factors: impacts on net consumer costs and supply chain constraints. The CEO has analyzed the potential impact of this window, door, and skylight standard and has summarized the findings in this report.

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Selected HB 23-1161 Legislative Text

[link] Selected text relevant to this analysis below:

6-7.5-102. Definitions. As used in this article 7.5, unless the context otherwise requires AND EXCEPT AS DETERMINED BY RULE PURSUANT TO SECTION 6-7.5-106 (1):

(53) "RESIDENTIAL BUILDING" MEANS A STRUCTURE THAT IS USED PRIMARILY FOR LIVING AND SLEEPING AND THAT IS ZONED AS RESIDENTIAL OR OTHERWISE SUBJECT TO RESIDENTIAL BUILDING CODES. FOR THE PURPOSES OF RESIDENTIAL WINDOWS, DOORS, AND SKYLIGHTS, "RESIDENTIAL BUILDING" MEANS A BUILDING THAT IS THREE STORIES OR LESS IN HEIGHT.

(54) "RESIDENTIAL DOOR" MEANS A SLIDING OR SWINGING ENTRY SYSTEM THAT IS INSTALLED OR DESIGNED FOR INSTALLATION IN A VERTICAL WALL SEPARATING CONDITIONED AND UNCONDITIONED SPACE IN A RESIDENTIAL BUILDING.

56) "RESIDENTIAL SKYLIGHT" MEANS A WINDOW THAT IS DESIGNED FOR SLOPED OR HORIZONTAL APPLICATION IN THE ROOF OF A RESIDENTIAL BUILDING, THE PRIMARY PURPOSE OF WHICH WINDOW IS TO PROVIDE DAYLIGHT OR VENTILATION. "RESIDENTIAL SKYLIGHT" INCLUDES A TUBULAR DAYLIGHTING DEVICE.

(58) (a) "RESIDENTIAL WINDOW" MEANS AN ASSEMBLED UNIT THAT:

(I) CONSISTS OF A FRAME THAT HOLDS ONE OR MORE PIECES OF GLASS OR OTHER GLAZING MATERIAL THAT ADMITS LIGHT OR AIR INTO AN ENCLOSURE; AND

(II) IS DESIGNED FOR INSTALLATION AT A SLOPE OF AT LEAST SIXTY DEGREES FROM HORIZONTAL IN AN EXTERNAL WALL OF A RESIDENTIAL BUILDING. (b) "RESIDENTIAL WINDOW" INCLUDES A TRANSOM WINDOW BUT DOES NOT INCLUDE A RESIDENTIAL SKYLIGHT.

(5) ON AND AFTER JANUARY 1, 2026, A PERSON SHALL NOT SELL, OFFER TO SELL, LEASE, OR OFFER TO LEASE ANY OF THE FOLLOWING NEW PRODUCTS IN COLORADO UNLESS THE EFFICIENCY OF THE NEW PRODUCT MEETS OR EXCEEDS THE FOLLOWING EFFICIENCY STANDARDS, AS APPLICABLE:

(j) RESIDENTIAL WINDOWS, RESIDENTIAL DOORS, AND RESIDENTIAL SKYLIGHTS INCLUDED IN THE SCOPE OF THE ENERGY STAR PROGRAM PRODUCT SPECIFICATION FOR RESIDENTIAL WINDOWS, DOORS, AND SKYLIGHTS MUST SATISFY THE NORTHERN CLIMATE ZONE QUALIFICATION CRITERIA OF THAT SPECIFICATION; EXCEPT THAT RESIDENTIAL WINDOWS AND DOORS THAT ARE CUSTOM DESIGNED FOR A HISTORICALLY DESIGNATED BUILDING AND REQUIRED IN ORDER TO MAINTAIN

THE HISTORIC NATURE OR CHARACTER OF SUCH A BUILDING ARE NOT REQUIRED TO SATISFY SUCH CRITERIA.

Selected SB 24-214 Legislative Text

[link] Selected text relevant to this analysis below:

6-7.5-105. Standards - effective dates - repeal. (5) On and after January 1, 2026, a person shall not sell, offer to sell, lease, or offer to lease any of the following new products in Colorado unless the efficiency of the new product meets or exceeds the following efficiency standards, as applicable:

(j) (I) EXCEPT AS OTHERWISE PROVIDED IN SUBSECTION (5)(j)(II) OF THIS SECTION, residential windows, residential doors, and residential skylights included in the scope of the Energy Star program product specification for residential windows, doors, and skylights must satisfy the northern climate zone qualification criteria of that specification; except that residential windows and doors that are custom designed for a historically designated building and required in order to maintain the historic nature or character of such a building are not required to satisfy such criteria.

(II) THE EXECUTIVE DIRECTOR MAY CONSULT WITH THE COLORADO ENERGY OFFICE TO EVALUATE THE STANDARD SET FORTH IN SUBSECTION (5)(j)(I) OF THIS SECTION FOR RESIDENTIAL WINDOWS, RESIDENTIAL DOORS, AND RESIDENTIAL SKYLIGHTS. IF THE EXECUTIVE DIRECTOR DETERMINES THAT THE STANDARD CANNOT REASONABLY BE MET BY MANUFACTURERS OF RESIDENTIAL WINDOWS, RESIDENTIAL DOORS, AND RESIDENTIAL SKYLIGHTS, THEN THE EXECUTIVE DIRECTOR SHALL SET AN ALTERNATIVE STANDARD WHICH MAY BE APPLIED INSTEAD OF THE STANDARD SET FORTH IN SUBSECTION (5)(j)(I) OF THIS SECTION AND THE EXECUTIVE DIRECTOR SHALL DISPLAY THE ALTERNATIVE STANDARD ON THE PUBLIC WEBSITE OF THE COLORADO DEPARTMENT OF PUBLIC HEALTH AND ENVIRONMENT NO LATER THAN JUNE 1, 2025. WHEN DECIDING WHETHER THE STANDARD SET FORTH IN SUBSECTION (5)(j)(I) OF THIS SECTION CAN REASONABLY BE MET, THE EXECUTIVE DIRECTOR SHALL TAKE INTO ACCOUNT THE FOLLOWING FACTORS:

(A) IMPACTS ON NET CONSUMER COSTS; AND
(B) SUPPLY CHAIN CONSTRAINTS.

Proposed window, door, and skylight standard

SB 24-214 and HB 23-1161 establish that on or after January 1, 2026, windows, doors, and skylights included in the scope of the ENERGY STAR program cannot be sold or leased for residential use in Colorado unless their rated performance satisfies the Northern climate zone ENERGY STAR specification for these products.[1] The law does not specify a version of the ENERGY STAR specification, so it likely refers to whichever version of the ENERGY STAR standard is currently in place. If the ENERGY STAR window, door, and skylight specification is updated in the future, the law likely requires that these products satisfy the updated specification in order to be sold in Colorado for residential applications.

The regulation would be implemented as a point-of-sale standard. It would be illegal to sell a window, door, or skylight product for residential use within Colorado if it does not meet the current ENERGY STAR specification. Enforcement would be managed by the Colorado Department of Public Health and Environment (CDPHE). HB 23-1161 notes that the primary enforcement mechanisms would be checking retailer and distributor compliance via online price checks and by developing an anonymous violation reporting system.

As written, the standard likely applies to residential window, door, and skylight products used in both new construction residential projects and renovations of existing residential housing. However, HB 23-1161 narrows the scope of residential buildings to only those “three stories or less in height”. This exemption likely primarily applies to large multifamily buildings. This exemption could make enforcement and compliance with the standard more difficult. Retailers and distributors would need to determine how many stories are in the building where the windows, doors, and skylights will be installed. A point-of-sale standard is easier to enforce and likely would have a higher level of compliance if it is applied to all residential buildings.

The standard likely does not apply to window, door, or skylight products used in garages, sheds, or accessory buildings that are not primarily used for living and sleeping since these buildings likely do not meet the definition of a residential building in HB 23-1161. That said, if retailers and distributors seek to sell non-conforming products for these specific applications, there could be enforcement complications.

Another potential area of confusion is window, door, and skylight products used in unconditioned basements, unconditioned sunrooms, and unconditioned porches. In HB 23-1161, only the definition of residential doors makes a distinction between conditioned and unconditioned space. Requiring the use of more energy efficient products in unconditioned spaces in residential buildings would provide little or no energy savings or greenhouse gas emission reductions, but allowing non-conforming residential products to be sold for use in these unconditioned spaces could create challenges with enforcement of the standard.

[1] There is an exception for windows and doors that are custom designed for historic buildings.

Analysis conclusions

Proposed window, door, and skylight standard is unreasonable

The Colorado Energy Office (CEO) has evaluated the regulation and standard set forth in HB 23-1161 and SB 24-214 and deems that the standard cannot be met by manufacturers without imposing too high of a financial burden on the majority of Colorado households. The standard would also significantly reduce consumer options for doors. For typical homes in Colorado it is estimated that installing vinyl vertical slider windows that meet the ENERGY STAR v7 Northern climate zone specification instead of baseline vinyl vertical slider windows with U-factor equal to 0.35 will cost an additional $1,500 to $2,500 per home. The estimated payback period for this incremental investment is found to be longer than 20 years for the majority of Colorado households. This length of time exceeds the typical warranty period for residential windows, and the investment likely would not pay itself back within the expected lifetime of the windows.

Furthermore, no other states have proposed similar window and door standards based on ENERGY STAR or have adopted energy codes requiring that windows and doors meet ENERGY STAR performance levels. Given Colorado's population makes up less than 2% of the U.S. population, it is unlikely that this standard alone would induce enough additional demand for ENERGY STAR windows, doors, and skylights to significantly decrease the cost of these products going forward.

Based on this analysis and conclusion, CEO recommends that the CDPHE propose an alternative standard that would have a more positive economic impact on Colorado consumers.

Alternative window, door, and skylight standard

CEO believes a residential window, door, and skylight standard should apply only to product U-factor and should not limit product solar heat gain coefficient (SHGC) in any way. By excluding SHGC from the standard, CDPHE would be providing homeowners and homebuilders with flexibility to decide if they wish to take advantage of passive solar heating in their home or if they instead prefer to prevent potential overheating in warm months. Simply establishing a maximum product U-factor would create energy savings for households and has no risk of potentially causing overheating discomfort to building occupants.

CEO proposes that CDPHE should base the alternative standard on the prescriptive maximum U-factor listed for vertical fenestration (i.e. windows and doors)[2] and skylights in the most recent edition of the residential International Energy Conservation Code (IECC).[3] CEO also proposes that this standard should only apply to residential doors with significant amounts of glazing,

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[2] The IECC defines "vertical fenestration" as windows that are fixed or operable, opaque doors, glazed doors, glazed block and combination opaque/glazed doors composed of glass or other transparent or translucent glazing materials and installed at a slope of not less than 60 degrees from the horizontal

[3] Specifically Table R402.1.2, "Maximum Assembly U-Factors and Fenestration Requirements"

(those defined as “>½-lite”)[4] so that consumer residential exterior door options are not significantly limited by the standard.

Based on the 2024 IECC, this proposed alternative standard would require windows, doors, skylights to meet the following criteria in order to be sold or leased for residential use in Colorado.

- Residential windows: U-factor of 0.30 or lower
- Residential skylights: U-factor of 0.50 or lower
- Residential doors, >½-lite: U-factor of 0.30 or lower
- Residential doors, other than >½-lite: exempted, no U-factor requirement

If any of these prescriptive maximum values are modified in future editions of the IECC, the state standard should be updated to match the latest edition of the IECC.

Based on the cost analysis in this report, the incremental cost to install windows with U-factor equal to 0.30 instead of baseline windows with U-factor equal to 0.35 is $530 for a typical home in Colorado. The payback period for this incremental investment is expected to be between 10 and 15 years for the majority of Coloradans. CEO believes there are likely no supply chain constraints that would prevent manufacturers from selling products that satisfy these standards. Furthermore, the IECC evaluates and considers product availability and affordability when deciding whether or not to decrease the prescriptive maximums for windows, doors, and skylights.

Potential language describing the proposed alternative standard is as follows:

On and after January 1, 2026, a person shall not sell, offer to sell, lease, or offer to lease any of the following new products in Colorado unless the efficiency of the new product meets or exceeds the following efficiency standards, as applicable:

Residential windows, residential >½-lite doors, and residential skylights must have U-factor equal to or lower than the maximum U-factor requirement for climate zone 5 listed in the “Maximum Assembly U-Factors and Fenestration Requirements” table (Table R402.1.2) of the most recent edition of the residential International Energy Conservation Code (IECC). If the IECC lists an alternative maximum U-factor requirement for a given product type for climate zone 5 installations in buildings at high elevation, the maximum U-factor requirement for high elevation installations in climate zone 5 shall be used for this standard for that product type. Window and >½-lite door products must satisfy the “Fenestration U-Factor” maximum requirement and skylight

[4] A “>½-lite” door can be defined as a door with greater than 900 square inches of glazing or a sidelite with greater than 281 square inches glazing (per NFRC 100). This definition includes ¾-lite and fully glazed doors and sidelites. This definition is used by ENERGY STAR: https://www.energystar.gov/sites/default/files/asset/document/ES_Residential_WDS_V7_Final%20Specification%202022.pdf

products must satisfy the “Skylight U-Factor” maximum requirement. Residential doors that do not meet the definition of >½-lite are not required to satisfy the criteria described above. A“>½-lite door is defined as a door with greater than 900 square inches of glazing or a sidelite with greater than 281 square inches glazing (per NFRC 100). This definition includes ¾-lite and fully glazed doors and sidelites.

Residential windows and residential doors that are custom designed for a historically designated building and required in order to maintain the historic nature or character of the building are not required to satisfy the criteria described above.

Background

Current window regulations in Colorado

There is currently no state regulation or standard or statewide building/energy code that governs minimum window, door, or skylight energy efficiency in the state of Colorado. Furthermore, there are no federal energy efficiency regulations governing these product types, so manufacturers and retailers in Colorado are currently free to sell any windows they choose. The Environmental Protection Agency (EPA) does include windows, doors, and skylights within the ENERGY STAR program, but this program is voluntary and manufacturers are not required to produce products that meet ENERGY STAR specifications.

Building and energy code factors

IECC adoption in Colorado

Many individual building jurisdictions in Colorado have adopted versions of the International Energy Conservation Code (IECC), a code that includes minimum efficiency standards for windows, doors, and skylights. As a result, residential new construction projects and some residential renovation projects in these jurisdictions are required to install windows with a specified minimum energy efficiency. For renovations and additions to residential homes, whether the project must adhere to the local building/energy code depends on the scope of the project and the specific rules in each jurisdiction. Replacing residential windows (without changing rough opening sizes or adding new window openings) does not always require a permit and thus the new windows may not need to adhere to the local energy code. Building an addition or changing window sizes generally does require a permit and these project types may need to adhere to local building and energy code.

Roughly 50% of residential window sales in the United States are for renovation projects, so there likely is a nontrivial number of windows being installed in Colorado residential projects that are not required to follow any building or energy code[5]. A statewide point-of-sale standard that makes it illegal to sell low energy efficiency windows would effectively target these project types that are not addressed by codes.

Overall there is non-uniform energy code adoption across jurisdictions in Colorado, with 64 jurisdictions having no energy code in place at all. That said, over 90% of the Colorado population lives in jurisdictions that have adopted the 2018 or 2021 versions of the IECC.

[5] "Study of the U.S. Market for Windows, Doors and Skylights" April 2022. FGIA

Table 1. Summary of energy code adoption in Colorado

IECC Version Adopted	**Number of Jurisdictions**	**Population (2022) in Jurisdictions**	**Percent of Colorado Population (2022)**
1977	1	3,805	0.07%
2003	2	2,488	0.04%
2006	24	36,108	0.62%
2009	9	31,173	0.53%
2012	7	30,992	0.53%
2015	24	181,180	3.10%
2018	132	1,544,679	26.45%
2021	80	3,903,060	66.83%
None	64	91,772	1.57%
Grand Total	**343**	**5,825,257**	**99.75%**

Since the passage of HB 22-1362, jurisdictions that update their building codes after July 1, 2023 are required to adopt and enforce an energy code that is equivalent to or stricter than the IECC 2021 code. This state law will increase the number of jurisdictions in Colorado that adopt the 2021 IECC over time, but it does not guarantee Colorado will achieve uniform energy code adoption throughout the state. Jurisdictions that do not update their building codes are not compelled by this law to adopt a new energy code. In the coming years there is likely to remain a mix of jurisdictions with no energy code adoption, 2021 IECC adoption, and 2024 IECC adoption.

IECC window efficiency specifications

As shown in Table 1, 66.8% of the state population lives in jurisdictions that have adopted the 2021 IECC, 26.5% live in jurisdictions that have adopted the 2018 IECC, and 1.6% live in jurisdictions that have not adopted an energy code. These three groups make up ~95% of the population in Colorado, so it is instructive to examine the minimum window[6] efficiency specifications for each group in detail. It is also instructive to compare these groups to the 2024 IECC because progressive jurisdictions are expected to adopt this version of the energy code in the coming years.

The IECC governs window efficiency by providing prescriptive maximums for both window U-factor and solar heat gain coefficient (SHGC). The U-factor of a window is a measure of how well a window prevents non-solar heat flow.[7] The lower the U-factor, the better a window is at preventing heat flow into or out of the building. SHGC is a measure of how much solar radiation from the sun transfers through the window. A window with a high SHGC lets more solar radiation into the home, allowing the sun to passively heat the home during the day. In the

[6] Note from hereinafter this analysis focuses on windows because they make up the largest portion of a typical building envelope

[7] Heat flow per unit area, time, and temperature difference. In this analysis all U-factor values are with units of BTU / hr / sqft / °F

winter this passive heating can reduce heating loads, but in the summer the passive heating can increase air conditioning loads.

Table 2 compares the maximum U-factor and SHGC for residential windows for different versions of the IECC. Colorado has counties in climate zones 4, 5, 6, and 7 with roughly 90% of the population residing in climate zone 5 (full breakdown in Table 3). Beginning in 2021 the IECC relaxed the U-factor maximum for climate zones 5, 6, and 7 when the window installation site was located 4,000 feet or more above sea level. The majority of Coloradans live above 4,000 feet so these relaxed values are most relevant for this analysis. While there are slight differences between versions of the IECC, there are not large discrepancies across the climate zones applicable to Colorado. In general the maximum U-factor is 0.30 to 0.32 and there is either no maximum SHGC or it is 0.40.

Table 2. Maximum U-factor and SHGC for residential windows. The stricter maximums in parentheses apply to installation locations below 4,000 feet above sea level.

	2018 IECC		*2021 IECC*		*2024 IECC*	
Climate Zone	**U-factor**	**SHGC**	**U-factor**	**SHGC**	**U-factor**	**SHGC**
1	N/A	0.25	N/A	0.25	0.50	0.25
2	0.40	0.25	0.40	0.25	0.40	0.25
3	0.32	0.25	0.30	0.25	0.30	0.25
4	0.32	0.40	0.30	0.40	0.30	0.40
5	0.30	N/A	0.32 (0.30)[8]	0.40	0.30 (0.28)	N/A
6	0.30	N/A	0.32 (0.30)	N/A	0.30 (0.28)	N/A
7	0.30	N/A	0.32 (0.30)	N/A	0.30 (0.27)	N/A

Table 3. Colorado residential building location breakdown by climate zone.

Climate Zone	Building Inventory [% of Total]	Building Area [% of Total]
4	0.8%	0.7%
5	89.7%	91.2%
6	4.1%	3.7%
7	5.4%	4.4%

Because jurisdictions can and do modify versions of the IECC, there is an added amount of diversity when examining the adopted energy codes for different cities in Colorado. Table 4 shows the amended residential window specifications in the codes for several jurisdictions in Colorado. Some examples of amendments are Aspen requiring triple pane windows, Denver reducing the maximum U-factor to 0.27, and Colorado Springs removing the maximum SHGC.

[8] Numbers in parentheses apply to installation locations below 4,000 feet above sea level.

Table 4. Maximum U-factor and SHGC for residential windows in select cities in Colorado.

Jurisdiction	Climate Zone	U-factor	SHGC	Percent of Co Population	Source
Denver City and Co	5	0.27 / 0.25[9]	0.40	12.2%	2022 Denver Building & Fire Code
Colorado Springs	5	0.32	N/A	8.3%	Pikes Peak Regional Building Code 2023
Fort Collins	5	0.28 / 0.25[10]	0.35	2.9%	Fort Collins Amended 2021 IECC
Boulder	5	0.27	0.40	0.7%	2024 City of Boulder Energy Conservation Code
Aspen	7	0.26 / 0.28[11]	0.35	0.1%	2021 Aspen Energy Code

Code compliance pathways

The IECC allows homebuilders to satisfy the prescriptive U-factor and SHGC maximums using the weight-average method. With this method you can install windows with a variety of U-factor/SHGC so long as the weighted-average values for all windows involved in the project is below the prescriptive maximums. As an example, a builder could use an equal number of like-sized windows with U-factor = 0.34 and U-factor = 0.26 and still meet a 0.30 U-factor requirement. The weighted-average method provides homebuilders with design flexibility. With respect to U-factor, these tradeoffs are useful when a low U-factor window cannot be affordably sourced for an oddly shaped window or window with an uncommon size. For SHGC, a builder may want to use very high SHGC windows on the south facing wall of a building to maximize passive solar heating.

The performance and energy rating index pathways are alternative compliance pathways for the IECC. These pathways offer homebuilders more flexibility in material and component selection. Homebuilders can make tradeoffs between building components such as using additional insulation in the walls and ceiling to make up for lower U-factor windows. Tradeoffs provide the opportunity to be flexible in building design and make component choices based upon cost, lead time, aesthetics, etc., while still meeting the required energy efficiency target for the building.

To summarize, Colorado currently has a diverse energy and building code landscape and is not expected to achieve uniformity in the near future. Even if there were uniform adoption of a single

[9] Where the proposed glazing area is greater than or equal to 15.0% of the conditioned floor area, as provided by Section R103.2, the lower U-factor shall not be exceeded
[10] Where the proposed glazing area is more than 30% of the wall area by elevation, as provided per section R103.2, the second U-factor shall be required
[11] Lower value must be followed for new construction and additions, higher value is for alterations. Windows must be triple pane except if they meet the requirements using air fill

energy code across the state, energy code still allows buildings to utilize windows and doors with a wide array of energy efficiency performance given the weighted-average method in the prescriptive pathway and alternative pathways that focus on overall building efficiency.

Key finding: the proposed window standard would make it illegal to sell lower performing residential windows, doors, and skylights in Colorado. Such a standard would decrease the amount of flexibility available to homebuilders because there would be no lower performance (and less expensive) windows, doors, and skylights available for purchase. As a result, homebuilders would not be able to take advantage of the tradeoffs allowed by the weight-average method and the performance energy rated index pathways in the IECC. The net result would be potentially increased project costs with marginal improvements in building energy efficiency.

ENERGY STAR window specification

The current ENERGY STAR standard for windows is version 7 and was adopted on October 23, 2023. This standard breaks the United States up into four zones as shown in Figure 1. Colorado contains regions in both the Northern and North-Central zones, but the proposed standard specifically states that the Northern climate zone specifications will be applied throughout the entire state. The window performance standards required to achieve ENERGY STAR certification are shown in Table 5.

For the Northern climate zone, ENERGY STAR v7 provides multiple pathways to product certification. Because heating loads outweigh cooling loads in cold climates, windows with low U-factor and low SHGC can provide equivalent energy savings to windows with moderate U-factor and high SHGC. Windows with higher SHGC allow for more passive solar heating in the winter and can reduce the heating load of the building. A low U-factor window with high SHGC would provide the most energy savings overall, but the windows available on the market with these specifications are relatively expensive. Windows with moderate U-factor and high SHGC often provide the shortest payback time for homeowners given their balance of moderate cost and high energy savings potential.

While windows with high SHGC can decrease heating costs, they also can cause occupant discomfort due to overheating in the afternoon and early evening when the Colorado sun shines brightly on the south and west facing walls of homes. Furthermore, high SHGC windows increase peak cooling loads in the summer. Homes that are best able to take advantage of passive solar heating without sacrificing occupant comfort are specifically designed to incorporate high SHGC windows. These homes generally are well insulated, have properly sized heating and cooling systems, incorporate window overhangs on facades with high solar exposure, and a limited amount of glazing on westward facing walls. Without these specific design considerations, high SHGC windows may offer a mixed experience for consumers: reduced heating costs at the expense of discomfort from large temperature fluctuations in the afternoon.

Figure 1. Map of climate zones from the ENERGY STAR v7 window specification

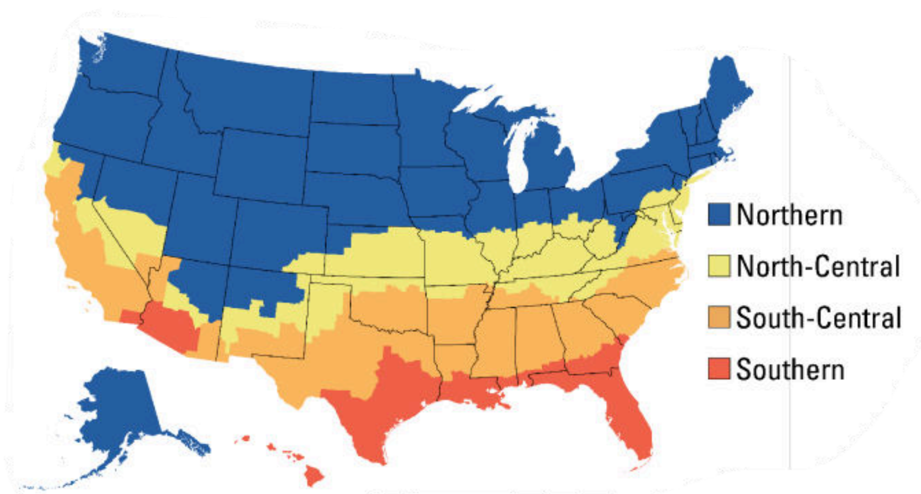

Table 5. ENERGY STAR v7 efficiency specification requirements for windows.

Climate Zone	U-factor	SHGC
Northern	≤ 0.22	≥ 0.17
	= 0.23	≥ 0.35
	= 0.24	
	= 0.25	≥ 0.40
	= 0.26	
North-Central	≤ 0.25	≤ 0.40
South-Central	≤ 0.28	≤ 0.23
Southern	≤ 0.32	≤ 0.23

ENERGY STAR update cadence

The EPA aims to use the ENERGY STAR program to drive innovation and differentiate more energy-efficiency products from market standard code-compliant products. In fact, EPA tracks improvements in building and energy code as an indicator for when the ENERGY STAR specification for a given product should be updated.

Another indicator tracked by EPA is the percentage of available products in the market that currently meet the ENERGY STAR specification in a given product category. For example, the EPA stated that 80-90% of residential windows for sale were ENERGY STAR certified under the previous Version 6 window specification.[12] EPA saw this high market share of ENERGY STAR

[12] https://www.energystar.gov/sites/default/files/asset/document/Response%20to%20Comments%20on%20Version%207.0%20Draft%201%20Specification.pdf

certified products as an indication that a more strict specification was needed to drive further improvement in window energy efficiency and began development of the Version 7 standard that is in place today.

It should be noted that window manufacturers disputed the market share numbers cited by EPA during the 2023 ENERGY STAR update cycle. Manufacturers pointed out that the data used by EPA did not track where windows were sold and installed. Windows that only met the less stringent Southern climate zone standard were still counted as ENERGY STAR certified even if they were installed in a Northern climate zone location. After receiving this feedback, EPA amended its data collection process so that it could eliminate ENERGY STAR products shipped to the wrong climate zone from the market share calculation. In late 2024, EPA reported new market share data showing that ENERGY STAR windows accounted for roughly 30-50% of windows sold in 2023. Additionally, the market share for products meeting the ENERGY STAR Most Efficient specification (U-factor ≤ 0.20) was less than 1%. This information points to purchasing ENERGY STAR certified windows being a consumer upgrade choice and not the market standard.

The EPA first introduced the windows, doors, and skylights ENERGY STAR standard in 1998. This standard was then revised in 2003, 2005, 2009, 2015, and 2023. On average, the ENERGY STAR window standard is revised every ~6 years, making a potential update to a Version 8.0 in the range of 2030-2033 plausible.

Key finding: as written, SB 24-214 and HB 23-116 would require the statewide window, door, and skylight standard to follow along with any changes in the ENERGY STAR standard. This arrangement could potentially be problematic for Colorado if the EPA were to significantly increase the energy efficiency standard in the coming years. In such a scenario, it could become difficult and/or expensive to source affordable windows for Coloradans if the window manufacturing industry is unable to readily produce windows that meet the standard. There is also a question of how the state standard would be affected if the ENERGY STAR program is shut down by the EPA.

High elevation and argon gas

One of the cheapest and most effective methods to increase the efficiency of a window is to fill dual pane or triple pane windows with argon gas and seal the gas between the panes of glass. This method is low cost, easy to manufacture, and widely adopted across the window industry. However, when you manufacture a sealed, gas-filled window at sea level and then bring it up to high elevation (>5,000-7,000 feet) the gas within the window wants to expand, leading to bowing of the window (the glass panes push outward). The majority of households in Colorado live at elevations above 5,000 feet and there are several mountain communities located above 9,000 feet. Thus, the effects of altitude on argon gas-filled windows is important for this analysis.

The effects of gas-filled window bowing can be merely cosmetic or can lead to window failure in extreme cases. The most common failure mode is seal failure which allows argon to leak out of the window and allows moisture to enter the window, decreasing window U-factor and potentially creating condensation issues. The extent of the effects and risk of window failure depends on a variety of factors including, elevation of the installation location, size and form factor of the window, thickness and type of glass used in the window (e.g. annealed vs. tempered), window type (e.g. casement vs. single hung) etc.

Generally manufacturers will only warranty gas-filled windows for use up to a given maximum elevation. Beyond that elevation, manufacturers often require that capillary breather tubes are incorporated into the window unit. These tubes allow gasses to move in and out of the window unit, providing an avenue for pressure regulation. Using capillary tubes prevents window bowing or seal failure, but also lets the argon escape from the window. The efficiency of windows that have capillary tubes is modeled assuming that the windows are just filled with air and does not include any contribution from argon. The simple trade off is that an air-filled window (e.g. a window with capillary breather tubes) can be installed at any elevation but it has a U-factor 0.02-0.04 lower than an equivalent argon-filled window.

The majority of window manufacturers are capable of producing and providing warranties for sealed, argon-filled windows that can be used at elevations up to 6,000-7,000 feet. At the higher end of this elevation range, the windows may be visually bowing but most manufacturers are confident the seals will not prematurely fail. As you go even higher in elevation, differences between manufacturers and product availability emerge. Manufacturers that produce their windows at high elevation (e.g. in Colorado) are generally able to warranty their sealed, argon-filled products to the highest elevations.

A common practice for manufacturers is to publish a chart showing which window types and sizes are able to be warrantied in which elevation ranges. Figure 2 shows the Elevation Limits Chart for Andersen 100 Series windows. The chart starts a 3,000 feet elevation on the left and moves to 10,000 feet on the far right column. The numbers in the chart refer to the window size (e.g. “2438” is 2 feet 4 inches wide and 3 feet 8 inches tall). From this figure, we see that the number of window options available decreases for higher elevations and some window types have no available options for 10,000 feet and above.

Because of the differences between manufacturer policies, it is difficult to make quantitative conclusions about the availability of sealed argon-filled windows in different regions of Colorado. That said, it is reasonable to conclude that the number of high performance, low U-factor window options available to households decreases the higher you go in elevation, especially as you go above 9,000 feet. Additional information about high elevation and argon-filled windows is available in the Appendix.

As a worst case scenario for Coloradans that live at very high elevation, it is important to examine the cost and availability of air-filled window products that meet the ENERGY STAR v7 Northern climate zone specification. Colorado consumers will always be able to purchase air filled window products since there is no added risk of seal failure with these products (they have capillary tubes installed). If a sealed, argon-filled product cannot be sourced or warrantied for a given location, the backup option is going to be an air-filled product. For this reason, the rest of this analysis provides data for air-filled products in addition to argon-filled products.

Figure 2. Chart with the elevation limits for 100 Series Andersen products of varying size.

Andersen® Product	3,000	4,000	5,000	6,000	7,000	8,000	9,000	10,000
100 Series Casement Windows		1620, 1626, 1630, 1636, 1640, 1646, 1650, 1656, 1660	2020, 2026, 2030, 2036, 2040, 2046, 2050, 2056, 2060, 2620, 3020	2660	2626, 2630, 2636, 2640, 2646, 2650, 2656, 3026	3056, 3060	3030, 3036, 3040, 3046, 3050	
100 Series Awning Windows		1616, 1620, 1626, 1630, 2016, 2616, 3016, 3616, 4016	2020, 2026, 2030, 2620, 3020, 3620, 4020		2626, 2630, 3026, 3626, 4026		3030, 3630, 4030	
100 Series Single-Hung Windows	1620, 2020, 2620, 3020, 3620, 4020	1626, 1630, 1636, 1640, 1646, 1650, 1656, 1660, 1666, 1670, 1676, 2026, 2030, 2626, 2630, 3026, 3030, 3626, 3630, 4026, 4030	2036, 2040, 2046, 2050, 2056, 2060, 2066, 2070, 2076, 2636, 3036, 3636, 4036	2640, 3040, 3640, 4040	2646, 2650, 2656, 2660, 2666, 2670, 2676, 3046, 3646, 4046	3050, 3650, 4050	3056, 3060, 3066, 3070, 3076, 3656, 4056	3660, 3666, 3670, 3676, 4060, 4066, 4070, 4076
100 Series Gliding Windows Active-Stationary or Stationary-Active	2010, 2016, 2020, 2026, 2030, 2036, 2040, 2046, 2050, 2056, 2060, 2610, 2616, 3010, 3016, 3610, 3616, 4010, 4016, 4610, 4616, 5010, 5016, 5610, 5616, 6010, 6016	2620, 2626, 2630, 2636, 2640, 2646, 2650, 2656, 2660, 3020, 3026, 3030, 3036, 3040, 3046, 3050, 3056, 3060, 3620, 4020, 4620, 5020, 5620, 6020	3626, 3630, 3636, 3640, 3646, 3650, 3656, 3660, 4026, 4626, 5026, 5626, 6026	4030, 4036, 4040, 4046, 4050, 4056, 4060	4630, 4636, 4640, 4646, 4650, 4656, 4660, 5030, 5060, 5630, 6030	5036, 5040, 5046, 5050, 5056, 5656, 5660	5636, 5640, 5646, 5650, 6036, 6050, 6056, 6060	6040, 6046
100 Series Gliding Patio Doors								5068, 50611, 5080, 6068, 60611, 6080, 8068, 80611, 8080
100 Series Patio Door Sidelights	1368, 13611, 1380	1668, 16611, 1680				2068, 20611, 2080		2668, 26611, 2680, 3068, 30611, 3080, 4068, 40611, 4080
100 Series Patio Door Transoms	1313, 1316, 1320, 1613, 1616, 1620, 2013, 2016, 2613, 2616, 3013, 3016, 4013, 4016, 5013, 5016, 6013, 6016, 8013, 8016	2020, 2620, 3020, 4020, 5020, 6020, 8020						

Window cost analysis

Incremental cost model

There is a great diversity of window products available on the market, which makes it challenging to quantitatively compare costs of windows with different energy efficiency performance. Windows can have different frame materials (vinyl, wood, aluminum, vinyl clad wood, etc.), different form factors (vertical slider, casement, picture, etc.), differing number of glass panes, differing glass coating type, and overall varying quality for each component. This cost analysis focuses only on vinyl frame vertical slider (e.g. double and single hung) windows in order to make this problem more tractable. Vinyl frame windows make up ~70% of residential window sales in the U.S., and vertical slider form factors account for ~60% of vinyl window sales.[13] Furthermore, vinyl frame windows provide a good value with both low cost and high energy efficiency and make up over 50% of sales in the residential window market. Focusing only on this one specific window type still provides valuable insights because this window type is the most likely window to be purchased by a Coloradan.

Using data from both ENERGY STAR[14] and from market price research, the cost of a basic builder grade dual pane vinyl window with one Low-E coating and no argon gas fill is estimated at $315 for a 15 sqft window. This window type is estimated to have a U-factor of 0.35 and is the market baseline for the rest of the cost analysis. This window type is chosen as the baseline because it represents the lowest efficiency window that would reasonably be installed in new construction or a renovation in a Colorado jurisdiction that has not adopted a version of the IECC. It is assumed that single pane windows or windows with no low-E coating, which have U-factors above 0.40, are not commonly installed in new residential projects.

The incremental cost and U-factor improvement of various window upgrades (e.g. foamed frame, a second low-E coating, third pane of glass, etc.) are then individually estimated (Table A1). By combining all possible window upgrades, one can estimate the approximate price of windows with U-factor varying from 0.35 to 0.20 (Tables A2 and A3). Component upgrade pricing and U-factor contribution was estimated using data from the EPA's ENERGY STAR program[15], discussions with window manufacturers, and secondary research by CEO staff.

There is significant uncertainty in these window pricing estimates, primarily because window manufacturers are unwilling or unable to share detailed component pricing data. Window prices are highly affected by aesthetics, brand, build quality, and manufacturer price markup, so isolated the relationship between U-factor and price is non-trivial. The prices determined via this analysis likely represent the cost of an "average" window for each U-factor and may be lower or

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[13] "Study of the U.S. Market for Windows, Doors and Skylights" April 2022, FGIA

[14] https://www.energystar.gov/products/energy_star_residential_windows_doors_and_skylights_version_7_0

[15] https://www.energystar.gov/sites/default/files/asset/document/ES_Residential_WDS_Draft%201_Criteria%20Analysis%20Report.pdf

higher than the retail prices charged by brand name window suppliers. Windows with wood or fiberglass frames are likely significantly more expensive, but are assumed to have a similar relationship between window price and U-factor. Figure 3 shows the modeled window price plotted as a function of U-factor for vinyl windows with and without access to sealed, argon-filled glass unit technology. A more detailed explanation of the price modeling is available in the Appendix. Table 6 tabulates these prices and compares them quantitatively. Appendix Tables A2 and A3 show the full window component composition for each data point, but as an example, a U = 0.26 window is estimated to have the following component breakdown:

- U-factor = 0.26, Argon-fill: Dual pane, 2 low-E coating, improved frame & spacer
- U-factor = 0.26, Air-fill: Triple pane, 1 low-E coating, basic frame

Window prices are inversely correlated with U-factor, starting at $315 for the market baseline window and reaching $437 and $463 for argon and air-filled windows with U-factor of 0.21, respectively. Prices are quite similar when comparing the air-fill only prices to those with argon-fill available. Utilizing argon reduces prices by 1-6% when a U-factor lower than ~0.3 is required. Some other key findings are as follows:

- When argon fill is available, dual pane windows can achieve U-factors down to 0.25, but triple pane windows are required to achieve a U-factor of 0.24
- With air fill only, triple pane windows are required to achieve a U-factor of 0.26
- There is a roughly 20-25% increase in price when moving from a dual pane window to a triple pane window (keep other variables approximately the same)

Figure 3. Plot of modeled window price vs. U-factor for vinyl frame vertical slider windows (15 sqft in size).

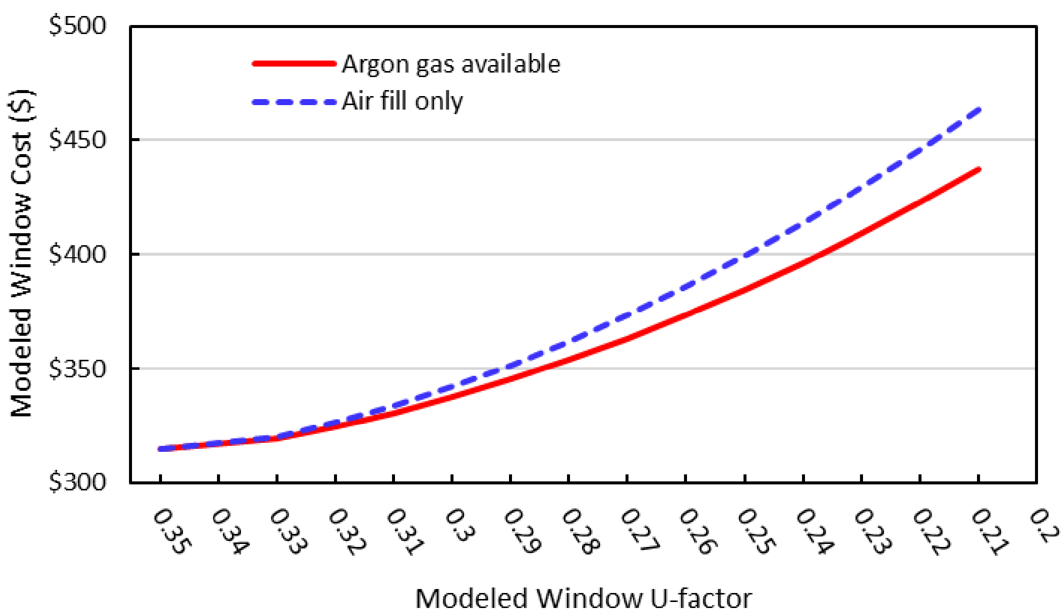

Table 6. Modeled window price vs. U-factor for vinyl vertical slider windows (15 sqft in size).

U-factor	Price, Argon Fill Available	Price, Air Fill Only	Percent Difference
0.35	$315	$315	0%
0.33	$320	$320	0.1%
0.32	$325	$326	0.5%
0.31	$331	$334	0.9%
0.30	$337	$342	1.4%
0.29	$345	$352	1.9%
0.28	$354	$362	2.4%
0.27	$363	$373	2.9%
0.26	$373	$386	3.4%
0.25	$384	$399	3.9%
0.24	$396	$414	4.4%
0.23	$409	$429	4.9%
0.22	$423	$446	5.4%
0.21	$437	$463	5.9%

Payback periods for window upgrades

Reasonable payback period

When creating the ENERGY STAR v7 window specification, the EPA chose 13 years as the amount of time a household should reasonably expect to recoup their incremental investment required to install ENERGY STAR windows (compared to installing only code compliant windows). Using a variety of sources, the EPA determined that the average homeowner in the U.S. stays in their home for approximately 13 years. Windows frequently last longer than 13 years and provide energy savings for their entire useful lifetime. However, EPA concluded that homeowners prefer to have investments pay off within the time they live in the home. Homeowners in Colorado typically stay in their homes for only ~10 years, 30% shorter than the national average.[16]

EPA also considered using payback times of 20 years because this time frame is the useful lifetime of a typical residential window. After a homeowner moves out of a home, the windows continue to provide energy savings for the new homeowner that moves into the home. Theoretically, the home buyer should value this energy savings and pay a slightly higher purchase price for the home. However, it is unclear if windows older than 13 years actually provide significant residual value during a home sale and it would be difficult to quantitatively incorporate any residual value into a payback period calculation.

Proposed changes to building and energy code are sometimes evaluated over a 30 year time period, which matches the average mortgage length in the U.S.[17] A timeframe this long is potentially out of scope for a window standard because residential window warranties are generally limited to a maximum 20 years. Thus, a homeowner is not guaranteed to see nameplate window energy performance after 20 years.

Key finding: when evaluating the impact of the proposed statewide window standard based on ENERGY STAR, a reasonable payback period for the incremental investment required to upgrade windows is likely between 10 and 20 years. In this analysis, window upgrades with payback periods longer than 15 years are considered an unreasonable burden on Coloradans.

Heat loss model

To evaluate the net cost impact of the proposed standard on Colorado consumers, the estimated payback time for various window upgrade scenarios is calculated. In all scenarios, the cost and energy performance of a lower U-factor window is compared to a baseline window with U-factor of 0.35. To calculate the payback period, the following equation is used:

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[16] https://www.nar.realtor/blogs/economists-outlook/how-long-do-homeowners-stay-in-their-homes
[17] https://www.energycodes.gov/sites/default/files/2021-07/residential_methodology_2015.pdf

$$Payback\ period\ (U_X) = \frac{A \times (Window\ cost, U_X) - A \times (Window\ cost, U_{0.35})}{(Annual\ cost\ from\ heat\ loss\ with\ U_{0.35}\ windows) - (Annual\ cost\ from\ heat\ loss\ with\ U_X\ windows)}$$

A is the total area of windows in the building (square feet) and the *window cost* as a factor of U-factor is pulled from Table 6. A relatively simple model was first used to calculate the amount of heat that is lost from the building envelope through the windows. This model does not take into account any passive solar heat gain that may enter the building and reduce heating costs or increase cooling costs. The cost of the heat loss is calculated as a function of U-factor with the following equation:

$$Annual\ cost\ of\ heat\ loss\ (U_{Factor}) = \frac{A \times U_{Factor} \times HDD \times 24 \times P_{Gas}}{AFUE \times 1{,}000{,}000} + \frac{A \times U_{Factor} \times CDD \times 24 \times P_{Electricity}}{SEER \times 1{,}000}$$

Again *A* is the total area of windows in the building (square feet), *U-factor* is in units of BTU / hr / sqft / °F, *HDD* is the annual heating degree days for the building location (°F-days), the number *24* accounts for the number of hours in a day, *P* is energy price, *AFUE* is the furnace efficiency, *CDD* is the annual cooling degree days for the building location (°F-days), and *SEER* is the air conditioning seasonal energy efficiency ratio (BTU / W-hr). The numbers 1,000,000 and 1,000 are unit conversions to convert from MMBTU to BTU and from kW to W, respectively.

In all scenarios, the building is assumed to be 2,380 sqft in size with 24 windows that are 15 sqft each (~15% glazing to floor area ratio). The AFUE is assumed to be 85% to represent an average between a typical low and high efficiency natural gas furnace, and the air conditioner SEER is assumed to be 14, the current federal minimum efficiency. Heating and cooling degree day data is sourced from the 2021 ASHRAE Handbook[18] with a base temperature of 65 degrees used for heating and 74 degrees used for cooling. The price of natural gas is assumed to be $11.8/MMBTU and the price of electricity is assumed to be $0.13/kWh.

Table 7 and 8 show the calculated energy cost savings and payback periods for a variety of locations throughout Colorado assuming all locations have access to sealed, argon-filled window units. Payback periods are found to be highly dependent on the location climate zone, with climate zone 6B and 7 locations showing shorter payback periods for low U-factor windows. In climate zone 5B, payback periods increase beyond 15 years if the window U-factor is decreased to 0.29 or below and payback periods exceed 20 years for U-factors below 0.26. By contrast, climate zone 6B and 7 locations see payback periods less than 15 years for upgrades to windows with U-factor down to 0.27. For U-factors below 0.26, the payback periods in climate zones 6B and 7 increase to beyond 15 years, but generally stay below 20 years. The ENERGY STAR v7 Northern climate zone specification requires U-factor of 0.22 or below for the low SHGC windows and between 0.26 and 0.23 for windows with high SHGC. For climate zones 4B and 5B, the payback period for an investment in ENERGY STAR windows is estimated to be between 20 and 30 years long. In climate zones 6B and 7, the payback period is estimated at 15 to 20 years.

[18] https://ashrae-meteo.info/v2.0/index.php?lat=39.833&lng=-104.658&place=%27%27&wmo=725650

Appendix Table A4 shows the payback periods calculated from the same exercise but with only air filled windows available. The trends are similar, but payback periods are increased overall because it costs slightly more to achieve the same U-factor with an air filled window when compared to an argon filled window. Analysis of air-filled windows is most relevant to climate zones 6B and 7 because these regions are at higher elevation and are most likely to see challenges sourcing seals, argon-filled windows. Households in climate zone 5B likely have access to many sealed, argon-filled window options on the market today. The lowest U-factor with a consistent payback period of 15 years or less is 0.29 for climate zones 6B and 7.

Key finding: The ENERGY STAR v7 Northern climate zone specification requires that windows have a U-factor of 0.26 or lower. This analysis finds that the majority of Coloradans would have payback periods at least 20 years long if required to invest in windows that meet the ENERGY STAR v7 Northern specification. An alternative window standard requiring window U-factor be 0.30 or below would produce payback periods of ~15 years for the majority of Coloradans.

Table 7. Average annual energy cost savings for window upgrades in various locations. Argon fill assumed available in all locations.

Average energy cost savings for different window upgrades, upgrading from a U = 0.35 Window														
City	**Elevation**	**Climate Zone**	U = 0.33	U = 0.32	U = 0.31	U = 0.30	U = 0.29	U = 0.28	U = 0.27	U = 0.26	U = 0.25	U = 0.24	U = 0.23	U = 0.22
Trinidad	5741	4B	$13.3	$19.9	$26.6	$33.2	$39.8	$46.5	$53.1	$59.8	$66.4	$73.0	$79.7	$86.3
Lamar	3704	4B	$13.9	$20.8	$27.8	$34.7	$41.7	$48.6	$55.6	$62.5	$69.5	$76.4	$83.4	$90.3
Denver	5289	5B	$14.6	$22.0	$29.3	$36.6	$43.9	$51.3	$58.6	$65.9	$73.2	$80.5	$87.9	$95.2
Colorado Springs	6181	5B	$14.8	$22.2	$29.5	$36.9	$44.3	$51.7	$59.1	$66.5	$73.8	$81.2	$88.6	$96.0
Grand Junction	4833	5B	$13.9	$20.9	$27.9	$34.8	$41.8	$48.8	$55.7	$62.7	$69.7	$76.7	$83.6	$90.6
Montrose	5720	5B	$14.9	$22.3	$29.7	$37.1	$44.6	$52.0	$59.4	$66.8	$74.3	$81.7	$89.1	$96.5
Durango	6670	5B	$16.7	$25.1	$33.5	$41.8	$50.2	$58.5	$66.9	$75.3	$83.6	$92.0	$100.4	$108.7
Alamosa	7533	6B	$19.8	$29.6	$39.5	$49.4	$59.3	$69.2	$79.0	$88.9	$98.8	$108.7	$118.6	$128.5
Craig	6190	6B	$20.2	$30.3	$40.5	$50.6	$60.7	$70.8	$80.9	$91.0	$101.1	$111.3	$121.4	$131.5
Eagle	6497	6B	$18.5	$27.8	$37.0	$46.3	$55.5	$64.8	$74.0	$83.3	$92.6	$101.8	$111.1	$120.3
Steamboat Springs	6879	7	$20.3	$30.5	$40.6	$50.8	$61.0	$71.1	$81.3	$91.5	$101.6	$111.8	$121.9	$132.1
Gunnison	7666	7	$22.6	$34.0	$45.3	$56.6	$67.9	$79.2	$90.6	$101.9	$113.2	$124.5	$135.8	$147.2
Aspen	7720	7	$20.1	$30.1	$40.2	$50.2	$60.3	$70.3	$80.4	$90.4	$100.5	$110.5	$120.6	$130.6
Leadville	9932	7	$25.8	$38.7	$51.6	$64.5	$77.4	$90.3	$103.2	$116.1	$129.0	$141.9	$154.8	$167.7

Table 8. Average payback time for window upgrades in various lLocations. Argon fill assumed available in all locations

Average payback period for different window upgrades, upgrading from a U = 0.35 Window														
City	**Elevation**	**Climate Zone**	U = 0.33	U = 0.32	U = 0.31	U = 0.30	U = 0.29	U = 0.28	U = 0.27	U = 0.26	U = 0.25	U = 0.24	U = 0.23	U = 0.22
Trinidad	5741	4B	8.1	11.5	14.0	16.1	18.0	19.8	21.5	23.2	24.9	26.5	28.1	29.7
Lamar	3704	4B	7.8	11.0	13.4	15.4	17.2	18.9	20.6	22.2	23.8	25.3	26.9	28.4
Denver	5289	5B	7.4	10.5	12.7	14.6	16.3	18.0	19.5	21.1	22.6	24.0	25.5	27.0
Colorado Springs	6181	5B	7.3	10.4	12.6	14.5	16.2	17.8	19.4	20.9	22.4	23.8	25.3	26.7
Grand Junction	4833	5B	7.7	11.0	13.3	15.3	17.2	18.9	20.5	22.1	23.7	25.3	26.8	28.3
Montrose	5720	5B	7.3	10.3	12.5	14.4	16.1	17.7	19.3	20.8	22.3	23.7	25.2	26.6
Durango	6670	5B	6.5	9.2	11.1	12.8	14.3	15.7	17.1	18.4	19.8	21.1	22.3	23.6
Alamosa	7533	6B	5.5	7.8	9.4	10.8	12.1	13.3	14.5	15.6	16.7	17.8	18.9	20.0
Craig	6190	6B	5.3	7.6	9.2	10.6	11.8	13.0	14.1	15.2	16.3	17.4	18.5	19.5
Eagle	6497	6B	5.8	8.3	10.0	11.6	12.9	14.2	15.5	16.7	17.9	19.0	20.2	21.3
Steamboat Springs	6879	7	5.3	7.5	9.2	10.5	11.8	12.9	14.1	15.2	16.3	17.3	18.4	19.4
Gunnison	7666	7	4.8	6.8	8.2	9.4	10.6	11.6	12.6	13.6	14.6	15.6	16.5	17.4
Aspen	7720	7	5.4	7.6	9.3	10.6	11.9	13.1	14.2	15.3	16.4	17.5	18.6	19.6
Leadville	9932	7	4.2	5.9	7.2	8.3	9.3	10.2	11.1	12.0	12.8	13.6	14.5	15.3

EnergyPlus model

The heat loss model analysis is useful, but it is limited because it does not account for the potential effects of passive solar heat gain from windows with high SHGC. During the creation of the ENERGY STAR v7 window specification, the team at Lawrence Berkeley National Laboratory (LBNL) used EnergyPlus v9.5 software to run more sophisticated energy simulations that incorporate a variety of additional factors including solar heat gain, building heating, ventilation, and air conditioning (HVAC) system type, building foundation type, and local weather data. They ran simulations for 268 window U-factor and SHGC combinations for a standard single family detached residential building in a variety of different locations across the U.S.. Within Colorado, LBNL simulated building energy usage in Trinidad (climate zone 4), Colorado Springs (climate zone 5B), Eagle (climate zone 6B), and Gunnison (climate zone 7).

For a more detailed payback period analysis, the results of these LBNL energy simulations were used in conjunction with the estimated incremental window cost data discussed previously in this report. The basic assumptions used in the EnergyPlus model are the same as those used in the simple heat loss model, allowing for comparison between the two methods. The standard building simulated is 2,380 sqft in size with a 15% glazing to floor area ratio. The price of natural gas is assumed to be $11.8/MMBTU and the price of electricity is assumed to be $0.13/kWh. Although these simulations were run in 2021-2022, the results are still applicable today because the energy prices used are very similar to current Colorado gas and electric prices. Additional EnergyPlus assumptions are noted in the Appendix.

Table 9 and 10 show the modeled annual energy savings and energy cost savings for a standard residential building in Colorado Springs based on the type of windows installed. The market baseline window type is assumed to have a U-factor of 0.35 and SHGC of 0.30. For a given SHGC, decreasing the window U-factor leads to increased energy savings. This effect is expected because decreasing the U-factor allows the windows to better insulate against heat loss. For a given U-factor, increasing the SHGC leads to increased energy savings. This effect is also expected in a heating dominated climate like Colorado and shows that passive solar heating can play a large role in reducing energy usage in residential buildings.

The energy cost saving results show a more nuanced result. Decreasing U-factor (assuming constant SHGC) still always leads to increased savings. However, increasing or decreasing the SHGC from the assumed 0.30 baseline (for any given U-factor) leads to a decrease in energy cost savings. This result likely stems from the low SHGC windows reducing passive solar heating and thus requiring more natural gas heating and high SHGC windows requiring more air conditioning in the summer.

Table 9. Modeled energy savings for various window upgrades for a standard residential building located in Colorado Springs. Data from LBNL via EnergyPlus v9.5.

Annual Energy Savings (GJ) (Blue shading indicates higher numbers while red shading indicates lower numbers)																		
Energy Star Zone	Northern																	
	SHGC																	
U-Factor	0.13	0.15	0.17	0.19	0.20	0.21	0.23	0.25	0.27	0.30	0.32	0.35	0.37	0.40	0.42	0.45	0.47	0.50
0.2	2.54	3.80	4.85	5.84	6.30	6.76	7.63	8.43	9.19	10.22	10.87	11.74	12.29	13.05	13.50	14.11	14.44	14.91
0.21	1.77	3.03	4.09	5.08	5.55	6.01	6.87	7.70	8.44	9.50	10.15	11.02	11.57	12.35	12.81	13.43	13.77	14.23
0.22	1.00	2.27	3.33	4.33	4.80	5.27	6.14	6.96	7.72	8.77	9.43	10.31	10.88	11.65	12.12	12.75	13.09	13.54
0.23	0.24	1.52	2.59	3.58	4.06	4.52	5.40	6.23	7.00	8.07	8.72	9.60	10.18	10.96	11.43	12.07	12.42	12.89
0.24	-0.53	0.76	1.84	2.84	3.31	3.79	4.68	5.50	6.28	7.35	8.02	8.91	9.49	10.28	10.75	11.40	11.74	12.23
0.25	-1.27	0.03	1.11	2.11	2.59	3.06	3.96	4.78	5.57	6.64	7.32	8.22	8.79	9.60	10.07	10.73	11.08	11.57
0.26	-2.01	-0.70	0.40	1.41	1.88	2.36	3.26	4.10	4.88	5.97	6.64	7.55	8.14	8.93	9.41	10.07	10.42	10.89
0.27	-2.74	-1.43	-0.33	0.70	1.20	1.67	2.58	3.42	4.22	5.30	5.98	6.90	7.48	8.26	8.74	9.40	9.76	10.25
0.28	-3.46	-2.14	-1.02	0.00	0.49	0.98	1.90	2.75	3.54	4.64	5.32	6.26	6.83	7.61	8.08	8.74	9.10	9.60
0.29	-4.17	-2.85	-1.73	-0.69	-0.19	0.29	1.22	2.08	2.88	3.98	4.66	5.60	6.18	6.96	7.42	8.08	8.45	8.94
0.3	-4.87	-3.54	-2.42	-1.37	-0.88	-0.39	0.55	1.41	2.23	3.33	4.02	4.97	5.53	6.31	6.78	7.42	7.80	8.30
0.31	-5.54	-4.26	-3.13	-2.08	-1.57	-1.07	-0.14	0.73	1.54	2.64	3.34	4.30	4.88	5.65	6.13	6.77	7.18	7.68
0.32	-6.21	-4.96	-3.83	-2.75	-2.25	-1.77	-0.83	0.06	0.86	1.98	2.68	3.63	4.22	5.01	5.51	6.15	6.53	7.05
0.33	-6.87	-5.65	-4.52	-3.45	-2.94	-2.45	-1.51	-0.62	0.20	1.31	2.02	2.98	3.57	4.37	4.86	5.51	5.91	6.44
0.34	-7.53	-6.35	-5.20	-4.13	-3.61	-3.12	-2.18	-1.29	-0.47	0.66	1.36	2.34	2.92	3.74	4.22	4.88	5.29	5.81
0.35	-8.19	-7.04	-5.87	-4.81	-4.30	-3.81	-2.85	-1.96	-1.13	0.00	0.71	1.69	2.28	3.08	3.58	4.25	4.66	5.20

Table 10. Modeled energy cost savings for various window upgrades for a standard residential building located in Colorado Springs. Data from LBNL via EnergyPlus v9.5.

Annual Energy Cost Savings (Green shading indicates higher numbers while red shading indicates lower numbers)																		
Energy Star Zone	Northern																	
	SHGC																	
U-Factor	0.13	0.15	0.17	0.19	0.2	0.21	0.23	0.25	0.27	0.3	0.32	0.35	0.37	0.4	0.42	0.45	0.47	0.5
0.2	$97.53	$103.39	$107.55	$110.68	$111.85	$113.18	$114.70	$115.48	$115.74	$114.22	$112.92	$109.45	$106.11	$99.66	$94.47	$85.42	$78.93	$69.10
0.21	$88.98	$94.92	$99.00	$102.29	$103.65	$105.02	$106.40	$107.62	$107.45	$106.67	$105.26	$101.48	$98.19	$92.19	$87.24	$78.48	$72.03	$61.86
0.22	$80.37	$86.21	$90.46	$93.90	$95.26	$96.66	$98.27	$99.30	$99.57	$98.56	$97.35	$93.77	$90.90	$84.70	$79.96	$71.05	$64.65	$54.34
0.23	$72.00	$77.95	$82.39	$85.60	$87.21	$88.44	$90.13	$91.46	$91.63	$91.12	$89.51	$86.13	$83.27	$77.40	$72.29	$63.68	$57.81	$47.70
0.24	$63.28	$69.47	$73.89	$77.32	$78.68	$80.17	$82.31	$83.18	$83.82	$83.18	$82.08	$78.91	$75.98	$69.98	$65.06	$56.58	$50.38	$40.77
0.25	$55.20	$61.57	$65.94	$69.40	$70.68	$72.13	$74.35	$75.40	$76.15	$75.16	$74.53	$71.53	$68.29	$62.65	$57.91	$49.50	$43.51	$33.78
0.26	$46.81	$53.04	$57.97	$61.40	$62.63	$64.22	$66.28	$67.50	$67.90	$67.54	$66.56	$63.38	$60.83	$55.01	$50.37	$42.51	$36.35	$26.33
0.27	$38.48	$44.76	$49.61	$53.37	$54.92	$56.14	$58.49	$59.63	$60.28	$59.75	$58.79	$55.85	$53.05	$47.33	$42.88	$35.00	$29.09	$19.56
0.28	$30.32	$36.79	$41.77	$45.24	$46.70	$48.30	$50.57	$51.86	$52.30	$52.08	$50.88	$48.34	$45.37	$39.90	$35.20	$28.04	$22.14	$12.64
0.29	$22.28	$28.74	$33.65	$37.40	$38.87	$40.34	$42.85	$44.07	$44.64	$44.51	$43.30	$40.52	$37.85	$32.48	$27.72	$20.59	$14.91	$5.46
0.3	$14.02	$21.09	$25.75	$29.63	$31.07	$32.33	$34.94	$36.21	$37.17	$36.78	$35.79	$33.14	$30.24	$24.80	$20.67	$13.36	$8.02	-$1.16
0.31	$6.32	$12.76	$17.85	$21.60	$23.28	$25.05	$27.40	$28.66	$29.53	$29.13	$28.22	$25.66	$22.99	$17.68	$13.56	$6.40	$1.37	-$7.80
0.32	-$1.51	$4.91	$10.00	$14.43	$16.12	$16.92	$19.62	$21.39	$21.90	$21.75	$21.03	$18.14	$15.93	$10.86	$7.14	-$0.12	-$5.56	-$14.52
0.33	-$9.29	-$2.69	$2.27	$6.32	$8.20	$9.59	$12.00	$13.78	$14.70	$14.26	$13.66	$11.15	$8.74	$3.81	$0.13	-$7.10	-$12.31	-$20.85
0.34	-$17.06	-$10.45	-$5.39	-$1.33	$0.82	$2.06	$4.58	$6.43	$7.20	$7.11	$6.40	$4.21	$1.44	-$2.87	-$7.00	-$13.89	-$18.70	-$27.44
0.35	-$25.06	-$18.32	-$12.80	-$8.74	-$7.15	-$5.56	-$2.88	-$1.02	$0.12	$0.00	-$0.69	-$2.91	-$5.26	-$10.29	-$13.97	-$20.63	-$25.46	-$33.99

When calculating the payback period for various window upgrade scenarios with the EnergyPlus simulation data, the incremental window cost estimates used were the same as those used in the Heat Loss Model Analysis above. The only exception is that $8.51 is added to the cost of any window with SHGC of 0.25 or lower. This cost increase accounts for the need to add a triple-silver coating in order to achieve very low SHGC.

Tables 11, 12, 13, and 14 show the estimated payback periods for window upgrade combinations in model residential buildings in Trinidad, Colorado Springs, Eagle, and Gunnison. Appendix Tables A5, A6, A7, and A8 show the same payback analysis, but for windows with only air-fill (no sealed argon-filled window option).

Overall the results are quite similar to the payback periods calculated using the more simple heat loss model. By comparing the results from both models, one can deduce that the heat transfer model is a good approximation for windows with SHGC between 0.27 and 0.32. As the SHGC is increased beyond 0.32, the results from the two models start to diverge.

Climate zone is the factor that most significantly affects estimated payback period. The lowest payback period found for an ENERGY STAR v7 Northern qualified window upgrade in each climate zone is 12.7 years, 17.5 years, 24.8 years, and 26.1 years for climate zones 7, 6B, 5B, and 4B, respectively. In all instances, the lowest payback period is achieved with a window that has high SHGC and U-factor between 0.24 and 0.26. A window with U-factor of 0.22, regardless of the SHGC, does not achieve a payback period below 15 years in any of the climate zones within Colorado.

This data also shows that payback period length is highly affected by window SHGC. In climate zones 4B, 5B, and 6B, increasing the SHGC beyond 0.40 by a small amount (while maintaining a U-factor of 0.26) leads to significantly increased payback periods. In Colorado Springs, increasing the SHGC from 0.40 to 0.45 changes the payback period from 25.4 years to 32.9 years. Furthermore, decreasing the SHGC below 0.27 is not economically advantageous in any climate zone present in Colorado. Decreasing the window U-factor is found to lengthen payback periods in all climate zones, because the incremental additional cost to obtain a lower U-factor window outweighs the expected energy savings that window can produce.

In climate zones 4B and 5B, payback periods of 15 years or shorter can be achieved with windows that have U-factor of 0.30 and SHGC of ~0.30. In climate zones 6B and 7, one can achieve a payback period of 15 years or lower with U-factors down to 0.28 and 0.25, respectively.

Key finding: requiring residential windows to meet the ENERGY STAR v7 Northern specification will result in payback periods greater than 20 years long for ~90% of Coloradans. Only Colorado households in the coldest regions of the state (climate zone 7) realize payback periods less than 15 years long when upgrading their windows to an ENERGY STAR v7 Northern qualified product. A window standard targeted at a U-factor of 0.30 (as opposed to ENERGY STAR) would reduce payback periods to ~15 years in all four climate zones in Colorado.

Table 11. Estimated payback period for window upgrade scenarios for a model residential building located in ***Trinidad*** (climate zone 4B). Scenarios marked "N/A" have negative payback periods due to energy costs increasing after the upgrade.

	SHGC (0.13 - 0.50)																	
U-Factor (0.22 - 0.34)	*0.13*	*0.15*	*0.17*	*0.19*	*0.20*	*0.21*	*0.23*	*0.25*	*0.27*	*0.30*	*0.32*	*0.35*	*0.37*	*0.40*	*0.42*	*0.45*	*0.47*	*0.50*
0.22	29.0	28.0	**27.3**	**26.9**	**26.8**	**26.8**	**26.8**	**27.0**	**25.3**	**26.2**	**27.0**	**28.8**	**30.4**	**34.1**	**37.3**	**45.0**	**51.7**	**69.2**
0.23	28.1	26.9	26.3	25.9	25.7	25.6	25.6	25.8	24.0	24.9	25.7	**27.6**	**29.3**	**32.9**	**36.3**	**44.7**	**53.0**	**74.0**
0.24	27.2	25.9	25.2	24.6	24.6	24.5	24.5	24.6	22.6	23.4	24.3	**26.1**	**27.9**	**31.7**	**35.4**	**44.7**	**55.0**	**83.3**
0.25	26.3	24.9	24.1	23.6	23.5	23.4	23.3	23.5	21.2	22.1	22.9	24.8	26.7	**30.7**	**34.9**	**45.3**	**58.0**	**102**
0.26	25.6	24.0	23.2	22.5	22.4	22.2	22.2	22.3	19.8	20.6	21.6	23.6	25.6	**30.0**	**34.7**	**47.7**	**64.7**	**147**
0.27	24.9	23.1	22.2	21.5	21.3	21.2	21.1	21.3	18.3	19.3	20.3	22.4	24.4	29.7	35.2	51.2	78.3	419
0.28	24.3	22.3	21.3	20.5	20.3	20.2	20.0	20.2	16.9	17.8	18.9	21.1	23.4	29.4	36.6	61.3	118	N/A
0.29	24.2	21.7	20.5	19.7	19.3	19.1	19.1	19.2	15.3	16.3	17.5	19.9	22.8	29.9	39.9	90.4	911	N/A
0.30	24.3	21.4	19.8	18.8	18.5	18.3	18.2	18.3	13.7	14.7	15.9	18.7	22.3	32.2	49.7	505	N/A	N/A
0.31	25.8	21.6	19.5	18.3	17.7	17.5	17.4	17.5	11.7	12.8	14.2	17.5	21.8	37.9	97.8	N/A	N/A	N/A
0.32	29.9	22.9	20.0	18.2	17.7	17.2	17.0	17.1	9.6	10.5	12.0	16.1	23.3	75.4	N/A	N/A	N/A	N/A
0.33	46.2	27.7	21.9	19.2	18.4	17.8	17.4	17.4	6.4	7.3	9.1	15.2	35.3	N/A	N/A	N/A	N/A	N/A
Payback periods in bold are window U-factor/SHGC combinations that meet the ENERGY STAR v7 Northern specification																		

Table 12. Estimated payback period for window upgrade scenarios for a model residential building located in ***Colorado Springs*** (climate zone 5B). Scenarios marked "N/A" have negative payback periods due to energy costs increasing after the upgrade.

	SHGC (0.13 - 0.50)																	
U-Factor (0.22 - 0.34)	*0.13*	*0.15*	*0.17*	*0.19*	*0.20*	*0.21*	*0.23*	*0.25*	*0.27*	*0.30*	*0.32*	*0.35*	*0.37*	*0.40*	*0.42*	*0.45*	*0.47*	*0.50*
0.22	34.7	32.4	**30.9**	**29.7**	**29.3**	**28.9**	**28.4**	**28.1**	**26.0**	**26.3**	**26.6**	**27.6**	**28.5**	**30.6**	**32.4**	**36.4**	**40.0**	**47.6**
0.23	34.2	31.6	29.9	28.8	28.3	27.9	27.3	26.9	24.7	24.8	25.3	**26.2**	**27.1**	**29.2**	**31.3**	**35.5**	**39.1**	**47.4**
0.24	34.1	31.0	29.2	27.9	27.4	26.9	26.2	25.9	23.3	23.5	23.8	**24.8**	**25.7**	**27.9**	**30.0**	**34.5**	**38.8**	**47.9**
0.25	33.9	30.4	28.4	26.9	26.5	25.9	25.2	24.8	21.9	22.2	22.4	23.3	24.4	**26.6**	**28.8**	**33.7**	**38.3**	**49.3**
0.26	34.3	30.2	27.7	26.1	25.6	25.0	24.2	23.8	20.6	20.7	21.0	22.1	23.0	**25.4**	**27.8**	**32.9**	**38.5**	**53.2**
0.27	35.3	30.3	27.4	25.4	24.7	24.2	23.2	22.8	19.1	19.3	19.6	20.7	21.7	24.4	26.9	33.0	39.7	59.0
0.28	37.4	30.8	27.1	25.0	24.2	23.4	22.4	21.8	17.8	17.8	18.2	19.2	20.5	23.3	26.4	33.1	41.9	73.5
0.29	41.6	32.3	27.6	24.8	23.9	23.0	21.6	21.0	16.2	16.3	16.7	17.9	19.1	22.3	26.1	35.1	48.5	133
0.30	53.0	35.2	28.9	25.1	23.9	23.0	21.3	20.5	14.5	14.7	15.1	16.3	17.8	21.7	26.1	40.3	67.2	N/A
0.31	91.7	45.4	32.5	26.8	24.9	23.1	21.1	20.2	12.7	12.9	13.3	14.6	16.3	21.2	27.7	58.6	275	N/A
0.32	N/A	88.8	43.6	30.2	27.0	25.8	22.2	20.4	10.6	10.7	11.0	12.8	14.6	21.3	32.5	N/A	N/A	N/A
0.33	N/A	N/A	138	49.5	38.2	32.7	26.1	22.7	7.4	7.6	8.0	9.8	12.5	28.5	818	N/A	N/A	N/A
Payback periods in bold are window U-factor/SHGC combinations that meet the ENERGY STAR v7 Northern specification																		

Table 13. Estimated payback period for window upgrade scenarios for a model residential building located in ***Eagle*** (climate zone 6B). Scenarios marked “N/A” have negative payback periods due to energy costs increasing after the upgrade.

	SHGC (0.13 - 0.50)																	
U-Factor (0.22 - 0.34)	*0.13*	*0.15*	*0.17*	*0.19*	*0.20*	*0.21*	*0.23*	*0.25*	*0.27*	*0.30*	*0.32*	*0.35*	*0.37*	*0.40*	*0.42*	*0.45*	*0.47*	*0.50*
0.22	38.0	34.2	**31.8**	**29.9**	**29.0**	**28.1**	**26.8**	**25.7**	**23.0**	**22.3**	**22.0**	**21.9**	**22.0**	**22.5**	**22.9**	**24.0**	**24.9**	**26.5**
0.23	38.7	34.3	31.7	29.4	28.5	27.7	26.1	24.8	21.8	21.2	20.8	**20.7**	**20.8**	**21.2**	**21.7**	**22.7**	**23.6**	**25.4**
0.24	40.1	34.9	31.8	29.2	28.1	27.1	25.5	24.0	20.9	20.0	19.7	**19.5**	**19.6**	**20.0**	**20.5**	**21.6**	**22.4**	**24.1**
0.25	42.4	36.0	32.0	29.0	27.9	26.8	24.9	23.3	19.7	18.8	18.5	18.3	18.3	**18.7**	**19.2**	**20.2**	**21.2**	**23.0**
0.26	46.7	37.7	32.9	29.2	27.9	26.6	24.4	22.7	18.7	17.6	17.3	17.1	17.1	**17.5**	**18.0**	**19.0**	**19.9**	**21.8**
0.27	54.7	41.3	34.7	29.8	28.1	26.5	24.1	22.2	17.6	16.4	16.0	15.8	15.9	16.2	16.7	17.7	18.7	20.7
0.28	74.6	48.3	37.9	31.3	28.9	27.2	24.1	21.8	16.5	15.2	14.7	14.4	14.5	14.9	15.3	16.4	17.4	19.5
0.29	166	65.3	44.7	34.5	31.4	28.5	24.6	21.8	15.3	13.8	13.4	13.1	13.1	13.5	13.9	15.0	16.1	18.4
0.30	N/A	147	64.8	42.7	36.4	31.8	25.9	22.1	14.2	12.4	11.9	11.6	11.7	12.0	12.4	13.6	14.7	17.2
0.31	N/A	N/A	250	67.1	50.5	41.3	29.6	23.6	12.8	10.7	10.1	9.9	9.8	10.2	10.7	11.8	13.0	15.9
0.32	N/A	N/A	N/A	N/A	172	84.6	41.4	27.7	11.5	8.9	8.2	7.8	7.8	8.2	8.6	9.9	11.2	15.3
0.33	N/A	N/A	N/A	N/A	N/A	N/A	188	45.7	9.8	6.2	5.6	5.1	5.1	5.3	5.8	7.0	8.4	14.4
Payback periods in bold are window U-factor/SHGC combinations that meet the ENERGY STAR v7 Northern specification																		

Table 14. Estimated payback period for window upgrade scenarios for a model residential building located in ***Gunnison*** (climate zone 7). Scenarios marked "N/A" have negative payback periods due to energy costs increasing after the upgrade.

	SHGC (0.13 - 0.50)																	
U-Factor (0.22 - 0.34)	*0.13*	*0.15*	*0.17*	*0.19*	*0.20*	*0.21*	*0.23*	*0.25*	*0.27*	*0.30*	*0.32*	*0.35*	*0.37*	*0.40*	*0.42*	*0.45*	*0.47*	*0.50*
0.22	39.3	34.0	**30.8**	**28.3**	**27.3**	**26.3**	**24.8**	**23.5**	**20.8**	**19.7**	**19.0**	**18.3**	**17.9**	**17.5**	**17.3**	**17.3**	**17.5**	**18.1**
0.23	41.5	34.8	31.0	28.2	27.0	25.9	24.3	22.8	19.9	18.7	18.0	**17.3**	**16.9**	**16.4**	**16.3**	**16.2**	**16.4**	**16.9**
0.24	44.7	36.2	31.7	28.2	27.0	25.7	23.8	22.2	19.0	17.7	17.0	**16.2**	**15.8**	**15.3**	**15.1**	**15.1**	**15.2**	**15.6**
0.25	50.6	38.6	32.5	28.6	27.0	25.7	23.3	21.8	18.0	16.7	15.9	15.1	14.7	**14.2**	**14.0**	**13.9**	**13.9**	**14.4**
0.26	61.5	42.6	34.3	29.4	27.4	25.8	23.1	21.1	17.1	15.6	14.9	14.0	13.6	**13.1**	**12.8**	**12.7**	**12.7**	**13.2**
0.27	90.7	50.8	38.1	30.9	28.3	26.1	22.9	20.8	16.1	14.5	13.8	12.8	12.4	11.9	11.7	11.5	11.5	11.9
0.28	248	70.5	44.5	33.8	30.0	27.3	23.3	20.5	15.2	13.4	12.6	11.6	11.2	10.7	10.4	10.2	10.2	10.6
0.29	N/A	175	63.0	40.2	33.8	29.8	24.1	20.7	14.1	12.3	11.4	10.4	9.9	9.4	9.1	8.9	8.9	9.2
0.30	N/A	N/A	164	59.1	43.8	35.6	26.2	21.2	13.2	11.0	10.1	9.0	8.5	8.0	7.8	7.6	7.5	7.7
0.31	N/A	N/A	N/A	218	86.9	55.6	32.1	23.5	12.1	9.6	8.6	7.5	7.0	6.5	6.3	6.1	6.0	6.1
0.32	N/A	N/A	N/A	N/A	N/A	742	55.7	29.9	11.0	8.0	6.8	5.8	5.3	4.8	4.6	4.4	4.3	4.4
0.33	N/A	N/A	N/A	N/A	N/A	N/A	N/A	63.2	10.0	5.6	4.5	3.5	3.2	2.8	2.6	2.5	2.4	2.5

Payback periods in bold are window U-factor/SHGC combinations that meet the ENERGY STAR v7 Northern specification

Window product availability in Colorado

To examine the availability of window products that meet the ENERGY STAR v7 Northern specification, one can examine the National Fenestration Ratings Council (NFRC) Certified Product Directory (CPD). NFRC is the body that certifies the vast majority of all window product labels. The CPD is a database containing all window manufacturer product types that have NFRC energy efficiency ratings. In order to label a window with rated U-factor and SHGC and submit it for ENERGY STAR certification, manufacturers must follow NFRC protocols when modeling window performance and must submit the results into the CPD.

Window manufacturers frequently model the energy efficiency of all potential window products (i.e. combinations of all glass types and frame types) and submit these products and efficiency ratings to the CPD. However, the manufacturers do not necessarily manufacture each product type and make it available for sale. Thus, the CPD represents all potential window products from manufacturers but is not actually an accurate count of the products available to consumers on the market. The products available in the market are just a subset of what is shown in the CPD.

Figure 4 shows a count of all the dual pane vinyl vertical slider window products registered in the CPD as of February 2025.[19] This data shows that the bulk of vinyl dual pane products have U-factors ranging from roughly 0.24 to 0.35 and the available SHGC ranges from 0.12 to over 0.50. Figure 5 shows the subset of these products that meet the ENERGY STAR v7 Northern specification. Dual pane products primarily meet the ENERGY STAR specification via the "Equivalent Energy Performance" pathway with U-factors of 0.25-0.26 and SHGC greater than 0.40. The number of dual pane products that can achieve U-factors below 0.24 is very limited.

This data shows that consumers that do not want high SHGC window products because of potential overheating concerns would likely need to purchase triple pane window products with U-factor of 0.22 or below. Based on the cost estimates in Table A2, moving from a dual pane window with U-factor of 0.26 to a triple pane product with U-factor of 0.22 increases the cost per window from $367 to $427.

[19] All NFRC CPD data was provided by NFRC to Lawrence Berkeley National Laboratory (LBNL) in February 2025 and the subsequent database analysis was performed by LBNL

Figure 4. Overall number of *dual* pane vinyl vertical slider window product lines in the NFRC CPD. The histogram on the right shows the data aggregated across all SHGC options.

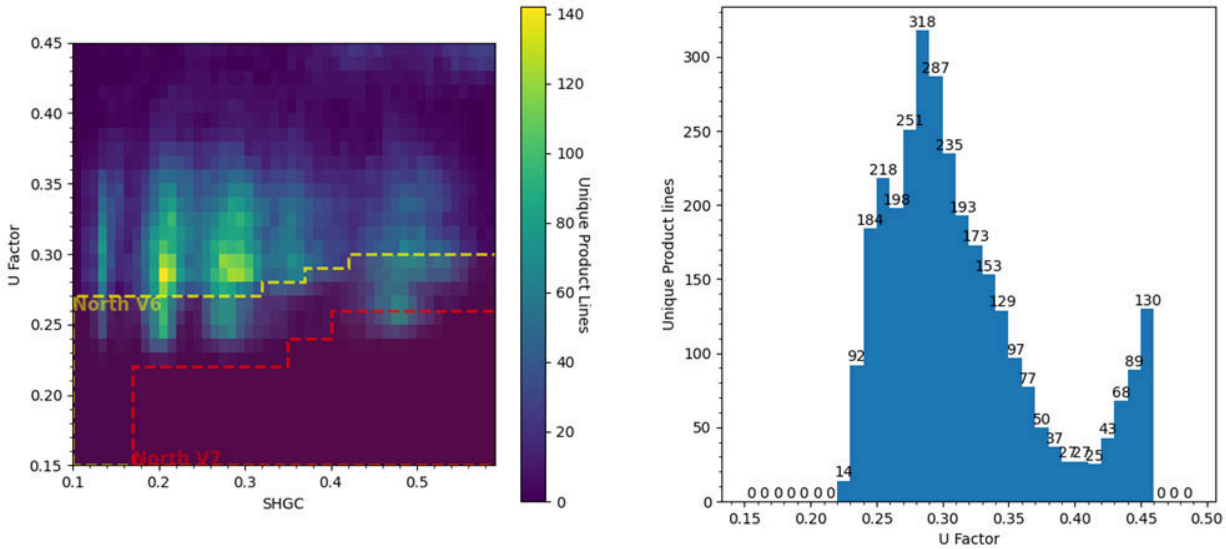
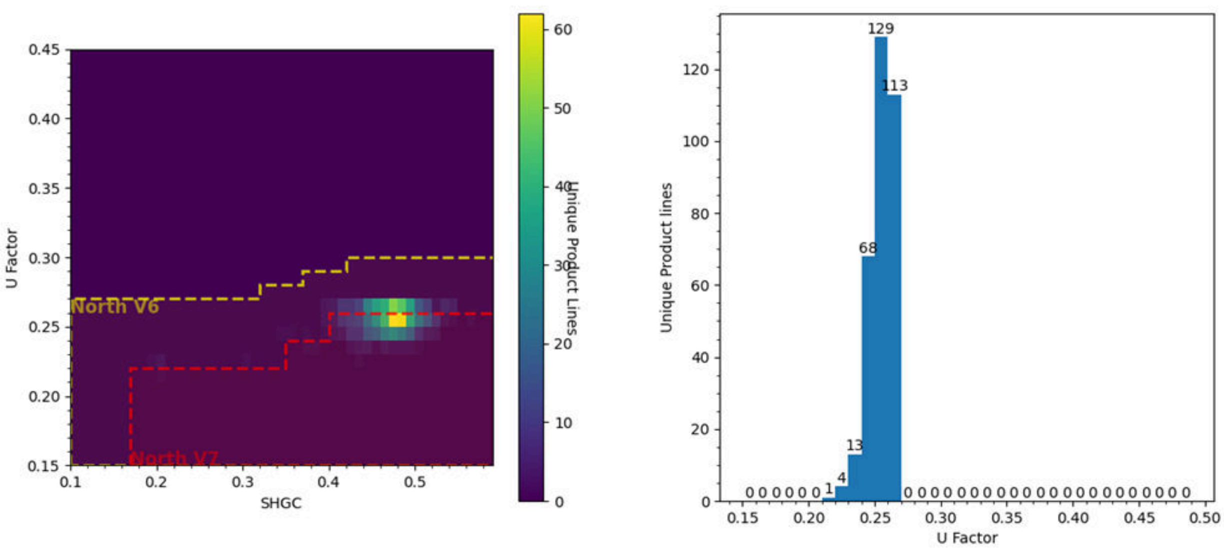


Figure 5. Number of *dual* pane vinyl vertical slider window product lines in the NFRC CPD that meet the ENERGY STAR v7 Northern climate zone specification (argon and air fill only). The histogram on the right shows the data aggregated across all SHGC options.



Figures 6 and 7 show the overall number of triple pane vinyl vertical slider products in the CPD and number of these products that meet the ENERGY STAR v7 Northern specification, respectively. There are a wide variety of triple pane product lines and the majority of them have U-factors between roughly 0.18 and 0.30. These products have a large range of potential SHGC, but predominantly have SHGC below 0.30.

Triple pane windows predominantly meet the ENERGY STAR v7 Northern specification with low U-factor (0.18-0.22) and SHGC between 0.17 and 0.3. Thus, triple pane products are able to simultaneously meet the ENERGY STAR v7 Northern specification and achieve compliance with the 2021 IECC window prescriptive specifications for climate zone 4 and 5. Thus, there are likely a sufficient number of ENERGY STAR certified triple pane product lines available for all Colorado consumers regardless of which climate zone or building jurisdiction they live in.

Figure 6. Overall number of *triple* pane vinyl vertical slider window product lines in the NFRC CPD. The histogram on the right shows the data aggregated across all SHGC.

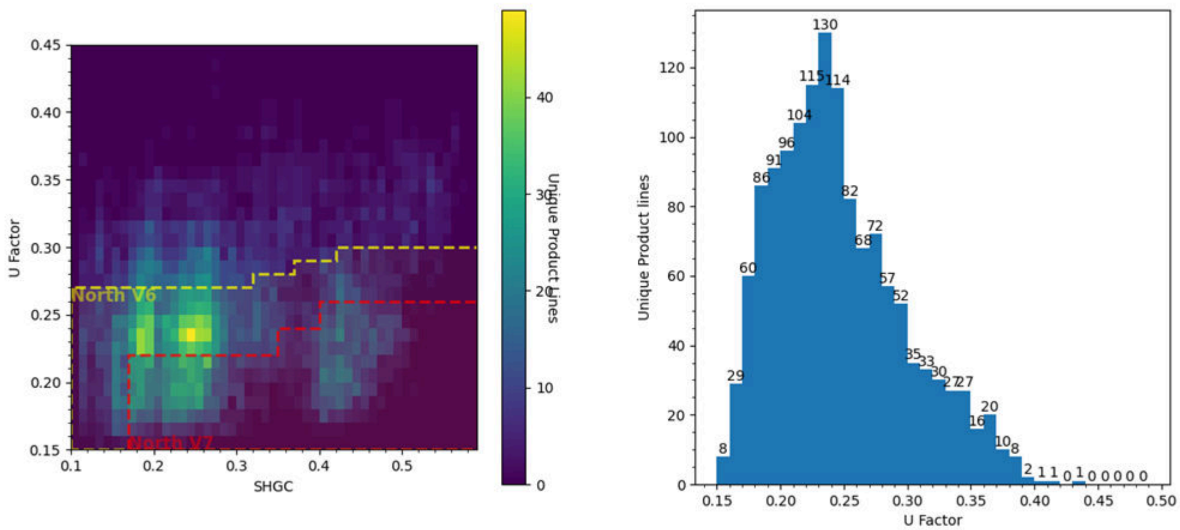
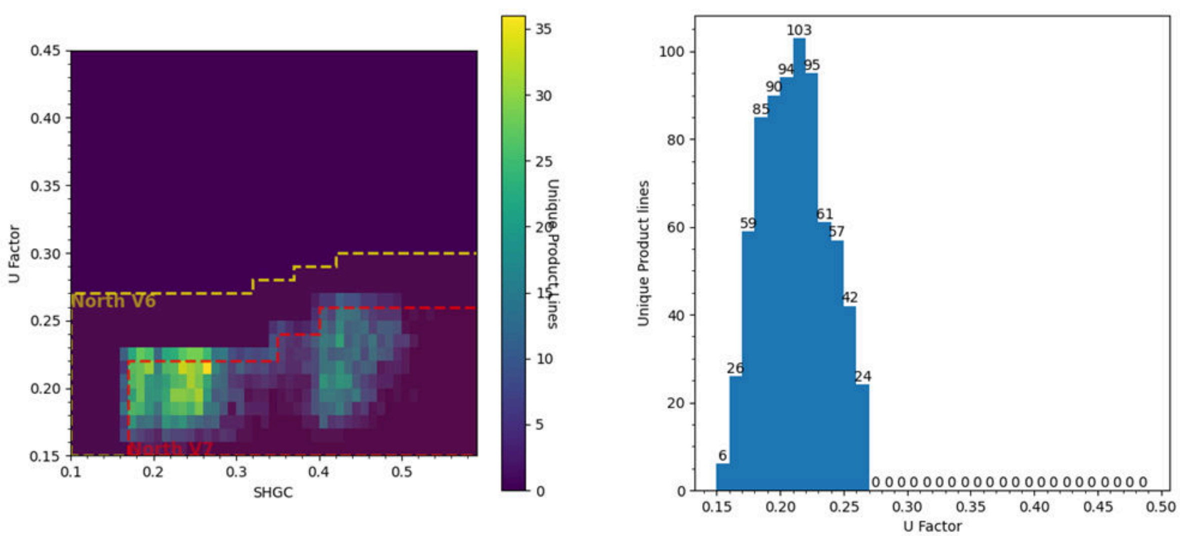


Figure 7. Number of *triple* pane vinyl vertical slider window product lines in the NFRC CPD that meet the ENERGY STAR v7 Northern climate zone specification (argon and air fill only). The histogram on the right shows the data aggregated across all SHGC options.



Air-filled window product availability

Figures 8 and 9 show the overall number of air-filled the available vinyl vertical slider dual pane and triple pane window product lines listed in the NFRC CPD and Figures 10 and 11 show the number of product lines that are able to meet the ENERGY STAR v7 Northern specification with air fill only. The bulk of air-filled dual pane window product lines have U-factors between 0.28 and 0.36. For air-filled triple pane window product lines, the most common U-factor range is between 0.23 and 0.32. There is a small number of air-filled window product lines that are able to meet the ENERGY STAR v7 Northern specification with a dual pane configuration. These are likely premium quality dual pane windows with multiple low-E coatings, foamed frames, and improved glass spacers. With triple pane windows, there are a significant number of air filled product lines that can meet the ENERGY STAR specification with either low or high SHGC window products.

The primary conclusion from this data is that if Coloradans that live at very high elevation are required to purchase air-filled windows that meet the ENERGY STAR v7 Northern specification, they likely will have limited dual pane window options and may be forced to consider triple pane window products. However, there appears to be an ample number of air-filled triple pane window options that meet the ENERGY STAR specification. While the proposed statewide window standard based on the ENERGY STAR v7 Northern specification may decrease the number of window products available for residents that live at very high elevation, the NFRC CPD shows that there are a significant number of air-filled window product lines that can satisfy the ENERGY STAR specification.

Figure 8. Overall number of air-filled *dual* pane vinyl vertical slider window product lines in the NFRC CPD. The histogram on the right shows the data aggregated across all SHGC options.

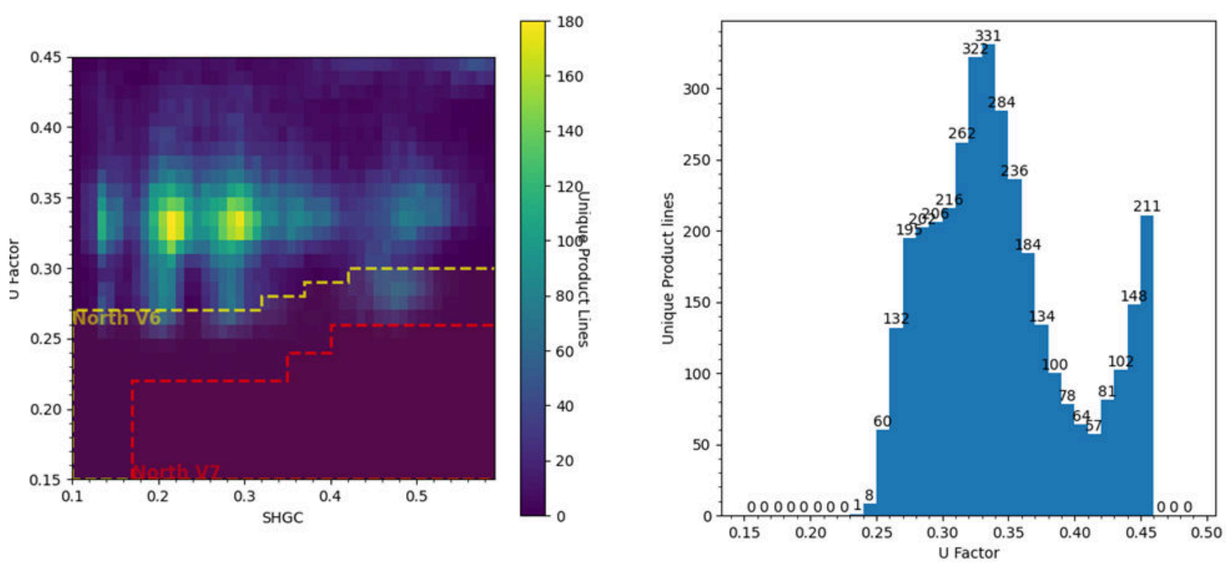


Figure 9. Overall number of air-filled *triple* pane vinyl vertical slider window product lines in the NFRC CPD. The histogram on the right shows the data aggregated across all SHGC options.

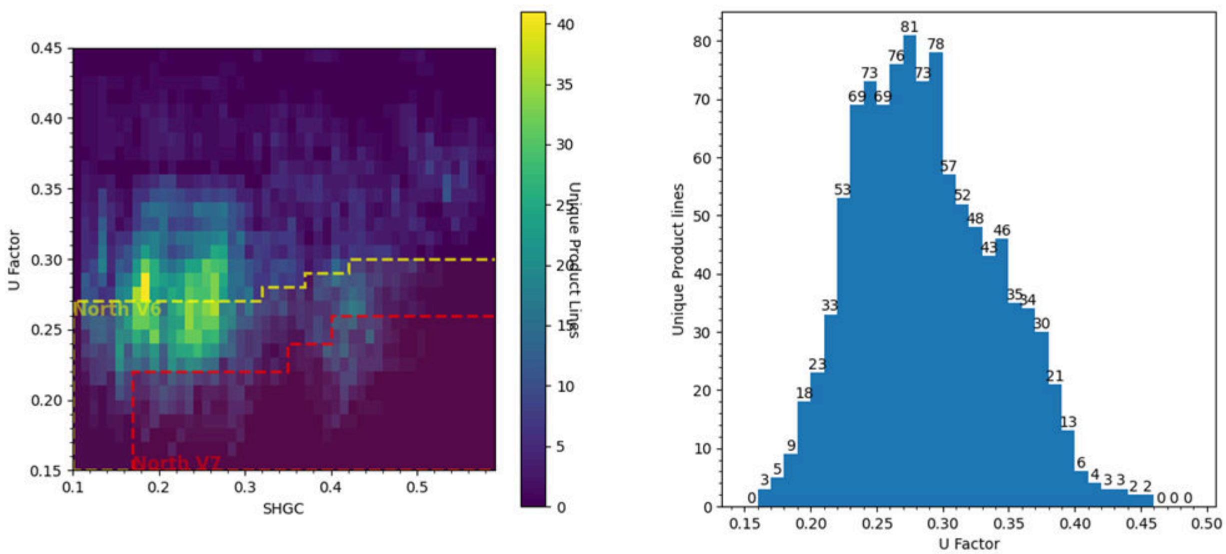


Figure 10. Number of air-filled dual pane vinyl vertical slider window product lines in the NFRC CPD that meet the ENERGY STAR v7 Northern climate zone specification. The histogram on the right shows the data aggregated across all SHGC.

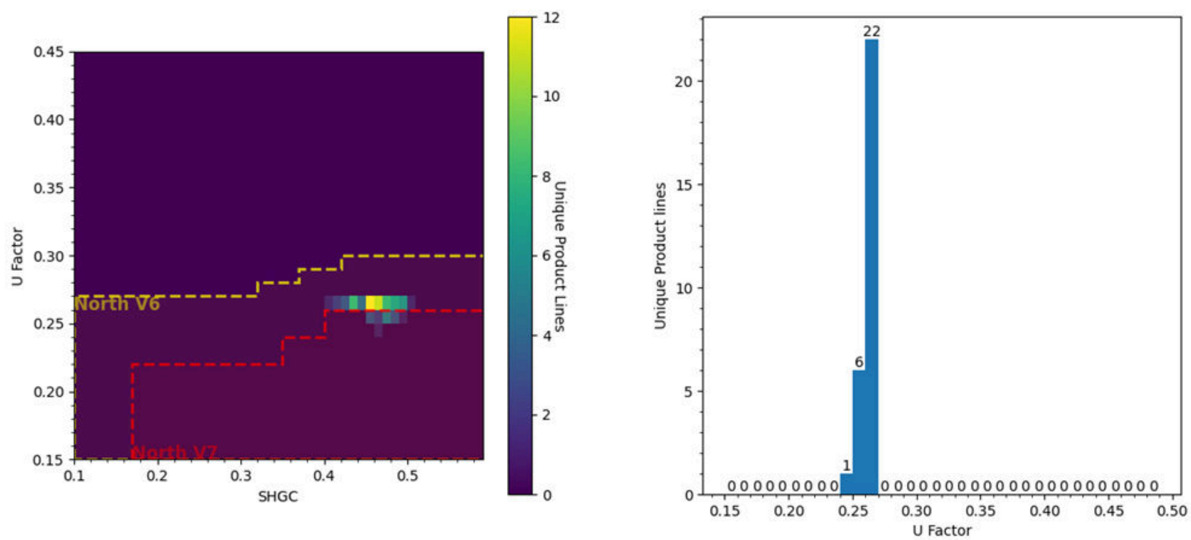
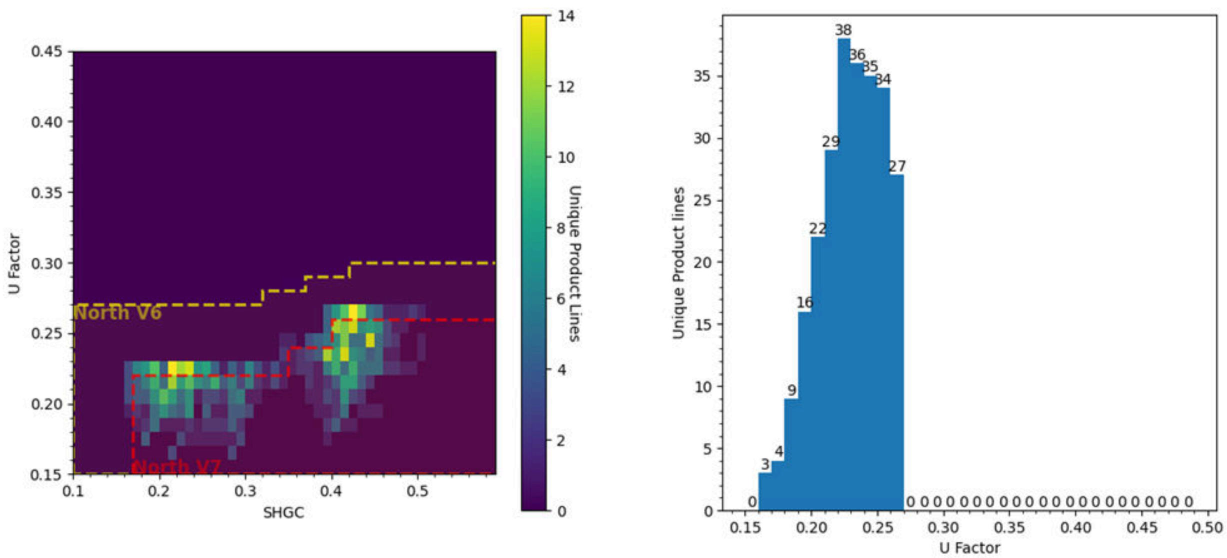


Figure 11. Number of air-filled *triple* pane vinyl vertical slider window product lines in the NFRC CPD that meet the ENERGY STAR v7 Northern climate zone specification.The histogram on the right shows the data aggregated across all SHGC.



Appendix

Manufacturing methods for high elevation argon windows

There are a few options available to window manufacturers that could increase the availability of sealed, argon-filled windows for high elevation. At least one manufacturer uses a mylar bladder system that allows argon to move out of the window unit and into the bladder to normalize pressure after the window is moved to higher elevation. This process works in theory, but requires the bladder to be removed after the window is installed and requires the installer to pinch off and seal the tube connected to the bladder. However, after speaking with a variety of window manufacturers, this process is not widely utilized and there is some skepticism that manually sealing a window in the field will lead to long term argon retention.

The most feasible solution to the high elevation issue is likely pre-pressurization of the argon gas in the window unit so that the pressure inside the sealed window matches the air pressure at the installation site. There are commercially available tools that can adjust the argon pressure in the window during the manufacturing process. In effect, the window would bow slightly inward when it was manufactured and then would flatten out when it was delivered to its destination elevation. Several manufacturers expressed confidence that pre-pressurized windows could be shipped to high elevation without significant concern that the window seals would be damaged during transit. To date, the practice of pre-pressurization appears limited to only high end window manufacturers and custom window orders. That said, during interviews several manufacturers expressed that they would consider adopting this technology if Colorado were to implement the ENERGY STAR v7 Northern climate zone standard.

It is difficult to estimate how much the pre-pressurization method would increase the cost of windows in Colorado. There is clearly some capital investment required for manufacturers to buy and install the necessary equipment. Manufacturers expressed that the necessary equipment is available to buy currently and is not prohibitively expensive. There would also be added administrative costs from tracking the elevation of every window order and pressuring all windows according to the order specifications. Lastly, there would be challenges for retail sales channels that rely on warehouses and stores with inventory. If a company sells windows through a brick and mortar retailer and does not know where the window will ultimately be installed, how do they know what pressure level to target? One can imagine a scenario where one window at the store is labelled for use between 5,000 - 7,000 feet and a different window is labelled for 7,000 to 9,000. There would likely be some added cost passed onto consumers attributed to that added stocking complexity. In the end, it seems reasonable to assume that pre-pressurizing windows will increase window cost at least marginally, but it is difficult to estimate the exact percentage increase.

Window pricing estimate data

The following window component prices and U-factor contributions were used to estimate the thermal performance (U-factor) and price of windows with varying U-factor.

Table A1. Window component upgrades and their corresponding incremental U-factor effect and incremental cost increase

Window Component Upgrade	Average U-factor decrease	Incremental cost increase (per 15 sqft)
Dual pane - lowest cost frame improvement	0.015	$5.0
Dual pane - improved frame and spacer	0.020	$13.6
Dual pane - foamed frame	0.015	$26.1
Dual pane - premium frame (foamed, spacer, frame improvements)	0.030	$39.7
Triple pane - foamed frame	0.010	$26.1
Triple pane - premium (foamed frame , improved spacer, frame improvements)	0.020	$53.3
Argon fill (either dual or triple pane)	0.020	$6.8
Roomside Low-E (either dual or triple pane)	0.035	$26.1
Upgrade to basic triple-pane	0.070	$73.7
Triple silver for SHGC <= 0.25 (either dual or triple pane)	(For SHGC <= 0.25)	$8.5

After combining the various components in Table A1, a list of the products with the lowest price for various U-factors was compiled. This data is shown in Tables A2 and A3.

Table A2. Estimated window prices for differing U-factor and the associated window component upgrades expected. For a 15 sqft vinyl vertical slider window with sealed, argon-fill as an available option.

U-factor	Price	Incremental Cost	Window Components
0.35	$315	$0	Dual pane, 1 low-E coating, air fill, basic frame
0.33	$320	$5	Dual pane, 1 low-E coating, air fill, improved frame

0.31	$327	$11.8	Dual pane, 1 low-E coating, argon fill, improved frame
0.29	$340	$25.4	Dual pane, 1 low-E coating, argon fill, improved frame & spacer
0.28	$353	$37.9	Dual pane, 2 low-E coatings,[20] argon fill, basic frame
0.26	$367	$51.5	Dual pane, 2 low-E coating, argon fill, improved frame & spacer
0.25	$393	$77.6	Dual pane, 2 low-E coating, argon fill, foamed frame & improved spacer
0.24	$401	$85.5	Triple pane, 1 low-E coating, argon fill, basic frame
0.23	$420	$104.8	Triple pane, 2 low-E coatings, air fill, basic frame
0.21	$427	$111.6	Triple pane, 2 low-E coatings, argon fill, basic frame
0.20	$453	$138.1	Triple pane, 2 low-E coatings, argon fill, foamed frame

Table A3. Estimated window prices for differing U-factor and the associated window component upgrades expected. For a 15 sqft vinyl vertical slider window with only access to air fill (no argon)

U-factor	Price	Incremental Cost	Window Components
0.35	$315	$0	Dual pane, 1 low-E coating, air fill, basic frame
0.33	$320	$5	Dual pane, 1 low-E coating, air fill, improved frame
0.31	$334	$18.6	Dual pane, 1 low-E coating, air fill, improved frame & spacer
0.30	$346	$31.1	Dual pane, 2 low-E coatings, air fill, basic frame
0.28	$360	$44.7	Dual pane, 2 low-E coatings, air fill, improved frame & spacer
0.27	$386	$70.8	Dual pane, 2 low-E coatings, air fill, foamed frame & improved spacer
0.26	$394	$78.7	Triple pane, 1 low-E coating, air fill, basic frame
0.23	$420	$104.8	Triple pane, 2 low-E coatings, air fill, basic frame
0.22	$446	$130.9	Triple pane, 2 low-E coatings, air fill, foamed frame
0.21	$473	$148.2	Triple pane, 2 low-E coatings, air fill, foamed frame & improved spacers

[20] The second low-E coating added is always a roomside low-E coating.

Note that not all U-factors are listed in each table. In some cases, there was no component combination that yielded a window for a given U-factor that was less expensive than all other windows with lower U-factors. As an example, only one component combination yielded a U-factor of 0.27 and it had an estimated window price of $386 (air filled dual pane with roomside low-E and a premium frame). This window type is not listed in Table A2 because the U-factor 0.26 window is estimated to have a lower price at $367. Thus, an economically rational consumer would not purchase the higher priced window with 0.27 U-factor. That said, the data in Tables A2 and A3 show that there is a general relationship between window price and U-factor.

To model this relationship and better estimate the cost of windows with all U-factors in the range of 0.33 to 0.20, the window U-factor and price data from Table A2 and A3 were plotted and a trendline was fit to the data using a second degree polynomial. The best fit trendline was then used to estimate the window price for any given U-factor (Figure 3). For the payback period analysis in this report, this modeled price data was used.

Figure A1. Estimated window price/U-factor data points and the best fit trendline used to model window cost vs. U-factor for windows that have argon gas fill available.

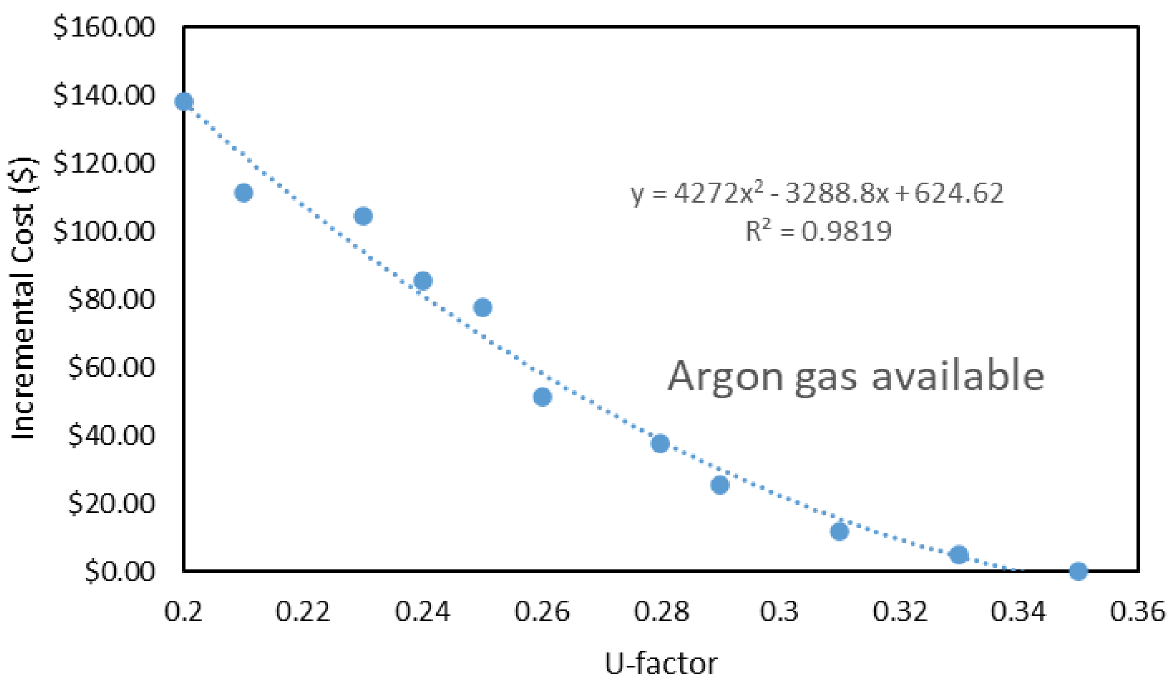


Figure A2. Estimated window price/U-factor data points and the best fit trendline used to model window cost vs. U-factor for windows that have only air fill available.

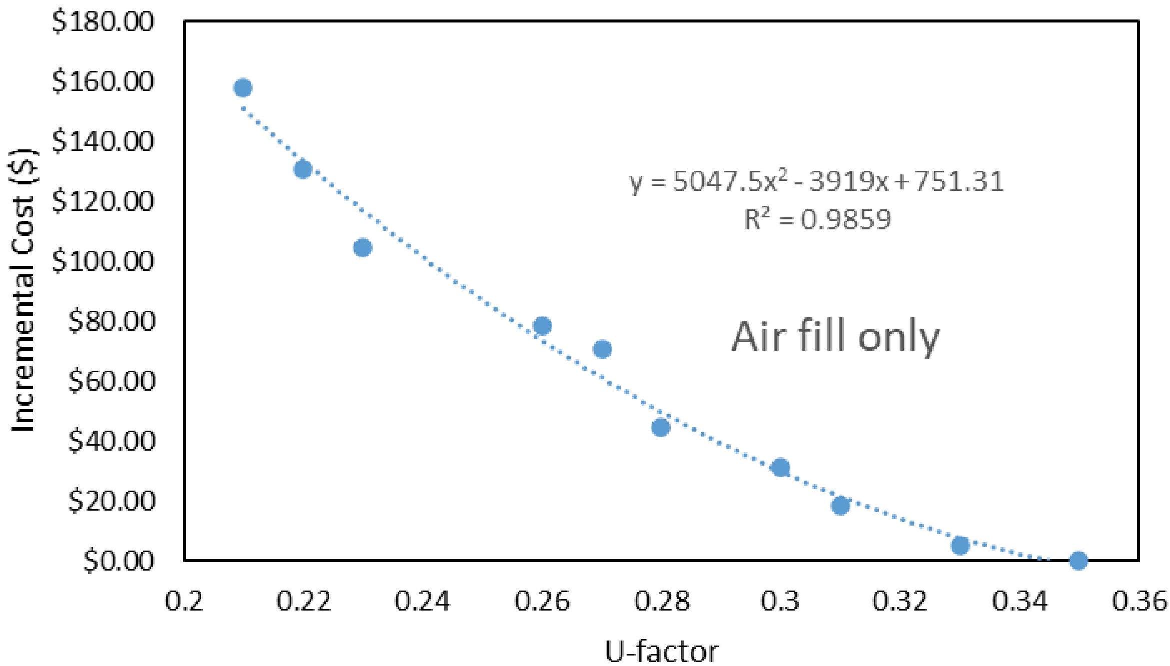
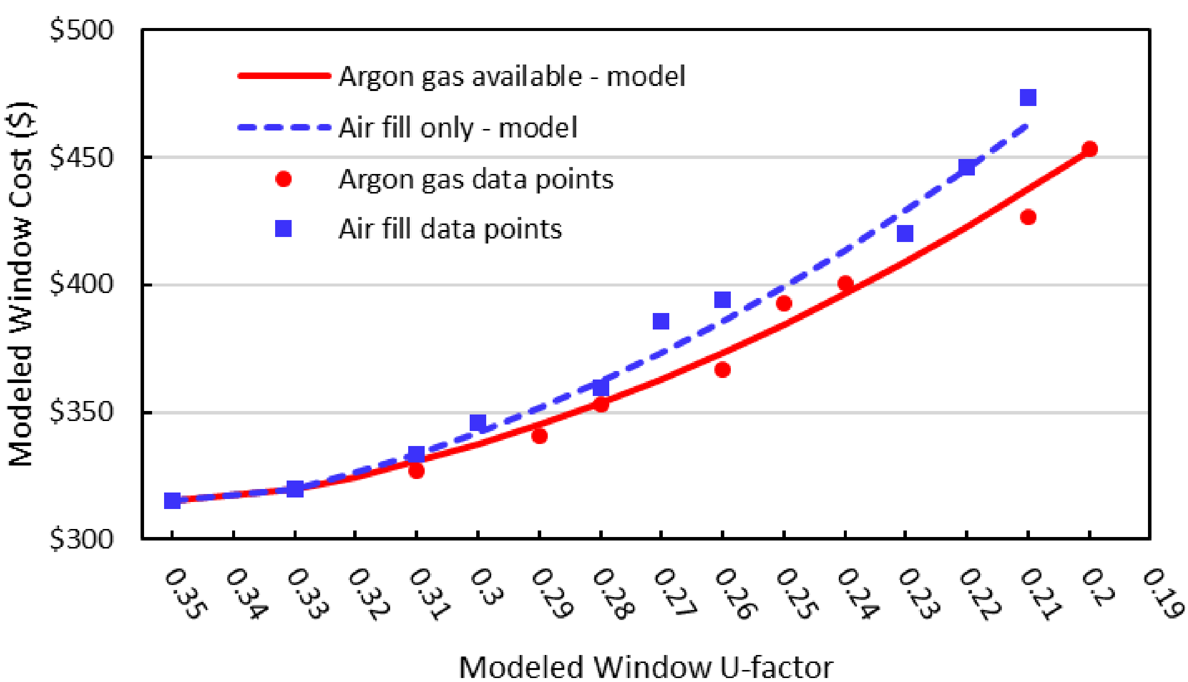


Figure A3. Comparison of modeled window prices (using the best fit trendline) and the data points generated by combining different window components (those combinations shown in Tables A2 and A3).



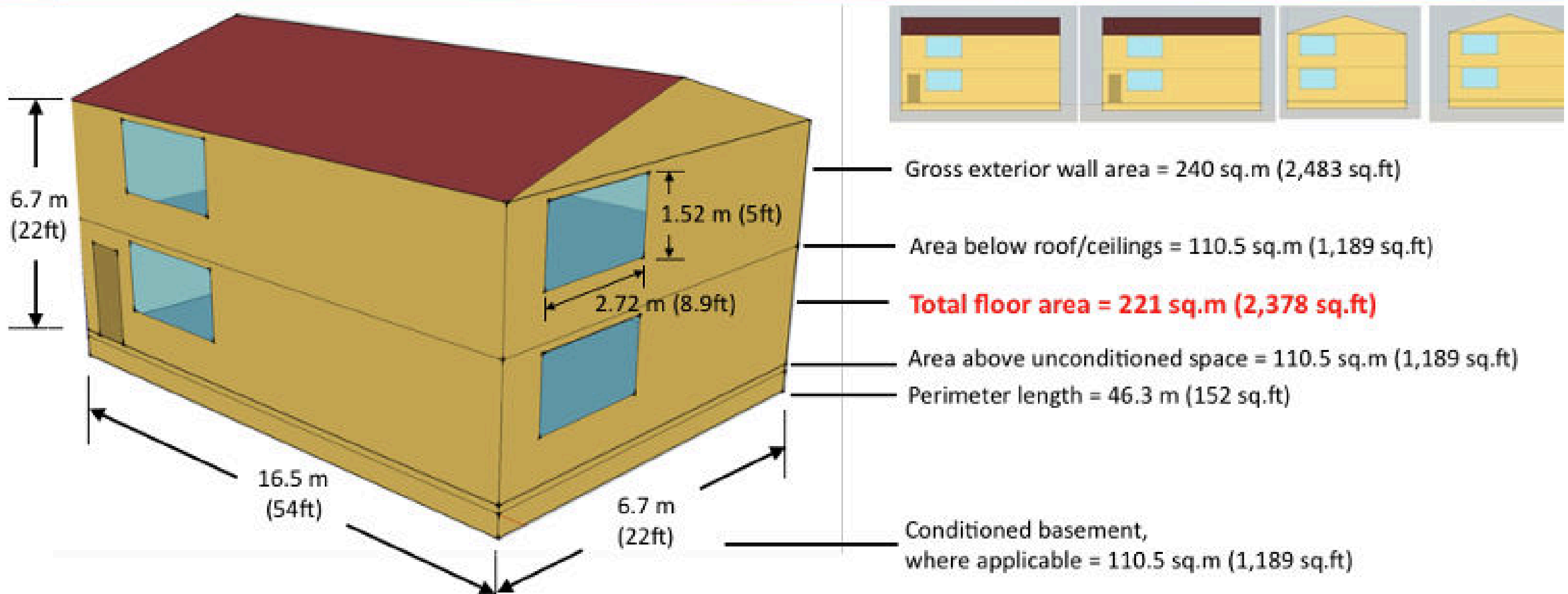
Heat loss model - payback period for air-filled windows

Table A4. Average payback time for various window upgrades in select Colorado Locations. Only air fill (no sealed argon window units) is available for these windows and cells with payback less than 13.5 years are highlighted as green.

Average Payback Period by Window Type, Upgrading from U = 0.35 Window (ALL AIR FILL, NO ARGON)														
City	**Elevation**	**Climate Zone**	U = 0.33	U = 0.32	U = 0.31	U = 0.30	U = 0.29	U = 0.28	U = 0.27	U = 0.26	U = 0.25	U = 0.24	U = 0.23	U = 0.22
Trinidad	5741	4B	9.0	13.6	16.8	19.5	21.9	24.1	26.2	28.2	30.2	32.2	34.1	36.0
Lamar	3704	4B	8.6	13.0	16.1	18.6	20.9	23.0	25.0	27.0	28.9	30.8	32.6	34.4
Denver	5289	5B	8.1	12.3	15.3	17.7	19.8	21.8	23.7	25.6	27.4	29.2	30.9	32.7
Colorado Springs	6181	5B	8.1	12.2	15.1	17.5	19.7	21.6	23.5	25.4	27.2	28.9	30.7	32.4
Grand Junction	4833	5B	8.5	13.0	16.0	18.6	20.8	22.9	24.9	26.9	28.8	30.7	32.5	34.3
Montrose	5720	5B	8.0	12.2	15.0	17.4	19.5	21.5	23.4	25.2	27.0	28.8	30.5	32.2
Durango	6670	5B	7.1	10.8	13.4	15.5	17.3	19.1	20.8	22.4	24.0	25.6	27.1	28.6
Alamosa	7533	6B	6.0	9.1	11.3	13.1	14.7	16.2	17.6	19.0	20.3	21.6	22.9	24.2
Craig	6190	6B	5.9	8.9	11.0	12.8	14.3	15.8	17.2	18.5	19.8	21.1	22.4	23.7
Eagle	6497	6B	6.4	9.8	12.1	14.0	15.7	17.3	18.8	20.2	21.7	23.1	24.5	25.9
Steamboat Springs	6879	7	5.9	8.9	11.0	12.7	14.3	15.7	17.1	18.4	19.7	21.0	22.3	23.5
Gunnison	7666	7	5.3	8.0	9.9	11.4	12.8	14.1	15.4	16.6	17.7	18.9	20.0	21.1

Aspen	7720	7	5.9	9.0	11.1	12.9	14.4	15.9	17.3	18.7	20.0	21.3	22.5	23.8
Leadville	9932	7	4.6	7.0	8.7	10.0	11.2	12.4	13.5	14.5	15.6	16.6	17.6	18.5

EnergyPlus v9.5 Simulation Assumptions and Inputs



Parameter	Assumption
Window area used - and number of 3'x5' windows that represents	33.075 sq.m (356 sq.ft) # of windows = 8 Window size = 2.72m x1.52m (8.9ft x 5ft) Equates to 23.8 windows of 3' x 5' dimensions per house
Shading assumed	2 west windows with shading overhangs
Window area (relative to conditioned floor area)	15% equally distributed to the four cardinal directions (or as required to evaluate glazing-specific code changes)
Door area	3.9 sq.m (42 sq.ft)
Internal gains	91537.71 kJ/day
Foundation system	Slab, Heated Basement, Unheated Basement, Crawl Space
Heating system	Natural gas furnace, heat pump, electric furnace.
Cooling system	Central electric air conditioning
Water heating	Same as fuel used for space heating, or as required to evaluate domestic hot water-specific code changes
Heating Setpoint	22.2°C (71.9°F)
Cooling Setpoint	23.9°C (75°F)

LBNL Energy Modeling Data Inputs and Sources*		
		Sources
Version of EnergyPlus	9.5	
Weather Data Source	TMY3, class I or II	
RECS data (source)	2015 RECS survey data	https://www.eia.gov/consumption/residential/data/2015/
Energy cost data (source)	D+R International	2019 EIA Energy Cost Data
House used for analysis	Single family detached house, 2006 IECC	https://www.energycodes.gov/development/residential/iecc_models
Window area used - and number of 3'x5' windows that represents	33.075 square meters # of windows = 8 Window size = 2.72m x1.52m Equates to 23.8 windows of 3' x 5' dimensions per house	
Shading assumed	4 west windows with shading overhangs	
HVAC systems considered - weighted averages	1. Natural gas furnace 2. Heat Pump 3. Electric Furnace 4. Oil Furnace	LBNL consolidated heating system approach
Foundation systems considered - weighted averages	1. Slab 2. Heated Basement 3. Unheated Basement 4. Crawl Space	LBNL consolidated foundation approach

*Energy usage is on an annual basis per home with characteristics described to the right.

EnergyPlus model - payback period for air-filled windows

Table A5. Estimated payback period for window upgrade scenarios for a model residential building located in ***Trinidad*** (climate zone 4B). Scenarios marked “N/A” have negative payback periods. AIR-FILL ONLY, no sealed argon-filled option available.

	SHGC (0.13 - 0.50)																	
U-Factor (0.22 - 0.35)	*0.13*	*0.15*	*0.17*	*0.19*	*0.20*	*0.21*	*0.23*	*0.25*	*0.27*	*0.30*	*0.32*	*0.35*	*0.37*	*0.40*	*0.42*	*0.45*	*0.47*	*0.50*
0.22	34.8	33.5	**32.7**	**32.2**	**32.1**	**32.1**	**32.1**	**32.3**	**30.7**	**31.7**	**32.8**	**34.9**	**36.8**	**41.3**	**45.2**	**54.5**	**62.7**	**83.8**
0.23	33.5	32.2	31.4	30.9	30.7	30.6	30.6	30.8	29.1	30.2	31.2	**33.4**	**35.5**	**39.9**	**44.0**	**54.2**	**64.2**	**89.8**
0.24	32.4	31.0	30.1	29.4	29.3	29.3	29.3	29.4	27.4	28.4	29.5	**31.7**	**33.9**	**38.5**	**42.9**	**54.3**	**66.7**	**101**
0.25	31.4	29.7	28.7	28.1	28.0	27.8	27.8	28.0	25.7	26.8	27.9	30.1	32.4	**37.3**	**42.4**	**55.0**	**70.4**	**124**
0.26	30.4	28.5	27.6	26.7	26.6	26.4	26.3	26.5	24.1	25.1	26.3	28.7	31.1	**36.5**	**42.2**	**58.0**	**78.6**	**179**
0.27	29.5	27.3	26.2	25.4	25.2	25.0	25.0	25.2	22.3	23.4	24.7	27.2	29.7	36.1	42.8	62.3	95.2	510
0.28	28.6	26.3	25.0	24.1	23.8	23.7	23.5	23.8	20.5	21.7	23.0	25.7	28.5	35.7	44.4	74.4	144	N/A
0.29	28.2	25.3	23.9	22.9	22.5	22.3	22.3	22.4	18.6	19.8	21.2	24.2	27.6	36.3	48.5	110	999	N/A
0.30	28.1	24.7	22.8	21.7	21.3	21.0	21.0	21.1	16.5	17.8	19.2	22.6	27.0	39.0	60.1	611	N/A	N/A
0.31	29.1	24.4	22.0	20.7	20.0	19.8	19.7	19.8	14.0	15.4	17.0	21.0	26.2	45.5	117	N/A	N/A	N/A
0.32	32.7	25.1	21.9	19.9	19.4	18.9	18.6	18.8	11.3	12.4	14.2	19.0	27.5	88.9	N/A	N/A	N/A	N/A
0.33	47.9	28.7	22.7	19.9	19.0	18.4	18.0	18.0	7.0	8.1	10.0	16.8	38.9	N/A	N/A	N/A	N/A	N/A
Payback periods in bold are window U-factor/SHGC combinations that meet the ENERGY STAR v7 Northern specification																		

Table A6. Estimated payback period for window upgrade scenarios for a model residential building located in ***Colorado Springs*** (climate zone 5B). Scenarios marked “N/A” have negative payback periods. AIR-FILL ONLY, no sealed argon-filled option available.

	SHGC (0.13 - 0.50)																	
U-Factor (0.22 - 0.35)	*0.13*	*0.15*	*0.17*	*0.19*	*0.20*	*0.21*	*0.23*	*0.25*	*0.27*	*0.30*	*0.32*	*0.35*	*0.37*	*0.40*	*0.42*	*0.45*	*0.47*	*0.50*
0.22	41.6	38.8	**36.9**	**35.6**	**35.1**	**34.6**	**34.0**	**33.6**	**31.5**	**31.8**	**32.2**	**33.5**	**34.5**	**37.0**	**39.2**	**44.2**	**48.5**	**57.7**
0.23	40.9	37.8	35.8	34.4	33.8	33.3	32.7	32.2	29.9	30.1	30.6	**31.8**	**32.9**	**35.4**	**37.9**	**43.1**	**47.4**	**57.5**
0.24	40.7	37.1	34.8	33.3	32.7	32.1	31.3	31.0	28.3	28.5	28.9	**30.0**	**31.2**	**33.9**	**36.4**	**41.9**	**47.1**	**58.1**
0.25	40.4	36.2	33.8	32.1	31.5	30.9	30.0	29.5	26.6	26.9	27.2	28.3	29.6	**32.3**	**34.9**	**40.9**	**46.5**	**59.9**
0.26	40.7	35.9	32.9	31.0	30.4	29.7	28.7	28.2	25.1	25.2	25.6	26.8	28.0	**30.9**	**33.8**	**40.0**	**46.8**	**64.6**
0.27	41.7	35.9	32.4	30.1	29.2	28.6	27.5	26.9	23.3	23.5	23.9	25.1	26.4	29.6	32.7	40.1	48.2	71.7
0.28	43.9	36.2	31.9	29.4	28.5	27.6	26.3	25.7	21.6	21.7	22.2	23.3	24.9	28.3	32.0	40.2	50.9	89.3
0.29	48.6	37.7	32.2	28.9	27.8	26.8	25.3	24.6	19.7	19.7	20.3	21.7	23.2	27.0	31.7	42.6	58.9	161
0.30	61.1	40.6	33.3	28.9	27.6	26.5	24.5	23.6	17.5	17.7	18.2	19.7	21.6	26.3	31.5	48.8	81.3	N/A
0.31	104	51.3	36.7	30.3	28.1	26.1	23.9	22.8	15.3	15.5	16.0	17.6	19.6	25.5	33.2	70.4	330	N/A
0.32	N/A	97.2	47.7	33.1	29.6	28.2	24.3	22.3	12.5	12.6	13.0	15.1	17.2	25.2	38.3	N/A	N/A	N/A
0.33	N/A	N/A	143	51.3	39.5	33.8	27.0	23.5	8.2	8.4	8.8	10.8	13.7	31.5	902	N/A	N/A	N/A
Payback periods in bold are window U-factor/SHGC combinations that meet the ENERGY STAR v7 Northern specification																		

Table A7. Estimated payback period for window upgrade scenarios for a model residential building located in ***Eagle*** (climate zone 6B). Scenarios marked "N/A" have negative payback periods. AIR-FILL ONLY, no sealed argon-filled option available.

	SHGC (0.13 - 0.50)																	
U-Factor (0.22 - 0.35)	*0.13*	*0.15*	*0.17*	*0.19*	*0.20*	*0.21*	*0.23*	*0.25*	*0.27*	*0.30*	*0.32*	*0.35*	*0.37*	*0.40*	*0.42*	*0.45*	*0.47*	*0.50*
0.22	45.5	40.9	**38.0**	**35.8**	**34.7**	**33.6**	**32.1**	**30.7**	**27.8**	**27.0**	**26.7**	**26.6**	**26.6**	**27.3**	**27.8**	**29.1**	**30.2**	**32.1**
0.23	46.2	41.0	37.9	35.2	34.0	33.1	31.3	29.7	26.5	25.7	25.3	**25.1**	**25.3**	**25.8**	**26.3**	**27.5**	**28.6**	**30.8**
0.24	47.8	41.6	37.9	34.8	33.5	32.4	30.4	28.7	25.3	24.3	23.9	**23.7**	**23.8**	**24.3**	**24.9**	**26.2**	**27.2**	**29.3**
0.25	50.5	42.9	38.2	34.6	33.2	31.9	29.6	27.8	24.0	22.8	22.4	22.2	22.3	**22.8**	**23.3**	**24.6**	**25.7**	**28.0**
0.26	55.5	44.8	39.0	34.7	33.1	31.6	29.0	27.0	22.7	21.4	21.0	20.8	20.8	**21.3**	**21.8**	**23.1**	**24.2**	**26.5**
0.27	64.7	48.9	41.1	35.3	33.3	31.4	28.5	26.2	21.4	19.9	19.4	19.2	19.3	19.7	20.3	21.5	22.7	25.2
0.28	87.7	56.8	44.6	36.8	34.0	32.0	28.3	25.6	20.0	18.4	17.9	17.6	17.6	18.1	18.6	19.9	21.1	23.7
0.29	193	76.1	52.1	40.2	36.6	33.2	28.7	25.4	18.6	16.8	16.2	15.9	15.9	16.3	16.9	18.2	19.6	22.3
0.30	N/A	170	74.7	49.2	42.0	36.6	29.8	25.5	17.2	15.1	14.4	14.0	14.1	14.5	15.0	16.4	17.7	20.8
0.31	N/A	N/A	283	75.9	57.1	46.7	33.4	26.7	15.4	12.9	12.2	11.9	11.8	12.2	12.9	14.2	15.6	19.1
0.32	N/A	N/A	N/A	N/A	188	92.7	45.4	30.4	13.5	10.4	9.7	9.2	9.2	9.6	10.1	11.6	13.2	18.0
0.33	N/A	N/A	N/A	N/A	N/A	N/A	195	47.4	10.8	6.9	6.2	5.6	5.6	5.9	6.3	7.7	9.3	15.8
Payback periods in bold are window U-factor/SHGC combinations that meet the ENERGY STAR v7 Northern specification																		

Table A8. Estimated payback period for window upgrade scenarios for a model residential building located in ***Gunnison*** (climate zone 7). Scenarios marked "N/A" have negative payback periods. AIR-FILL ONLY, no sealed argon-filled option available.

	SHGC (0.13 - 0.50)																	
U-Factor (0.22 - 0.35)	*0.13*	*0.15*	*0.17*	*0.19*	*0.20*	*0.21*	*0.23*	*0.25*	*0.27*	*0.30*	*0.32*	*0.35*	*0.37*	*0.40*	*0.42*	*0.45*	*0.47*	*0.50*
0.22	47.1	40.7	**36.8**	**33.9**	**32.7**	**31.5**	**29.7**	**28.1**	**25.2**	**23.9**	**23.1**	**22.2**	**21.7**	**21.2**	**21.0**	**21.0**	**21.2**	**21.9**
0.23	49.6	41.6	37.0	33.7	32.3	31.0	29.1	27.3	24.2	22.7	21.8	**21.0**	**20.4**	**19.9**	**19.7**	**19.7**	**19.8**	**20.4**
0.24	53.4	43.2	37.8	33.7	32.2	30.7	28.3	26.6	23.0	21.5	20.7	**19.7**	**19.2**	**18.6**	**18.4**	**18.3**	**18.4**	**19.0**
0.25	60.2	46.0	38.7	34.0	32.2	30.6	27.8	25.9	21.9	20.2	19.4	18.4	17.9	**17.3**	**17.0**	**16.9**	**16.9**	**17.5**
0.26	73.1	50.6	40.8	34.9	32.5	30.7	27.4	25.1	20.8	19.0	18.1	17.0	16.5	**15.9**	**15.6**	**15.4**	**15.5**	**16.0**
0.27	107	60.1	45.1	36.5	33.5	30.9	27.1	24.6	19.6	17.6	16.7	15.6	15.1	14.5	14.2	14.0	14.0	14.4
0.28	292	82.9	52.3	39.8	35.3	32.2	27.4	24.2	18.4	16.3	15.3	14.1	13.6	13.0	12.6	12.4	12.4	12.8
0.29	N/A	204	73.5	46.9	39.4	34.8	28.1	24.1	17.1	15.0	13.8	12.6	12.0	11.4	11.1	10.9	10.8	11.1
0.30	N/A	N/A	189	68.1	50.5	41.0	30.2	24.4	16.0	13.3	12.2	10.9	10.3	9.7	9.4	9.1	9.1	9.3
0.31	N/A	N/A	N/A	247	98.2	62.8	36.3	26.6	14.6	11.5	10.3	9.0	8.5	7.8	7.5	7.3	7.2	7.3
0.32	N/A	N/A	N/A	N/A	N/A	813	61.0	32.7	13.0	9.4	8.0	6.8	6.3	5.6	5.4	5.2	5.1	5.2
0.33	N/A	N/A	N/A	N/A	N/A	N/A	N/A	65.4	11.0	6.2	4.9	3.9	3.5	3.1	2.9	2.7	2.7	2.7
Payback periods in bold are window U-factor/SHGC combinations that meet the ENERGY STAR v7 Northern specification																		

Comparing ENERGY STAR and IECC specifications

Setting a statewide window standard based on ENERGY STAR requires all windows in the state to meet a reasonably high bar for energy efficiency, a bar that is by definition differentiated from code minimum efficiency standards.

In the IECC, the U-factor allowed for projects at elevations above 4,000 feet is 0.32 and 0.30 for the 2021 and 2024 versions, respectively. The highest U-factor allowed in ENERGY STAR v7 Northern climate zone is 0.26 for products with high SHGC and 0.22 for products with low SHGC. Thus, the ENERGY STAR v7 standard requires windows to be significantly more energy efficient when compared to recent IECC prescriptive requirements.

There is also an area of misalignment between ENERGY STAR v7 and the 2021 IECC, the most commonly adopted version of the IECC in Colorado. The 2021 IECC sets a maximum SHGC of 0.40 for climate zone 5 (the zone that includes ~90% of the Colorado population) and 4. Thus, the IECC is explicitly directing homebuilders not to install too many windows with high SHGC. The ENERGY STAR v7 standard requires that windows with U-factors of 0.25/0.26 must have SHGC ≥0.40 and windows with U-factors of 0.23/0.24 must have SHGC ≥0.35. Thus, for a builder to utilize only ENERGY STAR v7 windows with U-factor of 0.25 or 0.26 (the most affordable ENERGY STAR window option) the builder would need to utilize the performance or energy rating index code compliance pathways to avoid exceeding the prescriptive SHGC maximum. Otherwise the builder would only be able to install a certain portion of windows with high SHGC and would need to use the weighted average method to comply with the prescriptive maximum.

Note that there is no SHGC maximum in the IECC for climate zones 6 and 7, so this incompatibility is not an issue in those zones. Furthermore, the 0.40 SHGC maximum is removed for climate zone 5 in the 2024 version of the IECC, which will alleviate this issue in jurisdictions that adopt this version of the IECC. The maximum SHGC remains in place for climate zone 4 though.