Guidehouse

Commercial Building Fenestration Market Study

Prepared for:
The National Fenestration Rating Council

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guidehouse.com/esi

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Executive Summary

Buildings represent the largest sector of the U.S. energy economy, accounting for approximately 39% of total primary energy use. About 18% of all energy consumption[1] and 36% of all electricity consumption in the U.S. can be attributed to commercial buildings.[2] Commercial buildings include offices, healthcare, education, retail, hospitality, warehouses, public, institutional/assembly, and high-rise multifamily buildings. A variety of factors drive energy use in commercial buildings.

Energy consumption patterns depend on building type, size, and vintage, as well as the functions or services that take place in the building such as local climate and indoor occupant preferences. Space conditioning, heating, and mechanical ventilation are the primary end uses of energy in commercial buildings, accounting for 30% of total consumption.[3] Lighting is also a major contributor to primary energy use, contributing 7%.[4] Both sources of energy consumption in buildings are directly related to building envelope and, specifically, fenestration, which can significantly impact the amount of daylight levels and energy consumed by affecting heating and cooling loads due to heat gain and loss.

This study characterizes and assesses the U.S. commercial fenestration market.

It analyzes a groundbreaking amount of data that will ultimately support an estimate of national savings potential of energy efficient fenestration products in commercial applications to demonstrate the benefits of efficient façade and fenestration systems.

This study provides data and analysis on:

- Commercial fenestration market and fenestration selection process
- Installed commercial fenestration stock across the U.S. and fenestration sales estimates
- Current commercial building fenestration codes and market trends of installation to or above code.

The commercial fenestration market is significant, and adoption of energy efficient commercial fenestration provides an immense opportunity in energy savings in buildings. In the U.S., approximately 360 million square feet of glass vision area is sold every year according to Guidehouse data for commercial building new construction and retrofits (for exterior applications). In this report, we define fenestration as building exterior glass systems, not including attachments such as awnings, films, shades, and storm windows. Highly energy efficient fenestration is more prevalent in new construction, but the existing buildings market is substantial and represents an even greater opportunity to impact the nation’s building energy performance. Based on Guidehouse’s Global Building Stock Database and AAMA, approximately 21 billion square feet of glass vision area is installed in commercial buildings of which 14 billion square feet is in commercial and institutional properties, such as healthcare, education, retail, office, hotels, restaurants, warehouses, assembly. Multifamily buildings represent the remaining 7 billion square feet of glass vision area.

However, the commercial buildings fenestration market is complex and fragmented. A variety of supply-side stakeholders, including component manufacturers and fabricators, contractors, architects, code officials, and policymakers participate in the market. There are few consolidated sources of information on market dynamics and installed stock, as data on fenestration selections is rarely collected and reported in a comprehensive and organized manner.

Fenestration technologies have advanced over the past few decades, resulting in higher performing windows and systems. Advancements in building energy codes, growing interest in green buildings, financing innovation, and rebate availability also have been supporting growth in the energy efficient fenestration market. Yet, high efficiency fenestration is rarely the default selection of engineers, building owners, and architects around the country. There are many market barriers to adoption, including costs, fenestration selection process barriers, split incentives, fragmented market players, and more.

The adoption of energy efficient commercial fenestration represents a tremendous opportunity for energy savings especially in existing buildings.[i] Fenestration retrofits occur infrequently in existing buildings—only 14% of the commercial building fenestration stock was installed as a retrofit and around 65%-70% of commercial building installed stock contains fenestration installed over 20 years ago. Penetration of energy efficient products in the existing commercial building stock is also relatively low. For example, single-pane glass still represents an estimated 41% of the installed fenestration stock and low-emissivity (Low-E) coating is present in only 42% of the stock. Clear glass fenestration (not tinted or reflective, not Low-E coated, and high visible transmittance) makes about half of the installed stock (51%). About 58% of double and triple-pane fenestration are air-filled. Further, only 21% of installed stock have aluminum/metal frames with some type of thermal break and 50% are aluminum with no thermal break. In general, trends of fenestration characteristics by building vintage show that energy efficient fenestration is commonly used in newly constructed buildings, particularly in vintages from 2010 to 2020.

Fenestration sales from 2017 to 2020 show high proportions of higher performance and efficient fenestration. Double-pane and triple-pane glass represented 88% and 4% of the sales. Low-E coating glass comprised about 83% of the sales. Fenestration with tinted and/or reflective glass comprise about 50% of the sales, and aluminum/metal frames with some thermal break makes up 68% of sales. However, many energy efficient characteristics and emerging fenestration technologies still represent a small minority of commercial sales. For example, few sales were comprised of dynamic glazing (less than 1%), triple-pane glass (about 4%), and vacuum-insulated glass (less than 1%).

Though the adoption of energy efficient fenestration is improving with new construction, fenestration energy code compliance and associated impacts is uniformly difficult to measure and enforce across the country for many reasons. Little information is available or collected regarding commercial fenestration compliance, and in general, fenestration is a lower priority as part of building inspections. There are also challenges around both the performance and prescriptive compliance paths and specifically, the trade-offs in using the performance path that can result in less energy efficient fenestration than originally planned. Few parts of the country have dedicated energy code staff or budgets. Inspectors' time is not necessarily allotted for verifying energy code compliance, much less for fenestration and that time is not prioritized compared to life, health, and safety measures. Further, inspectors are often hesitant to delay construction due only to a lack of fenestration compliance documentation. Stakeholders cited training and technical support as well as dedicated energy code staffing as the most impactful methods to increase and enforce code compliance including fenestration.

Fenestration performance values often vary between plans, engineering drawings, performance models and what is ultimately installed in the field. Default or estimated fenestration values are typically used in plans and sometimes in performance models (if at all), and original fenestration can be value-engineered out after permit approval. Performance modeling can also be incorrectly performed or use dummy inputs to obtain a permit. Finally, site inspections are not typically required to verify what is installed and to confirm fenestration compliance. The most significant challenge and information gap for

[i] Energy efficient fenestration covers a range of products and window and framing characteristics including multiple glazings, use of Low-E coatings, gas fills, spacers, and thermal breaks between glazing layers as well as high performance framing.

inspectors is verifying compliance in the field or obtaining NFRC certifications for site-built or a combination of site- and shop-built fenestration.

Energy efficient fenestration adoption is largely hindered by market dynamics. For example, the energy efficiency programs identified in this study that are focused on commercial fenestration suffer from low market participation and from only a few market sectors such as small commercial. Participation in these programs are low, especially compared to other measures with a quicker payback and lower upfront cost like lighting. Cost reduction, improvements in fenestration selection processes, stakeholder education, improved data collection and policy requirements can all support growth in installed fenestration energy efficiency including the following specific areas (in no specific order):

- **Supporting building energy code compliance and enforcement as well as local stretch codes and other industry standards** to continue the trend of more stringent energy codes and industry standards serving as a main driver of energy efficient fenestration adoption. Building envelope backstops, where a limit is placed on the amount of envelope performance that can be traded off for buildings that take the performance pathway, can also be a powerful mechanism to ensure that fenestration and other building envelope technologies meet baseline efficiency standards rather than being compensated by energy efficient mechanical systems. Fenestration investments are especially significant because fenestration is often in place for between 20 to 40 years, whereas mechanical systems are often replaced every 15 to 20 years. Building envelope specific metrics and outcome-based building energy codes as well as improved usage and knowledge of building energy modeling tools are other example mechanisms. To effectively drive energy efficient fenestration adoption, the commitment to enforcing energy codes at various points in the construction process and verifying the energy codes are met in the field should be increased.

- **Reducing cost barriers to increase affordability of energy efficient fenestration** through various methods including easing certification and evaluation methods to identify and select energy efficient fenestration and ultimately improve economies of scale for U.S. manufacturers in the commercial market. In addition, innovations in the manufacturing and delivery process can aid in installed cost reductions. New business models like leasing façade systems can also help building owners to overcome high upfront costs and lack of access to capital.

- **Adjusting the design-bid-build process** can enable early and more serious consideration of fenestration efficiency and associated non-energy benefits in projects. More communication and utilizing an integrated design process with established energy efficiency targets between architects, engineers, and developers during a project's early stages can increase intentionality in fenestration selection. Further, glazing contractors and / or façade consultants could be brought in earlier to the design process to facilitate specification conversations before decisions are finalized on HVAC systems and to address appropriate sizing with the fenestration. More consideration of energy efficiency within the budget planning stage of a project can also reduce value engineering and make owners less reluctant to adopt energy efficient fenestration if it is already included in the cost.[5]

- **Increasing stakeholder education** because designers cannot specify what they do not know. There is often a lag between when new technologies are introduced and architect familiarity. Architects and engineers may not understand how fenestration improvements can lead to changes in HVAC sizing and lighting. Owners also need a better understanding of the benefits that come with energy efficient fenestration. If fenestration can be marketed in ways that owners care about (more modern, less condensation, increased thermal comfort, reduced noise and air leakage) then higher performing products are more likely to be installed. Analysis tools allow for a more rigorous assessment of energy and non-energy benefits of energy efficient fenestration, equipping architects with the ability to better inform their clients. Demonstration projects that install efficient fenestration also have the potential to increase market uptake by increasing confidence in newer technologies through successful case studies.[5]

- **Considering the nuances of the commercial building fenestration market in energy efficiency program design and offerings and utility program targets** is critical to successful uptake of program incentives. Most energy efficiency fenestration-specific commercial programs suffer from low uptake and from few market sector participants. Programs could benefit from focusing on separate building sectors (e.g., hotels, office building, medical complexes) and decision makers (e.g., building developers, large corporate building owners, small business owners) and their specific drivers.

- **Integrating buildings and building envelope into state and local greenhouse gas (GHG) target planning and policies.** State and city targets for GHG reductions are a powerful signal of commitment to energy efficiency. However, most GHG targets that exist in the U.S. do not currently include detailed strategies toward reaching stated goals especially as it relates to the building envelope. Further, supporting policies such as building energy use benchmarking, ratings, and emission caps can also play a significant role in improving installed commercial fenestration. Data on energy efficiency potential associated with higher performance fenestration can support implementation and policy actions.

This study addresses long-standing gaps in U.S. commercial fenestration market data, providing qualitative and quantitative data on the characteristics of installed fenestration stock and sales, market stakeholders and their motivations, market processes including impacts of rating and certification programs, code compliance, and other elements of the fenestration industry. It also provides a detailed account of the installed fenestration stock and sales across key characteristics, such as glazing type, number of panes, Low-E coating, frame materials, U-factor, presence of a National Fenestration Rating Council (NFRC) certification, and other measures. Not only does the study provide and consolidate a groundbreaking amount of data on the U.S. commercial fenestration market, it also reveals the benefit and the need to improve data collection and an understanding of the complex industry dynamics in the commercial buildings market. Continued research on this topic is important, especially a deeper dive into regional and state dynamics and implementation of onsite data collection or building audits to supplement and further validate available data from this report. The immediate next step for this effort is to estimate the energy savings potential of highly energy efficient fenestration based on this study to allow stakeholders to better prioritize areas for action and support of energy efficient commercial fenestration adoption.

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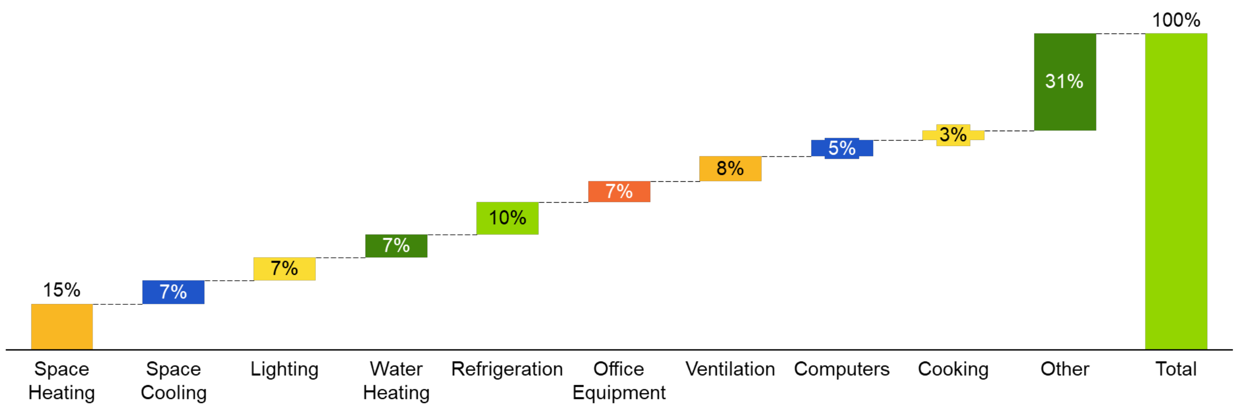
1. Introduction

1.1 Opportunity for Energy Efficient Fenestration in the U.S.

Buildings represent the largest sector of the U.S. energy economy. In 2020, the buildings sector accounted for 38 quads or 39% of total primary energy use. Approximately 18% of all energy consumption[6] and 37% of all electricity consumption in the U.S. can be attributed to commercial buildings.[7] Commercial buildings include offices, healthcare, education, retail, hospitality, warehouses, institutional/assembly, and high-rise multifamily buildings. In 2012, there were 5,557,000 commercial buildings in the U.S., occupying over 87 billion square feet.[8] For 2020, estimates place commercial floor space at 92.8 billion square feet, which is projected to increase to 124.7 billion square feet by 2050.[9] Although electricity use intensity is declining, commercial floor space is increasing at a faster rate, leading to an overall projected increase in electricity consumption.[10]

A variety of factors drive commercial building energy use. Energy consumption patterns depend on the functions or services that take place in the building, local climate, indoor occupant preferences, and building type, size, and vintage. The energy in commercial buildings is used for computers and office equipment, cooking, ventilation, water heating, space heating, space cooling, lighting, refrigeration, and other applications. Space conditioning, heating, and mechanical ventilation are the primary energy end uses in commercial buildings, accounting for 30% of total consumption as Figure 1-1 shows.[11] Lighting is also a major contributor to primary energy use, contributing 7% of total consumption.[12] Both sources of energy consumption in buildings are directly related to the building envelope and, specifically, fenestration.

Figure 1-1: Primary Energy Consumption in Commercial Buildings by End Use



Source: EIA AEO 2020.

As part of the building envelope, fenestration is central to building design and energy performance in the commercial built environment. Window design can have many impacts related to building performance and occupant comfort and preferences:

- Take advantage of desirable external conditions including natural light, outdoor views, and ventilation
- Protect occupants from harmful UV rays
- Mitigate undesirable environmental conditions such as wind, changes in temperature, and moisture issues
- Provide both added thermal and visual comfort across various climates

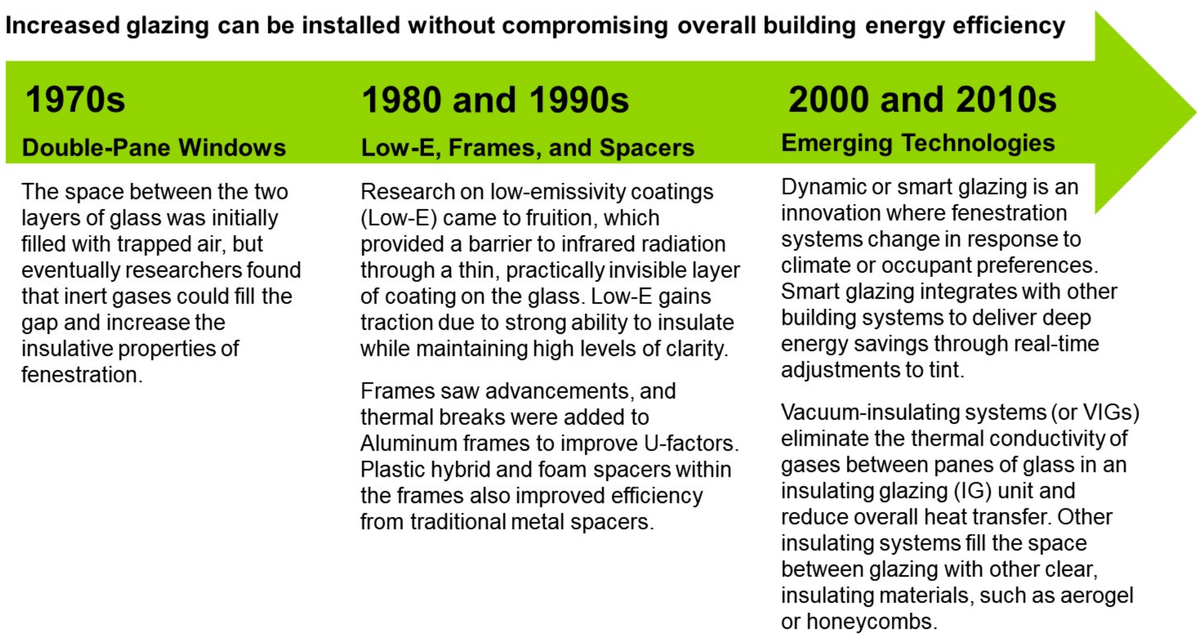
- Provide structural durability
- Alter the look of the building and the function of the glass depending on the type of glass or film used.

Fenestration—especially in commercial buildings—is also a source of architectural beauty and visual appeal, often making function, performance, and aesthetics equally important. In this report, we define fenestration as building exterior glass systems, not including attachments such as awnings, films, shades, and storm windows.

Fenestration significantly impacts the amount of energy consumed in commercial buildings by affecting heating and cooling loads due to heat gain and loss through fenestration as well as contributing to building air leakage. Much of the energy use attributed to fenestration is used to keep building occupants comfortable and maintain the indoor environment. Fenestration also impacts buildings' energy consumption through lighting: lighting loads can be reduced by leveraging fenestration's natural daylight through control and shading technology. In total, fenestration is responsible for approximately 10% of energy use in buildings and affects heating, cooling, ventilation, and lighting end uses.[13] However, energy use associated with fenestration varies based on many factors including climate zone, weather, building vintage, performance characteristics (e.g., U-factor, SHGC), orientation, associated shading systems, and window-to-wall ratio.

Technological advances in fenestration energy performance, cost reductions, voluntary certification programs, and more advanced building energy codes have contributed to shifting the commercial building stock toward better performing fenestration. Figure 1-2 shows major advances in window technologies that enabled increased energy efficiency in buildings over the past several decades. However, systemic challenges remain that inhibit market adoption, which are further addressed in Section 2.3.

Figure 1-2: Advances in Window Technologies Enable Energy Efficiency



Source: Guidehouse, Window Outfitters, Inc.[14]

Adoption of highly energy efficient commercial fenestration provides a tremendous opportunity in energy savings. The U.S. commercial fenestration market is significant. According to Guidehouse data, approximately 360 million square feet of glass vision area is sold every year in the U.S. for both new construction and retrofits/additions (for exterior applications). Though energy efficient fenestration is more prevalent in new construction, there is a substantial opportunity to replace fenestration in existing buildings to improve energy performance of the commercial building stock. The current installed fenestration stock has relatively low penetration of energy efficient fenestration technologies. Many existing buildings across the country could significantly benefit from a fenestration retrofit by seeing improvements in occupant comfort, reductions in their energy bill, and progress toward sustainability targets. However, fenestration retrofits also face significant barriers in buildings including high cost of installation and potential disruption to tenants.

The fenestration industry is fragmented and complex. Many different market players contribute to the production of a fenestration system and influence fenestration selection. This study explores how these market dynamics affect installed fenestration performance. Guidehouse used both primary and secondary data sources to overcome significant gaps in available data on the fenestration market. The study provides information on factors that affect fenestration selection and code compliance and includes data on characteristics of the U.S. installed fenestration stock and fenestration sales. This data will support fenestration market stakeholders and regulators in advancing energy efficient fenestration solutions in new construction and existing buildings.

1.2 Methodology and Scope

Scope

This study is a comprehensive evaluation of the current U.S. commercial fenestration market. It includes industry and technology trends, market players and processes, current fenestration installed stock and sales, fenestration code compliance impacts, and above-code fenestration programs. The study's purpose is threefold:

- Gain insights and understanding of commercial fenestration market intricacies
- Gather data necessary to support an estimate of national savings potential of energy efficient fenestration products in commercial applications
- Demonstrate the potential value of more energy efficient installed commercial façade and fenestration systems.

The commercial fenestration stock and sales characterization (summarized in Section 4) covers 11 key fenestration characteristics and five key building characteristics. The fenestration characteristics include details on the glazing type, glass panes, gas fill, window frame type, fenestration installation type, fenestration integration with façade, thermal performance factors, and the fenestration assembly type. Table 1-1 lists all data categories covered in this study.

Table 1-1: Scope of Fenestration Stock and Sales

Data Category	Description	Stratification
Installation type	Reason the current building fenestration was installed	New construction or retrofit (replacement)
Low-E coating	Microscopically thin, transparent coating that reflects long wave IR without compromising the amount of visible light that is transmitted and reduces emissivity of the glass. Spectrally selective coatings also reflect short wave IR.	Presence of Low-E coating Location of Low-E coating (surface number) Spectral selectivity Low-E coating technology

Data Category	Description	Stratification
Gas fill	Gas pumped inside double/triple-paned glass to improve the thermal efficiency	Air, argon, krypton, vacuum
	Material that is used to seal the gas-fill window edge	Material of seal (silicone, rubber, PIB, PU, other)[ii]
Frame type	Material for the supporting frame for the glazing of a window	Frame material (metal, wood, vinyl, fiberglass, other)
	Thermal break is a continuous barrier between the inside and outside window frames that reduces conductive thermal energy loss	Presence of thermal break[iii]
Integration with façade	How the fenestration is integrated into the building façade	Curtain wall, punched window, storefront, other
Number of panes	The number of sheets of glass within the window frame	Single, double, triple
Glazing characteristics	Glass that has been treated (film coating) to reduce the transmission of light and solar heat through it	Tinted
	Glass that has metal or metal oxide added to reduce the solar heat gain and glare from solar rays	Reflective
	Glass that has the fully reversible ability to change its performance properties, including solar heat gain coefficient (SHGC) and/or visible transmittance (VT)	Dynamic
	Non-tinted and non-reflective glass with high visible transmittance	Clear
Location of fenestration assembly	Location that the fenestration is assembled	Shop-built, site-built, combination
Window-to-wall ratio	Percent of the building façade that is comprised of fenestration	Gross façade (glass and opaque envelope) area for each building orientation
Window area	Total square feet of fenestration area for each side of the building (N, E, S, and W)	Gross fenestration area for each building orientation
NFRC certificate/label	Presence of NFRC certificate/label	Presence of NFRC certificate/label
Building location	The building census division, state, and climate zone	U.S. census division and Building America Climate Zone
Building vintage	The year or decade the building construction was completed	Year/decade
Gross floor area	Total square feet of floor area	Square feet
Number of floors	Should be an integer	(number)
Building type	The primary building activity	Education, healthcare, hospitality, multifamily, office, other, public, retail, service, or warehouse

[ii] Data on gas-fill seal materials was removed from the analysis results due to inconsistencies and lack of confidence in the survey results because multiple sealant types are often used.

[iii] Thermal breaks vary from low performance to high performance. There is also a difference between thermally improved and thermally broken (greater than 5.3 mm) per NFRC's definition. For simplicity in the response-based survey, the question was binary in terms of the presence of a thermal break or not.

Methodology Overview

For Sections 3-6 of this analysis (market process, installed stock, fenestration sales, and code compliance/above-code programs), Guidehouse used various combinations of three data streams: secondary research of available data, primary research of surveys or interviews, and Guidehouse's industry expertise.

Secondary Research Overview

Guidehouse reviewed literature including existing fenestration studies and reports from groups such as the Regional Energy Efficiency Organizations (REEOs); research national lab papers; organizations like ACEEE, Institute for Market Transformation and utility and energy efficiency programs. Other sources include data from the Building Codes Assistance Program (BCAP), U.S. Green Building Council (USGBC), local government documents, and an industry market report from the American Architectural Manufacturers Association (AAMA) (now Fenestration & Glazing Industry Alliance).

Data was collected by aggregating the following existing public building data sources:

- U.S. EIA 2012 Commercial Building Energy Consumption Survey (CBECS)
- U.S. EIA 2015 Residential Commercial Building Energy Consumption Survey for multi-family buildings only (RECS)
- The 2014 and 2018 Northwest Energy Efficiency Alliance Commercial Building Stock Assessment (NEEA CBSA)
- The 2006 California End Use Survey (CEUS)
- DOE Building Code Study (Code Study)
- Data provided from three efficiency programs: Austin Energy Incentives, Efficiency Works Incentives, and Port Angeles Incentives.

Primary Research Overview

Guidehouse interviewed fenestration stakeholders including the following:

- Industry subject matter experts
- Code officials
- Utility program managers; REEO representatives
- Manufacturers of glass, windows, frames and films, and manufacturer representatives
- Building architects and engineers.

The Guidehouse team conducted some interviews in the initial phase of the project to guide our work. Other interviews were conducted in the final stages to help fill remaining gaps in knowledge and review initial findings.

Primary research was also conducted through a survey implemented by Guidehouse of building architects, engineers, and contractors in the U.S. who provided fenestration data on 800 buildings. These responses were self-reported via an online survey.

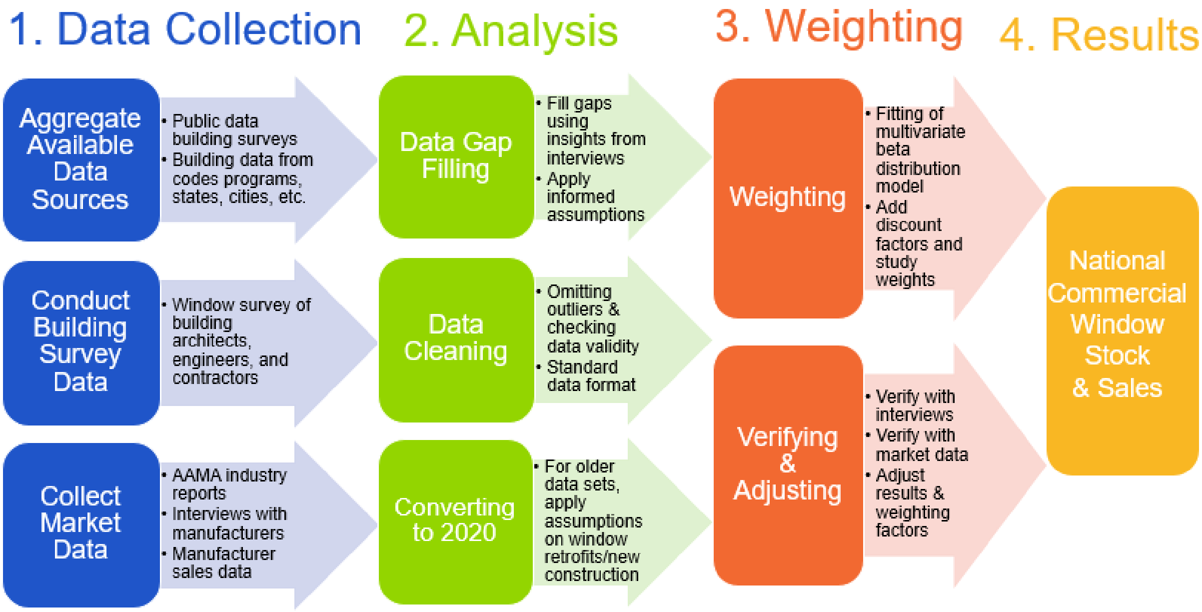
The synthesized findings from the literature review, industry interviews, and aggregated building data and survey are provided in Sections 2 through 6.

Installed Stock and Sales Methodology

Figure 1-3 summarizes the process for estimating the national installed stock and sales for commercial fenestration. First, Guidehouse located and aggregated existing public building surveys with fenestration data. Guidehouse also collected commercial fenestration data via a survey of U.S. building architects, engineers, and contractors who provided data on 800 buildings, which were built or had a fenestration retrofit between 2010 and 2020.

Market data was collected by analyzing the *AAMA 2017/2018 Study on the U.S. Market for Windows, Doors, and Skylights* (AAMA report); conducting interviews with manufacturers and industry experts; and gathering manufacturer sales data. This building and market data then were analyzed to fill gaps, cleaned to remove outliers and invalid data, and organized to convert older datasets to 2020 using data on fenestration sales and assumptions on retrofits and new construction. The data was combined and weighted using a multivariate distribution model, and Guidehouse adjusted the results as needed and based on interviews. More information on the analysis and weighting process is provided in Appendix A.

Figure 1-3: National Window Stock and Sales Methodology



Source: Guidehouse.

2. Industry Trends

2.1 Fenestration Technologies and Trends

Common Commercial Building Fenestration Types

Approximately 21 billion square feet of glass vision area (area of glazing in each window) is currently installed in commercial and multifamily buildings in the U.S. About 14 billion square feet is in commercial and institutional properties, such as healthcare, education, retail, office, hotels, restaurants, warehouses, assembly, and transportation. Multifamily buildings represent 7 billion more square feet of glass. Multi-layered glass is more common in colder regions while single-pane glass is more prevalent in warmer climates.[15] Fenestration can either be shop-built, assembled in a factory, and shipped as a unitized structure to the field, or site-built and assembled with different components (glass/glazing, frame, spacer, etc.) at the construction site. There are three types of façade integrations predominate in vertical commercial fenestration: curtain wall, storefront, and punched windows.

Figure 2-1: Façade Integrations

Curtain wall fenestration, as the name suggests, acts like a curtain hung from the building and is attached to outside floor slabs. W**indow wall fenestration** differs from curtain wall: instead of hanging from the floor slabs, fenestration is attached between slabs.

Storefront windows are similar to curtain wall in the they are both non-load bearing and have a similar appearance, however storefront systems are typically single span structures with frames anchored to the building structure and are limited to lower levels.

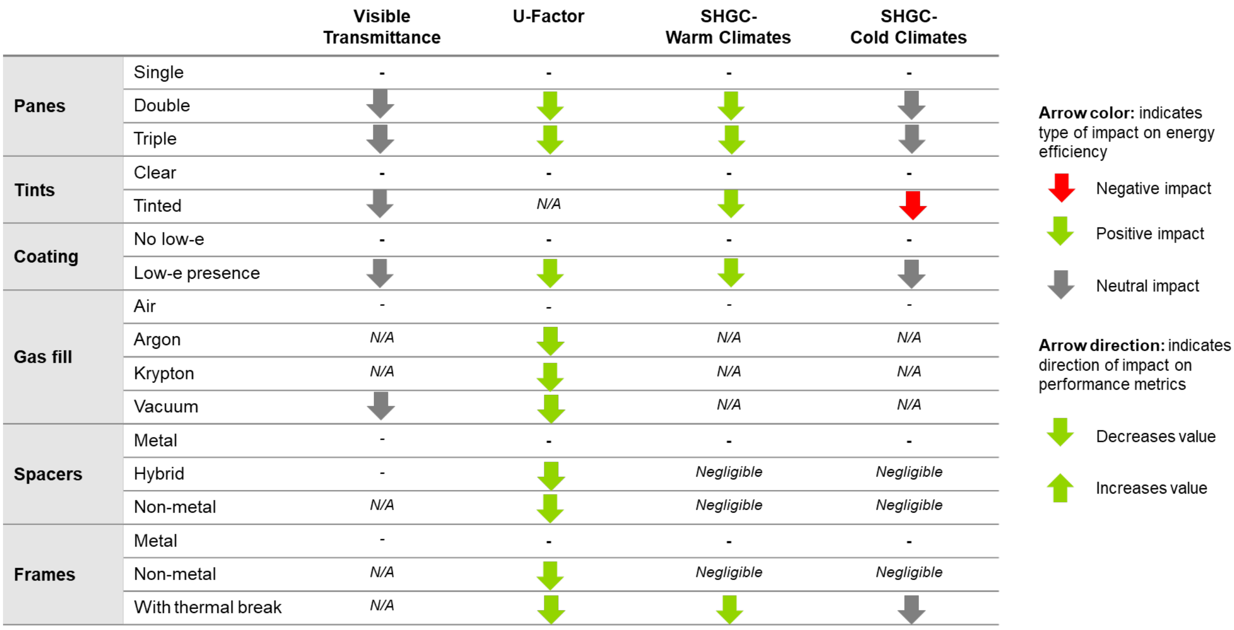
Punched windows are hole-like openings in a façade and are typically seen in residential applications and older and historic non-residential buildings.

Source: Guidehouse.

Fenestration Performance and Impacts

A fenestration system has many components, each providing different aesthetics, functionality, and energy performance characteristics. Changing the chemical or physical composition of the glazing material (such as adding a tint), applying layers of coating, adding layers of glass (potentially with gas fill), adjusting spacing, using different materials and thermal breaks in the frame, and using different spacer materials are five of the main ways to improve the energy performance of a window.[16] Three main measures are used to determine fenestration performance: U-factor, solar heat gain coefficient (SHGC), and visible transmittance (VT).[iv] Higher VT indicates that the glazing has higher visible light transmission; lower U-factors signify better insulation, and higher SHGCs demonstrate that more solar heat can pass through the glazing. Combined, different fenestration components result in wide variation in these performance indicators.

Figure 2-2: Window Characteristics' Impact on Window Performance Metrics



*Assumes baseline fenestration for comparison as single-pane, clear glass, metal framed assembly without Low-E.

Source: Guidehouse.

Table 2-1 outlines how different fenestration elements contribute to energy performance. In addition to fundamental elements such as number of panes, frames, and tint, performance is also impacted by operation, orientation, shading, and other features.

Table 2-1: Fenestration Components' Impact on Performance

Fenestration Component or Technology	Impact on Performance
Operation	Lower air leakage rates: Casement (windows hinged at the side), hopper (windows hinged at the bottom), awning (windows hinged at the top). Higher air leakage rates: Slider (windows with a sash that slides horizontally), single/double hung (windows with a sash that slides vertically).
Panes	Single-pane glazing allows for the most thermal energy transfer, while double-pane glazing can reduce heat loss by half. Triple-pane glazing (which contains either three layers of glass or two layers with a film suspended between them) can reduce heat transfer even further. However, triple-pane units can add weight and thickness to the window, requiring increased frame support.[17]

[iv] Air leakage data from the fenestration, while also important for measuring performance, was not collected and was out of scope for this report.

Fenestration Component or Technology	Impact on Performance
Tints	Changing from clear to tinted glass can reduce the solar heat gain coefficient (SHGC) and glare, but it has no effect on U-factor and decreases VT. Green and blue tints have higher levels of VT than bronze and gray tints. Depending on the region, a lower SHGC may be beneficial in the summer and harmful in the winter.[16]
Low-E coating	Low-E coating increases the insulating properties of glazing by reducing its ability to radiate energy. Low-E can be altered to include and exclude different parts of the infrared and visible spectrums, allowing varying levels of solar heat gain.
Gas fill	Filling the space between panes with argon or krypton improves insulation and overall performance. These gas fills reduce thermal conductivity of the gas r between glass layers. Krypton has better thermal performance than argon, but it is more expensive to produce, so it is not often used. Vacuum-insulated glazing (VIG) is an emerging technology for emptying the space between panes and delivers even higher thermal performance.
Spacers	Spacers hold panes apart and absorb the stress caused by differences in pressure and thermal expansion, prevent moisture from entering the unit and causing fogging, minimize gas loss, and reduce condensation. Aluminum spacers are typically used, but are thermally conductive, increasing the U-factor. Using less conductive materials, such as stainless steel and non-metal insulating materials in the spacer, which is then referred to as a warm edge spacer, can help mitigate this issue. Examples include plastic hybrid stainless steel spacers and foam spacers.
Frames and thermal breaks	Aluminum is the predominant material for metal frames as it is strong and durable, yet light and easily formed into shapes. Because aluminum has a high thermal conductivity, the U-factor of an aluminum frame is also high. Manufacturers can implement one or more thermal breaks to reduce the heat transfer through the frame members, potentially reducing frame heat loss by 3 times or more depending on materials and configuration used. There are many types and sizes of thermal break, and typically the wider the thermal break the better thermal performance of the frame. Non-metal frames, such as vinyl and fiberglass, provide better thermal insulation performance, but the structural performance is usually lower.
Orientation	Design decisions impact building energy performance and vary by climate zone and building characteristics. Orienting a building south in colder climates can increase solar heat gain and reduce energy use from heating. Warmer climates can benefit from northern orientation and minimizing direct sun exposure.[18] In addition, commercial buildings are often constructed with the longer sides facing north and south to minimize solar heat gain from the east and west.
Fenestration area	Higher glazing areas may lead to increases in energy use, especially when standard fenestration is used, but impact can be reduced with energy efficient windows and orientation design. Lower U-factors can be achieved through double and triple glazing, increasing performance for larger fenestration areas. With higher efficiency fenestration, larger windows may have lower U-factors than smaller windows due to the lower U-factor of the glass compared to the frame.
Shading	Using overhangs, awnings, screens, solar shades, and landscaping are effective ways to reduce solar heat gain before it reaches a window in warmer climates. Light-colored shades and drapes can also be used on the interior of a window for a similar effect, which can also impact occupant comfort and some direct heat loss in the winter.

Source: Efficient Windows Collaborative; Carmody & Haglund.

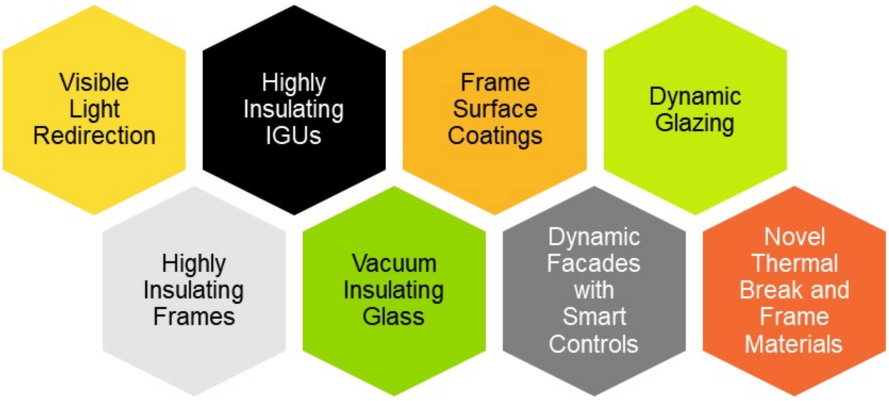
Emerging Window Technologies

In addition to what is widely available and currently installed in commercial buildings, there are newer, emerging technologies that only represent a small portion of the market. The following technologies represent significant future opportunities in improving fenestration performance:

- **Thin-glass triple center layers** represent a technological improvement that utilizes lightweight, thin, non-structural layers to offer a highly insulating glazed window product that can be easily incorporated into almost any existing window frame.
- **Vacuum-insulating systems** (or VIGs) nearly eliminates thermal conductivity of the gas between panes of glass in an insulating glass (IG) unit and reduces overall heat transfer with a Low-E coating. Small pillars are used to maintain the structural integrity of the glazing by keeping the two panes of glass separated.
- **Other insulating systems** fill the space between glazing with other clear, insulating materials, such as aerogel or honeycombs, which are still emerging technologies. Clarity can be compromised when using these components and, currently, aerogel is usually only produced in small quantities and sizes.[19]
- **Dynamic or smart glazing** is an innovation where fenestration systems change in response to climate, occupant preferences or programmed control logic. Thermochromic glazing changes transparency in response to temperature, respectively, and electrochromic glazing changes tint in response to an applied current or voltage.[20] A smart glass manufacturer explained that the overwhelming majority of dynamic glazing sales belong to electrochromic glazing with thermochromic technologies representing less than 2% of the smart glass market. Overall, all dynamic glazing technology is nascent and currently represents approximately 1% of the commercial fenestration market.

  Electrochromic glazing can be controlled manually or through a building automation system. Electrochromic glazing, especially when augmented by automated shading systems, can fully control daylighting, solar heat gain, and glare. The most advanced systems integrate electrochromic glazing with broader building systems and are IoT-enabled to respond to changes in temperature, occupancy, time of day, and weather to balance performance and occupant comfort.
- **Building integrated photovoltaics (BIPV)** is another emerging technology where a thin PV panel is integrated into glazing to absorb a portion of the visible light and solar energy, allowing the rest to pass through for some level of VT.[21] Costs and production technologies limit adoption.[22]
- **Daylight redirection** technologies can increase the amount of daylight that is available in interior spaces, thus reducing energy use with electric lighting.[13]

Figure 2-3: Window Technology Innovation Opportunities



Source: Efficient Windows Collaborative; Carmody & Haglund.

2.2 Market Trends Driving Energy Efficient Window Adoption

The energy efficient fenestration market is positioned for continued growth. The market has witnessed the adoption of high performance building programs and standards across the country, increases in energy efficiency policies at the state and local level, significant advances in commercial building energy codes, and growth in the prevalence of fenestration rating and certification programs. Additionally, market growth is supported by shifts in the real estate landscape such as more transparency surrounding building performance and value proposition of sustainability as well as available financing options for energy-related building improvements.

High performance building practices have increased market penetration over the past few years and are expected to continue to grow. Dodge Data Analytics' 2018 Green Building Market Report noted that 45% of U.S. respondents expected over 60% of their projects to be green in 2021, a projected increase from 32% in 2018.[23] The reasons for these types of building activities range from client demand to occupant health to voluntary environmental industry standards. Energy efficient building policies, programs, and industry standards are growing, which are then later cemented in better building energy codes.

Increase of Green Building Policies

States and localities across the U.S. are setting aggressive climate goals that require drastic energy consumption reductions. This includes installation of more energy efficient technologies in commercial buildings that will improve overall building energy performance. For example, cities are taking part in climate action initiatives such as the C40 cities network or the American Cities Climate Challenge through Bloomberg Philanthropies.

Green building-specific agendas and policies that serve as drivers for more energy efficient buildings

- Boulder, Colorado set a goal to reduce emissions by 80% by 2050 and aims to achieve net zero through building codes by 2031.[24]
- Madison, Wisconsin set the goal to reduce energy consumption across all building stock by 50% from the 2008 baseline by 2030.[25]
- New York City's unprecedented Climate Mobilization Act puts forth many goals, one of which is to tackle emissions from existing buildings with a goal to achieve a 40% reduction in greenhouse gas emissions from 2005 levels by 2030 and an 80% reduction by 2050.[26]

To accomplish such ambitious feats, state and local jurisdictions must address building energy consumption. As a result, many have made buildings a pillar of their clean energy plans. Building-focused policies geared toward incenting zero energy buildings are increasing, with examples in states such as in Oregon, California, and Illinois.[27] Lighting and HVAC are often prioritized first for commercial building energy reductions. However, building envelope improvements are also necessary to meet such rigorous consumption reduction goals and improve overall building performance.

Green building policies can be generally grouped into three categories:

- **Voluntary stretch codes, standards, and certifications** that are either public or private sector driven, including but not limited to the Leadership in Energy and Environmental Design (LEED) certification program via the U.S. Green Building Council; WELL building certification by the International WELL Building Institute, Building Research Establishment Environmental Assessment Method (BREEAM) certification, Living Building Challenge certification; International Green Construction Code (IGCC) developed by ICC, ASHRAE, USGBC, AIA, and IES;[28] New Buildings Institute 20% stretch code; and various state- and jurisdiction-specific stretch codes (such as those implemented in Massachusetts, California, and New York). Cities across the country are instituting policies that require these types of voluntary certifications.

  Interest in net zero commercial buildings has significantly increased in recent years

  - The Passive House Institute's PHIUS+ Passive Building Standard and certification is an example of a voluntary industry standard that provides cost-effective paths to net zero and net positive multifamily and commercial buildings.

  Almost all certifications include provisions for energy, occupant health/air quality, water efficiency, materials, siting, and the design process, but fenestration is not often specifically called out.[29] Fenestration plays a role in commercial LEED when awarding points for optimizing energy performance, improving thermal comfort, maximizing daylighting, and providing quality views. Points can be awarded for reducing solar heat gain, using low-emitting materials, such as in coatings and sealants, and considering environmental material attributes (life cycle analysis, environmental product declarations, recycled content, etc.).[30] However, better fenestration is not explicitly encouraged as part of the analyses required by LEED.

- **Building rating and benchmarking** policies provide transparency into building energy use by assessing and comparing building energy use data over time to improve decision-making and energy management.[31] State and local policies associated with ratings and benchmarking are either voluntary or required. In recent years, there has been an uptick in state and local commercial building benchmarking policies with specific requirements including in Washington, Oregon, California, Utah, Texas, Michigan, New York, New Jersey, Delaware, Connecticut. Major cities including New York City; Washington, DC; Boston, Massachusetts; Boulder, Colorado; Philadelphia, Pennsylvania; Portland, Oregon; and Seattle, Washington require the submittal of building energy use data typically through the U.S. Environmental Protection Agency's (EPA's) ENERGY STAR® Portfolio Manager®. These policies often outline the size and types of buildings included, the level of transparency necessary, and other requirements such as independent data verification. As of 2019, at least seven cities require >90% of commercial building square footage to report building energy use data.[32]

- **Building energy performance requirements** include policies that require building owners to act via building tune-ups, retrocommissioning, building energy assessments, or even penalties or restrictions based on energy consumption or carbon emissions. Many jurisdictions with benchmarking policies often require building energy performance tune-ups. Some policies require buildings of a certain size (or the lowest performing buildings) to comply with an energy assessment and tune-ups or recommissioning. Examples of these policies are active in Minneapolis, Minnesota; New York City; Orlando, Florida; San Francisco, California; San Jose, California; and Seattle and Washington State.

Green building policies can take the form of mandates, incentives, or somewhere in between, and usually include many layers of requirements and stakeholders. Utilities are also involved in some of these policies to provide incentives or energy use data. Additionally, some manufacturers provide information on the environmental and health impacts of their products to facilitate various certification processes.

As demand for more efficient buildings grows and processes become more complex, fenestration industry players will play an increasingly important role in navigating the certification landscape and providing highly energy efficient products.[35] Green building programs have helped set higher benchmarks, despite also having contributed to confusion within the industry due to the various processes and requirements.[36] Building architects, engineers, and

New local and state policies are poised to serve as strong drivers for building owners to invest in more energy efficient building products including, better fenestration.

- New York City's groundbreaking legislation, covered in Local Law 97, sets carbon emission caps for energy use in the city's largest buildings starting in 2024. It sets a limit on the amount of greenhouse gas emissions per building based on building size and class and applies penalties of $268 per metric ton over the limit for noncompliance as of 2019.[33]

- Similarly, Washington State recently adopted energy performance standards for commercial buildings over 50,000 square feet. This legislation sets policies that include incentives to building owners that exceed energy intensity targets and penalties to those that fail to meet the targets, which go in to effect in November 2020.[34]

construction or contractor firms will continue to play a significant role in understanding policy requirements and available options to address building envelope performance requirements.

However, the role of fenestration in meeting building-wide performance targets will likely be muted without more guidance on the potential contribution and benefits of energy efficient fenestration. The installation of energy efficient fenestration is not often explicitly required as part of policies to improve or design better energy performing buildings, and many architects employ other strategies to earn points or meet requirements. The commercial fenestration manufacturers interviewed for this study were fairly split on whether voluntary green building programs have a substantial impact on product offerings, whereas all interviewed generally agreed on impacts caused by building energy codes. Several stakeholders explained that some long-established certification and voluntary programs like LEED were more of a driver several years ago, but those program impacts are minimal now that codes are catching up and, in some cases, surpassing program requirements. However, other advanced voluntary commercial programs such as the Passive House Institute U.S. or the International Living Future Institute's Living Building Challenge can serve as drivers for further development and adoption of aggressive building energy codes.

Energy use and benchmarking data collected on commercial buildings as part of green building policies does not explicitly include fenestration data. For example, no benchmarking, disclosure, or performance policies were found that specifically required information on the fenestration installed in commercial buildings, which may make it difficult for building owners and policymakers to view fenestration as a priority in commercial building upgrades.

Building Energy Code Advancements

Building energy codes set minimum efficiency requirements for new and renovated buildings, assuring reductions in energy use and carbon emissions over the building's life. These codes and the jurisdictions that enforce them lay out requirements for the building envelope (insulation, fenestration, and air sealing), mechanical equipment, and lighting of a building. These minimum requirements are critical to driving the adoption of more energy efficient fenestration products in buildings. National model codes are updated on a 3-year cycle to continually improve building energy efficiency and provide multiple energy, environmental, health, and safety benefits. Advanced building energy codes serve as one of the most effective, and cost-effective, levers on a national basis to increase long-term energy efficiency in buildings.

However, the U.S. is a patchwork of different versions of code adopted and varying levels of compliance and enforcement. Many jurisdictions lack the funds, resources, and training support needed to prioritize and deliver the full benefits of building energy codes. Conversely, many state and local jurisdictions across the country are demonstrating leadership in adopting more stringent, advanced, beyond-code requirements on either a voluntary or mandatory basis. States such as California, Washington, Vermont, and New York and cities such as Boulder, Washington, DC, and Scottsdale are developing and adopting more stringent energy codes than ASHRAE 90.1 - 2016.

Building energy stretch or beyond codes are increasingly moving toward the construction of net zero energy commercial buildings. Most notably, the latest update to California's statewide energy code, 2019 Title 24, requires that all new buildings achieve net zero energy levels by 2030. Local governments in the state are also working to develop and implement stretch codes that are even more stringent than Title 24 and the California Green Building Code. The U.S. DOE Building Energy Codes Program tracks policies that exceed the most recent model IECC/ASHRAE codes, which currently include certain jurisdictions such as

Kansas, Texas, Colorado, California, Montana, Massachusetts, and New Hampshire. To meet such stringent above-code requirements, fenestration is a critical consideration for building designers, engineers, and owners due to significant impacts on heating and cooling loads. In California, the Title 24 code outlines specific compliance requirements including measurement of air leakage, determination of U-factor, SHGC, VT, and proper certification and documentation (e.g., NFRC Project Label Certificates). However, even in jurisdictions with aggressive stretch codes, compliance is critical—especially related to performance path options.

Several of the manufacturers interviewed for this study stated that building energy codes were the main driver for manufacturing higher performance products. As energy codes become more stringent, there will be less demand for more conventional and less efficient fenestration and more demand for higher performance fenestration that are necessary to meet advanced codes. With more advanced building energy codes that account for thermal performance (especially driven by individual jurisdictions' code adoption and enforcement), there is a significant opportunity for increased demand and installation of energy efficient fenestration systems, including better interfaces between walls and windows and thermal bridging. Even in locations with poor or no code enforcement, energy codes still drive energy efficient fenestration in that the building specifications and legal responsibility of the registered design professional start with the energy code. This liability and obligation under contractual documents between the architect, building owner, general contractor, and glazing contractor can be as influential as code enforcement in many locations where building department resources are limited. Finally, outcome-based energy codes based on energy performance and specific metrics for the building envelope, new metrics beyond EUI for modeling, and improvements in the usage of building energy modeling tools are other strategies that can further the impacts of advanced building energy codes.

Growth in Building Envelope Backstops in Building Energy Codes

Even with the most stringent energy codes, trade-offs can be made between building components to meet performance requirements (i.e., better performance in one component can offset worse performance in another). Certain cities have begun implementing building envelope backstops, where a limit is placed on the amount of envelope performance that can be traded off for buildings that take the performance pathway. Backstops are already in place in New York City, Washington State, and Massachusetts,[37] the latter of which provides the least flexibility in trading off envelope performance—the U-factor of the envelope times the area (UA) must meet prescriptive UA requirements.[38] An addendum to be added to the most recent version of ASHRAE 90.1 for a backstop is currently undergoing publication.

Building envelope backstops limit the practice of installing high efficiency HVAC systems and advanced lighting systems specifically to allow a higher percentage window-to-wall ratio with conventional fenestration products. The envelope backstops can pave the way for increased adoption of energy efficient fenestration including glazing and framing.[37] Fenestration-specific backstops also exist in discussion, but no jurisdictions have implemented such practices yet.

More Utility and Government Rebate Program Offerings

Electric utilities and federal, state, and local governments play a key role in the delivery of energy efficiency programs to consumers and are considered a low-cost, low risk policy option to reduce energy use in buildings and avoid additional generation and distribution costs and increasing electric grid reliability. These programs offer incentives for fenestration on either a prescriptive or whole-building performance basis. Energy efficiency programs can offer financial incentives in the form of tax credits, rebates, or financing mechanisms for consumers looking to replace or install high efficiency fenestration products in buildings.

Utility energy efficiency programs are increasing in savings captured and the number of programs offered

According to the *ACEEE 2020 Utility Scorecard*, utility energy efficiency programs are increasing in the level of savings captured and the number of program offerings. First-year energy savings increased by more than 3.2 TWh, or 20%, among the 51 utilities that were included in both the 2017 and 2020 editions of the *ACEEE Scorecard*.[39] Thirty-seven of the 51 utilities have adopted greenhouse gas reduction goals at varying levels; these utilities will need to ramp up energy efficiency efforts to meet their goals.[40] The level of commitment to energy efficiency and the innovation in programs is often tied to the level of state and local policies and regulatory framework.

Unlike tax credits, rebates are a faster way of realizing cost savings as they are applicable immediately after the purchase of a qualifying product.[41] Although there are no federal fenestration rebate programs, various programs exist at the state and local level (described in the Above-Code Fenestration Programs section). Energy efficiency requirements, incentives, and rebate amounts vary by program. The financial support offered by these rebate programs make investments in new energy efficient fenestration more affordable and help defray the cost of the investment.[42]

Though there is a significant energy savings opportunity associated with energy efficient fenestration in commercial buildings, the efficacy of current fenestration rebate programs is mixed. Some of the most successful utility rebate programs only reached 10% of eligible commercial customers and were most effective when bundled with HVAC and lighting improvements.[43] The changing nature of rebate programs may also pose a challenge for consumers. Besides the lack of visibility that hampers client participation, the variable nature of incentive structure and value (which are also tied to the availability of funds from the government or utility program) can challenge rebate program uptake for financing energy efficient improvements including fenestration.[44]

The stakeholder interviews with utility programs revealed the most significant hurdles to commercial fenestration rebate program participation:

- The long payback period relative to high capital costs
- Split incentive issues
- Lack of awareness of available technology options that meet customer needs including non-energy benefits like occupant comfort, usable space, and aesthetic desires.

Further, because of the longer payback period of fenestration compared to other technologies such as lighting, fenestration measures do not often fare well against required utility cost-effectiveness tests. The commercial buildings market is diverse, including a variety of building types and customer investment profiles ranging from small individually owned buildings to very large multi-building corporate portfolios. Utilities would likely benefit from more innovative, customer-targeted, or tiered energy efficiency programs for replacement or installation of commercial fenestration.

Utilities have begun to offer incentives to manufacturers for other energy efficiency measures. Upstream programs encourage manufacturers to produce more efficient products while midstream programs encourage vendors to include higher proportions of energy efficient products in the inventory.[44] PG&E has deployed an upstream program for efficient HVAC equipment to their commercial and industrial customers since 1998, demonstrating a 900% increase in market impact when shifting from downstream.

Increase in Energy Efficiency Financing Products

In addition to traditional loan and lease financing products available to commercial building owners and developers, there are now various specialized financing products specifically designed to support energy efficiency improvements or installations and help overcome market barriers related to lack of available capital or financing options. Example products include Commercial Property Assessed Clean Energy (C-PACE), on-bill loans, energy performance or service agreements, and others. These financial products can help drive adoption of energy efficient fenestration due to their high upfront cost and relatively long payback period.

Recent C-PACE Renewed Activity

Chicago recently saw its first C-PACE financing project, which included improvements of double-pane glass installed in five floors of a historic 1914 building turned boutique Marriott hotel. In this project, CounterpointeSRE provided $21.25 million in financing to the Prime Group, Inc., which is estimated to save an estimate $99,791 in the first year alone. In another recent C-PACE financing project, closed in April 2020, building property owners renovated the former Oscar Mayer headquarters in Madison Wisconsin into OM Station, a 1.7 million square foot mixed industrial and office modern space. According to Greenworks Lending, C-PACE was able to refinance over $7 million in project costs including new lobby windows among other upgrades to result in an estimated $246,200 in annual cost savings. According to the PACENation website, between 2019 and June 2020 alone, at least 18 reported C-PACE financing projects involving fenestration upgrades were closed.

Some of these solutions may support off balance-sheet treatment, which makes them more attractive in the commercial market.[45] As part of financing products, strategies to help overcome specific barriers include flexible underwriting, products that pass certain costs through to tenants, products that allow for transfer of a loan from one building owner to the next, and savings guarantees.

C-PACE programs have seen a reemergence in the last decade. PACE financing, used for energy efficiency and clean energy projects, is repaid as an assessment on a property's tax bill and stays with the property rather than the owner. More than 35 states plus Washington, DC, have C-PACE enabling legislation. More than $800 million in projects to date have been financed according to the U.S. DOE.

Savings-backed arrangements such as Energy Savings Performance Contracts (ESPC) typically involve the service provider assuming the performance risk of energy efficiency projects by guaranteeing and sharing in energy cost savings.[45] These types of contracts provide consumers with access to financing for energy efficiency retrofits and reduce risks, making energy efficiency investments more feasible.

In a typical ESPC, the client contracts with an Energy Service Company (ESCO). An ESCO:

- Provides all services necessary to design, implement, and monitor the project
- Tailors services to the needs of the client
- Arranges long-term financing
- Provides a guarantee that the savings accrued from the energy efficiency upgrade will cover the cost of the project.[46]

The ESCO essentially removes financial risk of the typically capital-intensive energy efficiency project for the end use customer. Large commercial projects such as municipal, university, school, and hospital institutions most often use ESPCs. ESPC revenues in North America were anticipated to amount to almost $7 billion in 2020 and to grow at a compound annual growth rate of 3.5% between 2020 and 2029.[47]

In the energy efficient buildings market, a broader shift is taking place toward energy as a service, which involves comprehensive energy management solutions and, as a result, financing innovations and new market players. For example, Energy Services Agreements and Managed Energy Services Agreements provide customers an opportunity to install energy technologies such as energy efficient fenestration, while only spending OPEX funds and outsourcing operations and management to a third party. Lighting and lighting control upgrades represent most of this market now. Though energy efficient fenestration improvements are less common than lighting or HVAC upgrades, innovative financing products could help alleviate market barriers inhibiting commercial investments in fenestration (e.g., longer payback period and high upfront capital costs).

Real Estate Investment Trusts Show Increasing Interest in Sustainability

What Is a REIT?

A REIT is a company that owns, operates, or finances income-producing real estate. Modeled after mutual funds, REITs provide investors the chance to own valuable real estate, present the opportunity to access dividend-based income and total returns.

Real Estate Investment Trusts (REITs) are a way to raise equity capital through public stock markets, which increases the number of potential investors, improves liquidity, and reduces overall financing costs. (REITs do not pay corporate income tax if they distribute at least 90% of their income as dividends and comply with the Internal Revenue Service tests). According to the National Association of Real Estate Investment Trusts (NAREIT), the total dollar value of the commercial real estate market is $15 trillion, of which REITs own approximately $3 trillion of gross assets.[48]

REITs own roughly 20% of the building stock and are keenly aware of sustainability issues within buildings.[49] However, REITs vary in their prioritization or commitments to energy efficiency and reductions in energy use but have the potential to serve as a future driver for more energy efficient products installed in commercial buildings including fenestration. According to NAREIT, approximately three-quarters of REITs reported achievement of some sort of green building certification in 2019. Many trusts face pressure to allocate funds to projects other than energy efficiency-related ones. However, evidence suggests that energy efficiency projects yield strong investment returns. One study found that a 3.5% increase in return on equity and a 1.3% increase in return on assets corresponded to a 1% point increase in a REIT's Global Real Estate Sustainability Benchmark.

Recent investment trends for REITs point to increasing interest in sustainability and green building metrics and specifically in energy efficiency retrofits as trusts seek to reduce electricity costs in their portfolios.[50] NAREIT collects voluntary data from REITs on energy use reductions as part of their Environmental, Social, and Governance (ESG) tracking. This data indicates that REITS have reduced their energy consumption in buildings every year since 2017. The publicly traded nature of REITs enables shareholders to put pressure on building owners to enact more sustainable and energy efficient practices. REITs can also rely on scale to reduce the cost of investment for energy efficiency technologies and implement more deep retrofits.[51] Given the rise of value related to ESG factors in evaluating potential investments, REITs face increasing pressure to embed building energy efficiency and energy use reductions as a key metric in managing their assets.

2.3 The Challenge for Energy Efficient Fenestration

There have been significant advances in fenestration technologies and a shift toward more energy efficient commercial building construction practices, policies, and incentives. However, the building construction industry faces challenges related to traditionally low margins, increasing project complexity, and building material costs, supply constraints, and fragmentation.[52] The construction market continues to experience pressures to reduce costs and improve profit margins while also satisfying building owner/developer desires for security, durability, resiliency, and aesthetically pleasing fenestration options—all at a reasonable cost. Engineering and construction firms often must weigh the tradeoff of installing high efficiency fenestration against other building system components like HVAC systems to stay within budget and meet customer desires. This often results in a lack of priority for fenestration systems.

There are many pressures on stakeholders in the market that often result in suboptimal fenestration choices. Chief among them are costs, building industry fragmentation, and complicated market processes:

- **High Cost:** The capital cost of efficient fenestration can deter developers from selecting these options and can lead to the installation of lower performing products due to value engineering.[53] For new construction, system-level approaches during the design phase can yield the greatest financial benefit. For commercial building retrofits, complete façade or glazing system replacements can be costly; however, secondary glazing systems can provide a less expensive and easier to install option (i.e., storm windows or in the future may include dynamic or vacuum glazing). Further, the avoided cost of full HVAC replacement can also help offset window upgrade costs. On the supply side, the cost of switching manufacturing processes can be high when transitioning from traditional to high performance fenestration, incentivizing suppliers to continue production as usual. Materials for energy efficient fenestration can also be expensive, a cost which is typically passed on to building owners.[53]

- **Low Risk Tolerance to New Products:** Although there are commercial building owners and developers who invest in green building practices, there are many whose primary goal is to expedite construction, control costs, and lower risks.[53] Industry players are more likely to use reliable products with which they are most familiar and are hesitant to try newer technologies or to consider picking different products than what they have used in the past. Risk tolerance plays a large role in the consideration of new technologies on the market such as VIG. However, many long existing energy efficient technologies like highly energy efficient thermal breaks, hybrid warm edge spacers, and glass coating technologies are readily available as part of fenestration systems but may not be prioritized over sticking with the products they already know. This is especially true for fenestration because product lifetimes are long and reliability is key.

- **Split Incentives:** Buildings are often sold after construction, and owners who purchase the building can shift the costs to tenants through higher rents. As a result, there is less motivation to reduce operating costs with energy efficient components.

- **Lack of Product Availability:** Manufacturers mentioned that their product investment is heavily influenced by code and noted that the performance compliance path allows for the installation of less efficient fenestration. However, the performance path can also use higher performing fenestration and tradeoff for less efficient systems elsewhere in the building. Manufacturers generally look to the prescriptive numbers as a base line for product development. These tend to be aggressive for SHGC in the South and U-factor in the North. For a manufacturer, the marginal cost of changing the SHGC is quite small whereas the marginal cost to change the U-factor is likely much higher. Not all manufactures will have products to cover the full range of climate zones and their production follows demand.

- **Fragmented Building Process:** The traditional design-bid-build process does not often allow for deep collaboration throughout development and may limit the ability of project teams to provide integrated solutions (largely depending on the project size). This can result in less efficient design given that components are specified separately, in different points in time, and by different groups. For example, HVAC system suppliers are typically involved early in the design process and often implement their own energy simulations to inform design. They must often make fenestration performance assumptions without input from glazing contractors, who are not involved until much later in the process. Furthermore, projects may implement specification building, which employs a one-size-fits-all approach to buildings. Projects that take this approach usually have lower costs and take less time, but they also have poor energy performance because external factors such as building orientation, climate, and surrounding buildings are not considered.[53] Architects may also design fenestration improperly (i.e., not according to AAMA guidelines for air infiltration) or misunderstand ambiguous specifications that lead to the installation of less efficient fenestration unintentionally, also due to a lack of onsite verification.[5]

- **Diversity of Existing Commercial Building Characteristics:** Existing buildings pose challenges to the adoption of energy efficient fenestration because it can be difficult to apply new technologies to the original configurations.[5] For example, double-pane glazing may be too heavy to be installed in an existing wooden frame. This is especially true for historic buildings where architects seek out products like the original. To maintain the traditional aesthetic, architects may select a product comparable to the original in both appearance and performance. Selecting a solution that increases efficiency while staying as close to the original design is often difficult.[5]

- **Other Systems Prioritized for Energy Efficiency Upgrades:** Many building owners wait until fenestration is no longer functional or until a planned whole-building retrofit to pursue a replacement. Additionally, energy efficiency improvements are rarely prioritized by building owners. When they are, fenestration is often last on the list of upgrades due to costs associated with fenestration and quicker ROI on other energy efficiency upgrades, such as HVAC control systems or lighting.

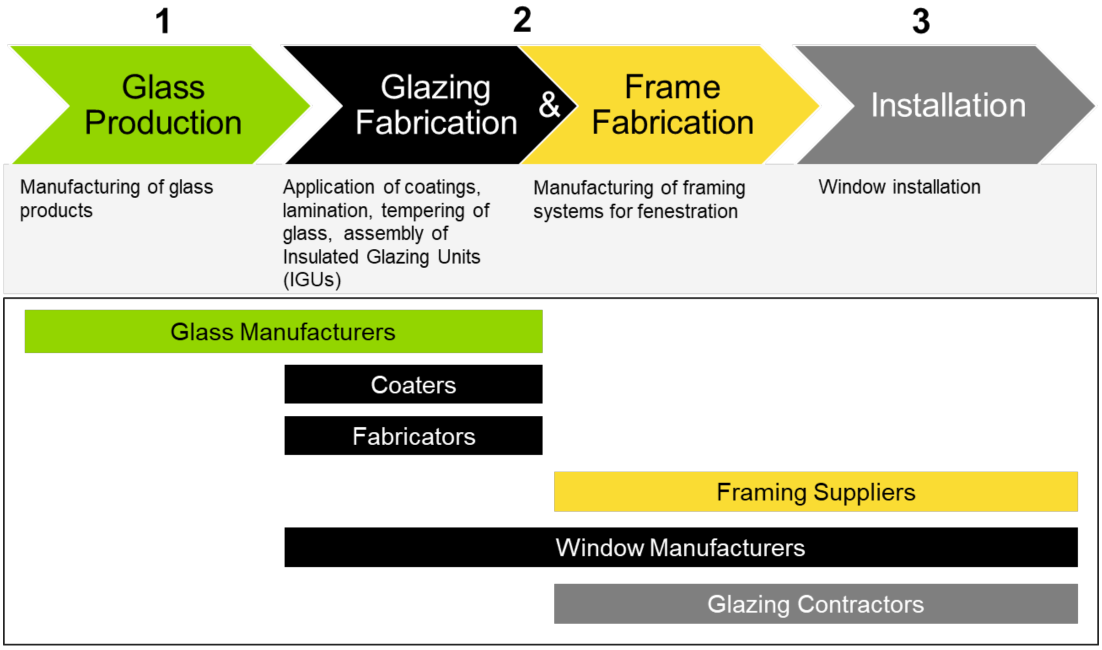
Costs, market processes, and prioritization of non-fenestration solutions for efficiency improvements inhibit wide adoption of energy efficient fenestration products. Lack of data on the characteristics of the installed fenestration stock and sales has historically been a barrier to assessing the full energy efficiency potential of reducing these market barriers and realizing efficiencies from higher performing fenestration installations and retrofits.

3. Market Players and Processes

3.1 Fenestration Value Chain

Fenestration supply is a fragmented market consisting of various players, including glass manufacturers, frame manufacturers, coaters, fabricators, and others. There are many companies that cut across the supply chain and perform a combination of functions. In addition to the core value chain segments Figure 3-1 outlines, some companies are also involved in a variety of additional services, including design and project management. For example, one company may provide project management, design, and performance, glazing fabrication and assembly, and site services/installation; another company may assist in architectural design, project management, installation, and fabrication.

Figure 3-1: Fenestration Supply Value Chain



Source: Guidehouse.

Fenestration products reach contractors and customers for installation through a variety of channels. Regardless of core position in the value chain, many market players have developed comprehensive capabilities in fenestration products, directly interfacing with contractors for installation. Table 3-1 summarizes the key fenestration supply value chain market players.

Table 3-1: Fenestration Supply Value Chain Market Players

Supply Player	Role in Value Chain
Glass Manufacturers	Produce automotive glass, specialty glass, and architectural flat glass from sand and cullet. These entities supply uncoated glass, Low-E coated glass, and tinted glass to glazing fabricators, or may treat and fabricate themselves and ship to fenestration manufacturers or glazing contractors in the field.

Supply Player	Role in Value Chain
Coaters	Purchase flat glass from manufacturers and apply coatings (including Low-E, reflective, tints, etc.) and treatments to the glass. They may also assemble the glass into IG units and ship the glazing directly to the field for assembly or to window manufacturers.
Glazing Fabricators	Usually do not apply coatings but will fabricate IG units and laminate, cut, heat strengthen, and temper purchased glass for curtain wall, storefront, and site-fabricated fenestration. Larger fabricators provide systems for bigger projects. Local fabricators, which are reactive to market demand and stock what is commonly specified, tend to work with small to medium sized buildings. These players have a large influence over the fenestration options available to glazing contractors.
Framing Suppliers	Manufacture framing systems for fenestration. Framing suppliers may ship frames directly to contractors or order glass and construct a unit themselves. Some specialize in certain types of frames and some are also involved in the installation process.
Window Manufacturers	Construct a window unit either glazed or unglazed and ship to glazing contractors. They usually provide punched windows to non-residential buildings like universities, hotels, and high-rise multifamily. Window manufacturers can receive their glass prefabricated and install it in the factory or manufacture only the frames to be glazed in the field by the glazing contractor. Some window manufacturers instead buy the glass from a manufacturer and assemble insulated glazing units in-house.
Glazing Contractors	Install shop-built and site-built fenestration. Some glazing contractors obtain their materials from multiple suppliers while others design their own frames and assemblies. These entities provide architects and owners with selections and can influence product type selection.

Source: Eley Associates; National Glass Association.

3.2 Fenestration Selection Processes

Four major stakeholder groups drive fenestration selection: architects, building owners/developers, contractors, and building engineers (e.g., structural, mechanical, electrical). The four groups are motivated by similar considerations in fenestration selection, chief among them are cost, appearance, and relationships in the industry. Window energy performance often takes a back seat in fenestration selections, as more energy efficient options have higher price points and are less familiar.

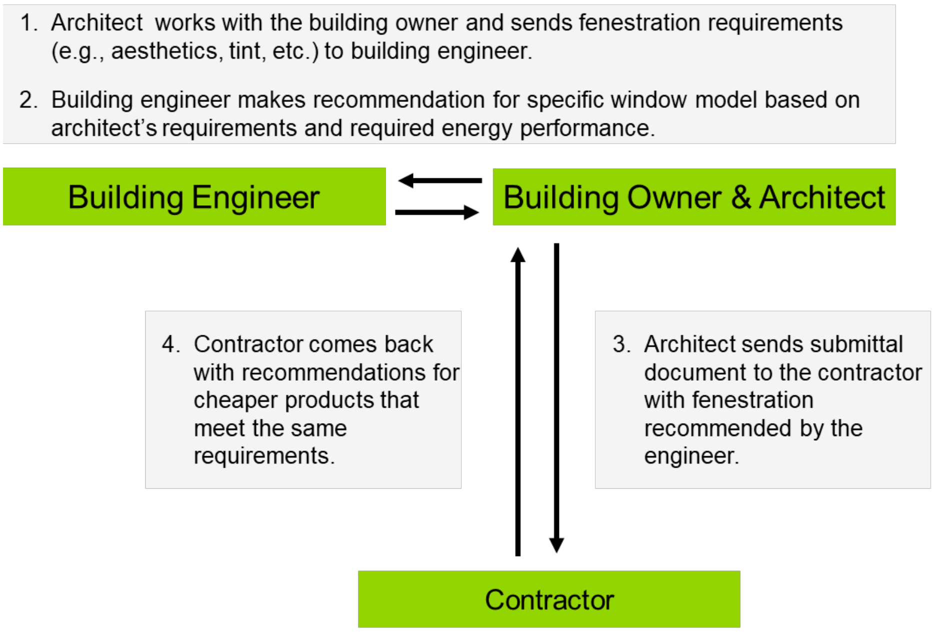
Table 3-2: Fenestration Selection Considerations by Demand Player

Demand Player	Key Window Selection Considerations
Architects	• Typically motivated by appearance of fenestration products to achieve clients' vision for building façade. • Are concerned with water, structural performance, and durability. • Tend to receive their technical information directly from the manufacturer. • Are limited in their fenestration choice by cost. • Have relationships with manufacturers that have become their go-to suppliers of fenestration products. Architects usually work with two to three companies and are familiar with just their products. These relationships are often built as much on customer service and ease of working with the manufacturer as the performance of the fenestration products.
Building Owners/Developers	• Usually driven by cost and often gravitate toward fenestration with the lowest initial price. • Have an interest in highly visible aesthetics to attract potential tenants. • Can be reluctant to adopt newer technologies.
Building Engineers (e.g., structural, HVAC, lighting, electrical)	• Recommend products to ensure that the architect's chosen fenestration system works in tandem with the specified HVAC and lighting systems.
Contractors	• Recommend alternative products based on architect's specifications and requirements, driven by industry relationships in making recommendations. • Motivated by competitive positioning to win the bid and focused on risk reduction, schedule, cost, and reducing overall call backs.

Source: Eley Associates; Interviews.

Fenestration selection is a collaborative process. An architect in coordination with the building owner usually plays the final decision maker role based on recommendations from building engineers, contractors, and client requirements. However, contractors play a significant role in final product selection, since architects often rely on their knowledge of different products to recommend cheaper alternatives to originally specified products. Additionally, façade consultants have recently started playing a greater role in the selection process by providing design architects, owners, and contractors with technical expertise on fenestration performance. Decisions on fenestration selection can change multiple times during the process.

Figure 3-2: Fenestration Selection Process



Source: Guidehouse.

Architects and building engineers use a variety of modeling tools to determine fenestration selections, ranging from building-wide modeling software to fenestration-specific programs. Most firms utilize a handful of tools with which they are most familiar and do not change their go-to programs often. The decision to use a specific tool is driven by the complexity of the problem. In many cases, only building-wide modeling is required. However, fenestration-specific software is used for complex assemblies. For example, THERM is a tool specifically used to look at the full fenestration assembly. The level of sophistication in the usage of different modeling tools varies greatly from one firm to another. Further, the accuracy of the modeling results depends on both the verity of the inputs and how well the model is implemented.

Figure 3-3: Common Modeling Tools

Building-Wide	Fenestration-Specific
AutoDesk Revit	COMFEN
eQuest	Optics
Design Builder	Radiance
Energy Plus	THERM
IESVE	WINDOW
Open Studio	SunHours
Sefaira	

Source: Guidehouse; Interviews.

Certain manufacturers also provide tools to help assist in the decision-making process. For example, YKK AP provides a tool called myThermal Assistant that enables the user to calculate overall system performance, including their products' specified glass characteristics.[54] Kawneer's Selector® Sun Shading Estimator tool calculates and compares the thermal performance of different fenestration systems used with Kawneer solar protection products.[55] These types of manufacturer-provided tools help with fenestration selection or demonstrating code compliance, depending on the jurisdiction.

In addition, the methodology for determining product thermal performance is generally standard in the building industry. Interviewed manufacturers were consistent in their statements regarding methodology used to determine product thermal performance. Berkeley Lab tools such as WINDOW and THERM are often used as are NFRC simulation procedures (100, 200, and 500) for determining U-factor, SHGC, VT, and condensation resistance through third-party laboratories. AAMA 507 was also mentioned as an often-used simulation procedure. For projects seeking to qualify for Passive House, other methods based on European standards are used, such as ISO 10077 for frame performance and EN673 and 410 for glass. However, a great deal of confusion exists in the market related to center-of-glass and whole assembly U-factor, which complicates thermal performance simulation calculations. Center-of-glass U-factor values are much easier to calculate and often incorrectly used in energy simulations, leading to eventual issues or wrong products installed. We observed this confusion in our survey responses and that center-of-glass and assembly U-factors and SHGC values are often interchangeably used by industry.

Considerations for Fenestration Selection Vary Across Project Types

Drivers of fenestration selection vary significantly based on code requirements, region, project types, and other characteristics. However, common trends inform fenestration selection across the U.S. market, including aesthetics and clarity, role of thermal performance relative to other factors, sustainability, and building type. Aesthetics and ability to meet performance and sustainability goals through non-fenestration technologies tend to determine fenestration selection:

- **Many stakeholders in the industry point to aesthetics as the main driver for fenestration selection.** Because fenestration is one of the first things that tenants and potential customers see, building owners will focus on and prioritize looks rather than performance.
  - Retail buildings usually want clear glass to present a more appealing shopping environment and reduce security risks that may arise from decreased clarity caused by tints or coating. Further, benefits in thermal comfort that typically come from energy efficient fenestration is minor since most people spend little time inside retail buildings.
  - For other types of properties that desire privacy rather than display (banks, for example), developers may prefer opaque or tinted glass.

What Stakeholders Are Saying…

A façade consultant in the Northeast explained that she often works on commercial projects where clear, single-pane glass is installed because architects and clients value that look, primarily in first floors of luxury buildings and storefronts. She also mentioned a project where energy goals were high, but the client was unwilling to compromise on the appearance of the façade. Instead, insulation, lighting, and mechanical systems were heavily adjusted to meet performance goals. Condensation, which can be an issue with single-pane units, was noted as an important factor, but installing thermally broken frames and higher performing HVAC helps to mitigate those effects.

- **Interviewees mentioned the value of thermal comfort** for commercial buildings where tenants occupy the space for longer periods of time. One incentive program administrator explained that, with higher performing fenestration, tenants can use the perimeter areas and increase usable floor area, which can have a significant positive financial impact for the building owner.

  - However, incentive program administrators also expressed that customers will typically employ lighting or HVAC measures before fenestration to achieve energy efficiency goals, usually due to the upfront cost. Payback periods are usually shorter for lighting and HVAC adjustments, which is an incentive for them to invest in these upgrades instead of fenestration.

- **Several stakeholders explained that new schools and government buildings tend to install more energy efficient fenestration whereas churches and strip-mall retail buildings install less efficient fenestration.** Schools and government buildings are built for longevity (usually not planning on being sold within the next few years), so stakeholders are more willing to take risks or try new energy efficient products and are comfortable with longer ROI timeframes. A dynamic glazing manufacturer mentioned that universities and high-end buildings are the typical customers that install their products. Conversely, buildings that are fettered to budget constraints like churches and small commercial retail tend to install lower cost and less energy efficient fenestration.
- **Building sustainability goals play a role in fenestration selection but have a limited influence compared to other drivers.** Building owners and developers that are driven by sustainability often opt to receive a LEED green building certification for the property.
  - While high energy performing fenestration is a pathway to earn points toward a certification, architects can use other strategies to gain enough points. Given many lower cost efficiency technologies, energy efficient fenestration is not necessarily prioritized. Fenestration is more often looked at through the lens of occupant health and productivity rather than energy performance.
  - When seeking to demonstrate a commitment to sustainability and attract environmentally conscious tenants and customers, developers prefer to install systems that are visible like green roofs or solar panels.[56] It is difficult to ascertain what is or is not an energy efficient fenestration simply by looking at it, whereas buildings with onsite solar and other visible structures present clear signs of green building.
    - While both fenestration and PV panels have the potential to significantly reduce operating costs, solar has the added benefit of available local, state, and federal rebates and incentives to reduce upfront cost.[56] Incentive programs are also available for fenestration (discussed in more detail in Section 6), but they are limited in number and scope.

Fenestration Rating and Certification Programs Drive Compliance but Rarely Fenestration Selection

Third-party rating and certification programs provide building owners, developers, and designers with information to make decisions on fenestration product selection. They allow manufacturers to demonstrate credibility and facilitate the customer experience. A subject matter expert explained that, when deciding between a rated window and a non-rated window, architects will almost always select the rated option because there is an added sense of legitimacy to the manufacturer's claims on product performance.

However, fenestration ratings and certificates are difficult to navigate in the commercial fenestration industry and have historically played a smaller role than in the residential market. In the residential sector, ENERGY STAR labels use NFRC ratings and can denote the amount of potential energy savings for installing one window as opposed to another. However, ENERGY STAR labels are typically not applied in commercial projects since fenestration systems are more unique, and the separate ENERGY STAR program for commercial buildings is aimed at total building performance, not any individual component. The absence of a facile, streamlined process leads to a weaker influence of rating and certification programs that assess thermal performance in the commercial building industry. One SME expressed that these programs are less like market drivers and more like enablers that allow stakeholders to influence the market.

Fenestration certifications that assess thermal performance and the fenestration system are less known in the building industry in comparison to structural building component-level certifications. An SME explained that the industry is familiar with the programs that certify air, water, and structural requirements (AAMA/WDMA/CSA 101/I.S.2/A440 [NAFS] for fenestration) but less aware of NFRC’s component modeling approach (CMA) that assesses energy performance. This is primarily because the former types of certifications are related to structural life safety and so are a necessity, whereas thermal certifications are often viewed as an added benefit.

Through secondary research and validation from interviews, we compiled a list of well-known fenestration rating and certification programs, as Figure 3-4 outlines. As the figure indicates, many fenestration certification programs are for components rather than an entire fenestration assembly, and NFRC leverages several of the component programs within their own certification.[57] NFRC is recognized as the leading fenestration assembly certification program for thermal performance. Other fenestration energy certifications like Passive House serve a more niche market. One boutique manufacturer who specializes in energy efficient fenestration mentioned the difficulty of marrying Passive House protocols with NFRC for U.S. projects, given that different methodologies are implemented for measuring thermal performance and different pathways are used for manufacturers to report their fenestration data. European and Canadian fenestration product manufacturers do not typically pursue compliance with North American fenestration standards. Although there is a compliance path available for Passive House rating systems that includes NFRC procedures, a manufacturer explained that the process is still complex and is a hurdle for U.S. fenestration manufacturers trying to penetrate the energy efficient fenestration market Additionally, the Canadian Standards Association (CSA) refers to NFRC procedures with other specific additional calculations required.

Figure 3-4: Fenestration Rating and Certification Programs

Window Assembly

National Fenestration Rating Council (NFRC)

American Architectural Manufacturers Association (AAMA)/North American Fenestration Standard (NAFS)

WDMA/NFRC Thermal Performance Certification

WDMA Hallmark Certification Program

Passive House Institute US (PHIUS) Verified Window Performance Data Program

Components

Safety Glazing Certification Council (SGCC)

Insulating Glass Certification Council (IGCC)/Insulating Glass Manufacturers Alliance (IGMA)

Keystone Certifications, Inc

National Accreditation and Management Institute (NAMI) Insulating Glass Certification Program

Associated Laboratories, Inc. (ALI) Sealed Insulating Glass Certification Program

Insulating Glass Manufacturers Association of Canada (IGMAC)

Source: Guidehouse; Interviews.

Despite NFRC's eminence, there is still much confusion in the industry regarding what NFRC certification means for commercial buildings. For residential projects, almost every window comes with an NFRC label attached that identifies a product's U-factor, SHGC, VT, and optional condensation resistance and air leakage rating. However, the commercial process is much less streamlined with different components from different manufacturers used to build facades, and often at the construction site.

Although NFRC offers CMA and Site-Built certificates in the commercial sector, various stakeholders cited the methods are complicated, time-consuming, and costly. As a result, stakeholders often opt for alternative measures to demonstrate fenestration compliance with the energy code. The CMA allows different fenestration components to be combined to determine energy characteristics of the whole window, after which a certificate is administered by an Approved Calculation Entity (ACE).[58] While this process exists, only 567 projects were CMA-certified out of an eligible 400,000 buildings between 2010 and 2015, yielding a market penetration of only 0.14%.[59]

"Projects are often being evaluated in accordance with NFRC procedures, but not actually obtaining an NFRC certificate.

A manufacturer representative mentioned that parts of the country with the highest CMA penetration (Seattle and the Pacific Northwest) have individuals who are educated on the certification process and passionate about enforcement. However, in areas where education is lacking, code officials are more willing to accept other forms of compliance documentation. Conversations with several stakeholders, one of which was an ACE, revealed that projects are often evaluated in accordance with NFRC procedures but do not actually obtain an NFRC certificate, and builders and code officials do not always understand the difference.

Alternative proof of compliance might include manufacturer documentation indicating self-certification in accordance with NFRC procedures or could even be a form with a manufacturer letterhead detailing the U-factor and SHGC of the component/system. Other accepted forms of compliance documentation are discussed in Section 5.

The confusion surrounding NFRC certification was evident in our survey, wherein the results showed that 85% of fenestration was NFRC-certified. Discussions with industry experts demonstrated that this figure was much too high and that survey respondents likely conflated NFRC certification with products evaluated in accordance with NFRC. Even if products are available in NFRC's Component Modeling Approach Software Tool (CMAST) or evaluated according to NFRC procedures, builders rarely will go through the trouble of officially obtaining a certificate, especially if one is not requested by a code official.

4. Installed Stock and Sales

4.1 Data Collection

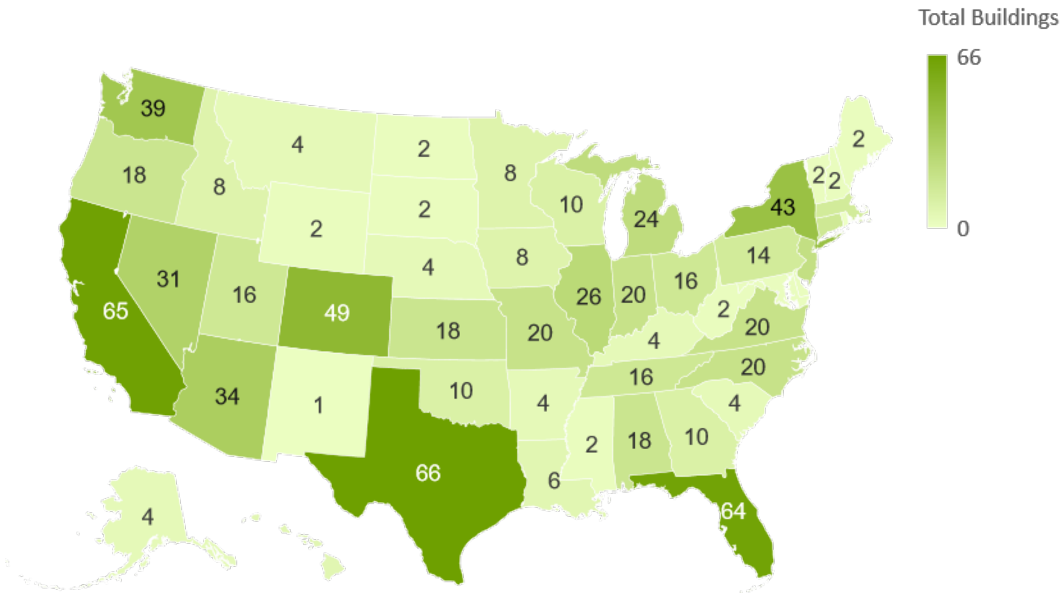
Data collection for the commercial fenestration installed stock and sales consisted of implementation of a national building survey; aggregation of existing building data sources; and gathering of fenestration market data, as detailed in the following sections.

Building Survey

Guidehouse designed the building survey to obtain data for both new and existing buildings and created questions based on market interviews. Though response-based building surveys have limitations such as biases and inaccuracies in inputted data, Guidehouse designed the survey to improve accuracy by targeting specific building professionals and providing thorough information on each data point. From interviews, Guidehouse specifically surveyed architects, building engineers, and contractors in the U.S. based on who could provide the most details on fenestration in individual commercial buildings based on their implemented building projects. The survey data was also thoroughly checked and cleaned to remove invalid data.

The survey consisted of 400 responses and 800 buildings from 49 states (see Figure 4-1), and eight different commercial building types. The buildings were either constructed or had fenestration retrofits from 2010 to 2020 (half from 2010-2015 and half from 2015-2020). The building types included in this survey were education, healthcare, hospitality, multifamily, office, other, retail, and public. The survey asked the respondents to input data on the fenestration of two recent commercial building projects, specifically for the most dominant type of fenestration in the building.

Figure 4-1: Survey Responses by U.S. State



Source: Guidehouse.

Table 4-1 presents the collected data points and completion rates. The initial results of the survey were analyzed and reviewed by manufacturers and industry experts. Adjustments to the inputted data were made based on this feedback, and invalid data inputs were corrected using the inputted glass/frame manufacturer information.

Table 4-1: Survey Data Points and Completion Rates

Data Point Collected	Completion Rate
State	100%
City	100%
Building Floor space	100%
Building Floors	100%
Project Year	100%
Building Type	100%
Percent Fenestration	100%
Total Fenestration Area	85%
Fenestration Area- North	39%
Fenestration Area- East	42%
Fenestration Area- South	43%
Fenestration Area- West	41%
Number of Glass Panes	100%
Fenestration Installed (new construction or retrofit)	100%
Fenestration Type	100%
Fenestration Built	100%
U-Factor	90%
SHGC	88%
Visible Transmittance	89%
Solar Transmittance	88%
Low-E Coating	100%
Low-E Surface number (if glass has Low-E coating)	100%
Low-E Spectral Selectivity (if glass has Low-E coating)	100%
Dynamic Glazing	100%
Gas Fill	78%
Gas-Fill Seal[v]	100%
Window Frame	100%
Thermal Break	100%
NFRC Certification	100%
Tint	100%
Tint Color (if glass tinted)	100%
Glass Manufacturer	89%
Glass Product #	84%
Frame Manufacturer	55%
Frame Product #	51%

[v] Data on gas-fill seal materials was removed from the analysis results due to inconsistencies and lack of confidence in the survey results because multiple sealant types are often used.

Building Data Sources

The building survey results were combined with existing public building survey sources: EIA 2012 Commercial Building Energy Consumption Survey (CBECS; U.S. EIA 2015 Residential Commercial Building Energy Consumption Survey for multi-family buildings only (RECS); the 2014 and 2018 Northwest Energy Efficiency Alliance Commercial Building Stock Assessment (NEEA CBSA); the 2006 California End Use Survey (CAEUS); DOE Building Code Study (Code Study); and data provided from three efficiency programs: Austin Energy Incentives, Efficiency Works Incentives, and Port Angeles Incentives (Programs).

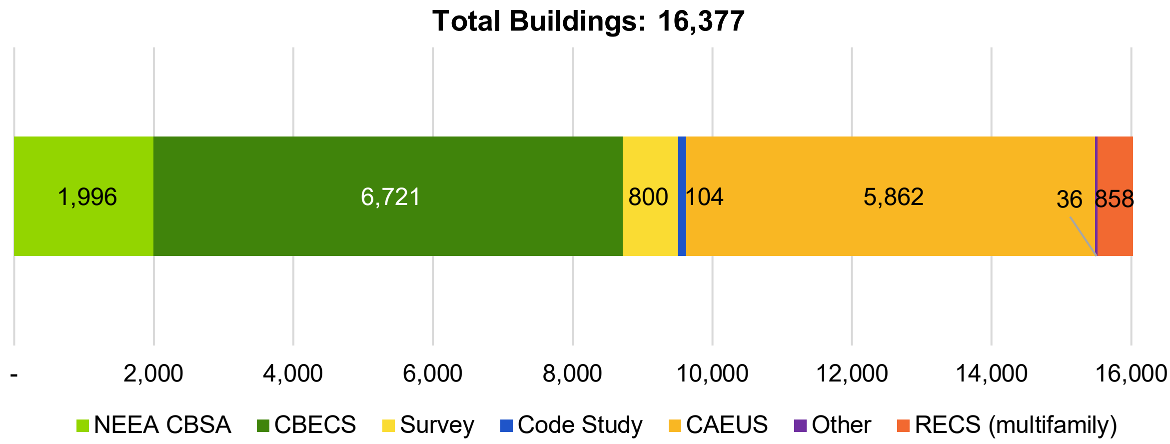
The availability of fenestration data in each of the data sources varies, as Table 4-2 shows. The building survey and NEEA CBSA provided the most comprehensive fenestration data. However, each of the key data needs were filled with two or more sources. To help fill gaps and convert existing public datasets to 2020, additional data were used on the fenestration market, sales from the AAMA market report, and sales data provided by manufacturers interviewed. In total, the aggregated data sources consisted of 16,377 buildings (see Figure 4-2). Because different data sources were used for different fenestration data categories, the results may not be comparable as certain data sources skew results to either new fenestration (Guidehouse building survey), older fenestration (EIA CBECS and RECS), or to certain regions of the country (CAEUS and NEEA CBSA). To mitigate this issue, several methods were used including weighting factors; more detail on this analysis is provided in Appendix A.1.

Table 4-2: Overview of Data Sources and Gaps

Fenestration Data Category	GH Survey	NEEA CBSA	Code Study	CAEUS	CBECS	RECS	Programs	Other	AAMA Report*	Manufacturer Sales*
Fenestration Area	✓	✓	✓			✓	✓	✓	✓	
Panes	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Glazing Type	✓	✓	✓	✓	✓			✓	✓	
Frame/Thermal Break	✓	✓	✓	✓		✓	✓	✓	✓	✓
Low-E Coating	✓	✓	✓	✓		✓		✓	✓	✓
Retrofit/New	✓	✓			✓		✓		✓	✓
Fenestration Type	✓	✓		✓				✓	✓	✓
Fenestration Vintage	✓	✓								
U-factor/SHGC	✓	✓	✓				✓			
Gas Fill	✓							✓		
Fenestration Installed	✓	✓			✓		✓			✓
NFRC Label	✓									

*Summary level data only.

Figure 4-2: Building Samples in Data Source



Market Data

Market data was collected through the *AAMA 2017/2018 Study on the U.S. Market for Windows, Doors, and Skylights* (AAMA report), interviews with manufacturers and industry market experts, and collected manufacturer sales data.

The results from the stock data and sales analysis were reviewed and verified using findings for a representative sample of manufacturers in the fenestration industry, including glass manufacturers, frame manufacturers, film and laminate manufacturers, shop-built fenestration manufacturers, and cross-cutting fenestration manufacturers. Manufacturers also provided key insights into current trends in the industry. In the Appendix, Table A-1 summarizes the manufacturer interviews conducted for this study.

4.2 Stock Results Summary

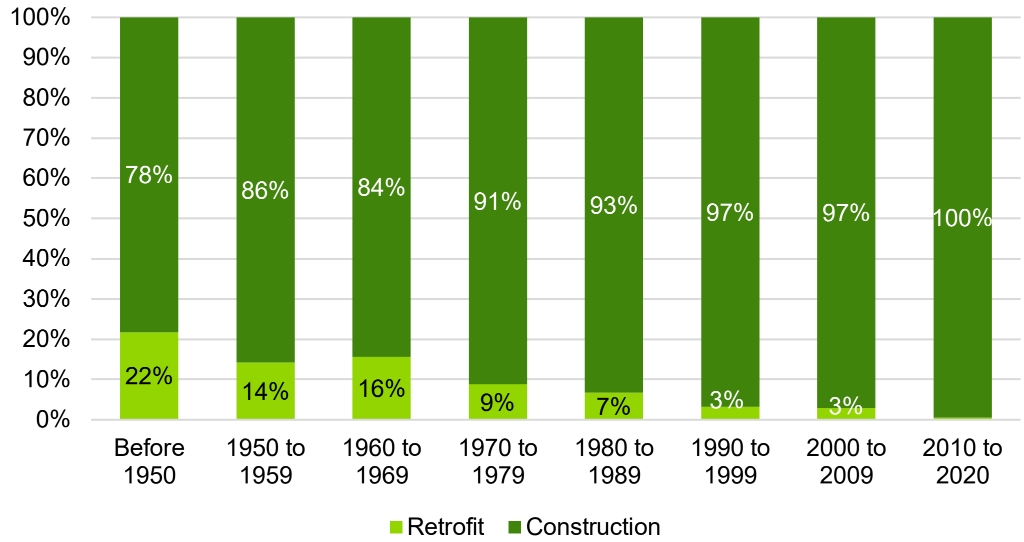
All results in this section are based on the aggregated installed stock building sample database, which consists of seven building survey sources from various years across the U.S. The methodology for analyzing and combining this data is available in Appendix A-1.

Figure 4-3 to Figure 4-24 summarize the national results and findings from the installed stock analysis. **All proportions shown in the tables and figures represent percentages of buildings and do not represent the overall area of glass.**

There is a significant opportunity associated with growing efficient fenestration adoption in commercial buildings. **Around 65%-70% of commercial building installed stock contains fenestration installed more than 20 years ago**. Energy savings potential in retrofits is especially large. Fenestration retrofits occur infrequently in existing buildings—only 14% of commercial buildings have fenestration installed as a retrofit.

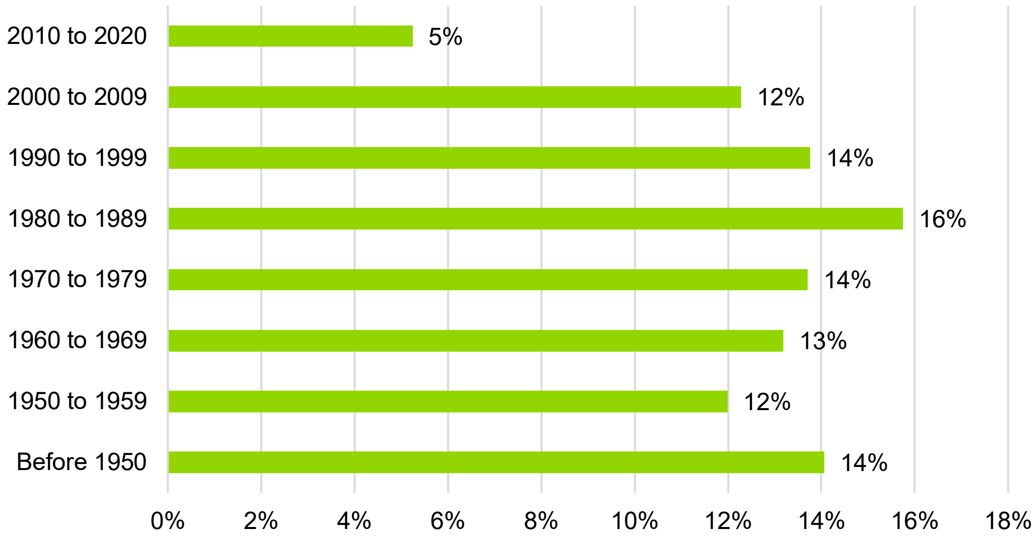
Figure 4-3 shows the fenestration installed by building vintage for retrofit versus construction applications.

Figure 4-3: Commercial Building Installed Stock Fenestration Installation Type by Building Vintage



Note: Construction refers to fenestration that remains from original construction and retrofit refers to fenestration that was replaced since original construction.

Figure 4-4: Commercial Building Installed Stock by Building Vintage



Inefficient fenestration still represents a significant proportion all commercial fenestration. The analysis results show that:

- 51% of commercial buildings have clear fenestration[vi] (Figure 4-5).
- 58% of commercial buildings have non-Low-E coating fenestration (Figure 4-6).
- 41% of commercial buildings have single-pane glass (Figure 4-10).
- 58% of commercial buildings with double or triple-pane fenestration have air-filled fenestration (Figure 4-11). The marine climate zone has the highest proportion of air-filled double/triple fenestration at 67% (Figure 4-13).

[vi] Note: Clear glazing refers to non-tinted and non-reflective glass with high VT.

- 71% of commercial buildings have aluminum/other metal window frames, of which about 21% have a thermal break (Figure 4-14).

Energy performance data was limited as only a few data sources included this information. The results showed that:

- The average U-factor reported by survey respondents was about 0.41 Btu/(h·ft^2·°F) +/- the standard deviation of 0.16 (Figure 4-16). The hot-humid climate zone has the highest average U-factor at 0.48 Btu/(h·ft^2·°F) +/- the standard deviation of 0.22 (Figure 4-17). However, the quality and usefulness of this result is highly questionable, as examination of the data shows there was a mix of center-of-glass U-factor and whole product U-factors reported. This reinforces the need for a practical cost-effective certification program to provide and increase use of whole product U-factors in the marketplace. In addition, due to lack of data from other sources, these values were taken primarily from the Guidehouse building survey (2010-2020) so results may be skewed toward newer fenestration.
- The average SHGC was about 0.35 +/- the standard deviation of 0.14 (Figure 4-16). The cold/very cold climate zone has the highest average SHGC at 0.39 +/- the standard deviation of 0.16 (Figure 4-17). This data also comes primarily from the Guidehouse building survey (2010-2020) so results may be skewed toward newer fenestration.

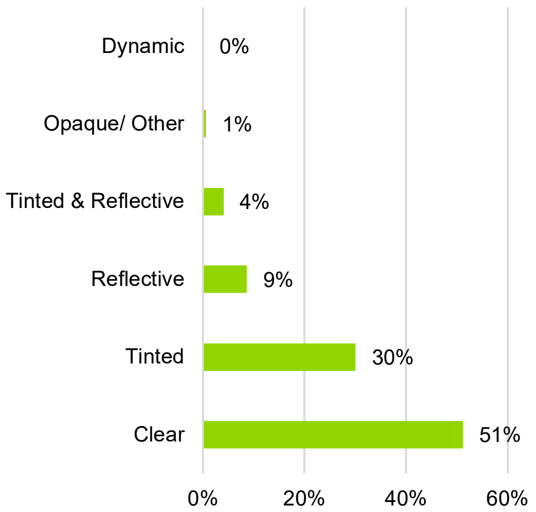
According to the Guidehouse building survey, more than 80% of fenestration was cited as being NFRC-certified. However, based on market interviews, this number is likely significantly lower for several reasons. Several experts suggested minimal to 5% of commercial building fenestration was NFRC-certified, which is more in line with NFRC's CMA Program's number of entries. Across our secondary research and interviews, site-built fenestration was consistently cited as a major challenge. Based on interviews and the misaligned survey results, we expect there is market confusion related to the various labels and different facets of the labeling process.

The window-to-wall ratio of the installed building stock is low as older buildings tend to have relatively less fenestration area per wall area; approximately 77% of the installed stock today has a window-to-wall ratio under 26% (Figure 4-18). **However, the average window-to-wall ratio in buildings is growing.** Over 80% of buildings constructed before 2000 have a window-to-wall ratio between 1% and 25%. Only 58% of buildings constructed after 2010 have a window-to-wall ratio between 1% and 25% and 42% have a window-to-wall ratio above 25% (Figure 4-20). Accordingly, curtain/window wall fenestration is growing in newly constructed buildings, representing 34% of total installed stock while punched windows comprise about 33% (Figure 4-21). About 41% of fenestration installed today are shop-built while 37% are site-built, while the rest are a combination (Figure 4-22).

In general, trends of fenestration characteristics by building vintage show that more **energy efficient fenestration is commonly used in newly constructed buildings, particularly in vintages from 2010 to 2020.** Section 4.4 details analysis of recent fenestration sales from 2017-2020 in new construction and fenestration retrofits.

Glazing Types

Figure 4-5: Commercial Building Installed Stock Glazing Types



Note: Clear glazing refers to non-tinted and non-reflective glass with high VT. Tinted glass refers to glass with an added color pigment and reflective glass refers to glass with a metal oxide coating. Both reduce visible light transmittance. Any of the glazing types above may be combined with Low-E coating.

Figure 4-6: Commercial Building Installed Stock Low-E Coating

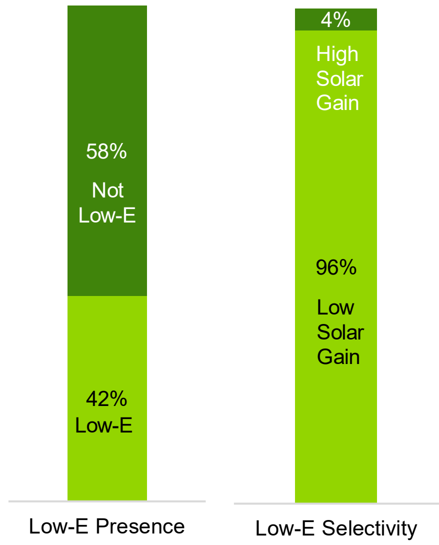
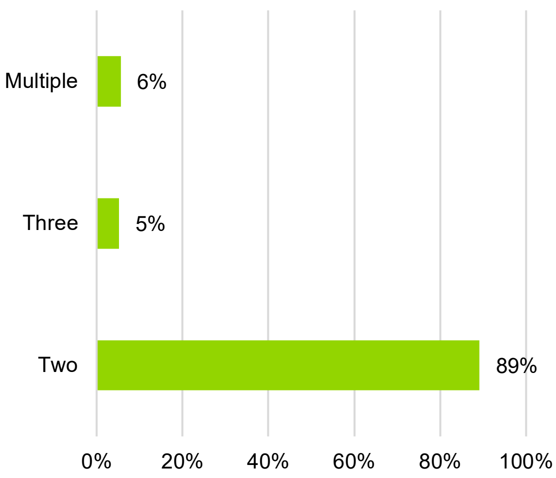
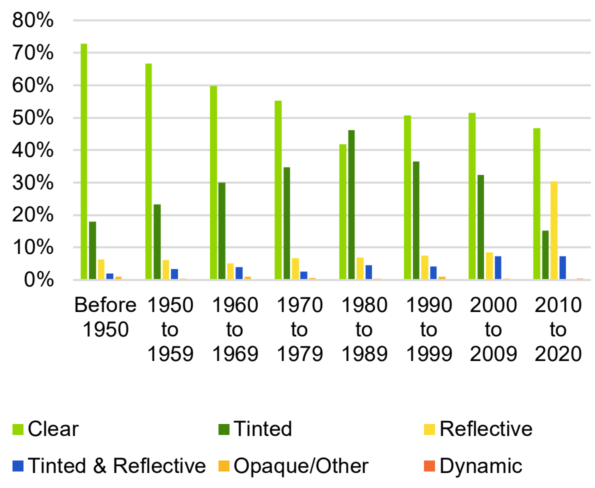


Figure 4-7: Commercial Building Installed Stock Low-E Surface Number



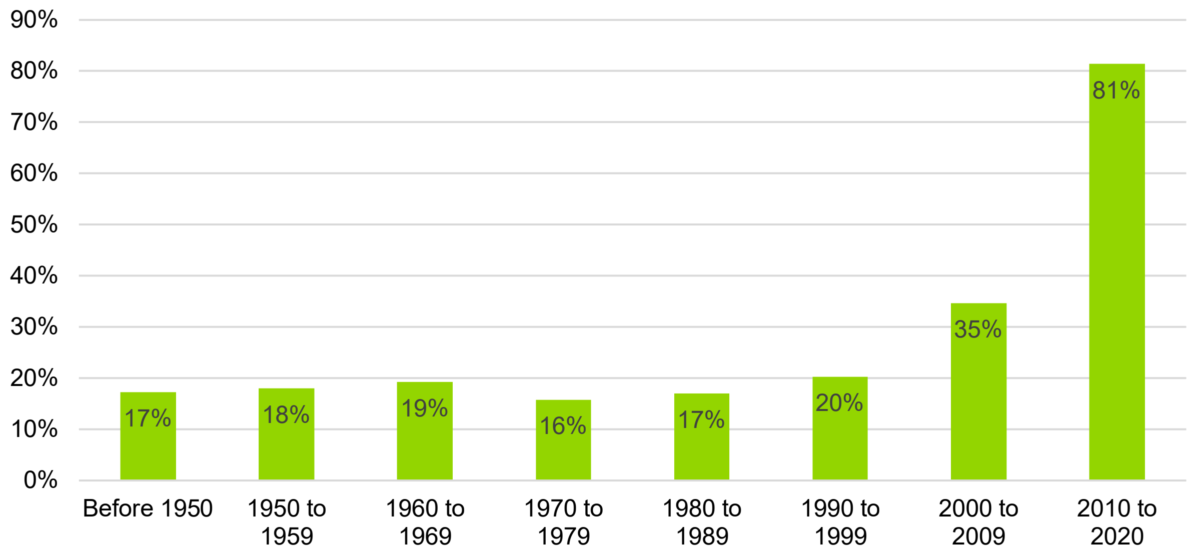
Note: Glass surfaces are identified by a number, starting with 1, which is the surface facing the exterior. Each pane of glass has two surfaces, so single-pane glass has two surfaces, double-pane glass has four surfaces, and triple-pane glass has six surfaces. Low-E coating is most often applied to surface 2 for low-solar gain and surface 3 for high-solar gain. Low-E coating can also be applied to multiple surfaces (often in triple-pane glass).

Figure 4-8: Commercial Building Installed Stock Glazing Type by Building Vintage



Note: Clear glazing refers to non-tinted and non-reflective glass with high VT. Tinted glass refers to glass with an added color pigment and reflective glass refers to glass with a metal oxide coating both reduce visible light transmittance. Any of the glazing types above may be combined with Low-E coating.

Figure 4-9: Commercial Building Installed Stock Low-E Coating by Building Vintage



Insulating Glass

Figure 4-10: Commercial Building Installed Stock Glass Panes

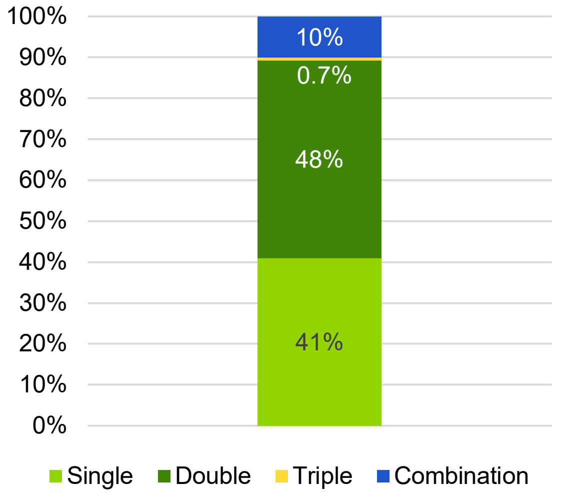


Figure 4-11: Commercial Building Installed Stock Insulated Glass Gas-Fill Types

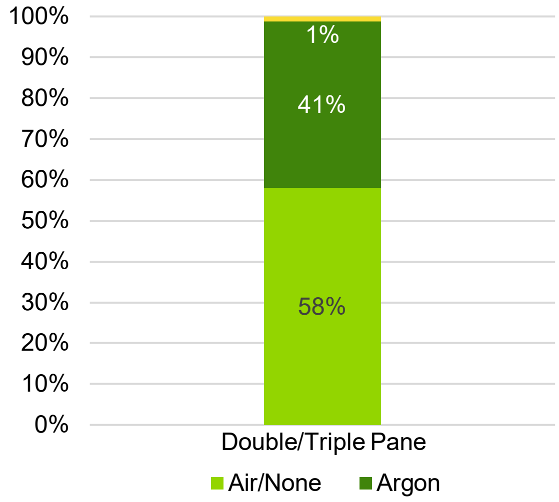


Figure 4-12: Commercial Building Installed Stock Glass Panes by Building Vintage

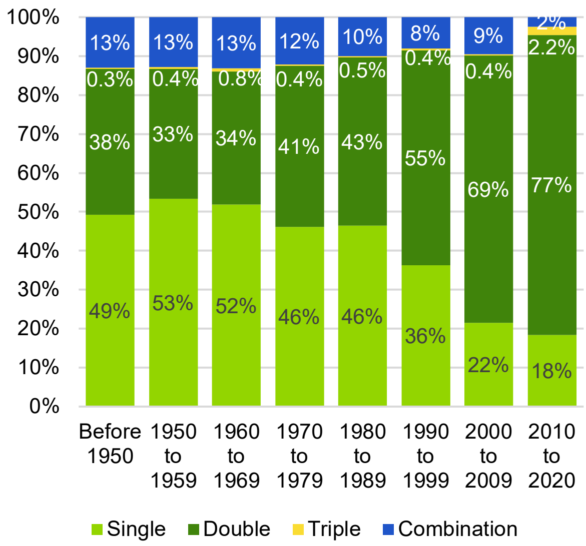
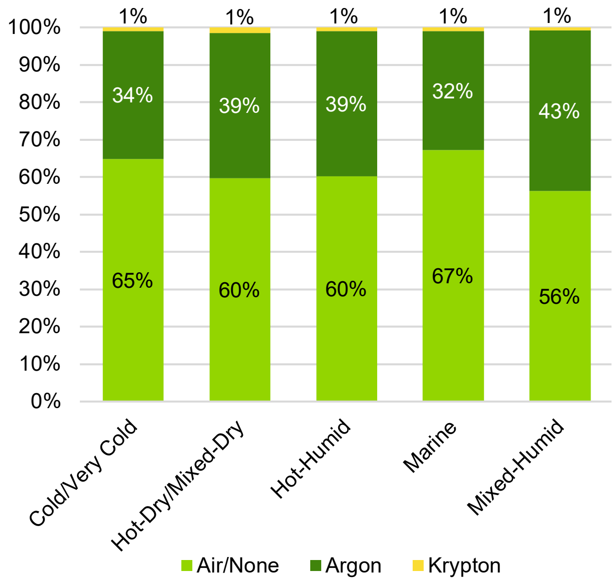


Figure 4-13: Commercial Building Installed Stock Gas-Filled Fenestration (Double/Triple Pane) by Climate Zone



Window Frames

Figure 4-14: Commercial Building Installed Stock Fenestration Frame Materials

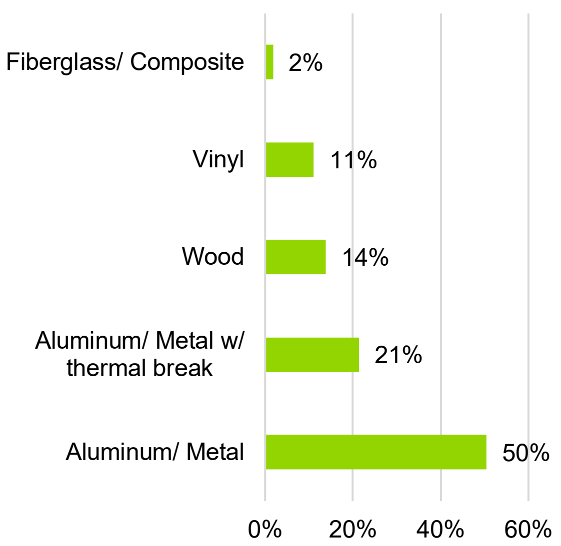
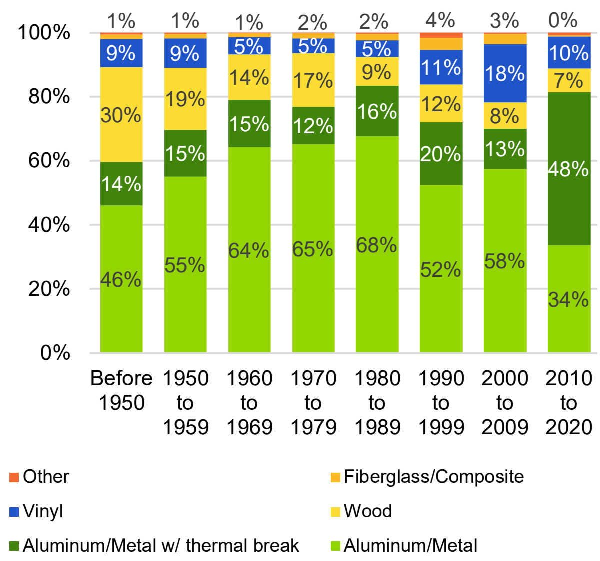
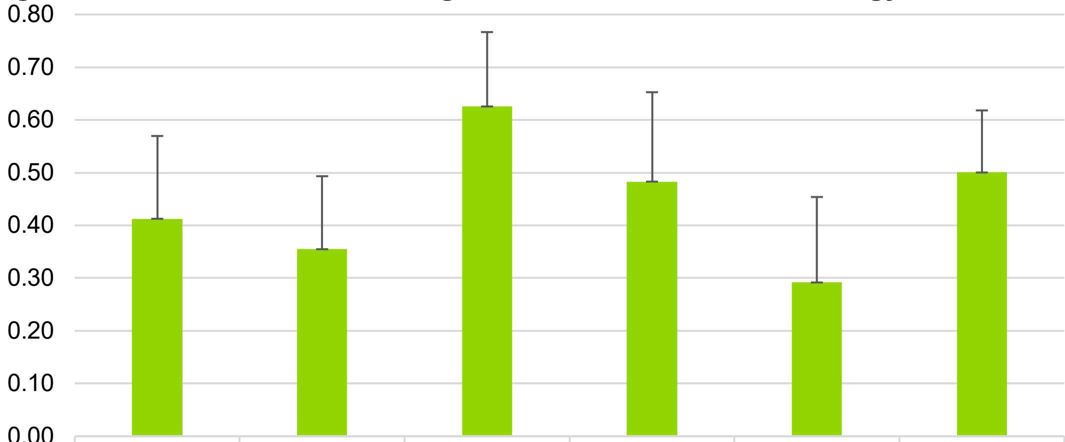


Figure 4-15: Commercial Building Installed Stock Fenestration Frame Material by Building Vintage



Thermal Energy Factors

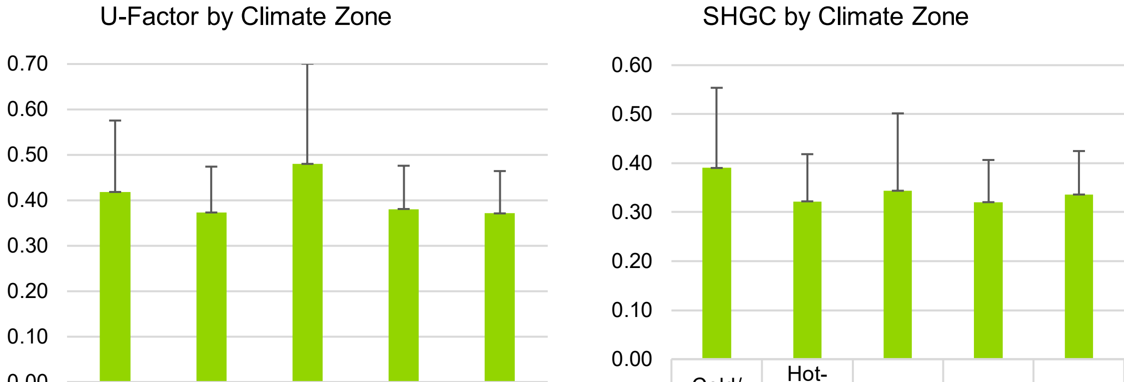
Figure 4-16: Commercial Building Installed Stock Thermal Energy Factors



	U-Factor	SHGC	Solar Reflectance	Solar Transmittance	Visible Reflectance	Visible Transmittance
Mean	0.41	0.35	0.63	0.48	0.29	0.50
Std Dev	0.16	0.14	0.14	0.17	0.16	0.12

Note: Error bars in the figure above represent the average +/- one standard deviation (SD). Values shown in the table are the mean of the modeled data and the SD, taken primarily from the Guidehouse building survey (2010-2020) and the DOE Building Code Study so results may be skewed toward newer fenestration. Also note that the U-factor results in particular appear to contain a mixture of center-of-glass and whole product values, making the reliability of this result more questionable.

Figure 4-17: Commercial Building Installed Stock Thermal Energy Factors by Climate Zone



	Cold/ Very Cold	Hot-Dry/ Mixed-Dry	Hot-Humid	Marine	Mixed-Humid
Average	0.42	0.37	0.48	0.38	0.37
Std Dev	0.16	0.10	0.22	0.10	0.09

	Cold/ Very Cold	Hot-Dry/ Mixed-Dry	Hot-Humid	Marine	Mixed-Humid
Average	0.39	0.32	0.34	0.32	0.34
Std Dev	0.16	0.10	0.16	0.09	0.09

Note: Error bars in the figure above represent the average +/- one SD. Values shown in the table are the mean of the modeled data and the SD, taken primarily from the Guidehouse building survey (2010-2020) and the DOE Building Code Study. The DOE Building Code Study (which surveyed older buildings) only included data from the Hot-Humid and Cold/Very Cold climate zones, which skewed the results for these climate zones relative to the others. Also note that the U-factor results in particular appear to contain a mixture of center-of-glass and whole product values, making the reliability of this result more questionable.

Fenestration Area

Figure 4-18: Commercial Building Installed Stock Window-to-Wall Ratios

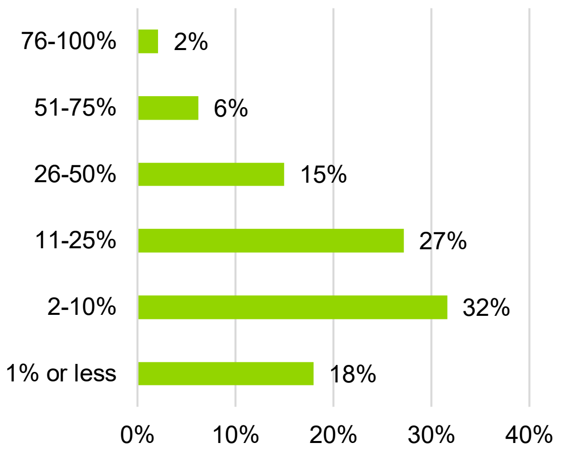


Figure 4-19: Commercial Building Installed Stock Average Fenestration Area per Building and Orientation

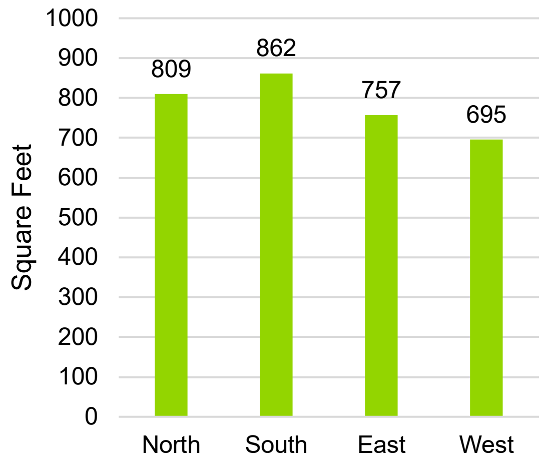
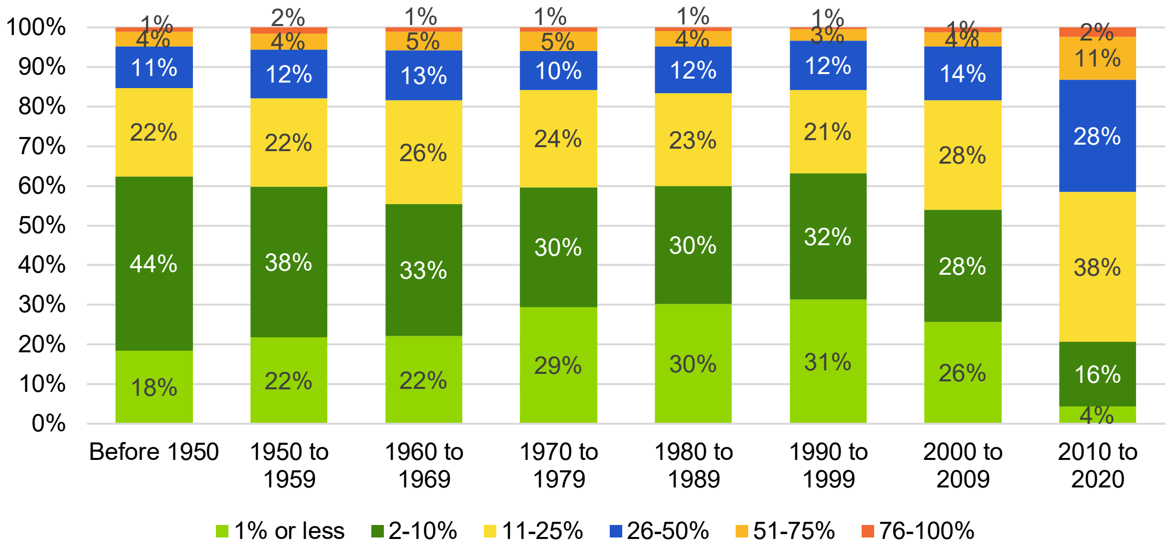


Figure 4-20: Commercial Building Installed Stock Window-to-Wall Ratios by Building Vintage



Note: Data from 2010-2020 comes primarily from the Guidehouse survey, which may skew the results from 2010-2020.

Fenestration Types

Figure 4-21: Commercial Building Installed Stock Fenestration Types

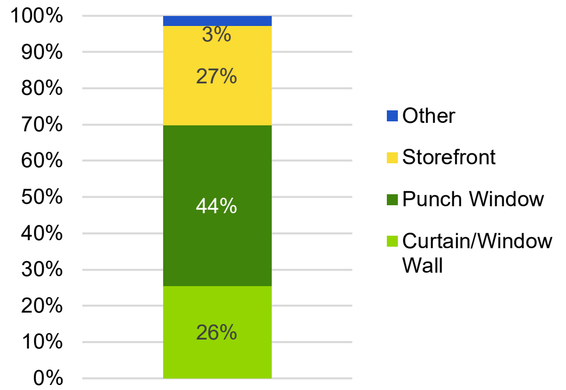


Figure 4-22: Commercial Building Installed Stock Location of Fenestration Assembly

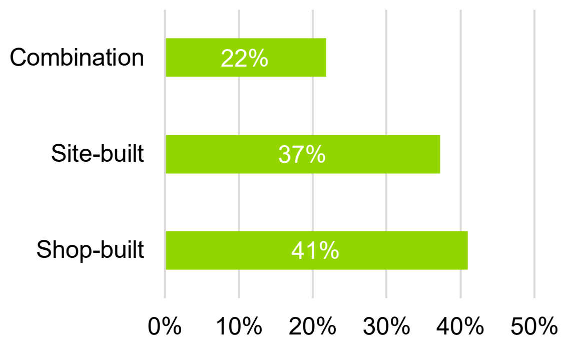


Figure 4-23: Commercial Building Installed Stock Fenestration Types by Building Vintage

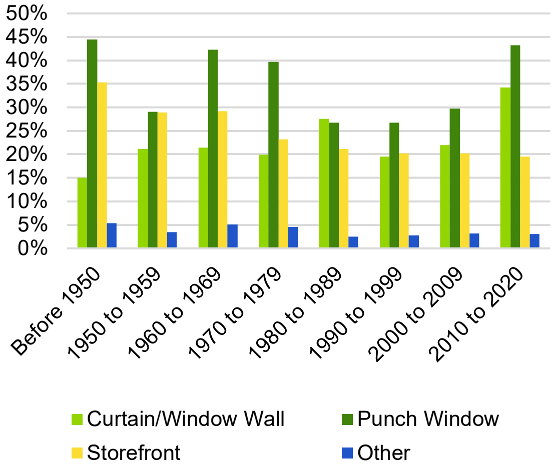


Figure 4-24: Commercial Building Installed Stock Location of Fenestration Assembly by Building Vintage

Note: Data from 2010-2020 comes primarily from the Guidehouse survey, which skewed the shift from shop-built to combination in these years.

4.3 Sales Data Analysis

Calculations of national fenestration sales data utilized the same methodology outlined for the installed stock. However, the sales data relied on three key data sources that included newly constructed buildings and retrofitted fenestration projects between 2017 and 2020: the Guidehouse building survey, NEEA CBSA 2018, and efficiency program data from Washington and Colorado. Combined, these sources represented a total of 424 buildings. In addition to these building sources, the sales analysis utilized data provided directly from glass and fenestration manufacturers and data from the AAMA industry report to verify and adjust findings. The results shown in this section represent an average of the fenestration sold for both new construction and retrofits from 2017 to 2020.

4.4 Sales Results Summary

Figure 4-25 to Figure 4-35 summarize national results and findings from the fenestration sales analysis from 2017 to 2020. **All proportions shown in the figures represent percentages of buildings and do not represent the overall area of glass sold.**

Most commercial fenestration sold in the U.S. from 2017 to 2020 were substantially higher performance and more efficient than the average commercial installed stock fenestration. Section 2.2 outlines the key drivers for higher performance fenestration shown in the results here. Overall, 64% of fenestration was sold for new construction and 36% of fenestration was installed for retrofit applications. The results of this analysis (from 2017 to 2020) showed that:

- Tinted or reflective fenestration[vii] represent about 43% of the sales (Figure 4-25).
- Low-E coating fenestration represent about 83% of the sales (Figure 4-26).
- Double-pane and triple-pane insulated glass represent about 92% of the sales (Figure 4-28).

[vii] Tinted glass refers to glass with an added color pigment and reflective glass refers to glass with a metal oxide coating. Both reduce visible light transmittance and either may be combined with a Low-E coating.

- Argon and krypton gas-filled fenestration represent about 49% of the sales (Figure 4-29).
- Metal window frames with a thermal break represent about 68% of the sales and non-metal frames represent about 9% (Figure 4-30).
- The average U-factor was about 0.34 Btu/(h·ft^2·°F) +/- the standard deviation of 0.08 (Figure 4-31).[viii] However, similar to the installed stock data in the previous section, the reliability of this result is questionable. Examination of the sales data shows there was a mix of center-of-glass U-factor and whole product U-factors reported. This reinforces the need for a practical cost-effective certification program to provide and increase use of whole product U-factors in the marketplace. The hot-humid climate zone had the highest average U-factor at 0.42 Btu/(h·ft^2·°F), and the cold/very cold climate zone had the lowest average U-factor at 0.32 Btu/(h·ft^2·°F).
- The average SHGC was about 0.34 +/- the standard deviation of 0.14 (Figure 4-33). The cold/very cold climate zone had the highest average SHGC at 0.36, and the hot-humid climate zone had the lowest average SHGC at 0.28 (Figure 4-32).

In addition, the 2017-2020 sales showed higher window-to-wall ratios on average relative to the installed stock.

- About 50% of buildings had a window-to-wall ratio above 25% with about 17% above 50% (Figure 4-33).
- About 36% were site-built and 50% were a combination of shop-built and site-built (Figure 4-34).
- About 34% of fenestration sold were curtain/window wall and 46% were punch windows (Figure 4-35).

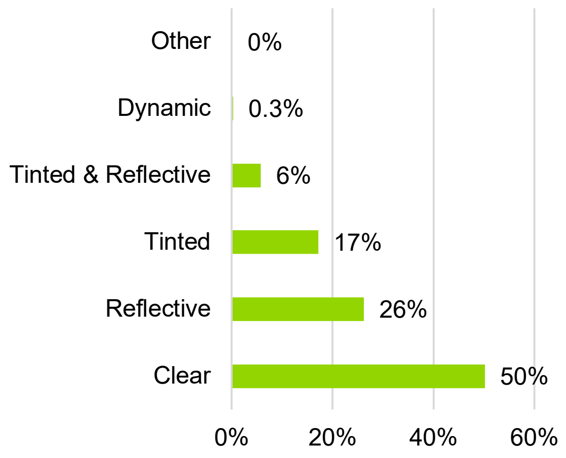
However, many energy efficient fenestration characteristics and emerging fenestration technologies still represent a small minority of commercial fenestration sales.

- Dynamic glazing comprised less than 1% of sales.
- Triple-pane glass comprised about 4% of sales.
- Vacuum-insulated fenestration comprised less than 1% of sales.

[viii] Note that the U-factor results appear to contain a mixture of center-of-glass and whole product values, making the reliability of this result more questionable.

Glazing Types

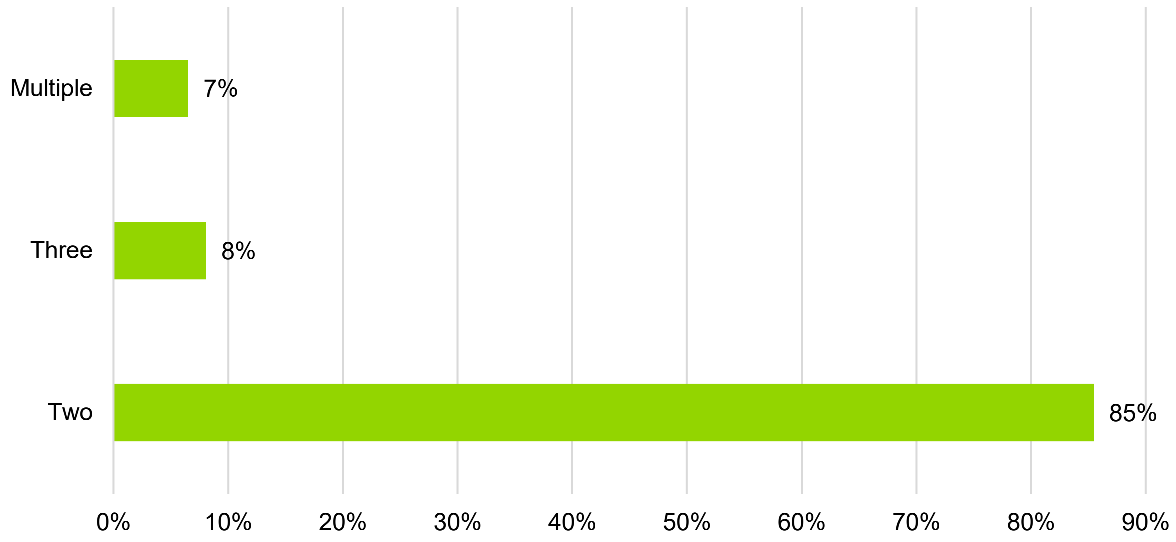
Figure 4-25: Commercial Building Fenestration Sales by Glazing Type



Note: Clear glazing refers to non-tinted and non-reflective glass with high VT. Tinted glass refers to glass with an added color pigment and reflective glass refers to glass with a metal oxide coating. Both reduce visible light transmittance and either may be combined with a Low-E coating.

Figure 4-26: Commercial Building Fenestration Sales Low-E Coating

Figure 4-27: Commercial Building Fenestration Sales Low-E Coating Surface Number



Note: Glass surfaces are identified by a number, starting with 1, which is the surface facing the exterior. Each pane of glass has two surfaces, so single-pane glass has two surfaces, double-pane glass has four surfaces, and triple-pane glass has six surfaces. Low-E coating is most often applied to surface 2 for low-solar gain and surface 3 for high-solar gain. Low-E coating can also be applied to multiple surfaces (often in triple-pane glass).

Insulating Glass

Figure 4-28: Commercial Building Fenestration Sales Glass Panes

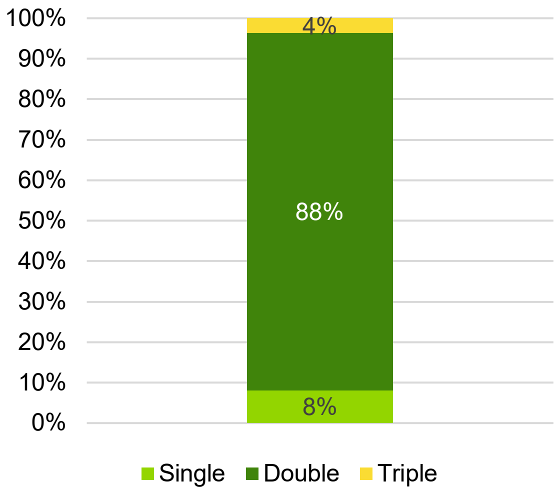
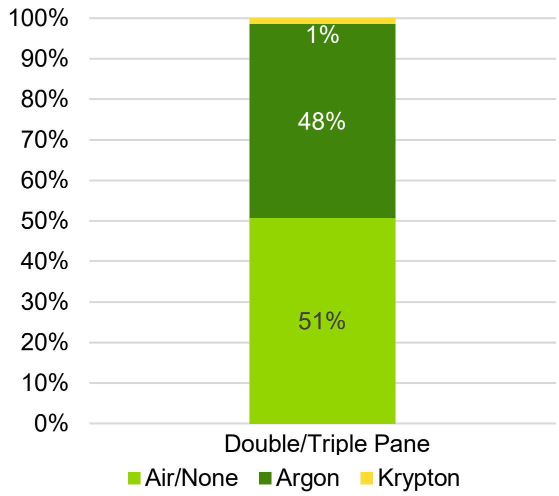
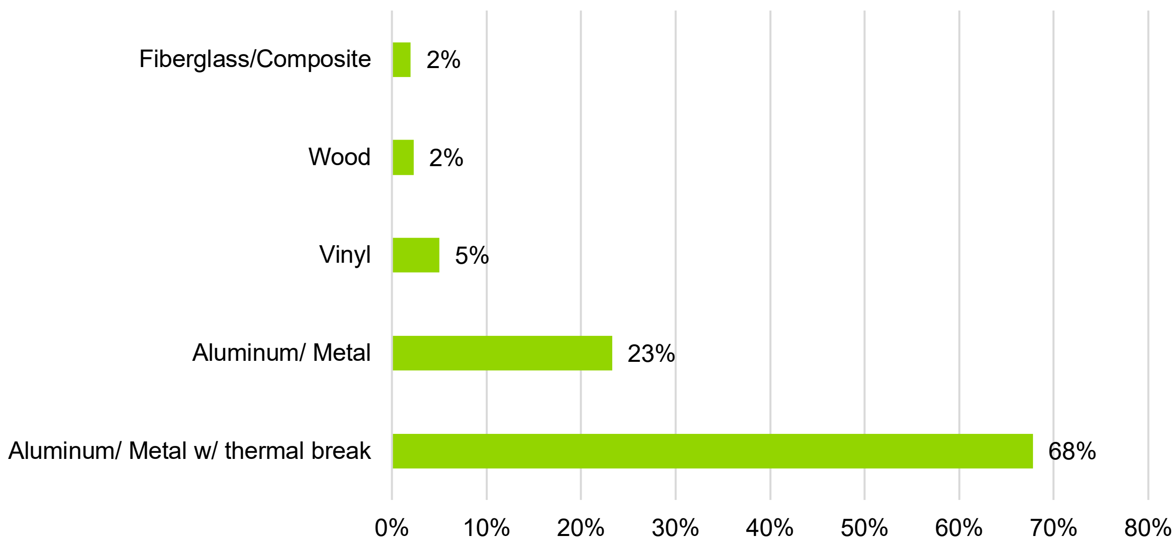


Figure 4-29: Commercial Building Fenestration Sales Insulated Glass Gas-Fill Types



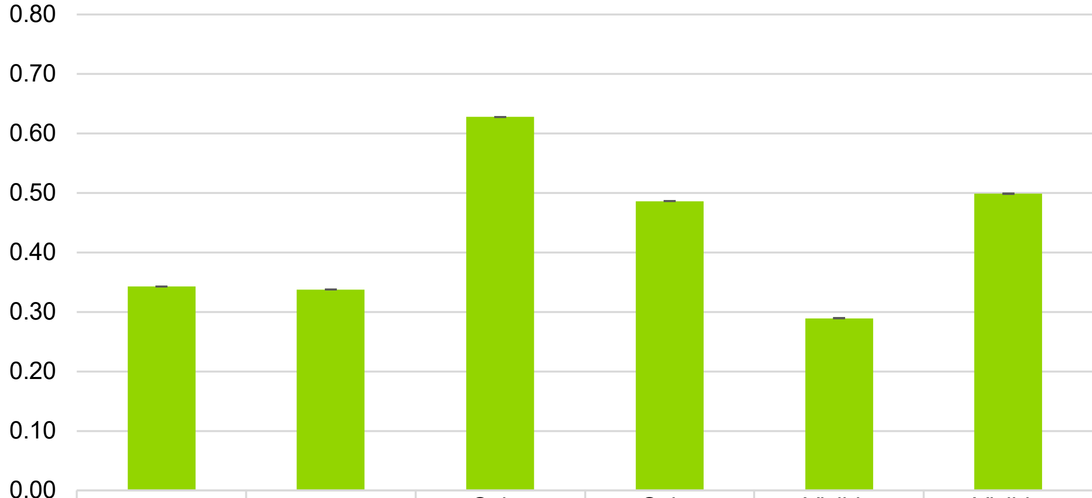
Window Frames

Figure 4-30: Commercial Building Fenestration Sales Fenestration Frame Material



Thermal Energy Factors

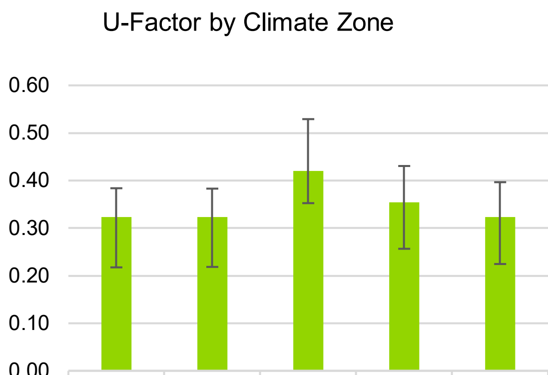
Figure 4-31: Commercial Building Fenestration Sales Thermal Energy Factors



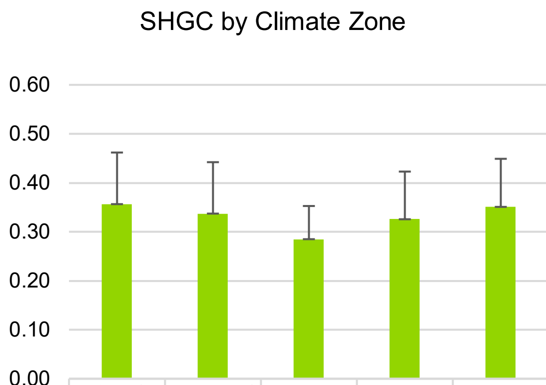
	U-Factor	SHGC	Solar Reflectance	Solar Transmittance	Visible Reflectance	Visible Transmittance
Mean	0.34	0.34	0.63	0.49	0.29	0.50
Std Dev	0.08	0.14	0.14	0.17	0.16	0.11

Note: Error bars in the figure above represent the average +/- one standard deviation. Values shown in the table are the mean of the modeled data and the standard deviation, taken primarily from the building survey (2010-2020). Also note that the U-factor results in particular appear to contain a mixture of center-of-glass and whole product values, making the reliability of this result more questionable.

Figure 4-32: Commercial Building Fenestration Sales Thermal Energy Factors by Climate Zone



	Cold/ Very Cold	Hot-Dry/ Mixed-Dry	Hot-Humid	Marine	Mixed-Humid
Mean	0.32	0.32	0.42	0.35	0.32
Std Dev	0.06	0.06	0.11	0.08	0.07

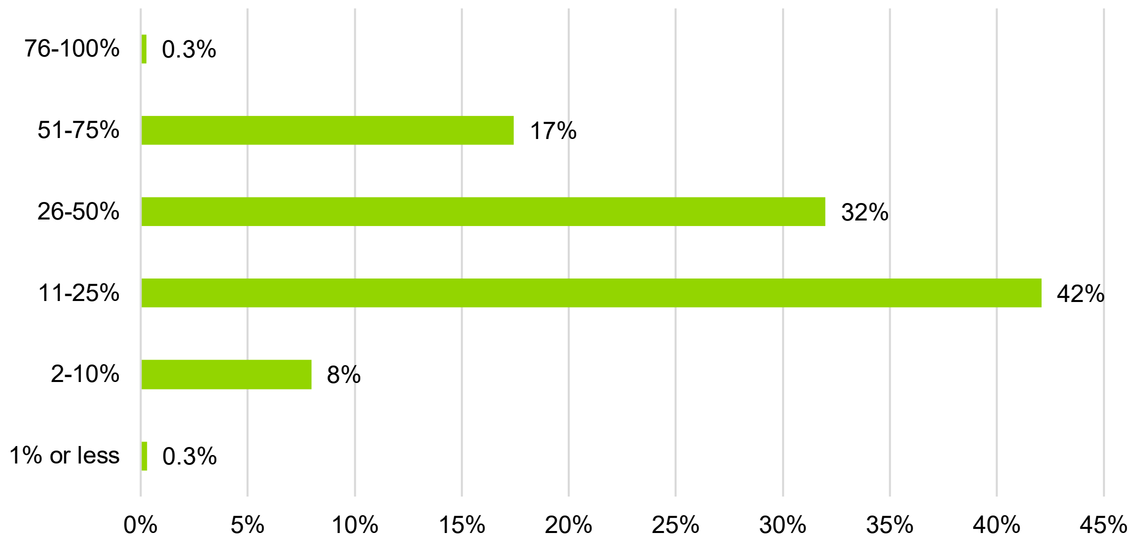


	Cold/ Very Cold	Hot-Dry/ Mixed-Dry	Hot-Humid	Marine	Mixed-Humid
Mean	0.36	0.34	0.28	0.33	0.35
Std Dev	0.11	0.11	0.07	0.10	0.10

Note: Error bars in the figure above represent the average +/- one standard deviation. Values shown in the table are the mean of the modeled data and the standard deviation, taken primarily from the Guidehouse building survey (2010-2020). Also note that the U-factor results in particular appear to contain a mixture of center-of-glass and whole product values, making the reliability of this result more questionable.

Fenestration Area

Figure 4-33: Commercial Building Fenestration Sales Window-to-Wall Ratio



Fenestration Types

Figure 4-34: Commercial Building Fenestration Sales Location of Window Assembly

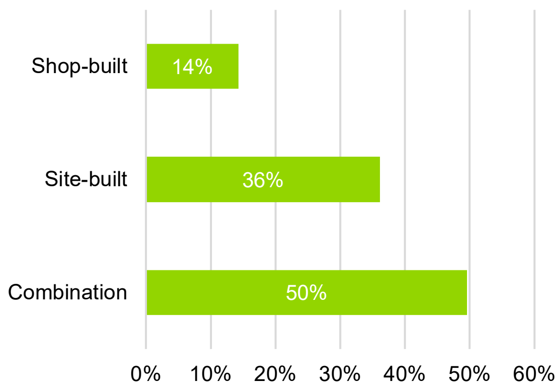
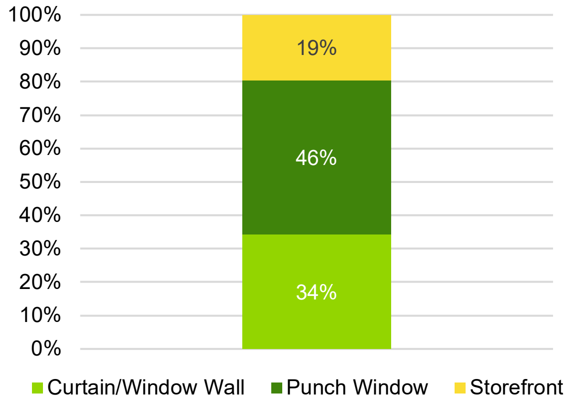


Figure 4-35: Commercial Building Fenestration Sales Window Types



5. Code Compliance Impacts

This section outlines the landscape for commercial energy code compliance and enforcement. Topics include code requirements, compliance pathways, situations surrounding enforcement, issues with measuring compliance, impacts, and above-code programs. To understand the various facets of fenestration building energy codes, we completed a combination of interviews and secondary research. Table A-1 shows a summary of the organizations contacted for primary data gathering. This part of the study was conducted from February through May 2020.

For secondary research, we primarily referred to information from the American Council for an Energy Efficient Economy (ACEEE), BCAP, the Institute for Market Transformation (IMT), the Efficient Windows Collaborative, and other organizations. We also looked at various code compliance studies to better understand what was happening at the local and state level. Although there was a large volume of studies available, many were over 5 years old and only provided summary level fenestration compliance data (not at the necessary level of granularity). For these reasons, we reviewed one code compliance report in depth for each climate zone for the most recent year.[ix] We also referred to preliminary data from DOE's Commercial Energy Code Field Study in two climate zones. Because quantitative data on code compliance is sparse and largely undocumented, we used primary interviews to research estimated compliance in the field.

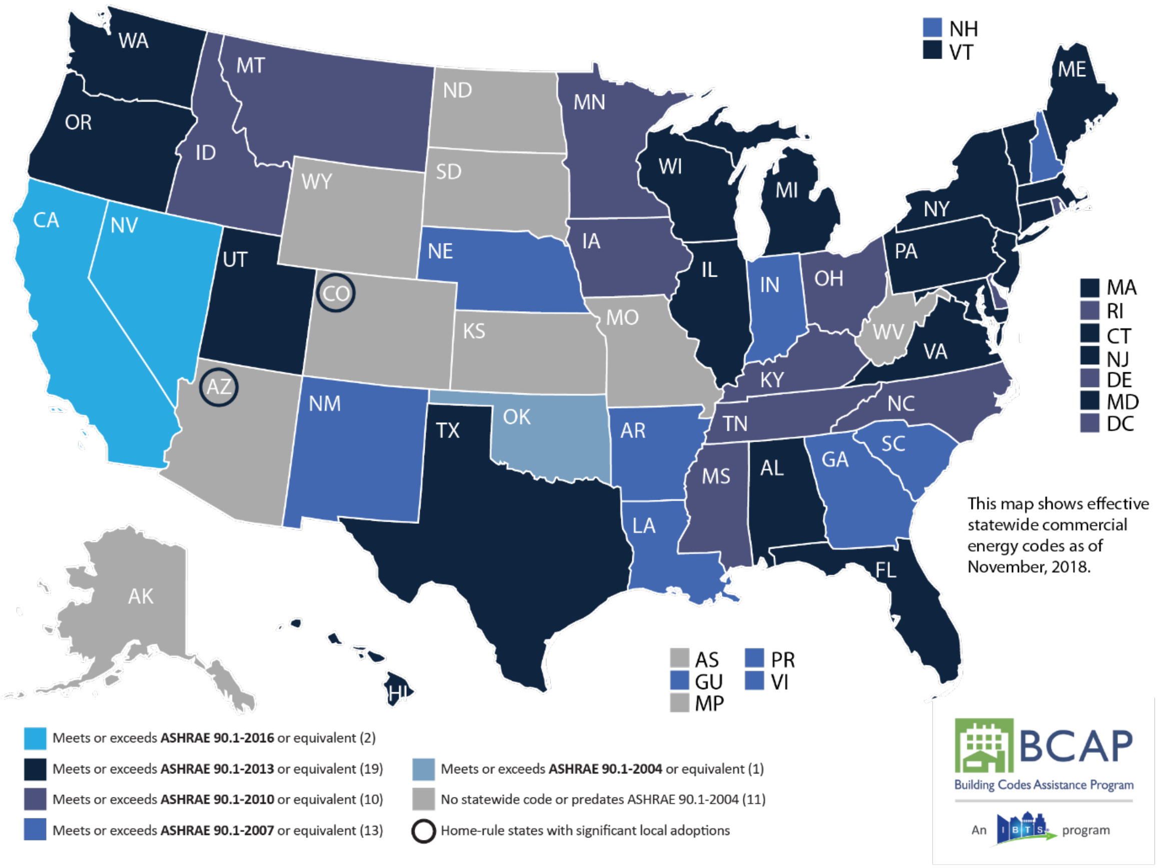
5.1 Fenestration Code Requirements Differ by Jurisdiction

In 1978, Congress mandated that all states begin implementing energy efficiency standards for new buildings. In 1992, the Energy Policy Act was passed, requiring all states to review and consider adopting the national model energy code. Thirteen years later, the most recent versions of ANSI/ASHRAE/IES Standard 90.1 Energy Standard for Buildings Except Low-Rise Residential Buildings (ASHRAE 90.1) and the International Energy Conservation Code (IECC) were specified as the model standards in the Energy Policy Act of 2005.[60] ASHRAE 90.1's and IECC's earliest energy code publications can be traced back to 1975 and 1998 respectively.[61, 62] These standards are reviewed and published every 3 years, usually adding increased stringency with each new version. Along with each update, DOE issues determinations on whether the new standard will lead to increased building energy efficiency as compared to the older version.[60]

Commercial building energy codes are adopted at the state or local level in the U.S. There is currently no mandated national energy code, but many jurisdictions adopt some variant of ASHRAE 90.1 or IECC standards for newly constructed fenestration aligned with their respective climate zones. Figure 5-1 highlights commercial energy code adoption. Each jurisdiction has its own processes for adopting and modifying its respective energy codes.[63] Jurisdictions will usually adopt and enforce new codes into their second or third year of publication and can maintain the code as is or can include strengthening or weakening amendments.[63] Some jurisdictions develop their own set of building energy efficiency codes. California, for example, adopts standards set forth in Title 24.[64] As Figure 5-1 indicates, codes adoption varies across the country and on a regional basis. Different philosophies exist related to commercial code adoption, compliance, and enforcement and are often specific to the market and based on resources, local decision-making, and politics. One interviewee from a region that adopted ASHRAE 90.1 – 2007 stated that the region's point of view is that 90%-100% compliance with a lower code is more desirable than raising the code and achieving little compliance.

[ix] No code compliance studies were found for Climate Zone 8 which is limited to certain municipalities in Alaska.

Figure 5-1: Status of Statewide Commercial Energy Code Adoption as of November 2018



Source: BCAP.

Table 5-1 and Table 5-2 detail prescriptive fenestration requirements for recent versions of ASHRAE 90.1 and the IECC. Maximum U-factor decreases as climate zone number increases, indicating more stringent insulation requirements for colder regions. Maximum SHGC increases as the climate gets cooler, indicating the importance of minimizing solar heat gain for warmer climates. Furthermore, when looking at past ASHRAE and IECC standards, requirements by climate zone typically become more stringent with each revision.

Table 5-1: 2021 IECC Prescriptive Fenestration Requirements

Climate Zone	1	2	3	4 & 5	6	7 & 8
Vertical Fenestration U-Factor Requirements						
Fixed fenestration	0.50	0.45	0.42	0.36	0.34	0.26
Operable fenestration	0.62	0.60	0.54	0.45	0.42	0.32
Entrance doors	.83	0.77	0.68	0.63	0.63	0.63
Skylight U-Factor Requirements						
Maximum U-factor	0.70	0.65	0.55	0.50	0.50	0.41
Maximum SHGC	0.30	0.30	0.30	0.40	0.40	NR

Source: New Buildings Insitute.

Table 5-2: ASHRAE 90.1-2019 Prescriptive Fenestration Requirements

Climate Zone	1	2	3	4	5	6	7	8
Vertical Fenestration (0%-40% of Wall)								
Maximum U-Factor								
Non-metal frame	*Same as metal framing fixed or operable*							
Metal frame, fixed	0.50	0.45	0.42	0.36	0.36	0.34	0.29	0.26

Climate Zone	1	2	3	4	5	6	7	8
Metal frame, operable	0.62	0.60	0.54	0.45	0.45	0.42	0.36	0.32
Metal frame, entrance door	.83	0.77	0.68	0.63	0.63	0.63	0.63	0.63
Maximum SHGC								
Fixed	.23	.25	.25	.36	.38	.38	.40	.40
Operable	0.21	0.23	0.23	0.33	0.33	0.34	0.36	0.36
Minimum Assembly VT/SHGC								
All vertical fenestration	1.1	1.1	1.1	1.1	1.1	1.1	1.1	1.1
Skylights (0%-3% of Roof)								
Maximum U-Factor								
All skylights	0.70	0.65	0.55	0.50	0.50	0.47	0.44	0.41
Minimum Assembly VT/SHGC								
All skylights	NR	NR	NR	NR	NR	NR	NR	NR

Source: ASHRAE.

The green construction codes, IgCC and ASHRAE 189.1, include more rigorous fenestration requirements.[65] Dallas, Texas, Phoenix, Arizona, and Boynton Beach, Florida are a few cities that have adopted the IgCC.[66]

Jurisdictions may also adopt voluntary reach codes that provide a framework for achieving higher energy savings. These reach codes may then feed into the next iteration of the required energy code. Because levels of adoption and procedures for adopting and updating energy codes vary greatly across the country and even from local jurisdiction to jurisdiction, it is difficult to obtain a full picture of compliance and enforcement levels in the U.S.

5.2 Prescriptive and Performance Compliance Pathways

Within each standard, there are two compliance paths: prescriptive and performance. The prescriptive approach requires that each individual building component meet minimum standard requirements. This means that the fenestration, roof, and walls of a building must meet a certain value, such as those seen in Table 5-1 and Table 5-2. This method ensures that each component of a building complies with code.[67] However, the prescriptive path has been criticized for being too restrictive and not allowing for enough creativity in the building design process. For example, fenestration that meets the aesthetic needs of a project but does not meet the required U-factor or SHGC for the region cannot be used to comply with codes through the prescriptive path. Additionally, designers who prefer a larger window-to-wall area than allowed in the code could not follow prescriptive requirements; instead they must take the performance compliance path.

Through the performance path, the overall building energy performance is modeled for compliance, rather than its components. The performance approach allows for greater flexibility in design but requires modeling to show that the building would perform just as well (if not better) than if prescriptive standards were implemented. Modeling practices can miss performance degraders such as thermal bridging and can lead to overestimates of level of envelope performance. There are various code-approved software tools available to simulate building energy performance.

If the performance pathway is chosen, trade-offs can be made between building components, both within the envelope and between the envelope and HVAC or lighting systems. If a building has extremely efficient fenestration, this might allow for less insulation in the walls (as required under the prescriptive method and vice versa).[67] DOE's COMcheck is typically used to assess whether the performance of proposed building components meet energy code requirements. CBECC-Com, EnergyPro, and IES Virtual Environment are also compliance software applications approved under Title 24.[68]

While there is more freedom in the design process, the performance path may allow for the installation of less efficient fenestration in favor of other energy efficient components.

Furthermore, when using trade-offs, buildings that technically have the same level of energy performance do not necessarily have the same indoor comfort or environmental quality. Structures with less efficient fenestration may be less comfortable around the perimeter and experience problems with condensation in colder climates.[69] Figure 5-2 outlines characteristics of commonly used compliance pathways.

Figure 5-2: Typical Characteristics of Prescriptive vs. Performance Pathways

Prescriptive	Performance
• Smaller commercial buildings • Estimated 9%-10% of projects by SME • May be chosen to avoid complexity of modeling software • Sometimes required to qualify for incentives	• Larger, more complex commercial buildings • Estimated 90% of projects by SME • Popular in larger cities with higher WWR • COMcheck or energy modeling reports may be required documentation • Sometimes required to qualify for incentives

Source: Guidehouse; Interviews.

Because of the complications that can arise when using the performance path, some jurisdictions have looked to implement building envelope backstops. These backstops require a minimum level of envelope performance regardless of whatever else is done in the building, effectively placing a limit on the extent of compliant trade-offs. New York City, Washington State, and Massachusetts already have backstops in place. The upcoming 2019 version of ASHRAE 90.1 does not have a backstop, but an addendum has been finalized related to backstops. This approach limits value engineering, especially when looking at longer vs. shorter-life building elements, which can have significant impact since envelope elements can be in place in existing buildings for more than 50 years. However, backstops can potentially suffer from the same drawbacks as the prescriptive path by limiting creativity. Moreover, if backstops are too stringent and do not consider other performance factors such as orientation and shading, they could cause more harm than benefit in energy efficient design.

Other compliance approaches include outcome-based and energy cost budget methods. Outcome-based codes set a target for energy use and provide tools for measurement and reporting to ensure that the completed building meets the established level of energy performance.[60] The energy cost budget method can be used under ASHRAE 90.1 and allows compliance for any building design with a simulated energy budget that meets or is

To obtain a building permit, commercial building plans must pass a plan review stage before construction.

During and after construction, code officials or third parties will perform site inspection or performance testing. Most officials cited COMcheck as the preferred compliance software, but some accept other software to verify code compliance.

below the energy budget of a reference design that meets prescriptive requirements. These approaches allow for the greatest flexibility in design.

Regardless of the chosen compliance path, each building code has requirements that must be met. ASHRAE 90.1 and IECC have mandatory requirements for U-factor, SHGC, VT, and air leakage values for fenestration and require that they be determined in accordance with NFRC procedures by an accredited, independent party.[61]

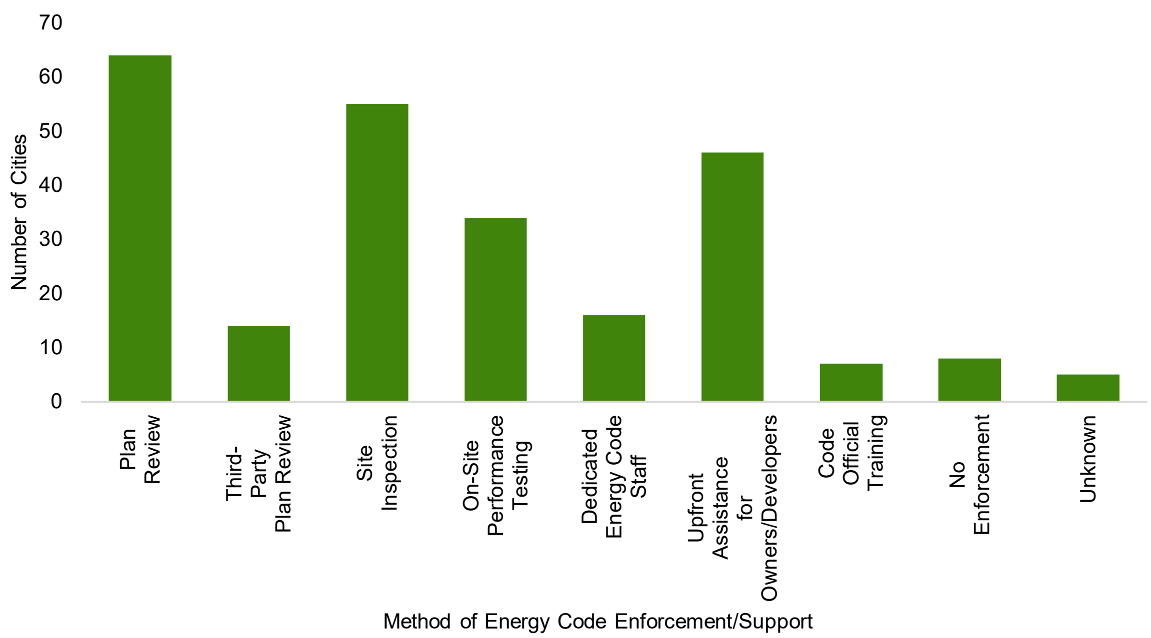
5.3 Methods and Challenges to Enforcing Fenestration Code Compliance

Guidehouse used ACEEE' s State and Local Policy Database and stakeholder interviews for insights into code enforcement. Jurisdictions across the U.S. institute a variety of measures to improve energy code compliance and often select enforcement methods based on dedicated budgets.

Cities employ different enforcement methods that may be voluntary, optional, or carried out by a third party. Most city building departments have officials who review code compliance at various stages in the building process. Figure 5-3 shows the number of major cities within ACEEE's database that institute each method of code enforcement and support. As of March 2020, ACEEE's database has 111 cities from the 100 largest metro areas across the U.S. Depending on the jurisdiction, some of the methods in Figure 5-3 are mandatory while others are voluntary, some allow for third-party implementation, while others require verification by the city building department.

Jurisdictions may require plan review, performance testing, or site inspection to ultimately enforce energy codes. Generally, most localities require energy code compliance at the plan review stage but do not necessarily verify during site inspections or performance testing. Many cities provide upfront support to developers, but relatively few have dedicated energy code staff and training for code officials. Eight cities instituted none of these methods, one of which had not adopted a commercial energy code (Wichita, Kansas).

Figure 5-3: Number of Cities within ACEEE Database that Engage in Each Method of Energy Code Enforcement/Support



Note: There were also several cities where methods were not found if methods used by the city were unverified (noted as "Unknown" in the figure).
Source: ACEEE.

Among the stakeholders interviewed, training and market support as well as dedicated staffing were referenced as the most impactful methods to increase and enforce code compliance.

- **Training and Support:** Certain localities provide education and training to code officials so that they can be informed on the latest updates to the code, best practices for measuring compliance, and other information that help facilitate the enforcement process. To increase compliance during the planning and design stages, some jurisdictions will also provide upfront technical support to building owners and developers. This type of support is available in cities across the country, including in Austin, New York City, Seattle, Los Angeles, and Tampa.[70]
- **Staffing Structure:** Jurisdictions may employ part-time, full-time, or third-party staff to improve compliance, but dedicated staff focused on the energy code is most impactful. Some building departments have generalist staff that perform all aspects of code enforcement; some have staff that specialize in specific building systems (i.e., mechanical, electrical, structural, etc.); and some have staff dedicated solely to energy code compliance. One code official mentioned that his jurisdiction sends out combo inspectors to verify various aspects of the building and has a set of green inspectors who perform spot checks and quality assurance inspectors for larger projects. According to an interviewee, Florida was the first state to require 2 hours of energy education to obtain certification from the state licensure board. A representative from SEEA (Southeast Energy Efficiency Alliance) noted a unique situation in Atlanta where compliance is managed by building inspectors, but enforcement is carried out by the police department. Several code compliance studies and interviewees stated that the staff structure with dedicated energy code personnel led to the most successful level of energy code compliance in localities.

Fenestration compliance is uniformly difficult to measure and enforce across the country for many similar reasons.

Fenestration Compliance Is Not a Priority

- Shortage of time and staff causes prioritization of life, health, and safety measures
- Inspectors seldom ask for NFRC certification for site-built fenestration
- Site inspection may not be required for fenestration compliance
- Construction is rarely delayed due to lack of fenestration compliance documentation

Through our conversations with individuals involved in the code enforcement process, various themes pertaining fenestration compliance challenges became apparent.

Several code officials and organizations across the country explained that fenestration energy code compliance is not a priority. Life, health, and safety measures are always prioritized while onsite, especially if there is no dedicated energy code staff in the jurisdiction. A SPEER (South-central Partnership for Energy Efficiency as a Resource) representative explained that, for most construction projects, compliance with commercial fenestration happens only at the plan review level and that there is rarely any dedicated field inspection at all. Further, a city code official in Colorado mentioned that site inspection is not required for fenestration. If fenestration pass the plan review, then they are assumed to be compliant onsite and officials will not look during inspection.

Even if a field inspection is required to comply with the commercial energy code, fenestration performance is frequently neglected as part of the inspection, especially with site-built fenestration.

What Stakeholders Are Saying…

A consultant and former code official that works across the U.S. noted that few jurisdictions take the time to verify fenestration energy code compliance and that **about 5% of jurisdictions in the U.S. are concerned with U-factor and SHGC performance characteristics.** However, they also mentioned that a lack of documentation does not necessarily indicate a lack of compliance and lower performance. The bottom line is we just do not know.

Although the 2018 IECC model code and many local building codes require testing in accordance with NFRC procedures for commercial fenestration, we found that code officials rarely look for certifications. At least six individuals across various regions note this in interviews. Shop-built fenestration that come as unitized structures, like those used in residential applications, may have an NFRC label attached and enable building officials to easily verify energy code compliance. However, site-built fenestration present complications because the total energy performance of the fenestration depends on the individual performance characteristics of the components, effectively requiring a more complex certification (see Section 3.2). For example, according to some Texas officials interviewed, some projects will result in a delay without a certificate, while others will continue without interruption depending on the jurisdiction. In Austin, Texas, a code official stated that approximately 5% of commercial projects are asked to provide certification. A SWEEP (Southwest Energy Efficiency Project) representative estimated that only about 20% of code officials ask for CMA information.

One SME estimated that about 25%-30% of COMcheck reports are incorrectly completed.

She mentioned that developers will input real values for the building components that they are truly interested in, then place whatever values are required for fenestration to make the COMcheck pass. Many reviewers see the green line on the COMcheck report and assume compliance, rather than looking into the specific calculations or inputs. Energy efficient fenestration is also often value-engineered out once a building permit is obtained.

Fenestration is usually already installed in the building once the inspector comes to the site, and most officials will not make developers remove fenestration or hold up construction due to a lack of documentation. In these instances, NFRC certification is rarely asked for, even if required by code. However, lack of code *enforcement* does not necessarily mean lack of code *compliance*. Fenestration performance in building specifications usually start with the energy code, as that is the legal responsibility of the registered design professional. One SME explained that the commercial building market is unique in that developers and architects are largely held accountable by contractual obligations and so will meet the owner's project requirements (including requirements for fenestration performance) to avoid a potential lawsuit. This model places the onus on architects and contractors rather than code officials to ensure compliance. In 2018, the Midwest Energy Efficiency Alliance (MEEA) compiled a report detailing findings from an Illinois Enforcement Survey on existing commercial buildings and the statewide energy code. Contrary to our interviews, most Illinois officials did not see lack of staff as the largest issue, but rather lack of understanding from builders and designers. During our MEEA interview, the representative stated that many officials depend on designers and builders for complying with the energy code, so it follows that any misinformation within this group would lead to the various parties blaming each other for any noncompliance issues.

Compliance Documentation Differs at Various Stages and Is Difficult to Verify:

- Performance modeling is often done incorrectly and simply to obtain a permit (25%-30% according to SME)
- Default or estimated fenestration values may be used in plans and models, if at all
- Fenestration is often value-engineered out post-permit approval
- Few officials will look to manufacturer specification sheets or shipping tickets

If fenestration is suspected to be noncompliant during the permitting process, code officials rarely hold up the project due to a variety of factors such as local politics, lack of information, or low probability of site inspection or repercussions. A Washington, DC code official shared an experience wherein the building department received an application with noncompliant fenestration and rejected the permit until compliant fenestration was specified. However, once the inspector arrived in the field, he found that the original fenestration had been installed and, as a result, required the project to change from a prescriptive to performance path to meet code. In another example, a former Colorado code official relayed an experience where they stalled a project because fenestration U-factor verification was not provided. They were then contacted by the city manager to not hold up the project and prevent revenue generation for the jurisdiction because of a window's U-factor.

Within the various stages of the compliance process, fenestration specifications can differ across documents, making enforcement more challenging. **Because fenestration is usually not yet selected at the permit stage, the fenestration performance values listed in the plans may be estimates.** Several code compliance studies found that fenestration energy specifications are often not included in plan drawings and require supplementary documentation to verify compliance or additional follow up on what is installed.

What Stakeholders Are Saying…

One Washington, DC code official explained that energy efficiency downgrades are not easily seen and thus there is **less liability to owners and developers than if they had made an apparent structural change.** By lowering the performance of certain building components, stakeholders can decrease the price of the project without significantly risking liability and affecting rentability.

To make matters more complicated, energy modeling is frequently completed incorrectly or using default values to obtain a permit. Default values allow developers to input performance characteristics that may be better performing than the products that ultimately go into the structure. This means that higher performance fenestration is being installed as compared to the energy model, but the exact performance values are unknown, affecting model accuracy. An interviewee stated that, in Florida, buildings can use the EnergyGauge tool to facilitate the permitting process, regardless of what is being installed. One code official mentioned that developers and engineers are often unwilling to then pay extra money to change initial design development energy models to update permit documents.

With the variety of energy modeling software tools available, the lack of standardization can make it difficult for a code official to do their job in a timely manner. **Consequently, interviewees expressed that it is typical for fenestration performance values to be different in the plan drawings, performance models, and the field.** With product selection constantly changing and each of these components being managed by different groups, it is difficult to stay organized and code officials do not always cross reference.

According to the interviewed code officials, NFRC certificates are rarely obtained because of either complexity or lack of clarity, making it more difficult to ensure compliance. In the absence of an NFRC label certificate, code officials who prioritize the energy code will look to other methods to obtain fenestration compliance documentation, including but not limited to manufacturer certificates, sales receipts, manufacturer reports, and shipping tickets. However, these methods do not often clarify center-of-glass versus assembly performance values and are difficult to distinguish. Figure 5-4 includes methods citied by individual code officials that prioritize energy code compliance.

Figure 5-4: Example Innovative Methods Used by Individual Code Officials to Assess Fenestration Compliance in the Absence of NFRC Label Certificates

"Some code officials will **accept any documentation as long as the U-factor and SHGC are specified**, using a letter from the manufacturer with an official letterhead as an example.

A D.C. code official obtains a **report on thermal energy performance from the manufacturer**, will calculate or estimate window performance based on glazing and frames selected, and **checks them against invoices**.

A code official in San Marcos, TX requires **energy performance documentation from manufacturers, registered design professional, or approved testing agency** to ensure fenestration compliance.

Texas code official requests **shipping tickets, researches the glazing, and cross-references his findings** with what was specified in the building plans.

In Colorado, one county code official **requires permit-holders to contact the manufacturer** and request information if energy specifications are not provided."

Source: Guidehouse; Interviews.

Many stakeholders cited a shortage of time and staff as the main reason behind compliance and enforcement challenges. A contact interviewed from the U.S. DOE's Building Energy Codes Program pointed out enforcement programs are a balance of time, money, and expertise. With a multitude of projects requiring inspection, a limited number of inspectors, and a finite number of hours in a day, code officials must decide how they are going to spend their time when they visit a construction site, especially when much of their day is spent driving from site to site rather than in an office.

Interviewees explained that many officials simply do not have the bandwidth to verify fenestration compliance and will focus on prioritizing life, health, and safety measures instead. Some code officials are also unable to determine what a compliant window looks like and will trust that architects, engineers, and contractors have ensured adequate energy performance per contractual obligations. Even if education programs are provided to support inspectors, there can be a time lag between code adoption, knowledge transfer, and enforcement. This is also true for developers and designers who may not have a robust understanding of their jurisdiction's commercial energy code.

Lack of Dedicated Energy Code Resources

- Time is not necessarily allotted for verifying energy code compliance and often competes with other measures
- Staff is not always educated on importance of energy code compliance and what it looks like
- Jurisdictions may not have dedicated budgets for staffing energy code officials and there is also a time lag between code adoption and knowledge transfer

Some interviewees provided suggestions to mitigate certain problems in the enforcement process. One official mentioned introducing a post-build requirement for checking fenestration specifications that goes through the project manager and architect and through the permit office. Another suggested proactively supplying CMA testing documentation at the time of plan submittal and updating it with the actual fenestration specifications at the time of energy/insulation inspection. An SME noted that having support from city officials and not catering to builders is integral, since developers will realize the consequences if jurisdictions take a hard stance and do not allow construction to proceed due to missing fenestration documentation.

What Stakeholders Are Saying…

One experienced code official noted that, as more stringent codes are adopted, it will become more difficult to enforce compliance given that suppliers will still have opportunities to sell noncompliant fenestration from their existing stock.

In addition to the traditional enforcement process, some local building departments will offer incentives for going above-code requirements or achieving green building certifications. Table 5-3 outlines these incentives.

Table 5-3: Summary of Energy Code Enforcement Incentives

Incentive Name	Definition[71]	Example Jurisdictions[72]
Up-zoning and floor area ratio bonuses	Bonuses that allow for higher value zoning or more density for projects that meet stretch code or green building standards	Atlanta, Georgia Austin, Texas Philadelphia, Pennsylvania
Tax incentives	Tax incentives used to mobilize investments and that may also be disbursed to projects exceeding codes	Baltimore, Maryland Cincinnati, Ohio Houston, Texas
Permit fee waiver/ reduction/rebate	Jurisdictions provide a waiver, discount, or rebate for permit fees during the permitting or construction completion stage for above-code projects	Anaheim, California Indianapolis, Indiana Tampa, Florida
Expedited permits and plan review	Approval of permits and plan reviews are expedited for exceeding code requirements	Albuquerque, New Mexico Miami, Florida Salt Lake City, Utah
Public funding	Projects exceeding code requirements may be eligible for public funding	Washington State

Source: New Buildings Institute; ACEEE.

5.4 Code Compliance and Enforcement Impacts on Fenestration

To understand the level of fenestration code compliance across the U.S., Guidehouse leveraged secondary research, code compliance studies, and interviews. However, we found that accurately measuring code compliance at any level was difficult, mostly due to lack of data.

We initially sought to estimate code compliance by assessing raw COMcheck data but found there were often multiple entries for one project and it was not possible to distill which entry was submitted for a permit versus those that were used for trying out different project component values and trade-offs. Further, COMcheck was not appropriate to assess prescriptive compliance since fenestration inputs may comply under the performance pathway, and there was no way to differentiate between reports that were ultimately used for performance compliance or to support prescriptive compliance.

> In energy code compliance studies, windows are often marked as noncompliant due to lack of certification or documentation, even if performance may have complied with code.

We also referred to code compliance studies and interviews but found these studies to focus mostly on new construction rather than existing buildings, to lack fenestration-specific data and to have statistically insignificant sample sizes. Although the studies reported relatively modest rates of envelope code compliance across climate zones (all above 64%), they also noted an inability to measure compliance when dealing with site-built fenestration. A 2018 Hawaii study reported that, of the 31 projects that were sampled, 23 had fenestration SHGC missing from the construction documents submitted to the city.[73] Because the documentation is missing, there was no way to determine fenestration compliance. Interviewees frequently echoed this finding, stating that "there is no way to know." Because documentation is either unavailable or unreliable, the level of code compliance and the resulting impacts cannot be adequately measured.

According to DOE's Commercial Energy Code Field Study, fenestration compliance was 54% for Climate Zone 2A and 12% for 5A.[x] When asked why compliance levels were so low, researchers stated that a lot of the documentation (i.e., NFRC certification) for U-factor and SHGC was not available and that they either inferred from plans, used manufacturer specification sheets, or assumed IECC default values based on fenestration construction, which often led to documented noncompliance even if the actual fenestration performance may have complied with the code. The quantititve results of the study also show a cited lack of NFRC certification in site-built fenestration as a consistent issue. It is important to point out that the primary issue is the lack of information, not necessarily the lack of performance.

Since the SHGC and U-factor of installed fenestration typically go undocumented, it is also difficult to measure the impacts on fenestration when measures are taken to better enforce codes. A Washington, DC code official expressed that better fenestration tends to be installed with better enforcement and the expectation of enforcement. A Texas inspector mentioned that compliance improves with outreach to building designers and training meetings. NEEA (Northwest Energy Efficiency Alliance) stated that the most successful localities, such as the Seattle and Portland metro areas, have devoted substantial resources for addressing code compliance and enforcement. Several manufacturers also explained that codes are what drive product supply for more efficient fenestration and that stricter enforcement leads to higher performance stock and consequently installation. Impacts would likely become more measurable if code enforcement in fenestration became more of a priority or more data on potential energy savings of fenestration became available.

[x] This is an upcoming study that will publish in late 2020.

6. Above-Code Fenestration Programs

6.1 Programs Methodology and Overview

To understand the current voluntary above-code fenestration programs in the U.S., Guidehouse researched utility, state, and local programs that advertised incentives specific to commercial building fenestration. Programs that offered rebates for residential projects and low-rise multifamily were excluded, as were those focused on a whole-building approach. We made these exclusions because many whole-building approach incentives did not require adjustments to fenestration, and projects often opted for other measures to achieve above-code requirements. To distinguish above-code programs, we compared fenestration requirements of each program to the most recent ASHRAE 90.1 or IECC standards and the local building code (where applicable). We contacted all administrators from the initial list of 19 programs and conducted interviews with nine programs. Following the interviews and further research, we condensed the final program list to 14, provided in Table 6-1.[xi]

Table 6-1: Above-Code Voluntary Fenestration Programs

Utility/Program Administrator	Program Name	Region	Climate Zone	Requirements and Benefits
Austin Energy	Window Treatments and Replacements*	Austin, Texas	3	Window film and solar shading: \$1.00/ft^2 for SHGC ≤ 0.37 or \$0.60/ ft^2 for SHGC 0.50-0.38 (retail storefront) Low-E window replacement: \$1.00/ft^2 for SHGC ≤ 0.27
Columbia River PUD	Commercial Window Replacement Program	Columbia County, Oregon	4	Pre-existing windows: single-pane (with storm windows), or double-pane metal framed Replacement: \$9.00/ft^2 for U-factor ≤ 0.30
Dominion Energy (administered by Honeywell)	Non-Residential Window Film*	North Carolina; Virginia	3, 4	SHGC ≤ 0.50 \$1.00/ft^2 for SHGC improvement > 0.40 \$0.85/ft^2 for SHGC improvement 0.30-0.40 \$0.65/ft^2 for SHGC improvement 0.20-0.30
Dominion Energy	ThermWise Weatherization Rebates	Utah; Wyoming	5, 6	Multifamily: \$2.50/ft^2 for U-factor ≤ 0.22
Efficiency Works: Platte River Power Authority	Business Rebate Program (Envelope)*	Fort Collins, Loveland, Longmont, and Estes Park, Colorado	5	Windows (Tier 1): \$3.00/ft^2 (retrofit) or \$1.50/ft^2 (new construction) for U-factor ≤ 0.30 and SHGC ≤ 0.25 Windows (Tier 2): \$6.00/ft^2 (retrofit) or \$3.00/ft^2 (new construction) for U-factor ≤ 0.18 and SHGC ≤ 0.22 Window film: \$1.50/ft^2 for SHGC ≤ 0.35
Emerald PUD	Window Upgrades for Commercial Windows	Eugene-Springfield Metro Area, Oregon	4	\$3.00/sf for U-factor ≤ 0.30
Energy Trust of Oregon	Windows and Sliding Glass Patio Doors	Portland, Oregon	4	Stacked structures with 5+ units (multifamily): \$3.00/ft^2 for U-factor ≤ 0.30 (pre-existing windows must be single-pane)
Idaho Governor's Office of Energy & Mineral Resources	State Energy Loan Program (Windows Addendum)	Idaho	5, 6	4% interest 5-year loan for energy projects: window replacement eligible for U-factor ≤ 0.32

[xi] This list may not be exhaustive given the time lapse between research and the writing of this report.

Utility/Program Administrator	Program Name	Region	Climate Zone	Requirements and Benefits
Idaho Power	Commercial Retrofit for Building Shell*	Idaho, Oregon	5, 6	Premium windows: \$2.50/ft^2 for U-factor ≤ 0.30
PacifiCorp: Pacific Power	Wattsmart Business - Building Envelope	California, Washington	4, 5	New construction/major renovation: \$0.34/ft^2 for U-factor ≤ 0.30 and SHGC ≤ 0.24 Retrofit (window): \$0.34/ft^2 for U-factor ≤ 0.30 and SHGC ≤ 0.33 Retrofit (window film): \$0.15/kWh annual energy savings
PacifiCorp: Rocky Mountain Power	Wattsmart Business - Building Envelope	Idaho, Utah, Wyoming	5, 6, 7	New construction/major renovation: \$0.35/ft^2 for U-factor ≤ 0.30 and SHGC ≤ 0.33 Retrofit (window): \$0.35/ft^2 for U-factor ≤ 0.30 and SHGC ≤ 0.33 Retrofit (window film): \$0.15/kWh annual energy savings
PG&E / California Multifamily New Homes	California Multifamily New Homes (CMFNH)*	California	3, 4 CA (11, 12, 13)	U-factor ≤ 0.22 Energy efficient windows: \$75/unit Triple-pane windows: \$150/unit + \$6/ft^2 of glazing
Port Angeles Public Works & Utilities	Commercial Conservation Rebates*	Port Angeles, Washington	4	Pre-existing windows: Single-pane (with storm windows), or double-pane metal framed Replacement: \$3.00/ft^2 for U-factor ≤ 0.30
Seattle City Light	Multifamily Weatherization Program*	Seattle Metro Area, Washington	4	Pre-existing windows: Single-pane or double-pane metal framed Replacement: \$6.00/ft^2 for U-factor ≤ 0.30 or \$8.00/ft^2 for U-factor ≤ 0.22

*Indicates an interviewed program.

Source: Guidehouse; Interviews.

Most incentive programs are in the Pacific Northwest, a region known for being particularly forward-looking regarding energy efficiency. A few programs also exist in the East Coast and Texas. During the interviews, many administrators in the Northwest cited the Bonneville Power Administration (BPA) as a reason for having a window incentive. According to an administrator at Seattle City Light, BPA, which is largely the source of funding for these incentive programs, has become increasingly concerned with weatherization and so utilities within their jurisdiction have been offering more programs aligned with that focus.

Aside from the regional clustering, almost every program is tied to renovation rather than new construction. Our conversations with code officials revealed that it is typical for commercial new construction to choose the performance pathway to meet codes. Consequently, prescriptive fenestration incentives are rare and whole-building rebates are more common for above-code new construction programs. Some examples include Alameda Municipal Power's New Construction Program, which offers rebates for new construction that exceeds California's Title 24 Building Energy Efficiency code by 10%, and DTE Energy's New Construction and Remodeling Program, which requires projects to result in energy savings that exceed the requirements in ASHRAE Standard 90.1-2007, LEED, or local building codes, whichever is more stringent.

When looking at the requirements and benefits associated with participating in each incentive, three programs stand out:

- **Dominion Energy's Non-Residential Window Film:** The Non-Residential Window Film program is the only program on the list that offers incentives for marginal improvements rather than a set U-factor or SHGC. As long as the resulting SHGC of the window is below 0.50, participants can receive a rebate anywhere from $0.65 to $1.00 depending on the magnitude of the improvement. This indicates that projects with high and low SHGCs for their existing windows can stand to benefit.

- **Efficiency Works' Business Rebate Program:** Efficiency Works' program has one of the most stringent requirements for its Tier 2 window rebate: U-factor and SHGC must be less than or equal to 0.18 and 0.22, respectively. The program administrator relayed that the requirements were put forth as a kind of research lab. In their 5 years working at the utility, the administrator just received their first application for the rebate last year, which they had initially thought was a mistake. Since then, only one other Tier 2 project has been completed to date.

- **California's Multifamily New Homes Program (CMFNH):** CMFNH's program stands out because of its generous rebate ($75/unit-$150/unit) and its offer on triple-pane windows. Although the program applies to both low- and high-rise multifamily buildings, the program administrator explained that mostly low-rise buildings participated in the program because builders felt pressure from more stringent residential energy codes.

  The administrator mentioned that commercial energy codes are about 10 years behind residential and, because of this, commercial developers are not as interested in energy efficient windows. With a limited budget for the program, buildings with less window area also were targeted to increase market penetration across buildings and indicate a shift in the market to more builders. CMFNH is currently closing out, but an updated statewide program is in the works to replace it and other California incentive programs starting in 2021.

6.2 Program Challenges, Opportunities, and Successes

Interviews with stakeholders highlighted several themes pertaining to above-code fenestration program similarities, challenges, and successes. Figure 6-1 shows common program characteristics found from interviews.

Figure 6-1: Above-Code Fenestration Program Common Characteristics

Typical Building Participants

"Mom and Pop," including offices, retail, restaurants, and hotels

- More small customers over larger corporate
- Large building owners do not see the ROI value as clearly for windows as competing improvements like lighting
- Older buildings were often cited
- No programs cited hospitals as participants except smaller medical offices

Number of Rebate Projects

Ranged from 1-2 per year to 30-70 per year

- Number of projects varied by jurisdiction and market size
- Larger jurisdictions like Seattle and areas of Virginia see projects range from 30-70 per year
- Some programs had substantially more residential uptake of window incentives than commercial

Program Duration

Ranged from a recent program start in 2020 to program start in 1986

- Dominion Energy's phase 2 window film program just started versus
- Seattle City Light's initial weatherization focused pilot launched in 1986 and still ongoing

Source: Guidehouse; Interviews.

Some administrators spoke to the impetus behind each program's creation and incentive structure. Most often, programs were looking for a cost-effective, non-residential incentive that would fit within a certain budget. Platte River Power Authority had conducted a few demand side management potential studies and identified windows as a promising measure. Responses varied for how certain U-factor and SHGC thresholds were determined. Most utilities designed their baselines in accordance with the local energy code. For example, Dominion Energy looked to Technical Reference Models from different states in similar climate zones. While no changes to any programs are expected in the immediate future, one utility mentioned that their incentive may be ending shortly due to market saturation.

Most program administrators did not encounter issues with installation. Some were not involved in installation and so were unaware of any problems, while others were engaged in the entire process and did not experience any significant complications. Seattle City Light stated that during the rare cases where there are installation issues, they have the power to withhold incentives until resolved. Many of the programs listed in Table 6-1 require an NFRC label or label certificate to qualify for rebates. Out of the 14 programs, nine mentioned NFRC certification explicitly, demonstrated either through a label or a U-factor or SHGC rated in accordance with NFRC. One administrator mentioned difficulty in obtaining NFRC certification for site-built windows. The administrator explained that they have tried to obtain NFRC certificates from the supplier but if that is unavailable, they will contact the manufacturer themselves.

For almost all programs, participation seems to be a challenge. Regardless of program size, several administrators noted across the total rebate projects received per year, the number of fenestration projects were negligible. Most interviewees explained that other energy efficiency improvements were prioritized, such as lighting with quicker paybacks and lower capital costs. Port Angeles added another issue wherein most of their commercial customers were small mom and pop shops that did not own the building but paid for utilities.

Due to split incentive issues, the program administrator said it is difficult to incentivize businesses to replace their windows.

> **Participation is a challenge for most programs, but those with more success market non-energy benefits**

Programs that had relatively high participation noted they marketed their rebates slightly differently depending on the target market and focused on non-energy benefits. For example, in ways that could be understood by a property manager. Seattle City Light noted that they focused on the non-energy benefits of window replacement such as reducing noise, increasing comfort, and reducing tenant turnover. The Dominion's window film program administrator expressed that aesthetics and reducing solar heat gain are big selling points for participants. The High Country Conservation Center mentioned that businesses are more likely to partake in energy efficiency improvements for sustainability recognition rather than for financial reasons, especially since energy costs are lower in Colorado. The impetus for window replacements in these programs seems tied more to aesthetics, comfort, sustainability as opposed to energy or economics alone.

Utilities also had lessons-learned to share on what has been done to date and how their programs could be improved:

- **Program education for the building designers and owner/developer community could improve understanding.** Austin Energy and Dominion Energy expressed that if designers and business owners were more educated on the energy benefits of window replacement, they would be more likely to realize the savings offered by their rebates. The administrator at Austin Energy mentioned that he would also like to eliminate barriers to the design community by providing tools that make participation as easy as possible. Because the customer usually is not the individual making the decision on fenestration characteristics, he explained the need to build the designer's expertise through tools that connect specifications to rebates and benefits.
- **Aesthetics and diversity of available products matter.** Dominion noted that its window film program was implemented in two phases. From phase one to now, it increased the $/ft^2 and SHGC requirement from 0.40 to 0.50 and changed requirements from darker film to lighter film. These changes made the program more advantageous to contractors because they now had more films that qualified for the incentive. Additionally, the lighter films appealed more to building owners' aesthetic tastes, increasing participation.
- **The more contractors and distributors aware of the program the better.** For program design, Seattle City Light found better success with allowing any installation contractor to participate in the incentive program rather than requiring a short finite list of participating contractors. Certain administrators stated that they

> **Marketing to contractors and distributors can lead to increased program uptake.**

noticed a significant rise in participation when they increased their focus on the distributors for other incentive programs. For example, the administrator from Platte River Power Authority mentioned that despite high rebates, they had little participation in their HVAC program. However, when they started working directly with distributors and increased their stock of energy efficient systems, participation skyrocketed. This indicates that utilities may have more success with window incentives if efforts are geared more toward the supplier of the product or service rather than the customer.

Former Above-Code Voluntary Programs

During our research for current programs, we also explored discontinued fenestration programs through secondary research and internal discussions with Guidehouse utility experts. Through our efforts, we only identified one recently discontinued above-code fenestration program, administered by MidAmerican Energy Company. Available in Iowa and Illinois, its Building Shell – Windows program for business operated in 2019 and offered a rebate of $25/unit for windows with a more efficient U-factor than required by the Illinois/Iowa Energy Code. We did not receive a response when we contacted MidAmerican for an interview.

7. Conclusions

7.1 Recommendations to Advance Energy Efficient Fenestration

Energy efficient fenestration technologies are proven and available in the market to reduce building energy consumption. Adoption is primarily hindered by market dynamics, rather than lack of technological innovation. As a result, cost reduction, especially related to manufacturing; increased value placed on energy and non-energy benefits; improvements in fenestration selection processes; stakeholder education; and regulations and policy can all support growth in installed fenestration energy efficiency.

More stringent energy codes historically have been the main driver of adoption. Continued advancement in energy codes and voluntary stretch codes, especially more focus on the building envelope and limiting trade-offs, is required to keep the fenestration market moving toward higher performing fenestration designs. Ensuring codes include measures that backstop fenestration would guarantee fenestration and other building envelope technologies meet baseline efficiency standards. Additionally, state and local initiatives or policies aimed at raising energy performance standards can incentivize manufacturers to supply more energy efficient products. In jurisdictions where the most recent model energy codes or more stringent codes have been adopted and enforcement is consistent, more efficient fenestration tends to be selected. However, interviews indicated that fenestration code enforcement is still lagging in many parts of the country. To effectively drive energy efficient fenestration adoption, the commitment to providing consistent performance information to help enable enforcing energy codes at various points in the construction process and field verification should be increased.

Cost barriers remain a key factor in the market, and several pathways including upfront rebates or incentives in addition to technological innovation are available to increase affordability of energy efficient fenestration. Implementing energy efficiency programs through rebates and incentives (both upstream and downstream) can help reduce upfront cost and increase adoption as well. Additionally, the growing market for energy efficient fenestration retrofits in existing buildings likely means more users will recognize and value the non-energy comfort benefits that complement the energy and cost savings payback. Growing demand also allows manufacturers to reach a larger market beyond new construction, improving economies of scale and allowing for cost reductions in production. More stringent energy codes and enforcement can also influence demand, product design, installation, and price of efficient fenestration.[53]

Adjusting the design-bid-build process can also enable early and more serious consideration of fenestration efficiency in projects. More communication and utilizing an integrated design process with established energy efficiency targets between architects, engineers, and developers during a project's early stages can enable energy efficient building envelopes by increasing intentionality in fenestration selection. Also, engaging glazing contractors or façade-specific consultants early in project stages, and as early as building engineers, is ideal to facilitate fenestration specification conversations before decisions are finalized on HVAC systems. More consideration of energy efficiency as well as non-energy benefits associated with high performance fenestration within the budget planning stage of a project can also reduce value engineering and make owners less reluctant to adopt energy efficient fenestration if it is already included in the cost.[5]

A certification program that increases the use of whole product performance metrics is necessary for better performance measurement and improvements in building energy code enforcement and consistency. The data collected in this study clearly shows there was a mix of center-of-glass U-factor and whole product U-factors reported, which indicates market confusion and the need for more clear metrics as well as more widespread use of whole product metrics.

Education was consistently cited as an area for improvement across the industry. Designers cannot specify what they do not know; however, there is often a lag between when new technologies are introduced and architect familiarity. Glass and entire fenestration systems are not always a focus in architecture school and mechanical engineers may not understand how fenestration improvements can lead to changes in HVAC sizing. Owners also need to have a better understanding of the benefits that come with energy efficient fenestration. If fenestration can be marketed in ways that owners care (more modern aesthetics, less condensation, increased thermal comfort) then higher performing products are more likely to be installed. Analysis tools, correctly used, allow for a more rigorous assessment of energy and non-energy benefits of energy efficient fenestration, equipping architects with the ability to better inform their clients. Demonstration projects that install efficient fenestration also have the potential to increase market uptake by increasing confidence in newer technologies through successful case studies.[5]

Considering the nuances of the commercial building fenestration market in energy efficiency program design and offerings and utility program targets is critical to successful uptake of program incentives. Most energy efficiency window-specific commercial programs suffer from low uptake and from few market sectors. Programs could benefit from focusing on separate building sectors (e.g., hotels, office building, medical complexes) and decision makers (e.g., building developers, large corporate building owners, small business owners) and their associated, specific drivers with targeted messaging and incentives.

Integrate buildings and building envelope data into state and local greenhouse gas target planning. State and city targets for GHG reductions are a powerful signal of commitment to energy efficiency. However, most GHG targets that exist in the U.S. do not currently include detailed strategies toward reaching stated goals. As local governments operationalize their targets in different sectors, like energy, and buildings, advocates are well-positioned to ensure that building envelope improvements, including fenestration, are considered as required areas of action. Further, existing state and local policies around building energy performance or benchmarking do not require data specific to the building envelope or fenestration. Collecting this building-level information, in addition to overall savings, can have a significant impact on informing and motivating the building industry to consider the importance of fenestration in overall building performance. Data on estimated energy efficiency potential associated with higher performance fenestration can also support and encourage implementation.

7.2 Recommendations for Further Research

The study took a comprehensive view of the U.S. commercial fenestration market, providing qualitative and quantitative data on the characteristics of installed fenestration stock and sales, market stakeholders and their motivations, market processes, code compliance, and other elements of the fenestration industry. This study completed an assessment at the national level, with consideration for regional dynamics. Guidehouse's research revealed there is significant benefit to data collection and understanding the complex industry dynamics in the commercial buildings market, especially at regional or state levels. Additional and ongoing research will support industry awareness of the benefits of high efficiency commercial façade and fenestration systems and identify gaps in available information, processes, or resources to support industry players in making decisions.

A deeper assessment into regional and state dynamics based on building characteristics in the diverse commercial buildings market is a recommended next step for fenestration market research. Regulations, market players, and fenestration performance needs vary significantly based on several factors, including geography, building type and use, vintage, and more. Guidehouse recommends periodic updates to this analysis as new data sources become available as well as the following areas of research:

- Conduct more research based on the findings presented in this analysis to further investigate including:
    - Market understanding of NFRC label certificate usage and benefits
    - Prevalence of single pane in certain scenarios
    - Prevalence of non-Low-E coating fenestration
    - Prevalence of aluminum/other metal and non-thermally broken frames including the size and type of the thermal break
    - Focused research on specific building types
    - Data collection on U-factor and SHGC for older building vintages, including resolving the differences between center-of-glass and whole-window properties
    - Understanding the low rate of fenestration retrofits in existing stock.
- Assess the level of import and export of energy efficient commercial fenestration products and the hurdles to U.S. manufacturers to compete or surpass the largely European-led market and bring the manufacturing to the U.S.
- Conduct building energy code compliance and enforcement surveys that involve onsite verification to better understand actual compliance rates for fenestration.
- Work with regional and state entities to conduct statistically significant commercial building surveys on an ongoing basis that include façade and fenestration system characteristics. Conduct onsite installed stock building surveys specific to fenestration especially in regions that lack data collected to date.
- Introduce fenestration-related standardized questions to a range of building data collection instruments associated with local, state, and federal building technologies surveys and energy consumption benchmarking in buildings.
- Assess the impacts of state and local aggressive climate goals that require drastic energy consumption reductions and the opportunities for energy efficient fenestration.
- Survey building owners on fenestration retrofits to understand level of customer awareness in diverse fenestration technologies and options, common barriers to fenestration replacement, and opportunities for interventions.
- Conduct further research to better understand, analyze, and quantify embodied carbon and recyclability of current fenestration materials and to develop new low-carbon fenestration and framing materials.
- Conduct further research to understand and quantify the types of commercial fenestration retrofits in the current commercial building stock including films, storm windows, shading systems, reglazing, and recladding.

A critical next step in further research is in process based on the findings outlined in this report. NFRC is sponsoring research to translate the data into a national estimate of the energy efficiency potential associated with fenestration retrofits and more efficient fenestration installations in new construction. The estimated savings value will provide critical insight into the significant remaining opportunity for further adoption of energy efficient fenestration in the commercial buildings market.

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Appendix A. Installed Stock and Sales Methodology

A.1 Data Analysis and Weighting

The commercial building data sources were combined by fitting a multivariate beta distribution model (dirichlet) to the count of buildings data for each categorical variable (fenestration characteristics). The number of counts directly affects the implied confidence for the proportions of each category and the effective weighting of each study. However, to sum the counts of each category across all studies regardless of factors like study coverage, recentness, or new construction and retrofits would not accurately reflect the installed stock. This was addressed through the following analysis approaches:

- **Transition Matrices:** Transition matrices applied to all the datasets except for the building survey conducted in 2020, which estimates how fenestration retrofits, new building construction, and demolitions may have affected the fenestration data from older building surveys. Guidehouse used the statistical building sample weights provided in each study, where available, to compute the population represented by that study. The weights show the number of buildings represented in each data point. A retrofit rate of 0.4% and variable construction rate (around 0.7% to 1.2% annually) were applied over the time period from the study year until 2020. A retrofit here represents a replacement to the current fenestration. To compute the new effective counts for each category, transition matrices dictating the changes to the categorical variables and were applied to these populations to show how retrofits and new construction would affect the results of older datasets. The transition matrices were based on fenestration market data collected through manufacturers sales data, the AAMA industry report, and the building survey. While only the counts from each study (not the weights) are used in our modeling effort, the distribution of these counts changed (in some cases significantly) due to consideration of retrofits and new construction.
- **Discount Factors:** Study counts were discounted by a discount factor computed as the inverse of the compounded construction rate from the study year through 2020, with the idea that the sample size of each study is effectively smaller at present due to unaccounted development. Because demolition, construction, and retrofits are only estimated in this analysis, this allowed us to remove counts from older studies (weighing them less) and more accurately reflect our uncertainty of changes in the underlying study population.
- **Study Weights:** A study weight factor was multiplied by the observed counts based on the estimated accuracy of the data (the study coverage, the completeness, and fidelity). The combination of this with the transition matrices and discount factors gave Guidehouse effective counts for each categorical variable, which better represents the trust and contribution of each study in the model. In some cases, studies were not factored in the model for certain groups at all. The 2015 RECS data, which is at the unit level, was not used to identify the distribution of building floors, as every observation is identically single-story and is not representative of the desired building population.
- **Final Adjustments:** Some figures were not included in the results due to limited available data for those variables or lack of confidence in the outputs. The initial results were compared to available data and information from manufacturers, manufacturer and industry expert interviews, and the AAMA industry report. Where results showed inconsistencies or deviated significantly from other available information, some data was removed or adjusted accordingly.

A.2 Summary of Stakeholders Contacted and Interviewed

Table A-1: Summary of Stakeholders Contacted and Interviewed

Organization Category	Number Contacted	Number Interviewed	Response Rate
Architecture and Engineering Firms	320	6	2%
Building Owners/Operators	16	1	6%
Cross-Cutting Manufacturers	76	2	3%
Glass Manufacturers & Coaters	26	5	19%
Frame Manufacturers	6	2	33%
Manufacturer Representatives	2	2	100%
Distributors and Glazing Contractors	41	2	5%
Code Officials	9	6	67%
Code Compliance Agencies (PNNL/BCAP/DOE/REEOS/IECC)	6	5	83%
Incentive Program Administrators	19	9	47%
Other: SMEs/Non-Profits/Trade Associations/Etc.	48	10	21%
Total	**569**	**50**	**9%**

About Guidehouse

Guidehouse is a leading global provider of consulting services to the public and commercial markets with broad capabilities in management, technology, and risk consulting. We help clients address their toughest challenges with a focus on markets and clients facing transformational change, technology-driven innovation and significant regulatory pressure. Across a range of advisory, consulting, outsourcing, and technology/analytics services, we help clients create scalable, innovative solutions that prepare them for future growth and success. Headquartered in Washington, DC, the company has more than 7,000 professionals in more than 50 locations. Guidehouse is led by seasoned professionals with proven and diverse expertise in traditional and emerging technologies, markets and agenda-setting issues driving national and global economies. For more information, please visit: www.guidehouse.com.