Commercial Replacement and Attachment Window Solutions

Market Characterization Report

June 26, 2026

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List of Abbreviations

Abbreviation	Definition
AERC	Attachments Energy Rating Council
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
ASTM	Advancing Standards Transforming Markets International
BPS	Building Performance Standards
CalMTA	California Market Transformation Administrator
CATI	Computer-Assisted Telephone Interviewing
CBECS	Commercial Buildings Energy Consumption Survey
CEC	California Energy Commission
CEUS	California Commercial End-Use Survey
CRAWS	Commercial Replacement and Attachment Window Solutions (program)
CSW	Commercial secondary window
DOE	U.S. Department of Energy
EIA	U.S. Energy Information Administration
EPIC	Electric Program Investment Charge
ESCO	Energy service company
GDP	Gross domestic product
GHG	Greenhouse gas
HVAC	Heating, ventilation, and air conditioning
IOU	Investor-owned utility
LEED	Leadership in Energy and Environmental Design
Low-E	Low-Emissivity
MTI	Market transformation initiative
NEEA	Northwest Energy Efficiency Alliance
NFRC	National Fenestration Rating Council
NLR	National Laboratory of the Rockies
NREL[1]	National Renewable Energy Laboratory
PG&E	Pacific Gas and Electric Company
PV	Photovoltaics
ROI	Return on investment
SCE	Southern California Edison
SDG&E	San Diego Gas & Electric Company
SHGC	Solar heat gain coefficient
VIG	Vacuum-insulated glass
WWR	Window-to-wall ratio

[1] The National Renewable Energy Laboratory (NREL) was renamed to The National Laboratory of the Rockies (NLR) on December 1, 2025.

1 Executive summary

This market characterization report is an output of the Phase II research for the Commercial Replacement and Attachment Window Solutions (CRAWS) Advancement Plan, finalized in September 2024.[2] *CRAWS* in this report specifically refers to *vacuum insulated glass* (VIG) and *commercial secondary windows* (CSW). CSW and VIG are retrofit products and are referred to as *advanced window solutions* throughout this report. Although still emerging, the CRAWS market shows strong potential, as these solutions enhance the energy efficiency and performance of existing windows without the need for full replacement.[3] The CRAWS market transformation initiative (MTI) offers a substantial opportunity to improve building envelope thermal performance; reduce heating, ventilation, and air conditioning (HVAC) loads; and enable downsizing of HVAC systems in need of replacement. VIG and CSW technologies can enable an "envelope first" approach that helps building owners maximize the efficiency of their decarbonization efforts (such as installing a downsized HVAC for the updated windows), while saving money by eliminating the need for full window replacement. Depending on the application, VIG can be up to 50% less expensive and CSW can be as much as 90% less expensive than full window replacement.[4]

This report discusses the California market for CSW and VIG, highlighting key barriers, opportunities, and impacts by examining demand- and supply-side dynamics, awareness of secondary windows, and the regulatory framework.

1.1 Objectives and methods

This market characterization report provides an overview of the commercial market for CRAWS in California. It characterizes the current saturation and market shares of CSW and VIG; assesses demand-side factors such as awareness, perceptions, and adoption barriers among market actors; identifies the costs and benefits associated with CSW and VIG; and reviews the relevant regulatory landscape. To accomplish the above objectives, the California Market Transformation Administrator (CalMTA) conducted primary and secondary research, including a literature review, interviews, and a survey, as summarized in Table 1.

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[2] CalMTA. 2024. *Commercial Replacement & Attachment Window Solutions Advancement Plan.* September 17, 2024. https://calmta.org/resourcereport/commercial-replacement-attachment-window-solutions-advancement-plan/

[3] U.S. Department of Energy. 2019. *Foundational Design Research. Building Technologies Office*. https://www.energy.gov/sites/prod/files/2019/12/f69/2019-bto-peer-review-report_0.pdf

[4] BetterBricks. 2025. Secondary Windows Rejuvenate Aging Office Building. https://betterbricks.com/wp-content/uploads/2025/03/915Broadway_SecondaryWindows_CaseStudy.pdf

Table 1. Summary of Research Activities

Audience or Task	Research Description	No. Completed
Secondary Research and Literature Review	Secondary data review and analysis; literature review of evaluation and market reports	14 articles/reports/presentations; 3 data sets
Manufacturers, Energy Service Companies (ESCOs), and Installers[5]	In-depth interviews	13
Commercial Tenants	In-depth interviews	6
Building Owners and Property Managers	In-depth interviews	8
	Quantitative survey	114

1.2 Key findings and conclusions

1.2.1 Finding 1: Window performance has a strong influence on a building's energy use

Buildings account for nearly 40% of the total U.S. energy use and about 75% of the country's electricity use, with much of that energy spent on maintaining comfortable indoor conditions.[6] According to a study by the Northwest Energy Efficiency Alliance (NEEA), windows represent roughly 15% of a building's exterior surface but account for about 40% of HVAC-related energy losses, equivalent to approximately 12% of total building energy use.[7]

Properly installed and well-performing windows can offer benefits, including peak load reduction, noise reduction, thermal comfort, visual aesthetics, and resilience to extreme weather conditions. However, investment in window and façade upgrades in general continues to be overlooked in favor of HVAC solutions.[8] The reality is that windows can play a notable role in a building's energy

[5] CalMTA team was able to interview only two installers. Due to the small sample size, the installer insights are not reported.

[6] National Laboratory of the Rockies. 2023. *NREL Researchers Reveal How Buildings Across the United States Do—and Could—Use Energy*. September 14, 2023. https://www.nlr.gov/news/detail/features/2023/nrel-researchers-reveal-how-buildings-across-the-united-states-do-and-could-use-energy.

[7] Northwest Energy Efficiency Alliance (NEEA). 2023. *Commercial Secondary Windows Field Test.* Retrieved December 18, 2023. https://neea.org/resource/commercial-secondary-windows-field-test/.

[8] Façade Tectonics Institute. 2024. *High-Performance Façades: Barriers to Widespread Adoption in Non-Residential and Multi-Family Buildings and Strategies to Overcome Them.* Prepared for the U.S. Department of Energy. https://www.facadetectonics.org/publications/collection/publications#entry:58756@1:url.

savings by reducing peak load and stress on an HVAC system.[9] Windows also provide additional non-energy benefits such as increased comfort and reduction of noise and glare.[10]

1.2.2 Finding 2: Market actors see meaningful benefits from window solutions adoption

Although familiarity with advanced window technologies remains low, market actors such as ESCOs recognize the potential non-energy benefits of CSW and VIG (see Table 2). While secondary windows have long been associated with helping preserve historic buildings (given that they do not require major renovations to frames or to the exterior of a building), they can also be applied to non-historic buildings to offer both energy savings as well as non-energy benefits.

Non-energy benefits

Non-energy benefits cited by CalMTA interviewees as well as in relevant literature include aesthetics, comfort, soundproofing, occupant safety, and long warranties. As shown in Table 2, manufacturers emphasize that CSW solutions tend to be less expensive and provide ease of installation compared to window replacement; however, these are not widely recognized benefits among other market actors. CalMTA interviews with ESCOs, manufacturers, and owners and managers highlighted that CSWs deliver occupant comfort benefits beyond energy performance. Participants consistently reported improved thermal comfort, with several interviewees emphasizing enhanced sound proofing. One university administrator (who was not very familiar with CSW) mentioned that they believed occupant safety was a benefit, a finding echoed by Evergreen Economics in the secondary window market characterization they developed for NEEA, noting that CSWs effectively reduced exterior noise.[11]

Table 2. Non-Energy Benefits of Advanced Window Solutions

Customer Benefit	Sources
Aesthetics	Manufacturer interviews, CalNEXT Commercial Windows Market Study[a]
Comfort	Manufacturer interviews, ESCO interviews, CalNEXT Commercial Windows Market Study, NEEA Secondary Window Market Characterization[b]
Soundproofing	Manufacturer interviews, ESCO interviews, CalNEXT Commercial Windows Market Study, NEEA Secondary Window Market Characterization
Long warranties	Manufacturer interviews

[9] National Renewable Energy Laboratory (NREL). 2022. *Pathway to Zero Energy Windows: Advancing Technologies and Market Adoption.* Prepared for the U.S. Department of Energy. April 2022. https://research-ub.nrel.gov/en/publications/pathway-to-zero-energy-windows-advancing-technologies-and-market-

[10] Navigant Consulting. 2018. *Commercial Windows Attachment (SGS) Initiative.* Prepared for NEEA. https://neea.org/wp-content/uploads/2025/03/commercial-window-attachments-sgs-phase-1-research.pdf

[11] Evergreen Economics. 2020. *Commercial Window Attachments: Secondary Window Market Characterization*. Prepared for NEEA. https://neea.org/wp-content/uploads/2025/03/Commercial-Window-Attachments-Secondary-Window-Market-Characterization.pdf

Customer Benefit	Sources
Cost effectiveness (CSW only)	Manufacturer interviews, NEEA Secondary Window Market Characterization
Ease of installation	Manufacturer interviews
Safety and security	Building owner interviews, NEEA Secondary Window Market Characterization

[a] *Energy Solutions. 2024. Commercial Windows Market Study and Measure Package Development. Prepared for CalNEXT.*

[b] *Evergreen Economics. 2020. Commercial Window Attachments: Secondary Window Market Characterization. Prepared for NEEA.*

Energy benefits

Secondary windows offer energy benefits. The Attachment Energy Rating Council highlighted several BetterBricks case studies that illustrate the performance of secondary windows. In one case study, an aerospace manufacturer that was experiencing thermal comfort complaints decided to retrofit its single-pane window inventory with secondary windows and achieved a 12% reduction in total building energy cost, resulting in $4,066 annual energy cost savings and representing a product payback period of 10.7 years.[12] The labor time needed to complete the installation of 331 window attachments was 3.5 days. Another study involving a 66,000 square-foot Montana University building achieved a 5.9 decibel reduction in noise level from outside noise and an 11% decrease in air leakage, along with improved thermal comfort.[13] Yet another study at a legal office in Portland, Oregon, showed a 13.4% reduction in air leakage in a 15,741 square-foot building built in 1925. Installation averaged 20 minutes per window.[14]

LuxWall, a manufacturer of VIG, commissioned a study comparing the company's Enthermal glass product against both an existing single-pane glass and a high-performance double-pane full replacement and found that its VIG product outperformed the competition on U-value, interior glass surface temperature, and energy and carbon emission savings. Compared to the existing single-pane glass, Enthermal glass had a 60% reduction in solar heat gain, 45% improvement in heat loss, and a 43% lower HVAC peak load. Enthermal glass also represented a two to three times higher return on investment (ROI) compared to high-performance double-pane full replacement.[15]

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[12] BetterBricks. 2025. *Secondary Windows Bring Stellar Savings for Aerospace Firm.* https://betterbricks.com/wp-content/uploads/2025/03/SecondaryWindows_Crane_CaseStudy_lr.pdf.

[13] BetterBricks. 2023a. *Secondary Windows Help Lead the Way to LEED Certification*. https://betterbricks.com/wp-content/uploads/2022/09/RomneyHall_Windows-Case-Study.pdf.

[14] BetterBricks. 2023b. *Road Noise Disturbs the Peace at Portland Law Firm*. https://betterbricks.com/wp-content/uploads/2025/03/SecondaryWindows_SBH-Law-Office.pdf.

[15] LuxWall. 2025. Enthermal™ product data sheet [PDF]. LuxWall. https://www.luxwall.com/wp-content/uploads/Enthermal-R18-Product-Data-Sheet_050725_LW00041.3.pdf.

1.2.3 Finding 3: Current incentives and building codes are insufficient to drive widespread adoption

Currently, there are only a few available incentive programs that help building owners offset the costs of secondary windows through tax benefits and credits. The 179 D Energy-Efficient Commercial Building Deduction offers a federal tax benefit for energy-efficient upgrades to lighting, HVAC, and building envelopes in both new and existing buildings that meet specific energy savings thresholds. Additional federal and state rehabilitation tax credits are available for qualifying properties. These programs are designed for broad energy efficiency improvements and not specifically for CSW, making them inadequate drivers of CSW adoption. Secondary windows, while improving thermal performance, often do not generate enough measurable energy savings to qualify for the full deduction. Additional non-tax-based program incentives are available through the California Energy Commission and state investor-owned utilities (IOU) (see Section 5.4, California programs, pilots, and incentives).

A recent market analysis found that incentives covering 40% to 50% of the incremental cost of secondary windows could substantially impact market adoption.[16] Further, the report suggested that disadvantaged communities should be awarded 150% above the prescribed incentive for any high-performance window solution project.[17] While advanced energy codes like California's Title 24 and New York City's Local Law 97 may influence demand, most manufacturers interviewed by CalMTA did not report actively tracking code changes.

1.2.4 Finding 4: Cost is a primary barrier to window improvements

High costs associated with traditional window replacements, often exceeding $150 per square foot, remain a major deterrent for building owners. Despite their lower price points and faster installation timelines, market adoption of VIG and CSW continues to be hindered by the high cost of window upgrades.

General window investment

Most commercial buildings continue to rely on single-pane windows, a major source of energy loss, yet less than 1% of windows are replaced annually.[18] Efforts to replace these windows are often hindered by persistent barriers—primarily, perceptions regarding costs, tenant disruption from installation, and extended project timelines.[19] U.S. Energy Information Administration (EIA)

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[16] Energy Solutions. 2024. *Commercial Windows Market Study and Measure Package Development*. https://calnext.com/wp-content/uploads/2024/05/ET23SWE0018_Commercial-Windows-Market-Study_Final-Report.pdf.

[17] Energy Solutions. 2024. *Commercial Windows Market Study and Measure Package Development*. https://calnext.com/wp-content/uploads/2024/05/ET23SWE0018_Commercial-Windows-Market-Study_Final-Report.pdf.

[18] SPR Consulting. 2023. *Innovative and Cost-Effective Solutions to Improve Building Envelope Performance*.

[19] NLR. 2022. *Pathway to Zero Energy Windows: Advancing Technologies and Market Adoption.* *https://doi.org/10.2172/1866581.*

2012 data show that window replacements occur at less than half the rate of HVAC and roof replacements, and at only a slightly higher rate than insulation.[20] One reason for this disparity is that HVAC engineers are involved early in renovation planning, providing free modeling and influencing design decisions, whereas window and façade designers are typically consulted later, limiting their impact on early-stage project decisions.

In interviews conducted by CalMTA with market actors (manufacturers, building owners and managers, tenants, and ESCOs), owners and tenants cited a perception of high upfront prices, uncertain ROI, and competing upgrade priorities (such as HVAC or roofing) as reasons for delaying or avoiding window improvements in general.

CSW and VIG retrofits

Retrofitting with technologies like VIG and CSW offers faster, less disruptive, and more affordable upgrades compared with full replacements. Many emerging energy efficiency technologies tend to be more expensive than incumbent solutions, creating cost-related barriers to adoption. In contrast, advanced window technologies, specifically CSWs and VIG, have proven to be more cost-effective alternatives compared to traditional full window replacements. Traditional full replacement projects typically cost $150 to $200 per square foot of window area and may take up to 48 months to complete, since they often require new framing and additional repairs beyond the glass itself.[21] In contrast, VIG installations are estimated at $80 to $120 per square foot, with timelines reduced to under 12 months. Importantly, VIG does not require frame replacement and minimizes tenant disruption, directly addressing some of the key concerns raised by building owners and operators. Similarly, CSWs require substantially less time than full replacements or VIG (60%–70% faster), with average costs of $38.15 per square foot.[22] Despite these advantages compared to traditional window solutions, market actor perceptions of the high cost for window upgrade persist, hindering market adoption.

Even when interest exists in CSW or VIG, competing capital needs often take precedence. CalMTA ESCO interviews reinforced this finding: cost was identified as a central barrier by multiple respondents. One noted that "windows typically do not sell unless the out-of-pocket expense is low," emphasizing that utility incentives or state subsidies are often critical to make projects financially viable. Across discussions with ESCOs, building owners, manufacturers, and tenants, the consensus was clear: upfront costs, limited financing options, and opportunity costs remain the most substantial obstacles to adoption.

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[20] NLR. 2022. *Pathway to Zero Energy Windows: Advancing Technologies and Market Adoption*. docs.nrel.gov/docs/fy22osti/80171.pdf.

[21] SPR Consulting. 2023. *Innovative and Cost-Effective Solutions to Improve Building Envelope Performance*.

[22] Energy Solutions. 2024. *Commercial Windows Market Study and Measure Package Development*. https://calnext.com/wp-content/uploads/2024/05/ET23SWE0018_Commercial-Windows-Market-Study_Final-Report.pdf.

Additional market barriers include limited product availability and the inability of market actors to differentiate among window technologies.[23]

Several factors have prevented market actors from embracing and seeking window solutions. Many barriers stem from a lack of awareness or knowledge regarding one or more aspects of window solutions or the installation process.

1.2.5 Finding 5: Persistent barriers inhibit the adoption of window solutions such as CSW and VIG

In addition to cost perception barriers, adoption of CSW and VIG technologies is slowed by low market awareness, supply chain limitations, inconsistent marketing, and misperceptions about performance and applicability, especially among key decision makers and midstream actors.

Low awareness

A common theme across literature is low levels of awareness of window solutions among key market actors. A 2021 report surveyed market actors about CSW and found that architects, glazing contractors, and property managers were all largely unaware of CSW products.[24] While architects and glazers expressed some level of awareness of CSW products, they associated them almost exclusively with historical buildings. Property managers who managed non-historical buildings had almost no exposure to CSW solutions. Other research found that architects, contractors, and consultants possessed a limited understanding of CSW nuances, including installation costs and processes relative to full window replacements, technical specifications and performance characteristics, and building code implications—that is, whether "secondary windows would meet build[ing] code requirements when code-related upgrades are triggered by larger renovations."[25]

CalMTA's survey of commercial building owners and managers revealed that the main factor preventing selection of CSW or VIG as a window replacement or upgrade solution was a lack of information (64% of respondents), followed by concerns about performance (43% of respondents). Only 7% of surveyed commercial building owners and managers reported cost as a

[23] Evergreen Economics. 2020. *Commercial Window Attachments: Secondary Window Market Characterization*. Prepared for NEEA. https://neea.org/wp-content/uploads/2025/03/Commercial-Window-Attachments-Secondary-Window-Market-Characterization.pdf.

[24] Cadeo Group. 2021. *Commercial Secondary Window Program Development Research*. Prepared for NEEA. https://neea.org/wp-content/uploads/2025/03/High-Performance-Windows-Market-Characterization-Study.pdf.

[25] Evergreen Economics. 2020. *Commercial Window Attachments: Secondary Window Market Characterization*. Prepared for NEEA. https://neea.org/wp-content/uploads/2025/03/Commercial-Window-Attachments-Secondary-Window-Market-Characterization.pdf.

factor that would prevent them from selecting CSW or VIG, suggesting that awareness of these technologies and their benefits is a key barrier in selecting them as a solution.[26]

CalMTA survey data among commercial building owners/managers shows relatively high familiarity with CSW (51% familiar, 34% very familiar) but very low familiarity with VIG (19% familiar, only 4% very familiar). Interviews, however, tell a different story, as most owners, managers, and tenants reported little to no awareness of either technology, while manufacturers rated their own familiarity high but saw limited knowledge among other market participants (building owners, etc.). The high level of reported familiarity with CSW may be explained, at least partially, by the lack of distinct product differentiation documented in prior studies.[27]

Supply chain constraints

While cost remains a critical challenge, supply chain constraints further complicate adoption—particularly for VIG. Although the CSW supply chain is well established, CalMTA interviews revealed that the VIG supply chain in the United States is still emerging. Manufacturers and ESCOs expressed concerns about tariffs, import dependencies, and rising lead times. These issues add risk and unpredictability to already expensive projects, exacerbating financial and logistical barriers to implementation. Additional challenges include a lack of product availability and the inability of market actors to differentiate between products.

Supply chain bypass

Research indicates that manufacturers tend to advertise secondary windows directly to end users since most orders for these products are custom, resulting in a very simple supply chain that bypasses distributors, wholesalers, and retailers.[28] However, this can cause a knowledge gap among midstream actors, perpetuating low awareness and knowledge and creating a barrier to adoption. Market actors expressed uncertainty about the commercial scale availability of secondary windows, with one architect commenting that they were familiar with only a "limited number of products that are

> "Currently [we sell] D2C [direct to customer] mostly, especially in residential and small commercial markets.
>
> - CSW Manufacturer

[26] CalMTA CRAWS Building Owner and Property Manager Survey Q F1: "What factors, if any, would prevent you from selecting CSW or VIG as a replacement or upgrade solution to your window needs? Please rank up to three factors, where #1 is the most important and #3 is the third-most important." (n=114). Results rounded to the nearest percentage.

[27] Evergreen Economics. 2020. *Commercial Window Attachments: Secondary Window Market Characterization*. Prepared for NEEA. https://neea.org/wp-content/uploads/2025/03/Commercial-Window-Attachments-Secondary-Window-Market-Characterization.pdf.

[28] Evergreen Economics. 2020. *Commercial Window Attachments: Secondary Window Market Characterization*. Prepared for NEEA. https://neea.org/wp-content/uploads/2025/03/Commercial-Window-Attachments-Secondary-Window-Market-Characterization.pdf.

mostly aimed at the residential market. Most of these manufacturers are not geared to provide quantity or schedule for commercial application."[29]

Limited marketing

Secondary windows are often undermarketed, with limited emphasis on their distinct value and differentiation from other window solutions. In fact, a recent market characterization report found that secondary windows are often presented as one product and referred to with various terms such as "storm windows, secondary windows, window insulation, and window systems," regardless of whether they are technically low-emissivity (low-E) storm windows or secondary glazing systems.[30] The authors of the report recommended that NEEA identify and use consistent terms to describe secondary windows in efforts to market and communicate the benefits of the technology.

Project bundling

Interviews with ESCOs indicated that CSW and VIG are rarely pursued as standalone projects; instead, they are bundled with HVAC, lighting, or envelope upgrades to improve ROI and minimize disruption. This suggests that adoption of secondary window technologies is largely dependent on integration with broader retrofit activities, with which incremental costs can be more easily justified.

Window lifespan

Commercial windows are often "set-and-forget" products, with lifespans ranging from 40 to 70 years. Unless failures such as water or air intrusion occur, replacements are rare and typically fall well beyond the 10-year warranty period.[31] Consequently, the market for window upgrades is stronger in new construction than in existing buildings, as owners often prioritize higher-maintenance systems like HVAC. Supply chain challenges and low awareness of product differentiation further reduce the urgency to pursue window replacements.[32] Since windows are a relatively low-maintenance product, they are often overlooked or disregarded in favor of other building upgrades, such as HVAC. The higher rate of replacement for HVAC over windows is partly due to the tendency for HVAC engineers and designers to be included early in building renovation planning phases compared to window or façade designers, who are generally

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[29] Evergreen Economics. 2020. *Commercial Window Attachments: Secondary Window Market Characterization*. Prepared for NEEA. https://neea.org/wp-content/uploads/2025/03/Commercial-Window-Attachments-Secondary-Window-Market-Characterization.pdf

[30] Evergreen Economics. 2020. Commercial Window Attachments: Secondary Window Market Characterization. Prepared for NEEA. https://neea.org/wp-content/uploads/2025/03/Commercial-Window-Attachments-Secondary-Window-Market-Characterization.pdf

[31] Energy Solutions. 2024. *Commercial Windows Market Study and Measure Package Development.Commercial Windows Market Study*. Prepared for CalNEXT. https://calnext.com/wp-content/uploads/2024/05/ET23SWE0018_Commercial-Windows-Market-Study_Final-Report.pdf

[32] NREL. 2022. *Pathway to Zero Energy Windows: Advancing Technologies and Market Adoption*. https://docs.nrel.gov/docs/fy22osti/80171.pdf

consulted during later phases. HVAC consultants typically provide modeling free of charge in the initial planning phase.[33] While window and façade designers may also provide free modeling services, they are typically consulted much later in the construction process than HVAC consultants, who have an opportunity to influence the early stages of project design and specification.

Misperceptions and disconnects

In the interviews with CalMTA, manufacturers highlighted affordability and ease of installation as benefits of CSW. In contrast, ESCOs frequently cite cost and complexity of window replacement or upgrade projects as barriers to adoption. This indicates a disconnect between the supply and demand sides of the market and merits additional research. ESCOs and building owners noted in the interviews that most window upgrades are a result of region-specific weather conditions and customers' desire to save energy.

Although previous studies indicate that awareness and knowledge are generally low among key market actors, there are several misperceptions that contribute to barriers to the adoption of window solutions. Customers and policymakers do not always view windows as an important source of a building's energy savings and believe that the costs for materials are expensive and prohibitive.[34] Other common misperceptions are that secondary window installations are time-consuming, invasive, and disruptive to tenants; that installations require workers with specialized skills; and that CSWs are a niche product, specific to historic building preservation.[35]

Most prevalent barriers to adoption

Table 3 highlights some of the common barriers uncovered in the CalMTA literature review.

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[33] Façade Tectonics Institute. 2024. *High-Performance Facades*. https://www.facadetectonics.org/publications/collection/publications

[34] Energy Solutions. 2024. *Commercial Windows Market Study and Measure Package Development*. Prepared for CalNEXT. https://calnext.com/wp-content/uploads/2024/05/ET23SWE0018_Commercial-Windows-Market-Study_Final-Report.pdf

[35] Evergreen Economics. 2020. *Commercial Window Attachments: Secondary Window Market Characterization*. Prepared for NEEA. https://neea.org/wp-content/uploads/2025/03/Commercial-Window-Attachments-Secondary-Window-Market-Characterization.pdf

Table 3. Barriers to the Adoption of Secondary Window Solutions

Barrier	Description	Source
Disproportionate Focus on Solutions that Require Frame Alteration	Technology advancements have tended to focus on glass rather than promoting solutions such as CSW and VIG that do not require alteration of frames for installation, which provide additional benefits related to cost, time, and effort to update window stock.	Commercial Windows Market Study and Measure Package Development. 2024. https://etcc-ca.com/reports/commercial-windows-market-study-and-measure-package-development
Lack of Awareness	According to secondary literature, there is a general lack of awareness of CRAWS products, their benefits, and range of applications.	Commercial Window Attachments: Secondary Window Market Characterization. 2020. https://neea.org/wp-content/uploads/2025/03/Commercial-Secondary-Window-Program-Development-Research.pdf
Lack of Product Differentiation	Secondary window providers do not consistently distinguish between low-E storm windows and secondary glazing system products.	Commercial Window Attachments: Secondary Window Market Characterization. 2020. https://neea.org/wp-content/uploads/2025/03/Commercial-Secondary-Window-Program-Development-Research.pdf
Lack of Available Information, Resources/Training	Many glaziers (i.e., installers or contractors) had concerns regarding the cleaning requirements, time on task, and whether the process required any special training. Although installation of CSW is relatively quick and easy, few options for learning and gathering information exist, aside from manufacturer demonstrations. This perpetuates the general lack of awareness regarding CSW.	Commercial Secondary Window Program Development Research. 2021. https://neea.org/wp-content/uploads/2025/03/Commercial-Secondary-Window-Program-Development-Research.pdf
Uncertainty of EUL/Performance	Questions persist regarding the service life of VIG, including durability in various climates and the equipment needed to evaluate and test their performance; concerns about condensation also persist.	Lawrence Berkeley National Laboratory. 2023. "VIG Summit." https://drive.google.com/file/d/1ukXOH8bnzaF6kRiqm292weYReF9sxKEa/view
First Cost/Low Risk	New products—those in early stages of product maturity or those that are less common—often come with a level of uncertainty; decision makers often avoid uncertainty and risk in favor of a business-as-usual approach.	High-Performance Façades. 2024. https://www.facadetectonics.org/download/cudfdakogthxeaxihcsztdmahfstvmuuzcnp

Barrier	Description	Source
HVAC Design Focus	Most projects are driven by HVAC designers and advocates who play a larger and more pronounced role earlier in the planning process than façade/window designers who tend to be consulted at later phases of a project.	High-Performance Façades. 2024. https://www.facadetectonics.org/download/cudfdakogthxeaxihcsztdmahfstvmuuzcnp
Flexible Building Codes	Old building codes allow for buildings' performance targets to be addressed through various means (e.g., lighting, HVAC) with no enforcement of window performance specifically. New codes in CA (Title 24) have attempted to address this; however, implementation may take some time.	Commercial Windows Market Study and Measure Package Development. 2024. https://calnext.com/wp-content/uploads/2024/05/ET23SWE0018_Commercial-Windows-Market-Study_Final-Report.pdf
Lack of Incentives	Expanding incentive programs, in addition to promoting the benefits of secondary windows, could increase market interest, but few programs currently exist to help building owners offset costs.	Commercial Windows Market Study and Measure Package Development. 2024. https://calnext.com/wp-content/uploads/2024/05/ET23SWE0018_Commercial-Windows-Market-Study_Final-Report.pdf

2 Introduction and target market

VIG is a type of insulated glass that consists of two glass panes separated by a vacuum-sealed space. Unlike standard double-glazed windows, which use air or inert gases between panes, the vacuum barrier in VIG reduces heat transfer, providing much higher thermal insulation—up to five times that of conventional double glazing. This design substantially improves energy efficiency and indoor comfort. VIG's slim profile makes it versatile for a wide range of architectural applications. VIG also minimizes condensation, prevents moisture buildup, and provides better soundproofing compared to standard double-glazed units.

CSWs offer a cost-effective solution for commercial buildings with outdated or inefficient windows. Instead of full window replacement, secondary windows provide a simpler upgrade that can reduce heating and cooling energy use by up to 20%. Depending on the product and application, they can cost up to 90% less than replacing the entire window system.

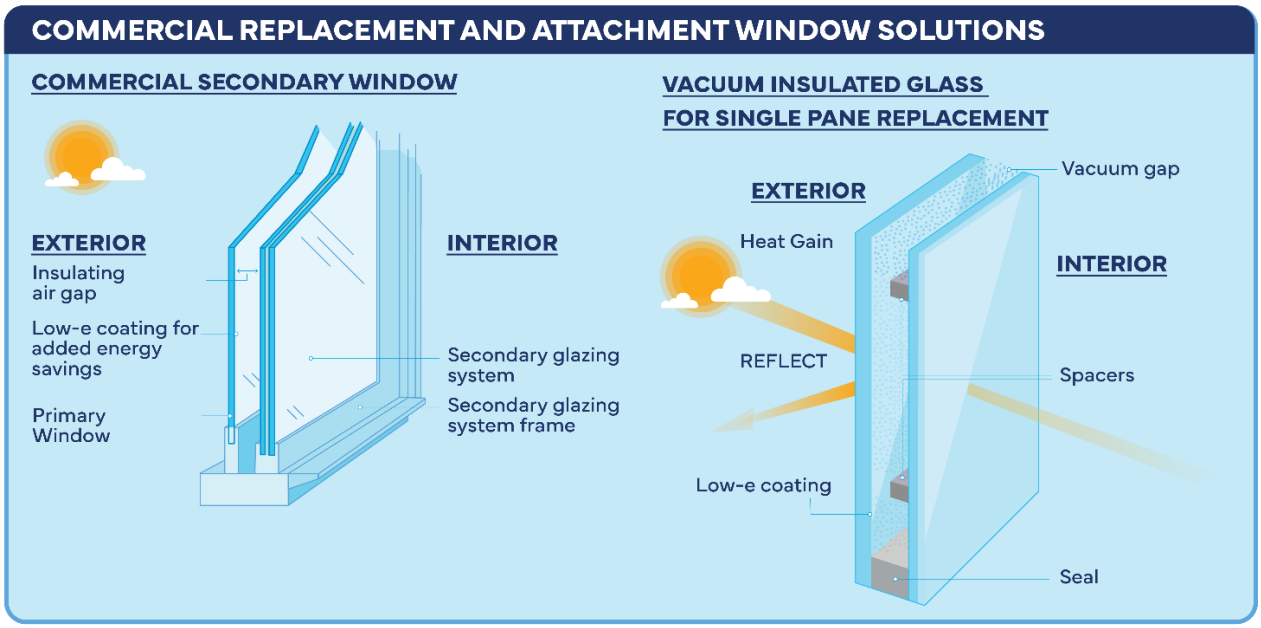
2.1 Product definitions

The product definitions from the advancement plan for this MTI have remained unchanged:

- **Commercial Secondary Windows (CSW)** in this context are attached to the interior or exterior of an existing window, creating an insulating air pocket between the new and existing panes. CSW can have one or more panes and low-E coatings; multiple panes can have insulating gases or a vacuum between the two CSW panes, creating additional insulating value.
- **Vacuum-Insulated Glass (VIG)** units replace existing single-pane windows while retaining use of the existing frame. The units are composed of two glass panes separated by spacers and hermetically sealed around the edges. Vacuum drawn on the void space between glass panes results in an R-10 to R-15 insulating value of the glass unit (R-5 to R-10 for the complete installed assembly).

Figure 1. Commercial Replacement and Attachment Window Solutions shows a simplified rendering of CSW and VIG.

Figure 1. Commercial Replacement and Attachment Window Solutions



Source: CalMTA, 2025.

2.2 Target market

The target market for this MTI is commercial buildings constructed before 2000 that still have single-pane windows or double-pane clear windows. Since the State of California did not

mandate double-pane windows until 2000, many of these buildings retain single-pane windows, which are a key target for decarbonization efforts.[36]

In this research, CalMTA focused on specific segments of the commercial market. The team made this decision because owner-occupied buildings tend to have a longer ownership horizon and a stronger business case for efficient window investments than do commercial real estate properties where occupants or renters generally pay for utilities. As a result, CalMTA identified the municipal, university, school, and healthcare markets as the first likely target.[37,38] The team also included hospitality and historic buildings in the research because VIG and CSWs offer these buildings substantial non-energy benefits, such as soundproofing and comfort improvements.

3 Methodology

3.1 Secondary research and literature review sources

CalMTA completed a literature review of published research and analyzed available secondary data pertaining to baseline and advanced window technology. Specifically, the team utilized the U.S. Census and the United States Energy Information Agency's (EIA) CBECS 2018,[39] the National Laboratory of the Rockies's (NLR), formerly known as the National Renewable Energy Laboratory (NREL), ComStock tool,[40] and the California Energy Commission's (CEC) CEUS to gain insights into window saturation levels, building stock characteristics, and other insights relevant to commercial buildings in California.[41]

CalMTA also reviewed publicly available technical market research documents and conducted searches using tools such as Google Scholar, Semantic Scholar, and Science.gov on window technologies, adoption rates, manufacturer priorities, and end-user behavior.

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[36] Eley, C. and B. Pennington. 2002. *Requiring High Performance Windows in California*. Proceedings of the 2002 ACEEE Summer Study on Energy Efficiency in Buildings. American Council for an Energy-Efficient Economy. https://www.aceee.org/files/proceedings/2002/data/papers/SS02_Panel4_Paper09.pdf

[37] CBECS 2018 was used as one of the data sources. municipal buildings are categorized under offices in CBECS segmentation. Municipal buildings are a part of this analysis but are segmented under offices because of the above data classification issue.

[38] During the research phase, CalMTA found that the EIA's Commercial Buildings Energy Consumption Survey (CBECS) categorizes municipal buildings as "offices." Since this data serves as the primary source for estimating square footage and building energy characteristics in California, CalMTA included municipal buildings within the "offices" market segment in this report

[39] U.S. Energy Information Administration. 2022. 2018 Commercial Buildings Energy Consumption Survey: Building Characteristics. https://www.eia.gov/consumption/commercial/data/2018/

[40] National Renewable Energy Laboratory. 2024. ComStock. https://comstock.nrel.gov/

[41] California Energy Commission. 2022. California Commercial End-Use Survey. https://www.energy.ca.gov/data-reports/surveys/california-commercial-end-use-survey

3.1.1 NLR ComStock (2018)

ComStock was the primary dataset for this analysis (baseline year 2018), based on the bottom-up model that uses multiple data sources, statistical sampling methods, and advanced building energy simulations to estimate the annual energy consumption of the commercial building stock across the United States. ComStock's baseline represents the U.S. commercial building stock as it existed in 2018. This dataset is particularly valuable for its detail, including approximately 40,000 building models created specifically for California.

A key consideration when using ComStock is that it represents around 75% of the commercial floor space and does not include some key building types such as grocery stores and colleges/universities, among others.[42]

For the baseline building configurations, ComStock utilizes four key input properties to define the windows: the number of panes (single, double, or triple), the glazing type (clear, tinted, or reflective), the frame material (wood, aluminum, or thermally broken aluminum),[43] and the presence or absence of a low-E coating. These properties are important because of their influence on window energy performance and the availability of data for modeling.

In addition to these descriptive characteristics, ComStock provides simulated output data that quantifies the energy-related performance of the windows. These simulated metrics include the average window solar heat gain coefficient (SHGC), which measures how much of the sun's heat is transmitted through the window (0 to 1; lower SHGC is better for reducing heat gain); the average window U-value, which indicates the rate of heat transfer through the window (measured in Btu per square foot per degree Fahrenheit per hour [Btu/sq ft/°F/hr]; lower U-value means better insulation); and the average window visible light transmittance, which represents how much visible light passes through the window (0 to 1; higher transmittance means more natural light). These simulated values offer insights into the thermal and optical performance of the modeled window systems.

3.1.2 EIA 2018 commercial building energy consumption survey (CBECS)

CBECS is a national sample survey that collects information on the stock of U.S. commercial buildings, including their energy-related building characteristics and energy usage data (consumption and expenditures).[44] CBECS serves as a primary data source for building types and

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[42] National Renewable Energy Laboratory. 2024. ComStock Reference Documentation. https://docs.nrel.gov/docs/fy25osti/92766.pdf

[43] Thermal break technology involves inserting non-conductive materials between conductive elements within a window frame. While materials like aluminum are commonly used in windows for their strength and sleek appearance, they also conduct heat very efficiently. In conventional window frames, this allows heat to pass through easily, resulting in substantial energy loss. Please see for detail Window Types and Technologies | Department of Energy

[44] U.S. Bureau of Economic Analysis. 2024. GDP by State: https://www.bea.gov/data/gdp/gdp-state.

characteristics that are not fully represented in the ComStock dataset. CalMTA leveraged data from CBECS to estimate the commercial floor space in California.

CalMTA did not use CBECS as the sole primary dataset for assessing the entire California commercial sector for this study for two main reasons. First, the published data is typically representative at the broader Pacific Census Division level, which includes Alaska, California, Hawaii, Oregon, and Washington. Although California represents approximately 75% of this division in terms of both GDP and population, the data is not exclusively focused on California. Second, the sample size for the Pacific Census Division in the 2018 CBECS is relatively small, consisting of 828 observations.

CBECS collects information primarily through surveys and provides a different set of window characteristics than those in ComStock. Based on survey responses, CBECS includes variables such as window glass type (which relates to the number of panes and is categorized as single-layer glass, multilayer glass, combination of both, or no windows), whether the building has tinted window glass (yes/no), and whether it has reflective window glass (yes/no). CBECS also captures information on the window-to-wall ratio (WWR) by asking respondents to select a range that best describes the "percentage of the exterior wall surface of this building that is covered with window glass or glass doors." CBECS does not provide metrics for thermal and optical performance (such as U-value or SHGC). This distinction is important to note when utilizing the datasets for detailed analysis of window performance and its impact on energy use.

3.1.3 California commercial end use survey (CEUS) California Energy Commission 2022

The 2022 California CEUS provided the most recent data used in this report. The survey collected data from over 24,000 commercial facilities in California, primarily through rigorous on-site surveys and inspections. Based on the survey instrumentation and data collection methodology, the level of detail captured by CEUS is considerably greater than that available in CBECS. Furthermore, the sampling strategy employed for CEUS allows representative analysis at the service territory level for the five largest electric utilities in California, offering valuable localized insights.

Conducted in 2022, CEUS provides a more up-to-date snapshot of the commercial building stock and energy use in California than the 2018 ComStock and CBECS data. However, the full dataset is not publicly accessible; only summary statistics are available. Additionally, detailed information specifically pertaining to windows from the 2022 CEUS has not yet been publicly released. Nevertheless, this analysis includes a summary of floor space information from CEUS to provide a point of comparison, highlight differences between ComStock and CEUS, and engender discussion about the suitability of modifying ComStock data to match CEUS.

3.2 Stakeholder and market actor interviews

To gain a comprehensive understanding of the CSW and VIG market, CalMTA conducted in-depth interviews with a diverse group of stakeholders, including manufacturers, installers, ESCOs, building owners and managers, and tenants.

3.2.1 Manufacturer, ESCO, and installer interviews

CalMTA conducted interviews with CSW and VIG manufacturers, as well as ESCOs who work with CSW and VIG, to understand market trends, costs and benefits, and perceptions of market barriers and opportunities. The team gathered contact information via personal relationships and knowledge, as well as secondary internet research and consultation with CalMTA's Equity Sounding Board. The Equity Sounding Board consists of a group of eight professionals who work with or in environmental and social justice communities and provide insight regarding market transformation initiatives. Between April and June 2025, CalMTA conducted in-depth interviews with six manufacturers, two installers, and five ESCOs. The interview guides are included in Attachment C.

CalMTA interviewed employees from six manufacturers of CSW and VIG technologies. Table 4 lists key firmographic indicators for the firms interviewed.

Five of six manufacturers were engaged in research and development and conducted market assessment and marketing activities. Four of six manufacturers engaged with technology deployment activities, including the manufacturer that did not conduct either research and development or market assessment.

Table 4. Manufacturer Firmographics

Interviewee Title	Solutions Manufactured	Location of Manufacturing Facilities	Number of Employees
Founder & CEO	CSW	Portland, OR	35
Founder & CEO	VIG	Detroit, MI	1 (plus 2 contractors)
President	CSW	Lewisville, CO and Pittsburgh, PA	200
Founder & CEO	VIG	Waukesha, WI[a]	6
President	CSW	Houston, TX	10
Vice President	CSW	Cincinnati, OH	45

Source: CalMTA Manufacturer Interviews (n=6)

[a]: *This manufacturer has a laboratory facility in Waukesha. They are in the process of building a production facility elsewhere in Wisconsin, though they declined to give a specific location.*

CalMTA interviewed representatives of five ESCOs. Table 5 lists key firmographic indicators for the firms interviewed.

ESCOs interviewed serve a diverse pool of clients in the industrial, municipal, commercial, education, and healthcare sectors. This pattern held regardless of company size, with both small and large ESCOs working across a wide variety of building types.

Table 5. ESCO Firmographics

Interviewee Title	Sector(s) Served	Locations Served	Number of Employees
President & Founder	Industrial, municipal, commercial, education, healthcare	CA, NV, AZ	60
Co-Founder & CEO	Commercial, industrial, education, healthcare	Nationwide; heavy presence in NY	1,200
COO	Education, municipal, healthcare, commercial	WA	2,100
Senior Project Manager	Education, municipal, healthcare	Nationwide; heavy presence in the Northwest and East Coast	2,000
Senior VP	Commercial, industrial, residential	Nationwide/international	55

Source: ESCO interviews (n = 5)

CalMTA interviewed owners of two commercial window installers representing the construction and window industries in California, as summarized in Table 6. Both businesses operated in the Bay Area within PG&E's service territory. Given the small sample size, insights from installer interviews are not reported.

Table 6. Installer Firmographics

Interviewee Title	Sector(s) Served	Location of Installations	Number of Employees
Owner	Commercial, Residential	Bay Area, CA	2; hires additional contractors for large jobs
Owner	Commercial	Bay Area, CA	35

3.2.2 Building owner and manager interviews

CalMTA conducted interviews with owners, property managers, and facilities managers of commercial buildings, with a focus on municipalities, universities, schools, and hospitals. The goal of these interviews was to understand the priorities and behaviors of decision makers regarding the window stock in their buildings, their knowledge and perceptions of CSW and VIG technologies, any tools or resources they use when planning window replacements or upgrades, and their knowledge of and participation in incentive programs meant to defray the cost of conducting window replacements or upgrades. Between February and June 2025, CalMTA completed eight in-depth interviews with owners and property managers of commercial buildings in the university, primary/secondary school, and healthcare sectors.

The research team conducted multiple rounds of outreach to municipal building managers. However, response rates were low. Additionally, it was difficult to identify individuals with the appropriate knowledge and authority to speak about plans for building envelope upgrades in municipal buildings.

Table 7 lists key firmographic indicators for these respondents.

Table 7. Building Owners and Managers Firmographics

Interviewee Title	Industry	Number of Buildings	Age of Building (estimated)	Sq Ft (estimated range)	Percentage Single Pane
Director of Facilities Management	Hospital	5	Don't know	3,000-18,000	10%*
Executive Director	Office	2	2000 and 2020	50,000 and 80,000	0%*
CEO	Hospital	3	1970-1980	Don't know	Don't know
Project Manager, Social Impact	Hospital	75	1970s and 2000s	Don't know	50%
Facilities Director	University	3	1950s	13,000-24,000	100%
Executive Director	Schools	6	2000	Don't know	100%
Director of Safety and Transportation	University	20	1920s, 1940s, new construction	Don't know	75%
Energy and Sustainability Manager	Schools	72	Don't know	Don't know	100%

Source: CalMTA Building Owner/Manager interviews (n=8).
Data provided for age of building, square footage, and percentage of single-pane windows are estimates.
**Indicates that buildings have recently undergone window replacement.*

3.2.3 Commercial tenant interviews

CalMTA conducted interviews with tenants of commercial buildings to understand how (if at all) they engage with the window replacement or upgrade decision-making process, their familiarity with CSW and VIG technologies, and the level of influence they have on window replacement or upgrade decisions. Between April and June 2025, CalMTA conducted six in-depth interviews with tenants of commercial buildings. Table 8 lists key firmographic indicators for these tenants.

Commercial tenant demographics and characteristics varied across industries, roles, and business sizes. Interviewed tenants were in predominantly older, multi-tenant buildings constructed between the 1880s and 1980s. Tenants reported annual revenues for their businesses that range from $300,000 to $3 million, with most tenants occupying leadership roles such as owner, executive director, or manager. All interviewees shared their buildings with other businesses.

Table 8. Commercial Tenant Firmographics

Interviewee Title	Industry	Annual Revenue	Age of Building	Owns Building?	Number of Employees
Manager	Education	Don't know	10 to 20 years old	No	5
Owner/dance instructor	Fitness	Don't know	1880	No	6

Owner	Health and Wellness	$300,000	1980s	No	3
Director of HR and Operations	Staffing	$3 million	1970s	No	11
Executive Director	Fitness	$600,000	1980	No	14
Executive Director	Nonprofit	$2 million	1960s	No	20

Source: CalMTA commercial tenant interviews (n=6)

3.3 Building owner/manager survey

CalMTA surveyed a sample of building owners and property managers representing the targeted segments in California to gain an understanding of the factors that influence window upgrade decision making, awareness of and willingness to switch to efficient window solutions, and barriers that inhibit widespread adoption of efficient window solutions in the state. The survey instrument is included in Attachment C.

3.3.1 Survey Sampling Plan

CalMTA fielded the survey from May 19, 2025, to June 23, 2025, targeting owners and facility managers of commercial buildings in the targeted segments in California that met at least one of the following criteria:

- Building built before the year 2000
- Contains single-pane windows
- Contains double-pane windows without a low-E coating

CalMTA terminated the survey for building owners representing buildings that did not meet any of the above criteria.

The survey team used Qualtrics' sample services to recruit participants, drawing from a network of over 20 online panel providers. Respondents were randomly invited to participate based on screening criteria designed to ensure alignment with the study's target population. Qualtrics applied standard data quality protocols, including exclusions based on participation frequency and respondent category eligibility, to minimize response bias and ensure data integrity.

The team recruited participants using Computer-Assisted Telephone Interviewing (CATI) and completed the survey by phone. Interviewers screened respondents to ensure that they met the qualification criteria and then administered the full survey during the same call. This approach helped ensure high response quality and allowed for clarification of any complex or technical questions during the interview process. Qualtrics provided incentives to respondents upon completion.

The team completed a total of 114 surveys. To ensure representation across key commercial building types, the team applied quotas across five building types: office, healthcare, non-university school, college, and lodging. In addition to the 114 completed surveys by building type, the team also conducted surveys across "other" building types and ensured representation within the sample for all electric utility providers, including Pacific Gas and Electric Company (PG&E), Southern California Edison (SCE), and San Diego Gas & Electric Company (SDG&E).

The team designed the sampling plan to achieve 85% confidence with ±15% precision at the stratum level (by building type and utility, excluding "other").

3.3.2 Survey weighting approach

CalMTA developed the survey sample frame focusing on specific building segments, including college/university, healthcare, lodging, offices,[45] and schools (non-college/university). The building types the team excluded from detailed analysis represent approximately 63% of the state's total commercial floor space. For example, the analysis excluded warehouses.[46] Table 9 shows that the five included building types account for approximately 3,284 million sq ft of commercial floor space.[47]

Table 9 California Commercial Floor Space

Building Type	Sq ft (in Millions)
College/university	174 [48]
Healthcare	427
Lodging	342

[45] CBEC was used as one of the data sources. Municipal buildings are categorized under offices in CBEC segmentation. Municipal buildings are a part of this analysis but are segmented under offices because of the above data classification issue. https://www.eia.gov/consumption/commercial/building-type-definitions.php#Office

[46] Warehouses (both conditioned and unconditioned) were excluded from the market characterization and target market due to the low window area and low potential for energy savings. The window to wall ratio for warehouses is very low, thus minimizing the potential energy impact of window improvements compared to the opaque building envelope. Accurate information on the exact window to wall ratio for warehouses, but the DOE prototype model has a window to wall ratio of 0.7% [NR Report] representing an estimate of national building stock. In addition, warehouses only represent 0.7% of the commercial building window stock by area in California, [Market Study] making it a less substantial market segment for our window MTI.
The low energy use intensity of warehouses also limits the potential energy savings. Storage (0.9 kWh/ft2), unconditioned warehouse (2.6 kWh/ft^2), and conditioned warehouses (4.9 kWh/ft^2), represent the lowest energy use intensity of all of the building types in the California Commercial Saturation Survey, [Commercial saturation study] compared to an average of 10.2 kWh/ft^2.

[47] U.S. Energy Information Administration. 2024. *Commercial Buildings Energy Consumption Survey: Building Type Definitions*. https://www.eia.gov/consumption/commercial/building-type-definitions.php#Office

[48] We used college/university and others category from CBEC 2018 to fill data gaps in this analysis. Therefore, numbers in Tables 4 and 5 will not align by simple calculation.

Office	1,314
School (non-College/university)	1,028
Subtotal	**3,284**
Other [49]	**5,681**
Total floor space	**8,965**

Note: Primary source is NLR ComStock 2024. For College/university we used CBECS 2018 scaled by 75% to match the GDP of California in the Pacific West. Results rounded to the nearest percentage.

To account for differences in targeted population square footage by commercial building types, the team weighted survey results using a targeted population total over sample total approach, deriving sample totals from the survey data. The targeted population only includes the building types that are outlined in Table 9. The survey results are normalized to the targeted population of market segments by building type in California's building stock. This weighting approach ensured that findings accurately reflected the perspectives of decision makers responsible for smaller properties within a sample building type as well as targeted population building types comprising a larger share of total square footage. The survey responses represent the square footage of the buildings owned or managed by the respondents. The sample approach (summarized in Tables 10, 11, and 12) ensured that each analysis aligned with the intended unit of measurement and yielded meaningful insights by building type, attributable to the target population and across the broader market. Details about the weighting methodology are provided in 0.

Table 10. Achieved Sample by Utility and Building Type

Building Type	PG&E	SDG&E	SCE	Others	Total
College	5	3	12	4	24
Healthcare	2	3	16	2	23
Lodging	12	2	4	5	23
Office	11	3	4	3	21
School	13	1	5	4	23
Total	**43**	**12**	**41**	**18**	**114**

Source: CalMTA CRAWS Building Owner and Property Manager Survey Q A8 "Which electric utility provides your power at the buildings you own/manage?" and Q B1 "Which of the following types of buildings do you currently own or manage? Please select all that apply." (n=114)

Table 11. Achieved Sample by Role and Building Size (in sq ft)

Square Footage	Property/Facility Manager	Building Owner	Total
0 - 10,000	3		3

[49] Weighting excluded the 'Other' category.

Square Footage	Property/Facility Manager	Building Owner	Total
10,001 - 25,000	12	12	24
25,001 - 50,000	38	8	46
Over 50,000	39	2	41
Total	**92**	**22**	**114**

Source: CalMTA CRAWS Building Owner and Property Manager Survey Q A2 "What is the most appropriate description of your role? Select all that apply." Q B2 "What is the approximate total square footage of your [TYPE] buildings?" (n=114)

Table 12. Achieved Sample by Region and ESJ Status

ESJ Status	Coastal	Inland	Total
ESJ	3	16	**19**
Non-ESJ	57	38	**95**
Total	**60**	**54**	**114**

Source: CalMTA CRAWS Building Owner and Property Manager Survey Q B2 "Please list the ZIP codes where your [TYPE] buildings are located." (n=114)

4 California window characteristics

CalMTA conducted an analysis using data from primary and secondary sources to characterize the California market for windows, as well as the current saturation and market shares of CSW and VIG. This section presents the analysis of findings.

4.1 Total commercial floor space in California

To estimate the market saturation of windows, CalMTA first developed an estimate of the total commercial floor space in California using three primary data sources: the 2018 CBECS, NLR's ComStock 2024, and the 2022 California CEUS. Table 13 presents a summary of the estimated floor space by building type group and specific building type. Table 13 also identifies building types not covered by the ComStock model.

Table 13. Total Commercial Floor Space in California by Data Source (Million Sq ft)

Building Type Group	Building Type	ComStock	2018 CBECS	2022 CEUS
Education	Schools	1,028	861	686
	College	Not covered	174	384
Retail	Food/Grocery	Not covered	88	242
Healthcare	Healthcare	427	461	480
Lodging	Hotels	342	466	472
	Dorms and Other Lodging	Not covered	157	NA
Office	Office	1,314	1,574	2,093

Building Type Group	Building Type	ComStock	2018 CBECS	2022 CEUS
Food Service	Food Service	162	146	224
Retail	Strip and Standalone Malls	984	818	1,126
	Enclosed Malls	Not covered	77	-
Warehouse	Warehouse	2,220	2,220	1,398
Survey Sample Total*	Covered in sample	3,110	3,284[50]	
Others	Others	Not covered	1,993[51]	1,704
Total		**6,477**	**9,033**	**8,809**

Source: NLR ComStock 2018, EIA CBECS 2018, CA CEUS
Note: The "others" category includes laboratories, nursing homes, post offices, vacant buildings, and public order buildings for CBECS, and miscellaneous buildings for CEUS. CBECS data is available for Pacific Census division, which includes states of Alaska, Hawaii, Oregon, Washington, and California. We have scaled the data by 75% to more closely approximate CA data. The CBEC microdata was weighted using the weights provided in the microdata. ComStock figures were also weighted using their own weights provided in the microdata. CEUS numbers reported in the above table represents aggregates that were weighted.

**Subtotal reflects the sum of building types included in the survey sample and aligned across ComStock, CBECS, and CEUS for comparability. "Others" categories are excluded from the subtotal.*

As shown in Table 13, there are considerable differences in the estimated floor space of building types across the three datasets. Offices and warehouses exhibited the largest discrepancies in reported floor space between ComStock and CEUS data. For office buildings, ComStock reports 1,314 million sq ft, while CEUS estimates a substantially larger 2,093 million sq ft, a difference of approximately 779 million sq ft. Conversely, for warehouses, ComStock shows 2,220 million sq ft, whereas CEUS reports 1,398 million sq ft, a difference of about 822 million sq ft.

A portion of these substantial differences can be attributed to variations in the sampling strategies and data collection methodologies employed by each survey. For instance, ComStock's reference documentation states, "Warehouses, representing distribution centers, light manufacturing, showroom and truck terminal spaces, encompass a large number of functions including office spaces. However, ComStock does not disambiguate these spaces."[52] This suggests that a single building classified as a "warehouse" in ComStock may include substantial office areas that are not separately categorized. On the other hand, CEUS seeks to identify the function of mixed-use spaces by asking respondents to specify the percentage of the building allocated to different

[50] This was the total used for sample weighting (3,110+174=3,284). Please see Table 9 for details.
[51] For CBECS, the key sub-categories included in 'Others' are Public Assembly (686 million sq ft), Religious buildings (397 million sq ft), Vehicle Servicing and Storage (373 million sq ft) and Vacant buildings (135 million sq ft).
[52] National Renewable Energy Laboratory. 2025. ComStock Reference Documentation: 2024 Release 2

functions. Given this variance, we leverage publicly available data sources to develop a comprehensive understanding of the California market and address existing data gaps.

4.2 Commercial floor space by window type

This section provides a detailed characterization of commercial floor space in California based on key window attributes. CalMTA examined the distribution of floor space by the number of panes per glazing unit, comparing findings from the review of ComStock and CBECS data. Next, CalMTA reviewed the types of window frames prevalent in the commercial sector, highlighting their correlation with pane configurations and analyzing the presence and absence of low-E coatings across the window stock. The team also surveyed owners and managers of commercial buildings in California. The sample was representative of the segments identified in the target market. For further details on survey firmographics, see Section 3, Methodology, of this report.

4.2.1 Number of panes

To evaluate the consistency and coverage of window characteristics across datasets, Table 14 compares total commercial floor space by windowpane and glass type for building types common to both ComStock and CBECS. This approach enabled direct assessment of the window characteristics captured by each source, while minimizing any differences arising from variations in building type coverage.

As shown in Table 14, a comparison of matching building types in ComStock and CBECS shows discernible differences in the reported distribution of windowpane characteristics, which also reflects the distinct methodologies of the two data sources. The ComStock data, derived from detailed building energy models informed by various data sources, categorizes windows primarily by number of panes: single, double, and a small percentage of triple. The filtered subset of matching building types shows that single-pane windows account for the largest share of floor space at 52%, followed closely by double-pane windows at 48%. Triple-pane windows represent a marginal proportion of windows, rounding to 0%.

The filtered CBECS data shows a different distribution of glass type. Multilayer glass is the largest category at 46% of the filtered floor space, aligning closely with the combined proportion of double-pane windows in ComStock (48%). However, the distribution of single-layer glazing differs more substantially. Single-layer glass accounts for 27% of the filtered CBECS floor space (compared to 52% in ComStock); however, unlike ComStock, CBECS contains a notable additional category: "Combination of both," representing 20% (1,307 million sq ft). This category likely captures buildings in which both single-layer and multilayer windows are present, a condition that might arise from partial window upgrades in buildings originally constructed with single-pane windows.

Table 14. Comparison of Commercial Floor space by Windowpane/Glass Type California

Glass Type	ComStock		2018 CBECS	
	Million Sq ft	Proportion	Million Sq ft	Proportion
Single-Pane/Single-Layer	3,355	52%	1,786	27%

Glass Type	ComStock		2018 CBECS	
	Million Sq ft	Proportion	Million Sq ft	Proportion
Double-Pane/Multilayer – No Low-E Coating	1,374	48%	3,032	46%
Double-Pane/Multilayer - Low-E Coating	1,735			
Triple-Pane/Multilayer	13	0%	N/A	N/A
Combination of Both	N/A	N/A	1,307	20%
No Windows	N/A	N/A	419	6%
Total	**6,477**	**100%**	**6,545**	**100%**

Source: NLR ComStock 2018 (filtered), EIA CBECS 2018 (filtered to only consider building types covered in ComStock).

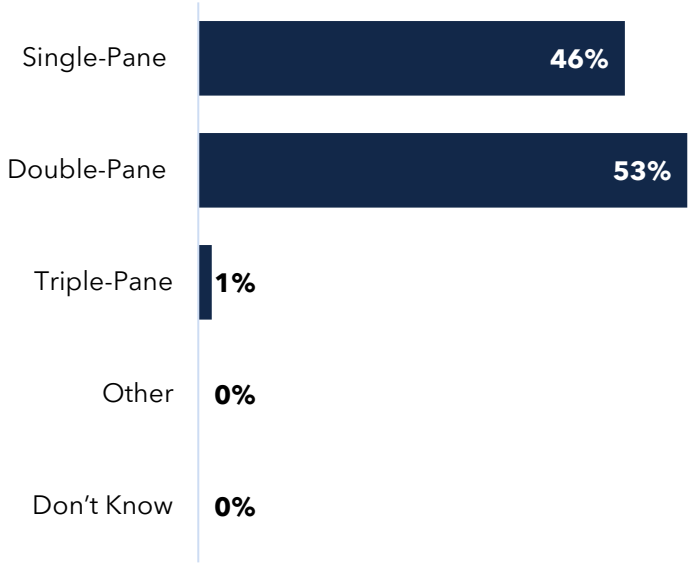
Note: ComStock data distinguishes by the number of panes based on modeled inputs. CBECS uses survey categories for glass types based on respondent reports and does not distinguish between double-pane/multilayer clear and low-E coating glass types. The total floor space for which glass type data is available for matching building types in CBECS is 7,037 million sq ft, which is the sum of the pane distribution counts for the filtered building types. This is slightly less than the total floor space reported for these types (7,240 million sq ft) in the original source data, indicating some floor space with an unreported glass type.

Note: Percentages may not sum to 100% due to rounding.

These variations underscore that while both datasets provide valuable insights into California's commercial window stock, the nature and precision of the information available for detailed analysis differ due to the distinct methodologies of modeled inputs versus surveyed responses regarding building characteristics.

CalMTA's survey also asked respondents about the distribution of different windows currently installed in all the buildings they own or manage, to characterize the baseline saturation of windows in California. As shown in Figure 2, respondents reported that 46% of the windows across their buildings are single-pane and 53% are double-pane. Triple-pane windows account for only 1% of windows, while other types account for approximately 0%. These proportions are consistent with those calculated using ComStock data (Table 14).

Figure 2. Average Distribution of Window Types Reported by Respondents



Source: CalMTA CRAWS Building Owner and Property Manager Survey QB3: "Please estimate the percentage of each type of window that is installed across all the buildings you own or manage. Each row should sum to 100%." (n=114). Results rounded to the nearest percentage.

4.2.2 Frame type and low-E coatings

CalMTA examined the distribution of windowpane types by frame material and the presence of low-E coatings to further characterize ComStock's window stock data.

Table 15 provides the distribution of floor space by windowpane type and frame material. A substantial portion of single-pane windows, comprising 2,604 million sq ft, have aluminum frames, while wood frames are exclusively associated with single-pane windows (751 million sq ft). Double-pane windows are more diverse and are associated with both aluminum (1,661 million sq ft) and thermally broken aluminum frames (1,449 million sq ft). From an energy performance perspective, thermally broken aluminum frames offer superior insulation properties compared to standard aluminum frames by reducing heat transfer through the frame material itself.

Table 15. ComStock Floor Space by Windowpane and Frame Material (million sq ft), California

	Single	Double	Triple	Total
Aluminum	2,604	1,661	-	4,264
Thermally Broken Aluminum	-	1,449	13	1,461
Wood	751	-	-	751
Total	**3,355**	**3,110**	**13**	**6,476**

Source: ComStock (2018)

Note: Some totals may vary slightly due to rounding or inherent dataset aggregation.

Low-E windows utilize a transparent coating that blocks infrared radiation, helping to keep heat outside during warm weather and inside during cold weather. The market penetration of these energy-efficient technologies has grown substantially. For instance, in the United States, windows incorporating low-E coatings had achieved greater than 80% market share in the residential sector and more than 50% in the commercial sector by 2017.[53]

CalMTA's analysis of ComStock data shows that windows with low-E coatings are exclusively multi-pane; approximately 56% (1,735 million sq ft of floorspace) of double-pane windows are equipped with a low-E coating. All single-pane windows, totaling 3,355 million sq ft of floor space, do not have low-E coating.

Table 16. Commercial Floorspace by Number of Panes and Low-E Coating, California

	Single	Double	Triple	Total
Low-E Coating	-	1,735	13	1,748
No Low-E Coating	3,355	1,374	-	4,729
Total	**3,335**	**3,109**	**13**	**6,477**

Source: ComStock (2018)

Note: Some totals may vary slightly due to rounding or inherent dataset aggregation.

4.2.3 Window characteristics by building vintage

CalMTA's analysis of the ComStock dataset highlights substantial changes in window characteristics across building vintages, reflecting evolving construction practices and growing emphasis on energy efficiency over time. Table 17 presents the window characteristics for commercial buildings according to ComStock, disaggregated by construction vintage. Specifically, the percentages within each row illustrate the proportion of that vintage's total commercial floor space that features a given number of panes, type of frame material, or the presence of a low-E coating. The final column indicates total commercial floor space for each building vintage, which serves as the basis for these percentage distributions. Approximately 56% of the floor space in the ComStock dataset is more than 45 years old (representing buildings constructed before 1980).

[53] U.S. Department of Energy. 2015. EERE Success Story—Energy-Efficient Smart Windows are Lowering Enegy Costs. https://www.energy.gov/eere/success-stories/articles/eere-success-story-energy-efficient-smart-windows-are-lowering-energy

Table 17. ComStock Window Characteristics Across Building Vintage as a Percentage of Building Floor Space

Building Vintage	Number Of Panes		Frame Material			Low-E Coating		Total Million sq ft
	Single	Double & Triple	Aluminum	Thermally Broken Aluminum	Wood	Low-E	No Low-E	
Before 1980	58%	42%	71%	16%	13%	18%	82%	3,619
1980-2000	53%	47%	73%	15%	12%	24%	76%	2,145
After 2000	14%	86%	20%	77%	3%	80%	20%	712

Source: ComStock (2018)

Window characteristics, frames, and coating are further detailed below:

- **Number of panes:** The data suggests a clear trend towards more thermally efficient multi-pane windows in newer commercial buildings. For structures built before 1980, most of the floor space (58%) has single-pane windows, while 42% has double- or triple-pane. This proportion shifts substantially in more recent construction. Buildings from 1980 to 2000 have a 53% share with single-pane and 47% with double- or triple-pane windows. The most striking difference occurs in buildings constructed after 2000, for which single-pane windows account for only 14% of the floor space, while double- and triple-pane windows represent 86%.
- **Frame material:** A distinct evolution can be seen in the types of window frame materials used across building vintages. In older commercial buildings constructed before 1980, aluminum frames are most prevalent, accounting for 71% of the commercial floor space, followed by thermally broken aluminum at 16% and wood frames at 13%. The 1980 to 2000 vintage shows a similar distribution, with 73% aluminum, 15% thermally broken aluminum, and 12% wood. However, a substantial shift occurs in buildings constructed after 2000. For these newer structures, thermally broken aluminum frames dominate 77% of commercial floor space, while standard aluminum frames drop drastically to 20%, and wood frames comprise only 3%. This trend highlights the increasing adoption of more advanced and energy-efficient frame materials in modern building practices.
- **Low-E coatings:** The penetration of low-E coatings also varies with building age. For commercial buildings constructed before 1980, only 18% of the floor space features low-E coated windows, with the vast majority (82%) lacking this technology.[54] Adoption rates rise substantially in the subsequent vintage, with 24% of floor space in 1980 to 2000 buildings having windows with low-E coatings, while 76% do not. For buildings constructed after 2000, 80% of the floor space includes windows with low-E coatings, and 20% does not. This overall

[54] Please note that this analysis reflects percentages of the total commercial building stock in California, including segments outside of the target market for this CalMTA report.

trend demonstrates a substantial increase in the incorporation of low-E technology into window systems in newer constructions compared to older ones, reflecting a growing awareness of and regulatory push towards improved thermal performance.

4.3 Window-to-wall ratio by building characteristic

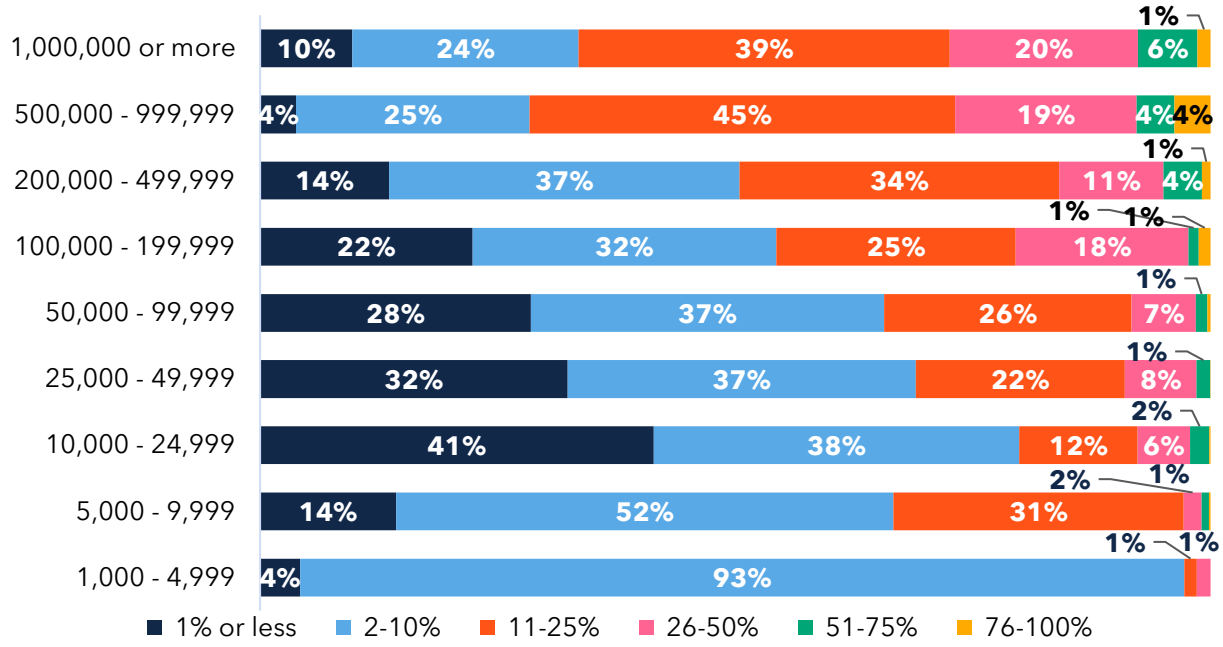
This section provides a detailed characterization of the WWR in California based on key building attributes. The analysis includes the distribution of floor space by the WWR from ComStock data, followed by the relationship between WWR building vintage and building type.

4.3.1 Number of panes

Figure 3 presents a comparison of the WWR percentage bins by commercial floor space, binned into size categories presented in the ComStock dataset. Each bar represents 100% of the buildings in that size range; each colored block represents the proportion of buildings in that range with a given percentage of WWR.

WWR tends to decrease with building size. Approximately one-third of the largest buildings, those with over 500,000 sq ft, have WWRs of 10% or less. Among buildings between 100,000 and 500,000 sq ft, roughly half have WWRs of 10% or less. Whereas roughly two-thirds of buildings between 5,000 and 100,000 sq ft have WWRs of 10% or less. Buildings in the 10,000 to 25,000 sq ft range have the greatest share of buildings with WWRs of 1% or less, at approximately 40%. Among the smallest buildings, 97% have WWRs of 10% or less.

Figure 3. WWR Percent Categories by Building Size

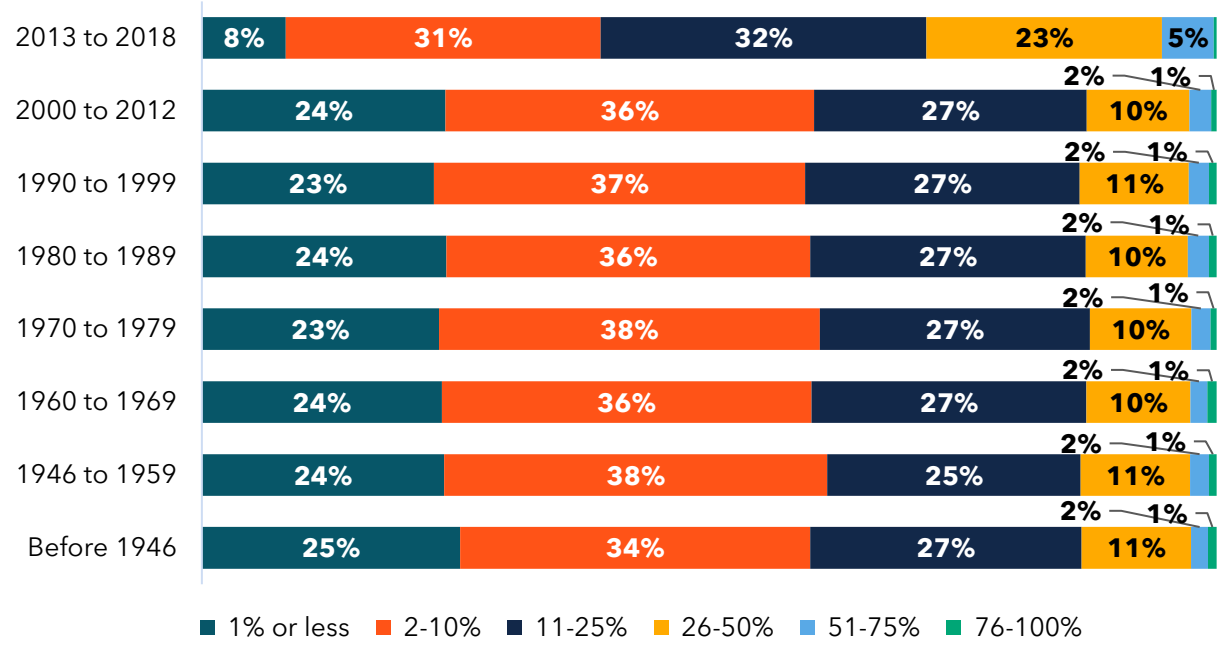


Source: ComStock 2018. Results rounded to the nearest percentage.

Figure 4 compares WWR percentage thresholds by building vintage, arranged into building vintage categories as presented in the ComStock dataset.

WWR distributions are similar across building vintages, with approximately 60% of buildings having WWRs of 10% or less. Only buildings constructed after 2013 show a clear difference, with just 40% having WWRs of 10% or less and a higher proportion falling into the 26% - 50% and 51% - 75% WWR ranges. Existing research indicates the reason for a shift to higher proportions of greater WWR percent ranges could be due to several factors, including design innovation for reduced energy consumption, improved indoor air quality, the rise of green building design to achieve certification, resiliency strategy to prevent premature structural aging, and occupant comfort – which can lead to improved productivity and overall well-being.[55]

Figure 4. WWR Percent Categories by Building Vintage



Source: ComStock 2018. Results rounded to the nearest percentage.

Figure 5 compares WWR percentage bins by building type.

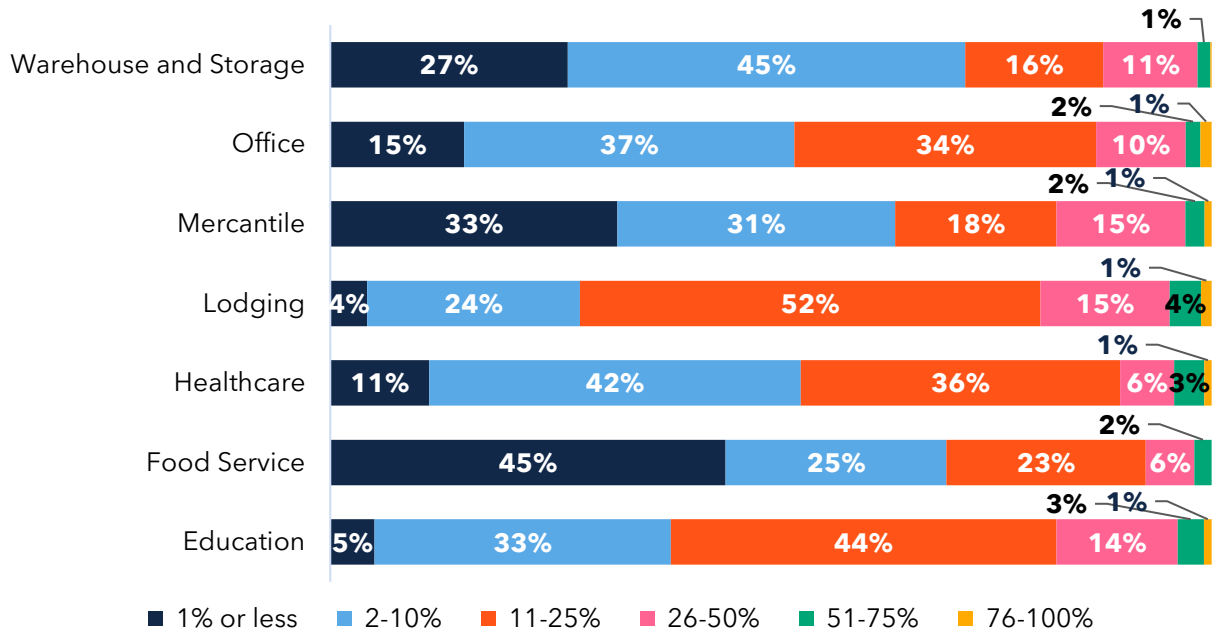
Warehouse and food service buildings have the highest proportion of structures with WWRs of 10% or less. Office and healthcare buildings show similar WWR distributions, with approximately half of the buildings in each category having WWRs of 10% or less. Nearly half of food service and one-third of mercantile buildings have a WWR of just 1%, the highest share among all building

[55] Fernandes, L., Harris, C., and Praprost, M., et. al. 2025. *Energy Impacts of Nationwide Window Upgrades in Commercial Buildings.* Lawrence Berkeley National Laboratory. Commercial_window_market_report_v2.05c_luis_fernandes_0.pdf

types. In contrast, lodging and education buildings have the largest share of buildings with WWRs between 11% and 25% (but represent only about 1% of the overall building stock).

Warehouse and storage WWRs may skew high because ComStock data are not disambiguated for floor space within buildings with mixed use, particularly mixed office and warehouse buildings, as noted in the discussion in Section 4.1, Total commercial floor space in California.

Figure 5. WWR Percent Categories by Building Type Group



Source: ComStock 2018. Results rounded to the nearest percentage.

4.3.2 Window area by pane type

This section presents a comparison of window areas in California by windowpane type and building type group. The analysis looked at the distribution of floor space by pane type from ComStock data and the distribution of floor space by WWR and building type. Table 18 presents the distribution of single, double, and triple pane windows by building type.

Across all building types, slightly more than half of commercial floor space has single pane windows, with the remaining having double pane windows. Education and office buildings have the lowest share of single-pane windows, at 50% and 51%, respectively. Triple-pane windows represent a very small share of commercial floor space, with all categories of building having proportions of triple-pane windows that round to 0%.

Table 18. Percent of California Commercial Floor Space by Building Type and Number of Panes

Building Type	Single	Double	Triple	Total
Education	50%	50%	0%	100%
Retail	54%	46%	0%	100%
Healthcare	56%	44%	0%	100%
Lodging	54%	46%	0%	100%
Office	51%	49%	0%	100%

Source: NLR ComStock 2018.

Table 19 presents commercial floor space with single-, double-, and triple-pane windows by building type in millions of sq ft. Across all building types, single pane windows account for the largest share (130 million sq ft), followed by double pane windows,

Table 19. California Commercial Window Area (millions of sq ft) by Building Types and Number of Panes

Building Type	Single	Double	Triple	Total
Education	14	14	0	28
Retail	30	26	0	56
Healthcare	11	10	0	21
Lodging	11	8	0	19
Office	64	62	0	127
Total	130	120	0	251

Source: NLR ComStock 2018. Note: Values are rounded to the nearest million square feet. Totals may not sum exactly due to rounding.

Table 20 shows the annual HVAC energy use per square foot by building type and windowpane type.

HVAC energy intensity (expressed as kBtu/sq ft/year) generally decreases among most building types as the number of panes increases. The mean energy intensity for retail and healthcare buildings are exceptions, though the median energy intensity follows the same trend, suggesting some outlier buildings with high energy intensities.

Table 20. California Mean and Median HVAC Energy Intensity (KBTU/sq ft/year) by Commercial Building Type and Number of Panes

Building Type	Single		Double		Triple		Overall	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Education	73.66	60.09	69.66	58.03	44.90	44.90	71.69	59.05
Retail	64.76	60.44	61.71	57.63	65.34	54.41	63.37	59.11
Healthcare	36.68	30.55	33.62	29.32	38.31	22.67	35.23	29.87
Lodging	13.84	10.10	13.58	10.04	6.21	6.21	13.71	10.05
Office	37.70	33.21	34.55	30.72	31.77	30.31	36.20	32.06
Food Service	132.23	118.24	131.10	118.58	117.31	95.48	131.65	118.49

Building Type	Single		Double		Triple		Overall	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Warehouse	5.38	3.24	5.23	3.03	5.12	3.66	5.30	3.13
Overall	44.21	36.71	41.99	33.83	38.86	29.03	43.16	35.30

Source: NLR ComStock 2018

Further analysis of ComStock data (Table 21 and Table 22) separates results for windows with and without low-E coatings. CalMTA reviewed median energy intensity values for double pane windows between building types. The median HVAC energy intensity for double-pane windows in healthcare facilities without low-E coating was 30.80 kBtu/sq ft/year, compared to 28.13 kBtu/sq ft/year for facilities with low-E. The data indicates that pane count alone does not consistently reduce energy use: some double-pane windows without low-E coatings perform even worse than single-pane windows. In contrast, the addition of low-E glazing generally lowers energy use intensity across building types.

Table 21. California Mean and Median HVAC Energy Consumption Intensity (kBtu/sq ft/year) by Commercial Building Type and Number of Panes (No Low-E)

Building Type	Single		Double		Triple		Overall	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Education	73.66	60.09	72.30	60.70	-	-	73.28	60.28
Retail	64.76	60.44	130.60	118.59	-	-	64.54	60.16
Healthcare	36.68	30.55	35.06	30.80	-	-	36.22	30.68
Lodging	13.84	10.10	13.47	11.19	-	-	13.73	10.39
Office	37.70	33.21	63.94	59.22	-	-	37.43	33.07
Food Service	132.23	118.24	36.73	32.57	-	-	131.76	118.40
Warehouse	5.38	3.24	5.26	3.04	-	-	5.34	3.17
Others	-		-	34.88	-	-	-	-
Overall	44.21	36.71	42.75	60.70	-	-	43.79	36.19

Source: NLR ComStock 2018

Table 22. California Mean and Median HVAC Energy Consumption Intensity (kBtu/sq ft/year) by Commercial Building Type and Number of Panes (With Low-E)

Building Type	Single		Double		Triple		Overall	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Education	-	-	67.70	56.12	44.90	44.90	67.54	55.69
Retail	-	-	131.45	118.56	117.31	95.48	59.90	56.08
Healthcare	-	-	32.49	28.13	38.31	22.67	32.53	28.10
Lodging	-	-	13.67	9.39	6.21	6.21	13.63	9.36
Office	-	-	59.86	56.08	65.34	54.41	32.88	29.47

Building Type	Single		Double		Triple		Overall	
	Mean	Median	Mean	Median	Mean	Median	Mean	Median
Food Service	-	-	32.89	29.47	31.77	30.31	131.36	118.54
Warehouse	-	-	5.20	3.02	5.12	3.66	5.20	3.03
Others	-	-	41.37	33.01	38.86	29.03	-	-
Overall	-	-	67.70	56.12	44.90	44.90	41.35	32.96

Source: NLR ComStock 2018

4.4 CSW market size

CalMTA obtained 2023 and 2024 sales data from three national CSW manufacturers (Table 23). One CalMTA market expert believes these sales may represent approximately 60-70% of the overall secondary window market, but CalMTA was unable to identify another source to substantiate this estimate. The data provided covers only the commercial sector.

The products sold by these manufacturers fall under the CSW category but are marketed under various names and brands. For confidentiality and clarity, the data is reported in total square footage. CalMTA analysis indicates that roughly 18% of sales from these manufacturers occurred in California. Data from secondary sources such as CBECS (2018) and CEUS (2022) indicate that California accounts for 9% of the total commercial floor area in the United States[56,57] - implying that these CSW manufacturers sell more product in California relative to the total square footage of commercial buildings.

[56] U.S. Energy Information Administration (EIA). 2021. Commercial Buildings Energy Consumption Survey (CBECS) Table B1: Summary table: total and means of floorspace, number of workers, and hours of operation, 2018. September 2021 (revised December 2022). PDF available at: https://www.eia.gov/consumption/commercial/data/2018/bc/pdf/b1.pdf

[57] Baroiant, S., Mort, D., Alereza, T., and Dohrmann, D. 2023. 2022 California Commercial End-Use Survey (CEUS): Final Report. Prepared by ADM Associates, Inc. for the California Energy Commission. Publication Number: CEC-200-2023-017. February 2024. Available from https://www.energy.ca.gov/sites/default/files/2024-02/2022%20CEUS%20Final%20Report_ada.pdf

Table 23. Manufacturer Reported California and Total U.S. Average Annual CSW Sales (2023 and 2024)

	Square Footage	Dollars
California[58]	20,136	$ 765,168 [59]
Total U.S.	110,597	$ 4,202,686
Estimated California Share of U.S. Sales		18%

Source: Sales data provided by individual manufacturers of CSW. (CalMTA 2025).

To put these sales estimates in context, CalMTA used secondary data sources to estimate the size of California's commercial window market. One industry report projects the total U.S. commercial window market at $3.11 billion in 2024.[60] Based on this data, we estimate California's commercial window market at approximately $280 million, including retrofit and new construction.[61] CalMTA is unable to estimate the size of the retrofit market alone and therefore unable to quantify the market share of CSW sales. However, CalMTA believes that CSW currently represents a very small proportion of the commercial retrofit market.

4.5 Market conditions for advanced window solutions: manufacturer, ESCO, and building owner perspectives

4.5.1 Manufacturers

Three of the four CSW manufacturer employees interviewed by CalMTA self-reported an estimated number of units sold nationwide in 2024. Their estimates were inconsistent with the 2023 and 2024 national sales data CalMTA obtained directly from manufacturers reported in the previous section, which were separate from the employee interviews. One of the CSW manufacturers interviewed reported producing only custom units and could not provide an average annual estimate, as the quantity produced changes drastically from year to year. Both VIG manufacturers interviewed reported producing either very few units or prototypes only.

4.5.2 ESCOs

To assess market conditions from the ESCO perspective, CalMTA asked respondents to discuss the typical profile of their projects, the percentage of projects that include building envelope or

[58] Sales were reported by zip code; CalMTA mapped zip codes to estimate California Sales

[59] Based on estimated square price per square foot of $38, as shown in Table 28.

[60] Grand View Research. 2024. U.S. Commercial Windows Market Size, Share & Trends Analysis Report by Mechanism (Swinging, Sliding), by Frame Material (Vinyl, Wood, Metal), by End Use (New Commercial), by State, and Segment Forecasts, 2025-2030. December 5, 2024. https://www.grandviewresearch.com/industry-analysis/us-commercial-windows-market

[61] Using data from CEUS and CBECS, we estimate that California represents roughly 9% of the total U.S. commercial window market, which corresponds to approximately $280 million (based on $3.11 billion × 0.09).

window upgrades, current demand trends, the level of competition respondents experience, and the tools they use to model their projects.

All five ESCOs reported working on commercial buildings. Projects were most frequently completed in college/university, healthcare, and office facilities (three responses each), followed by non-college/university schools (two responses).

ESCOs reported wide variation in project sizes and window areas. One cited working on buildings from 100,000 to two million sq ft, including a past project with 292 windows and an upcoming one with 6,000. Another noted that entire buildings are often upgraded, with 10% to 100% of windows replaced. Others described projects ranging from 10,000 to over 1 million sq ft. One mentioned a Northern California project with 80,000 sq ft of glazing.

On average, 49% of projects included envelope upgrades, while only 18% included window upgrades. Envelope upgrades were more common across all respondents, with one reporting that 100% of projects involve envelope upgrades. In contrast, window upgrades were less common, reported in just 10% to 25% of projects.

Most ESCOs interviewed reported that window upgrades were included in only a small share of their projects in 2024. One estimated that windows were included in about 25% of projects, while another estimated they were included in 10% of projects, typically when clients had larger budgets. One noted that window upgrades are often avoided due to poor payback and another mentioned concerns regarding complexity.

ESCOs shared mixed views on demand for window solutions, though several common themes emerged, such as limited demand due to a lack of education, weak utility incentives, and minimal program support. One respondent described demand as reactive, driven by visible damage or broader renovations. While some noted growing interest as clients become more informed, affordability[62] and logistical challenges remain key barriers. Two respondents mentioned that windows add the most value when integrated with major remodels.

Respondents generally agreed that the window solutions market is competitive, though perspectives varied as to why this is the case. One noted that products like double-pane windows are difficult to differentiate. While several ESCOs indicated they do not compete directly with window contractors, they face intense competition for clients, making business development challenging. One respondent emphasized that limited funding, rather than competition, is the main barrier to securing projects.

[62] Affordability contextualized within the interviews was noted in broad generalized context, rather than incorporating specific criteria. The term was used subjectively by respondents, based on non-specific perceptions of the overall window market.

Respondents shared mixed experiences with projects aimed at reducing energy use or greenhouse gas (GHG) emissions. One reported that every project they undertake includes these goals, while another noted that such targets are less common and typically pursued as part of broader performance upgrades. A third respondent highlighted the challenge of balancing emissions goals with financial constraints, explaining that clients often seek GHG reductions that can be achieved within a five-year payback period.

4.5.3 Building owners and managers

To assess market conditions from the building owner and manager perspective, CalMTA asked about respondents' views on current window solutions, including performance and upgrade experiences. These interviews were additional to the surveys conducted with this segment. CalMTA also asked about respondents' motivation for pursuing upgrades, and whether they receive comfort-related complaints or face challenges regulating indoor temperatures.

Building owners and managers communicated broad awareness that replacing or upgrading windows is important for optimal building function. Two of eight respondents had already upgraded their single-pane windows with double-pane windows; of the remaining six, one had concrete plans to make the same upgrade and four expressed varying degrees of interest in a comprehensive window upgrade. Five of six respondents who had not yet made upgrades to their buildings' windows said that their primary motivator to do so was internal comfort; this was also the main reason given by both respondents who had completed window upgrades. Two respondents said they were not considering window upgrades at all. In all cases, respondents indicated that they had not pursued window upgrades due to the cost and logistical difficulty of completing these projects. More information about these motivators can be found in Section 6.11.

Among buildings that had not undergone window upgrades, respondents commonly reported issues with thermal comfort (six of six), noise infiltration (five of six), and impaired window functionality (four of six). They also said that most existing windows (75% to 100%) are single pane.

5 Policies and programs

5.1 Key findings

- Stringent building codes, such as New York City's LL97 and California's Title 24, are key factors advancing window technologies, as traditional double-pane windows often are unable to meet emissions or efficiency targets.[63]

[63] California Energy Commission. 2022. 2022 Building Energy Efficiency Standards (Title 24, Part 6). Sacramento, CA https://www.energy.ca.gov/programs-and-topics/programs/building-energy-efficiency-standards/2022-building-energy-efficiency

- Most manufacturers do not actively track code developments, relying instead on informal updates, while ESCOs depend on dedicated engineering teams to stay compliant.
- Permitting requirements for window projects vary widely by region. Manufacturers interviewed by CalMTA largely dismissed permitting as a barrier. However, hospital facilities managers described the permitting process as a major obstacle.
    - ESCOs view building codes as a double-edged sword—sometimes driving upgrades but often adding complexity, cost, and risk to retrofit projects, leading customers to favor simpler improvements that avoid triggering additional code-compliance requirements.
    - Building owner familiarity with building performance standards varies by role, but those aware emphasized that code compliance is essential for accessing public funding. However, many decision makers delegate permitting and regulatory responsibilities to staff or consultants.

Primary windows must comply with state regulations such as California Title 24, Part 6 (Building Energy Efficiency Standards).[64] The federal ENERGY STAR program does not cover secondary windows; eligibility for tax credit or rebates (e.g., under the Inflation Reduction Act)[65] requires ENERGY STAR–certified performance, which sets standards for energy efficiency based on climate zones. Voluntary programs such as utility-based programs promote the adoption of secondary windows by providing financial incentives or financing. Industry associations and other organizations also develop standards and performance ratings.

5.2 State regulations

As federal standards do not cover fenestration, states are free to set their own window efficiency requirements. In California, these are outlined in the state's energy code, and fenestration is governed by Title 24, Part 6, with the 2025 update.

5.2.1 Title 24

Title 24, Part 6 of the California Code of Regulations, also known as the Building Energy Efficiency Standards, sets mandatory requirements for the energy performance of windows (also called fenestration) in both residential and nonresidential buildings. The Title 24 requirement for windows applies to all new construction and projects that require permits. In the case of retrofits (alterations), the standards apply if the area of the windows that are being changed are more than

[64] California Energy Commission. 2025. *Building Energy Efficiency Standards*. Sacramento, CA.
[65] U.S. Congress, *Inflation Reduction Act of 2022*, H.R. 5376, 117th Congress, https://www.congress.gov/bill/117th-congress/house-bill/5376

a total of 150 sq ft.[66] These standards are designed to reduce energy consumption related to heating, cooling, and lighting.

Windows must meet specific performance metrics such as U-factor, SHGC, and visible transmittance, which vary by climate zone. The 2025 update to Title 24 introduces a mandatory fenestration backstop of a 0.47 U-factor for vertical glazing in new construction, additions, and alterations, alongside specific U-factor and relative SHGC limits for alterations. Compliance is typically verified through National Fenestration Rating Council (NFRC)-certified ratings and is required for new construction, additions, and certain retrofit projects. Title 24 also limits the percentage of window area relative to wall area (WWR) and includes daylighting and control requirements for some commercial applications. These regulations are updated every three years: the 2022 version is currently in effect since Jan 1, 2023; and the 2025 standards, which are already adopted, go into effect Jan 1, 2026. It is worth noting that these requirements apply only to VIGs, and not to CSWs, since Title 24 does not currently regulate attachment products other than window film.

5.2.2 Industry Associations, Standards, and Ratings

There are several organizations in the window and fenestration industry that support professionals involved in the design, manufacturing, installation, and specification of windows. These groups collaborate to develop industry standards, conduct and share research, provide professional education, advocate for energy efficiency policies, and offer networking opportunities across various roles (e.g., manufacturers, contractors, architects, and consultants).

Some notable national organizations include the following:

- **National Fenestration Rating Council (NFRC).** Labeling is the primary method for certifying and comparing the energy performance of residential and commercial windows, doors, and skylights in the U.S. and is mandatory for ENERGY STAR qualification. It is voluntary in general building product labeling but widely adopted across the industry.
- **Attachments Energy Rating Council (AERC).** The primary organization responsible for developing standardized rating and certification procedures for window attachment products, including secondary glazing systems such as CSWs. The AERC label provides independently verified data on thermal and optical performance, allowing comparison of attachment products based on metrics such as energy savings and comfort. Participation in AERC's rating program is voluntary but increasingly recognized across the industry as a credible means of demonstrating energy performance and supporting utility incentive eligibility.

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[66] California Energy Commission. 2025. 2025 Building Energy Efficiency Standards for Residential and Nonresidential Buildings: Title 24, Part 6, and Associated Administrative Regulations in Part 1. Sacramento, CA. Publication Number CEC-400-2025-010. https://www.energy.ca.gov/publications/2025/2025-building-energy-efficiency-standards-residential-and-nonresidential

- **Advancing Standards Transforming Markets International (ASTM)** develops standardized testing methods widely used to evaluate the performance and safety of windows.
- **Leadership in Energy and Environmental Design (LEED).** While not a labeling system for windows, LEED projects can earn credits in the Energy and Atmosphere category by incorporating high-performance fenestration.
- **Window & Door Manufacturers Association.** Represents manufacturers and suppliers of windows, doors, and skylights. The association publishes performance standards and engages in federal and state policy advocacy.
- **Fenestration and Glazing Industry Alliance (formerly AAMA and IGMA).** Provides product performance standards, certification programs, technical documents, and market research for residential and commercial fenestration products.

5.3 Potential regulations that impact CRAWS market

In addition to compliance with California's Title 24 energy code, other policies and regulatory frameworks are under development that could materially influence the state's fenestration market. Building performance standards are one such policy that will likely affect the CRAWS market.

5.3.1 Building performance standards

Building Performance Standards (BPS) are policies that mandate existing commercial and large multifamily buildings to achieve and sustain specified energy efficiency and emissions performance thresholds aligned with clean energy adoption and greenhouse gas mitigation objectives. These standards are designed with inherent flexibility, allowing state and local jurisdictions to tailor implementation strategies to their specific building stock, climate conditions, and policy priorities, while ensuring compliance with measurable performance benchmarks within defined compliance periods.

In 2021, the federal government committed to supporting building performance standards aimed at achieving zero-emission requirements by providing funding programs and technical assistance from agencies, such as the U.S. Department of Energy (DOE) and the U.S. Environmental Protection Agency, to local and state governments that commit to implementing them. California now has state-level momentum toward a statewide BPS strategy. Many cities and counties are actively developing or adopting local BPS-type rules (examples in California include Chula Vista as an early adopter and many big cities exploring or near-adopting BPS policies).[67] Looking ahead, potential statewide BPS in California (expected around 2029 to 2030) and the eventual codification of low U-factors as prescriptive baselines could accelerate adoption, especially if cost-effectiveness thresholds are met in future code cycles.

[67] Local Energy Codes. 2024. Building Performance Standards Issue. June. https://localenergycodes.com/content/june-2024?

The policy landscape is also shaped by advanced building standards such as New York City's LL97, which mandate high levels of efficiency for major retrofits that are often achievable only by including advanced window solutions. The U.S. DOE has made funding available for advanced glazing, including VIG manufacturing expansion,[68] and in 2024 launched an initiative offering a $2 million prize pool to spur the development of energy-efficient commercial glazing systems. These investments contribute to the adoption of advanced window solutions, although changing priorities at the federal level may negatively impact their likelihood of success.[69]

While improving window performance has traditionally been a higher priority in colder climates, California's high solar heat gains, especially during peak load periods, highlight the need for better-performing windows to support the state's aggressive decarbonization goals.

While these prescriptive and mandatory requirements do not yet demand the very low U-factors VIG can achieve, the performance-based compliance path—which most builders use—strongly favors high-performance glazing, positioning VIG as a strategic compliance measure. While there are no federal mandatory fenestration standards, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) 90.1 and International Energy Conservation Code model codes provide incremental U-factor improvements in certain climate zones, and the NFRC, International Organization for Standardization, and ASTM are advancing VIG-specific performance and durability standards.

Barriers remain, particularly in the lack of an NFRC rating method for VIG in single-pane replacement applications, uncertainty about long-term performance degradation, and the use of default ratings that understate actual performance.

The CEC has initiated efforts to advance fenestration technologies and promote secondary window solutions to enhance building energy efficiency and has conducted multiple studies on façade solutions as a part of Electric Program Investment Charge (EPIC).[70] These research efforts have become a driving force for policy change.

5.4 California programs, pilots, and incentives

CalMTA reviewed existing programs, pilots, and incentives supporting the installation of advanced window solutions in California (Table 24). Few programs specific to advanced window solutions are currently available in the state. Most of these opportunities provide funding or

[68] U.S. Department of Energy. 2024. DOE's Building Technologies Office Awards 15 Small Business Grants to Develop Promising Building Technologies. July. DOE's Building Technologies Office Awards 15 Small Business Grants to Develop Promising Building Technologies | Department of Energy

[69] U.S. Department of Energy. 2024. CX-029985: Building Envelope Innovation Prize Secondary Glazing Systems. February. https://www.energy.gov/nepa/articles/cx-029985-building-envelope-innovation-prize-secondary-glazing-systems

[70] California Energy Commission. 2020. High-Performance Integrated Window and Façade Solutions. CEC-500-2020-001, https://www.energy.ca.gov/sites/default/files/2021-05/CEC-500-2020-001.pdf

rebates for energy-efficient technologies in general and measure compliance using whole-building energy use models, such as Normalized Metered Energy Consumption, rather than specifically incentivizing advanced window solutions.

Table 24. Programs, Pilots, and Incentives Supporting Installation of Advanced Window Solutions in California

Program/Initiative	Type	Applicability to Advanced Window Solutions	Source
CEC GFO-22-501	Grant program	Supports high-performance window retrofits in existing commercial buildings	California Grants Portal
SDG&E Normalized Metered Energy Consumption	Pay for performance via model	Incentivizes efficiency-enhancing retrofits, including window replacements	Savings at the Meter - SD Energy Edge for SDG&E Customers
SoCalGas Customized Incentives	Investor-owned utility (IOU) incentives	Incentivizes efficiency-enhancing retrofits, including window replacements	Business Equipment Rebates | SoCalGas
SCE Window Incentives	IOU incentives	Incentives are available for efficient window retrofits and window film	32nd Ed SolutionsDirectory2021Feb_Draft 5 review.pdf
179D Commercial Buildings Deduction (Federal)	Federal tax deduction	Provides up to $5.65 per square foot deduction for envelope energy savings, including windows	Energy-efficient commercial buildings deduction | Internal Revenue Service

5.4.1 Perceptions about regulatory landscape

CalMTA interviewed manufacturers, ESCOs, building managers, and owners to gather their perspectives on the regulatory environment influencing business operations in California. When relevant, the team specifically asked about the impact of existing building codes on manufacturing and sales processes, including how these codes influence decisions about the types of equipment produced. The team probed whether any regulations particularly encourage or discourage the manufacturing and sale of CSW or VIG. Respondents were asked about permit requirements for installing their equipment and how often they obtain permits versus completing installations without them. CalMTA tailored interview questions to each respondent group: manufacturers, ESCOs, building managers, and owners. See Attachment C for details. CalMTA also surveyed building owners and managers to assess their awareness of available programs that support window upgrades.

Perception and awareness among manufacturers

CalMTA asked manufacturers of VIG and CSW technologies for information about any regulations or policies that affect their business (positively or negatively). Three of six manufacturers said that existing building codes have little to no impact on their business, while three mentioned the

beneficial influence of high-efficiency standards in certain cities, especially New York City, with its extremely stringent Local Law 97 (LL97), which sets efficiency standards and GHG emissions reduction targets for most buildings above 25,000 sq ft.

One manufacturer also mentioned Boston, Seattle, Denver, and San Francisco as cities with above-baseline efficiency standards and said that they have "doubled down on sales activity" in these cities due to their strict building codes.

A VIG manufacturer mentioned that California code is already "tuned to high-performance double-pane windows," meaning that their products are well positioned to fulfill stringent regulatory requirements.

Five of six manufacturers reported that they do not make any special effort to stay up to date on building codes, as they do not consider it important to their business. The sixth manufacturer said that they keep informed by conducting regular activities such as reading trade publications and news wires.

Four of six manufacturers do not predict any substantial changes to building codes moving forward, while the other two expect to see increasingly stringent energy-efficiency standards as more technology becomes available and affordable.

When asked whether their products typically require permits to install, four stated they do not, while two said they don't know or that it depends on where the project occurs. The consensus among manufacturers is that permitting is not a serious obstacle to most CSW and VIG projects. However, a facilities manager for a large hospital network disagreed, describing an extremely onerous approval, design, and permitting process for any retrofit affecting hospital buildings in California. Neither of the interviewed hospital administrators had pursued or conducted any kind of window upgrades due to the perceived extreme difficulty of getting approvals. According to the California Department of Healthcare Access and Information, window glazing replacement (such as with CSW) does not trigger a review or permitting process, whereas a full window and frame replacement (such as with VIG) would trigger a field review and permitting process.[71] This suggests that healthcare decision makers might be more likely to pursue CSW projects if they were aware that they do not trigger a field review.

ESCOs

CalMTA asked ESCOs about any building codes or policies affecting their businesses. Respondents agreed that building codes can notably impact retrofit projects, often acting as a constraint. One noted that exceeding certain thresholds can trigger added requirements and costs, reducing ROI and sometimes causing projects to be canceled. This one respondent further

[71] California Department of Health Care Access and Information. 2025. "FREER Manual." August 14, 2025. Microsoft Word - FREER Manual_Revised 08-13-2025-FINAL

explained that to avoid this, many customers opt for simpler, maintenance-focused improvements that do not require full code compliance. Two respondents pointed to the challenge of meeting strict regional codes.

Experience varied regarding the impact of building codes on window upgrades. One respondent identified California's Title 24 as a deterrent due to its high stringency. Another explained that code requirements can be triggered when renovations exceed a certain percentage of the building's floor area, which can indirectly necessitate window or envelope upgrades. However, not all respondents considered codes to be a factor, with one reporting no awareness of any code provisions influencing window upgrades in their projects.

Several respondents also noted that recent code changes have increased regulatory complexity and added costs, particularly for retrofits. One cited a major shift in 2013, when performance-based requirements were introduced, leading to stricter window and envelope standards that made retrofits harder to finance. Others pointed to state and local policies that are raising compliance expectations.

All respondents reported that their engineering teams are primarily responsible for staying current with building code changes by engaging with municipal officials; attending conferences and webinars; and maintaining regular contact with industry peers, investors, and manufacturers

Looking ahead, all respondents expect building codes to continue evolving, with one respondent anticipating that cities will push for stricter energy and performance standards. Another noted that changes occur every two years and often introduce complexity and costs that discourage compliance, especially when compliance is loosely enforced or lacks clear financial returns for building owners. Another predicted a stronger focus on decarbonization and electrification, though they noted windows may only play an indirect role in meeting those goals. Finally, one respondent mentioned they expect cities to lead future code tightening in the absence of strong federal action.

In terms of permitting, respondents generally agreed that permits are required for many, but not all, equipment installations. Requirements vary depending on the equipment type and project scope. For example, certain retrofits or projects that exceed a threshold value or floor area percentage can trigger permitting needs, while smaller upgrades may not. Two respondents reported that permits are always required and consistently secured for their projects, reflecting a strong culture of compliance. Another emphasized that permitting needs vary by jurisdiction and project details. Overall, permit adherence appears to be standard practice, though the specific triggers depend on local regulations and project characteristics.

Building owners and managers

CalMTA asked decision makers about their familiarity with BPS and the impact that regulatory policies have on their motivations to address building performance, as well as their

understanding of the permitting process required to undertake major building projects in California.

Three of the eight respondents were familiar with BPS, two were somewhat familiar, and the other three had little to no awareness of BPS. Of the five who had some level of familiarity with BPS, they all mentioned the important role that BPS and other regulations play in their decision-making regarding alterations to their buildings. They all stressed the need to stay compliant with all required policies and codes because the availability of public funding is contingent on it. Two respondents who said they were somewhat familiar with BPS stated that they adhere to compliance regulations just enough, so they meet the requirements, but do nothing "above and beyond to improve the quality of their (university) buildings. Two respondents with no general functional knowledge of BPS or building codes said that they were not concerned with that information and delegated such responsibilities to others (both operated hospital buildings, including a CEO).

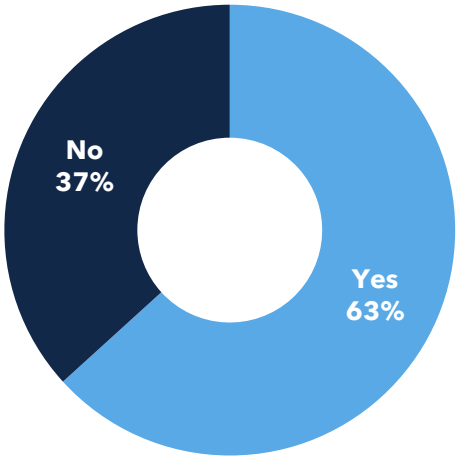
> "They make a big impact. Our funding and financing are contingent upon being up to code and in line with regulations."
>
> -Hospital facilities manager

The lack of knowledge regarding codes and regulations appears to vary based on the role of the decision maker, as it is possible that a CEO could have the ultimate say on building upgrades, little awareness of regulations, and thus rely on others to stay abreast of certain details when necessary.

Understanding and awareness of the permitting process associated with window upgrades was generally low. Most respondents had not even considered window replacements, thus never considered the permitting process. Two were familiar with HVAC permits and questioned whether the process for windows was similar.

CalMTA also gauged the awareness of regulatory policy related to energy efficiency and windows among managers and building owners in the survey. As shown in Figure 6, CalMTA found that 63% of commercial building owners and managers are aware of current or potential regulatory policies that might affect them.

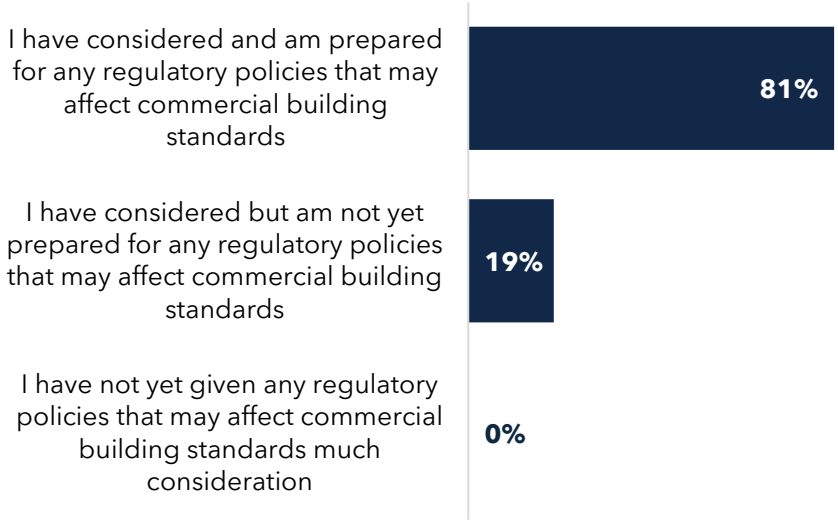
Figure 6. Regulatory Policy Awareness



Source: CalMTA CRAWS Building Owner and Property Manager Survey Q G5: "Are you aware of any current or potential regulatory policies that may affect the way you operate your business in California, particularly how you make decisions regarding building upgrades?" (n=114). Results rounded to the nearest percentage.

To assess awareness and preparedness related to regulatory policies, the survey asked respondents to describe their level of consideration regarding performance standards for commercial buildings in California (Figure 7). Among commercial building owners and managers who were aware of the current or future regulatory policies, 81% have considered and are prepared for their impact.

Figure 7. Regulatory Policy Awareness and Preparedness

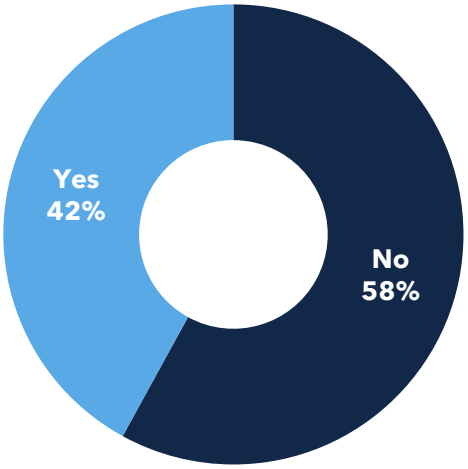


Source: CalMTA CRAWS Building Owner and Property Manager Survey Q G7: "Which of the following statements best describes your level of consideration and preparation regarding regulatory policies that may affect performance standards for commercial buildings in California" (n=85). Results rounded to the nearest percentage.

5.4.2 Awareness of the available incentive programs

The survey also assessed awareness of available incentive programs supporting window upgrades. CalMTA found that 42% of commercial building owners and managers are aware of energy efficiency or decarbonization programs (Figure 8).

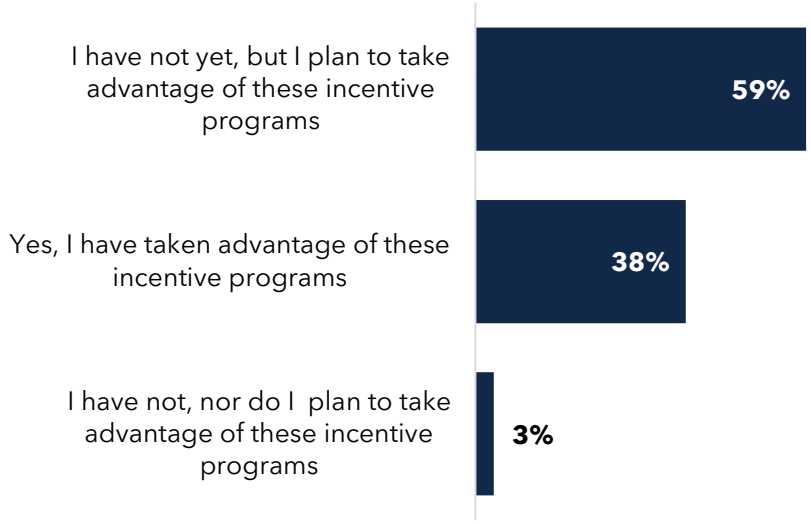
Figure 8. Awareness of Window Solutions Incentive Programs



Source: CalMTA CRAWS Building Owner and Property Manager Survey Q G1: "Do you know of any energy efficiency or decarbonization programs that provide financial support, incentives, or tax rebates for window solutions to buildings in California?" (n=114). Results rounded to the nearest percentage.

The survey asked respondents who reported they were aware of incentive programs whether they had participated in programs offering financial support, incentives, or tax rebates for window solutions. As shown in Figure 9, of the 42% of commercial building owners and managers aware of energy efficiency or decarbonization programs, 38% have taken advantage of these incentive programs, while 59% said they plan on taking advantage of these programs.

Figure 9. Incentive Program Usage among Building Owners and Property Managers who are Aware of them



Source: CalMTA CRAWS Building Owner and Property Manager Q G2: "Have you or do you plan to take advantage of any of these programs that provide financial support, incentives, or tax rebates for window solutions?" (n=56). This question was asked of respondents who indicated in G1 that they are aware of energy efficiency or decarbonization programs providing financial support, incentives, or tax rebates for window solutions in California.

6 Demand side characteristics

6.1 Key findings

- Most buildings owned and managed by survey respondents were large, with 76% exceeding 25,000 sq ft. The most common size range was 25,001-50,000 (40% of buildings in the sample), followed by buildings over 50,000 sq ft (36%).72
- In the decision-making process pertaining to renovations, owners have a primary role.

[72] These percentages represent unweighted counts of survey respondents since they describe sample characteristics rather than population-level estimates.

- Forty-seven percent of commercial building owners and managers reported that tenants have 'no or very little influence,' 50% reported 'some influence,' while only 3% said that tenants have 'a lot of influence.'73

- Apart from manufacturers, awareness of VIG technologies is low across market actors. ESCOs, building owners, and tenants consistently reported limited familiarity. Even where awareness exists, customers often lack understanding of benefits, costs, or installation processes.
- Eighty-five percent of surveyed commercial building owners and managers reported familiarity with CSW. Fifty-one percent said that they were 'familiar' and 34% said they were 'very familiar.'74
- Manufacturers and ESCOs most frequently cite cost as the primary barrier to adopting both CSW and VIG, emphasizing that high upfront costs and uncertain ROI deter projects, particularly when competing with other capital improvements like HVAC or roofing.
- When asked what factors would prevent them from selecting CSW or VIG as a window replacement or upgrade solution, building owners cited limited information about CSW and VIG and concerns about performance, durability, and maintenance as the primary adoption barriers.
- Manufacturers cited a wide range of CSW benefits, such as soundproofing, improved comfort, easy installation, and minimal installation disruption. They also acknowledged drawbacks, including condensation, aesthetic concerns, and incompatibility with structurally unsound existing windows.
- Manufacturers and ESCOs described VIG as having superior technical performance compared to CSW but note that VIG adoption remains limited due to supply chain immaturity, high costs, and skepticism from the market.
- Building owners reported that improving comfort and reducing noise are primary motivations for pursuing upgrades, but decision-making is often delayed due to concerns over project costs, disruptions to operations (especially in healthcare settings), and a lack of information about available alternatives.

CalMTA surveyed decision makers (i.e., building owners and managers) and interviewed manufacturers, commercial tenants, building managers, and ESCOs. Additionally, the team conducted secondary research to gain a better understanding of the factors influencing window purchases, the willingness to adopt CSW or VIG, and the key barriers limiting broader adoption of

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[73] CalMTA Building Owner/Manager Survey Q B17 "*How much influence, if any, do tenants in the [TYPE] buildings you own or manage have in terms of selecting the types of renovations or upgrades to buildings? (e.g., HVAC, windows, lighting, insulation, etc.)*" (n=114)

[74] CalMTA Building Owner/Manager Survey Q D1 "*Prior to this survey, how familiar were you with CSW?*" (n=114).

these efficient technologies in California. The following sections present detailed findings from the survey and interviews related to demand side market characteristics.

6.2 Commercial building market decision making

Decision-making about building renovations is a complex process involving many market actors.[75] Factors such as occupancy status (leased/rented versus owned), tenure of the tenant/owner, and overall economy influence renovation decisions around energy efficiency. A study by NEEA found that renovations involve multiple decision makers and various factors interacting with each other.[76] The study indicated that while owners hold ultimate authority over large strategic initiatives, property managers often act as tenant advocates to owners.

CalMTA reviewed both secondary and primary data to better understand the decision-making process behind window renovations. The team surveyed building owners and managers, asking them specifically if they were decision makers. Table 25 shows the breakdown of survey respondents by owners and managers. The distribution aligns with the NEEA study cited above, which found similar patterns in decision-making. An overwhelming majority (86%) of building owners said they alone make the decision, whereas only 1% of building managers said the same.[77]

Table 25. Distribution of Building Managers and Owners

Role	I make the decision	Notable influence	Total
Building Owner	19	3	22
Building Manager	1	91	92
Total	**20**	**94**	**114**

Source: CalMTA CRAWS Building Owner and Property Manager Survey Q A1 "How much influence do you have on decisions regarding major renovations or retrofit projects to the buildings you own or manage?" (n=114) and Q A2 "What is the most appropriate description of your role?" Select all that apply. (n=114)

6.3 Building characteristics and occupancy dynamics

To characterize building use and estimate square footage, CalMTA asked respondents about the types of buildings they owned or managed, their estimated size, and their primary use.

Table 26 shows that most buildings in the CRAWS sample were large, with 76% exceeding 25,000 sq ft.[78] The most common size range was 25,001-50,000 (40% of buildings in the sample), followed by buildings over 50,000 sq ft (36%). Only 3% of buildings were smaller than 10,000 sq ft. College and healthcare buildings were the largest, with all college-affiliated buildings reported

[75] Stanitsa, A., Hallett, S.H., and Jude, S. 2022. *Investigating Key Factors Influencing Decision-Making in the Design of Buildings and Places: A Survey of Stakeholders' Perception*. Architecture, Structures and Construction, 2, 381–401. https://doi.org/10.1007/s44150-022-00058-5.

[76] Ethnos Inside, LLC. 2024. *Better Bricks Commercial Building Decision Making Study* Better Bricks Study

[77] Results are unweighted since they describe sample characteristics rather than population-level estimates.

[78] Results are unweighted since they describe sample characteristics rather than population-level estimates.

at over 25,000 sq ft. and 74% of healthcare buildings over 50,000 square feet. Schools (non-college/university) buildings also skewed large, with 83% above 25,000 sq ft.

This distribution of building sizes is generally consistent with secondary data sources, such as ComStock.

Table 26. Building Size (sq ft)

Building Type	0 - 10,000	10,001 - 25,000	25,001 - 50,000	Over 50,000	Total
College	-	-	9	15	24
Healthcare	-	1	5	17	23
Lodging	1	6	9	7	23
Office	2	13	6	-	21
School	-	4	17	2	23
Total	**3**	**24**	**46**	**41**	**114**

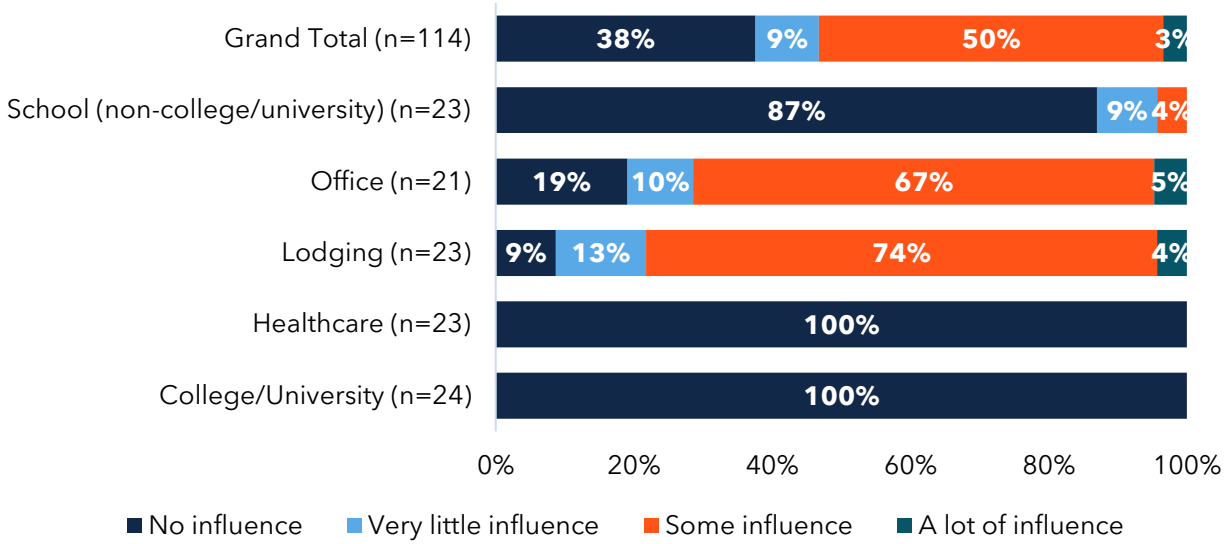
Source: CalMTA CRAWS Building Owner and Property Manager Survey Q B1: "Which of the following types of buildings do you currently own or manage? Please select all that apply." (n=114); and Q B2 "What is the approximate total square footage of your [TYPE] buildings?" (n=114) Note: this table reflects unweighted data from the sample.

6.4 Occupancy and tenant responsibility

The survey asked commercial building owners/managers about the extent to which tenants influence decisions related to building renovations or upgrades (e.g., HVAC, windows, lighting, and insulation). Figure 10 summarizes responses by building type. Overall, 47% of commercial building owners/managers reported that tenants have no or very little influence over renovation or upgrade decisions, while 50% reported some influence. Only 3% of commercial building owners/managers indicated that tenants have a lot of influence.

Tenant influence over renovation and upgrade decisions was highest among lodging and office building owners/managers. Seventy-four percent of lodging building owners/managers and 67% of office building owners/managers reported that tenants have some influence over renovation and upgrade decisions. One hundred percent of college/university and healthcare building owners/managers reported no tenant influence over renovation and upgrade decisions, while tenant influence was minimal in schools (87% of school building owners/managers reported no influence).

Figure 10. Tenant Influence on Renovation and Upgrade Decisions by Building Type

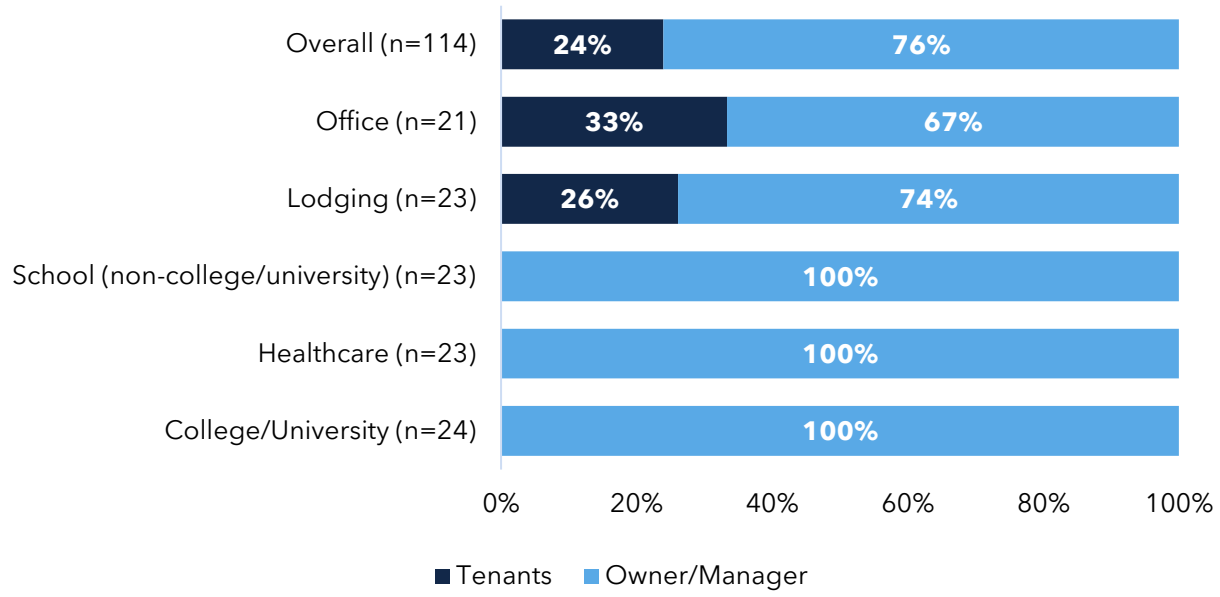


Source: CalMTA CRAWS Building Owner and Property Manager Survey Q B17: "How much influence, if any, do tenants in the [TYPE] buildings you own or manage have in terms of selecting the types of renovations or upgrades to buildings? (e.g., HVAC, windows, lighting, insulation, etc.)" (n=114). Results rounded to the nearest percentage. Percentages may not sum to 100% due to rounding. A single "lodging" respondent indicated that their tenants have a lot of influence over these decisions; applying weights caused this to round to 0%.

The survey asked commercial building owners/managers about who typically pays the utility bills in the buildings they own or manage. Figure 11 summarizes utility bill payment responsibility by building type. Overall, 76% of commercial building owners/managers said they pay the utility bills themselves, while 24% reported that tenants are responsible. This finding suggests that owner-paid utilities in the selected segment present a clear opportunity for energy-efficiency upgrades.

Utility payment responsibility varies by building type. School, healthcare, and college/university building owners/managers all reported that utilities are paid entirely by the owner or manager (100% of represented square footage). Seventy-four percent of lodging and 67% of office building owners/managers reported that owners/managers paid utilities.

Figure 11. Responsibility for Paying Utility Bills by Building Type



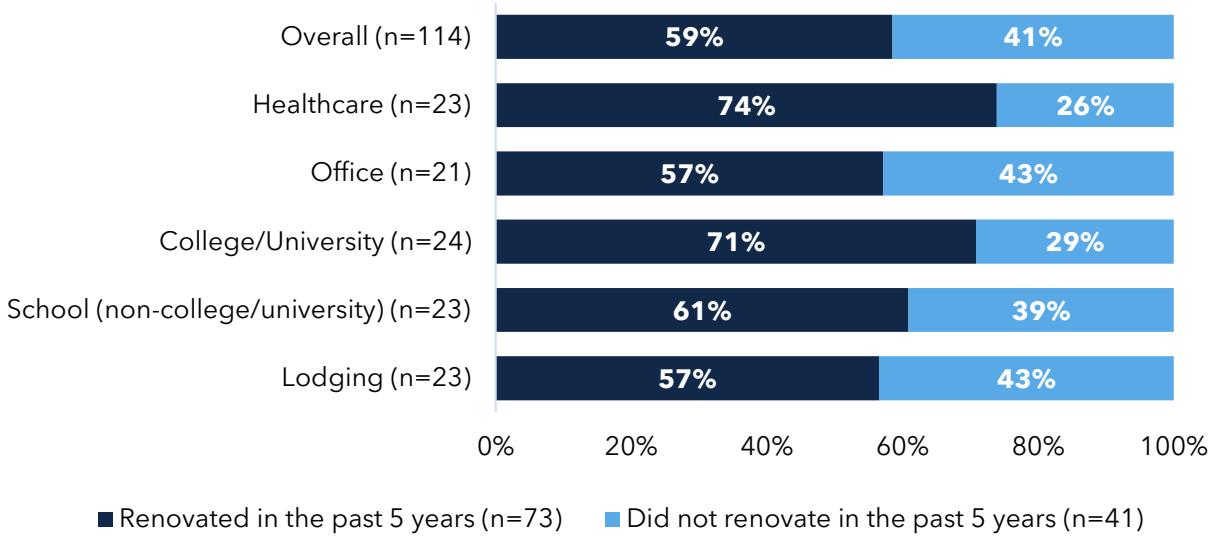
Source: CalMTA CRAWS Building Owner and Property Manager Survey Q B18: "Who pays the utility bills in the [TYPE] buildings you own or manage?" (n=114). Results rounded to the nearest percentage. The "owner/manager" portion of the Overall responses comprises answers from building owners who reported that they pay the utility bills and answers from building managers who reported that the owner pays the bills.

6.5 Renovation history

The survey asked commercial building owners/managers about major renovations during the last five years, defined as projects affecting more than 50% of the square footage of a given building that they own/manage. Generally, renovations are a prime opportunity for upgrades. As displayed in Figure 12, 59% of commercial building owners/managers reported a major renovation or large retrofit on at least one of their buildings within the past five years. Note that these data do not indicate the proportion of square footage that has undergone major renovation, but rather the proportion of building owners/managers (weighted by building type) who reported that at least one building under their purview has undergone a major renovation.

Renovation activity varies by building type. Healthcare and college/university building owners/managers reported the highest rates of recent renovations, at 74% and 71%, respectively. Sixty-one percent of school building owners/managers reported recent renovations while 57% of office and lodging building owners/managers reported recent renovations.

Figure 12. Major Renovation on One or More Building in the Past 5 Years, by Building Type

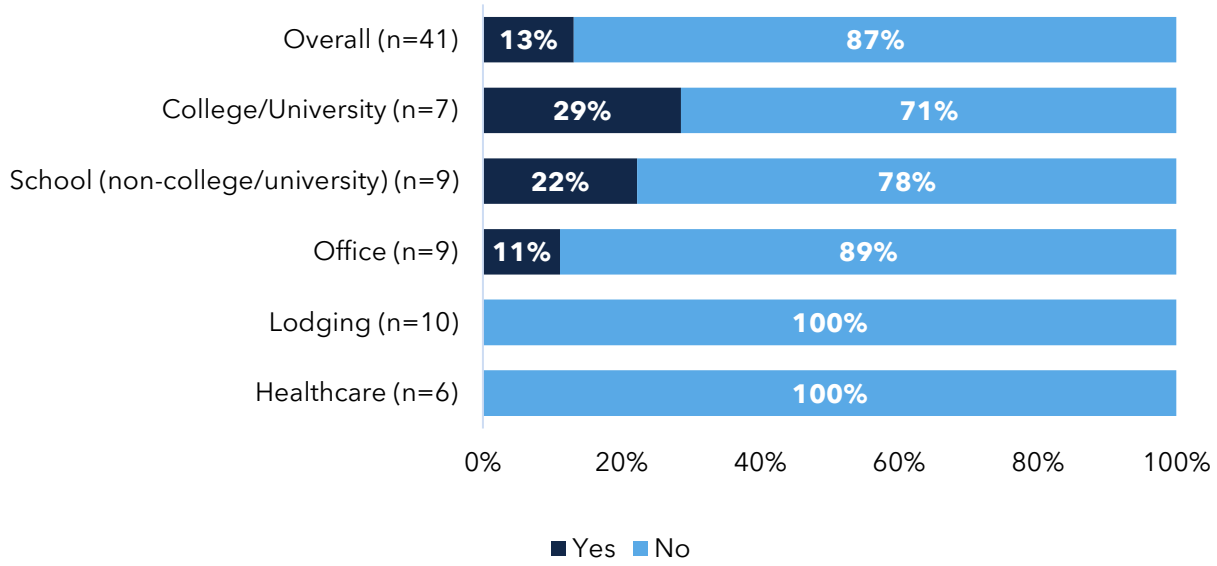


Source: CalMTA CRAWS Building Owner and Property Manager Survey Q B6: "How many of your [TYPE] buildings have undergone major renovations or large retrofit projects within the past 5 years? For the purposes of this survey, a major renovation or large retrofit is a project affecting more than half the square footage of the building." (n=114). Results rounded to the nearest percentage. Respondents who reported that none of their buildings were renovated in the past five years are shown as "Did not renovate in the past 5 years." While those who reported that one or more of their buildings were renovated are shown as "Renovated in the past 5 years."

6.6 Future renovation plans

The survey asked building owners/managers about their renovation and retrofitting plans for the next five years. Owners/managers who responded that the building(s) under their purview had not undergone any major renovations or retrofits within the past five years were then asked about their future renovation/retrofit plans during the next five years. Figure 13 summarizes building owner/manager renovation plans by building type. Overall, 13% of commercial building owners/managers reported plans to renovate or retrofit at least one of the buildings they own or manage in the next five years, whereas 87% reported no plans. College/university building owners/managers were the most likely to report planned renovations (29%), followed by school building owners/managers (22%) and office building owners/managers (11%). None of the respondents who own or manage healthcare or lodging buildings reported any planned renovation.

Figure 13. Future Renovation Plans for One or More Buildings by Building Type



Source: CalMTA CRAWS Building Owner and Property Manager Survey Q B11: "Are you (owner or manager) planning for any of your building(s) to undergo major renovations or large retrofits within the next 5 years?" (n=41). This was a follow-up question asked only of respondents who, in Q B6, indicated that their buildings have not undergone a major renovation or large retrofit. Results rounded to the nearest percentage.

6.7 Purchase drivers and window upgrade behaviors and strategies

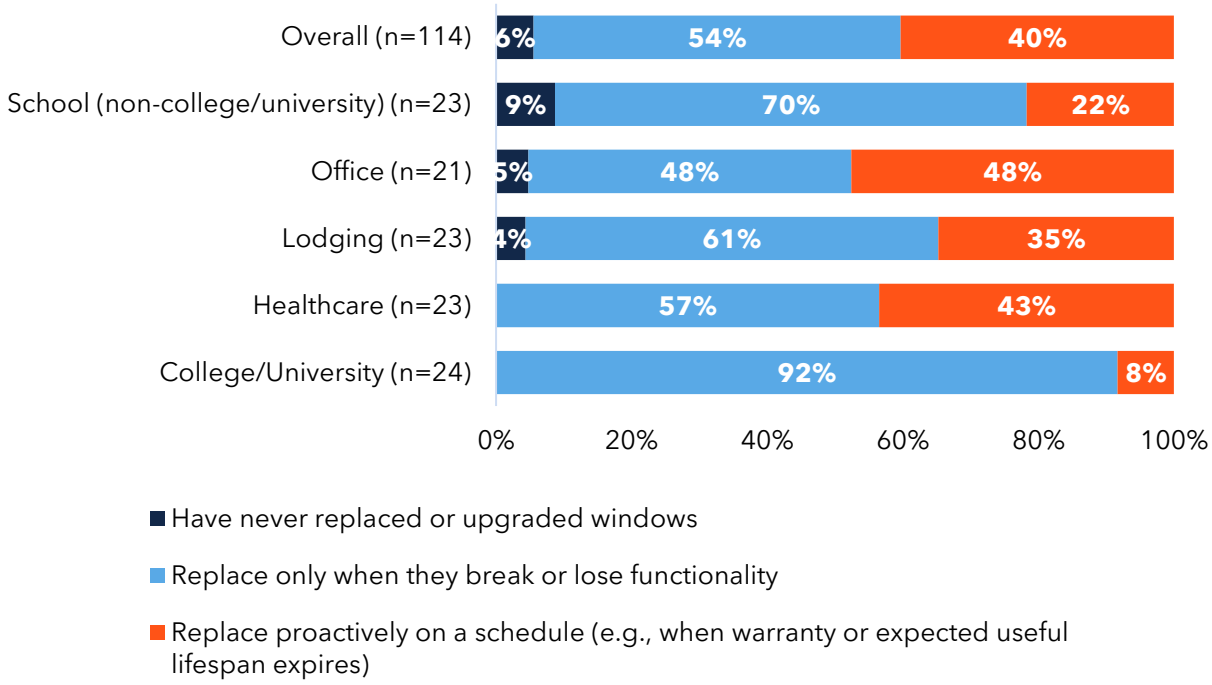
6.7.1 Window upgrade strategies

To better understand how and when window upgrades occur, the survey asked commercial building owners/managers about their replacement strategies. The findings suggest that window replacements are often more reactive than planned. Figure 14 shows that 54% of commercial building owners/managers replace windows only when they break or lose functionality. A smaller share (40%) replaces windows proactively on schedule, while 6% of commercial building owners/managers said they have never replaced or upgraded windows. Existing research indicates that only a small portion of the single-pane window stock is replaced each year. In a study by Energy Solutions on behalf of CalNEXT, one market actor interviewed stated that "about 40 percent of all commercial buildings still have the original single pane glass with aluminum

frames."[79] In the same study, one survey respondent noted that "less than one percent of [commercial] windows get replaced per year."[80]

According to CalMTA survey respondents, 48% of office building owners/managers,[81] 43% of healthcare building owners/managers, and 35% of lodging building owners/managers replace windows proactively on schedule. In contrast, school building owners/managers (22%) and especially college/university building owners/managers (8%) are the least likely to do so. Nearly all college/university building owners/managers (92%) reported replacing windows only upon failure.

Figure 14. Window Replacement Strategies by Business Type



Source: CalMTA CRAWS Building Owner and Property Manager Survey Q B19: "Thinking specifically about windows, what is the most common approach you take to replacing or upgrading the windows in your buildings?" (n=114). Results rounded to the nearest percentage. Percentages may not sum to 100% due to rounding.

[79] Energy Solutions. 2024. *Commercial Windows Market Study and Measure Package Development*. Prepared for CalNEXT. Commercial Windows Market Study and Measure Package Development. One explanation for low adoption levels is the lifespan of a commercial window. Among CalNEXT survey respondents, the life of a commercial window was estimated to be from 40 to 70 years, depending on upkeep and frame material.

[80] While there are some who placed the average closer to 25 to 30 years, the reality is that unless there is a window failure, such as water or air intrusions, window replacements are rare. (pg. 21).

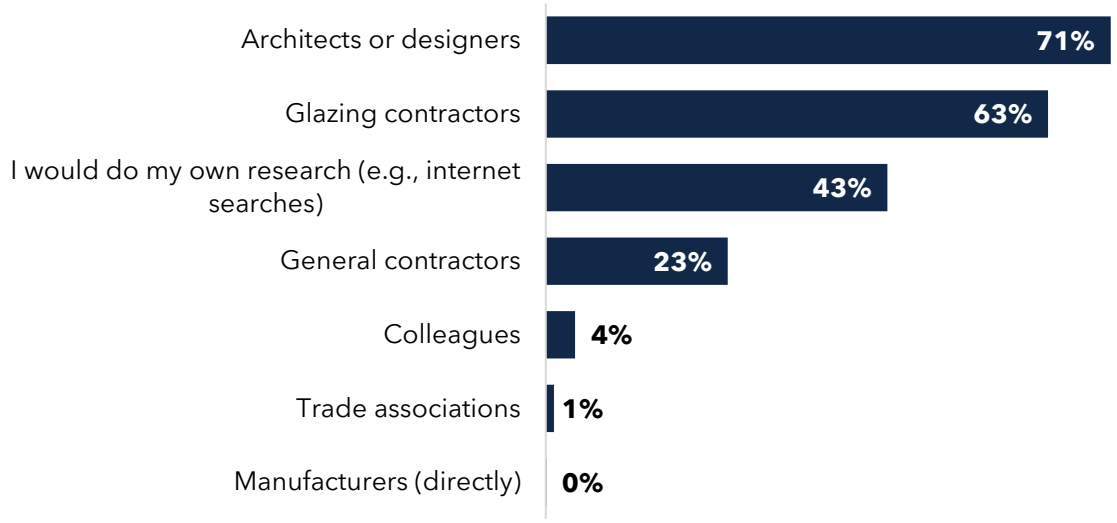
[81] CalMTA did not screen for recent renovations during the interview screen.

6.7.2 Information sources

The survey also examined where decision makers turn for information and guidance during the window replacement process. Understanding these information channels will help identify key influences and potential market leverage points. Figure 15. Information Sources for Window Replacement or Upgrade Considerations

illustrates that 71% of commercial building owners/managers rely on architects or designers, while 63% rely on glazing contractors when considering window replacements or upgrades. Forty-three percent of building owners/managers reported conducting independent research, such as internet searches. Only 23% of commercial building owners/managers reported consulting general contractors, while only 4% reported consulting colleagues.

Figure 15. Information Sources for Window Replacement or Upgrade Considerations

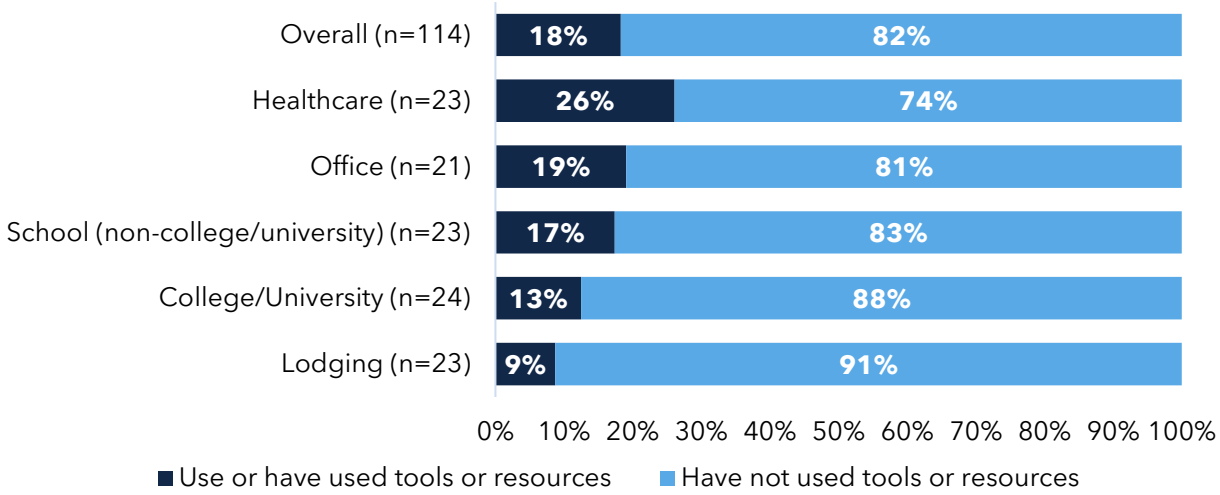


Source: CalMTA CRAWS Building Owner and Property Manager Survey Q B20: "If you were to upgrade or replace your windows, which source(s) would you consult to get information? Please select all that apply." (n=114) Results rounded to the nearest percentage.

The survey and interviews probed the use of tools, models, and calculators in the window upgrade or replacement decision-making process. Figure 16 shows that 82% of surveyed commercial building owners/managers have not used tools, models, calculators, or other resources to determine whether to install high-efficiency window solutions, where 18% had used these tools or resources. Healthcare building owners/managers reported the highest use (26%), followed by office building owners/managers (19%). Lodging building owners/managers reported the lowest usage rates (9%). Healthcare and office respondents who reported using tools mentioned specific modeling software packages, such as EnergyPlus, BEopt, EnergyPro, eQUEST, COMFEN, and Revit. Respondents noted they had adopted these tools between 2005 and 2024, typically as part of broader energy modeling or building design processes. Suggestions for improvement focused on enhanced speed, usability, integration with BIM tools

like Revit, and features to support more complex window geometries or compare multiple design options side by side.

Figure 16. Use of Tools or Resources to Evaluate High-Efficiency Window Solutions



Source: CalMTA CRAWS Building Owner and Property Manager Survey Q B21: "Do you use or have you used any tools, models, calculators, or other resources to determine whether to install high-efficiency window solutions?" (n=114) Results rounded to the nearest percentage.

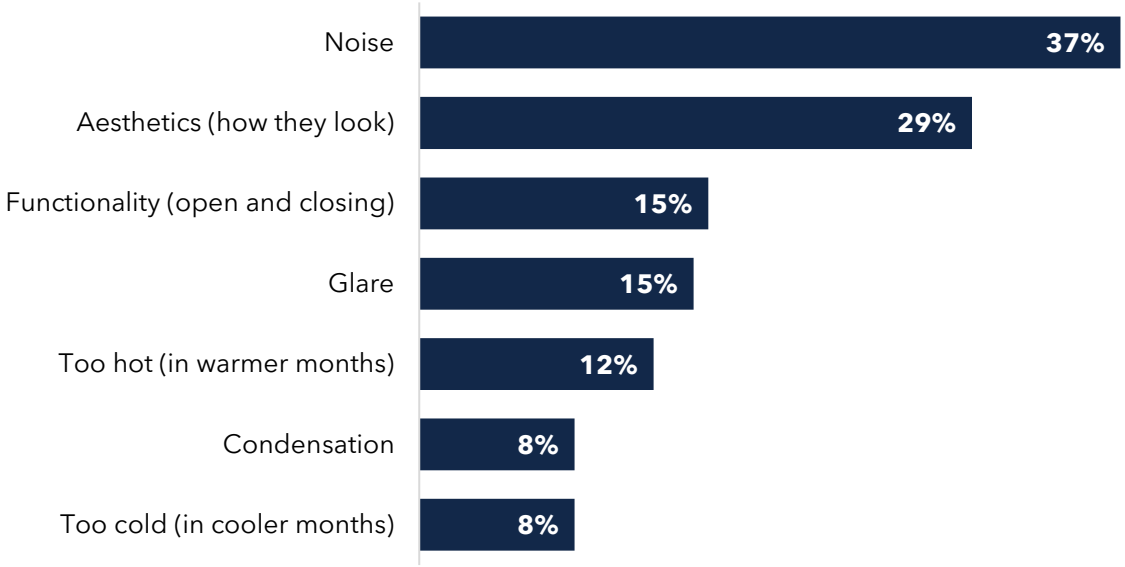
ESCO interview respondents also reported using modeling tools to evaluate window solutions, often before making proposals. Common tools included eQUEST, Trane, Energy Toolbase, and custom Excel-based models tailored to specific needs. Firms with large engineering teams cited decades of experience and active collaboration with software providers to refine these tools. However, one respondent noted the lack of a standardized methodology, pointing out that many tools do not fully account for factors like altitude, pressure, or location-specific conditions.

6.8 Satisfaction with current window inventory

6.8.1 Tenant feedback and complaints

The survey asked building owners and property managers which aspects of window performance they receive negative feedback or complaints about. As Figure 17 summarizes, the four most frequent topics of window-related complaints received by building owners and managers were noise (37%), aesthetics (29%), and functionality and glare (both 15%).

Figure 17. Topics of Window-Related Complaints

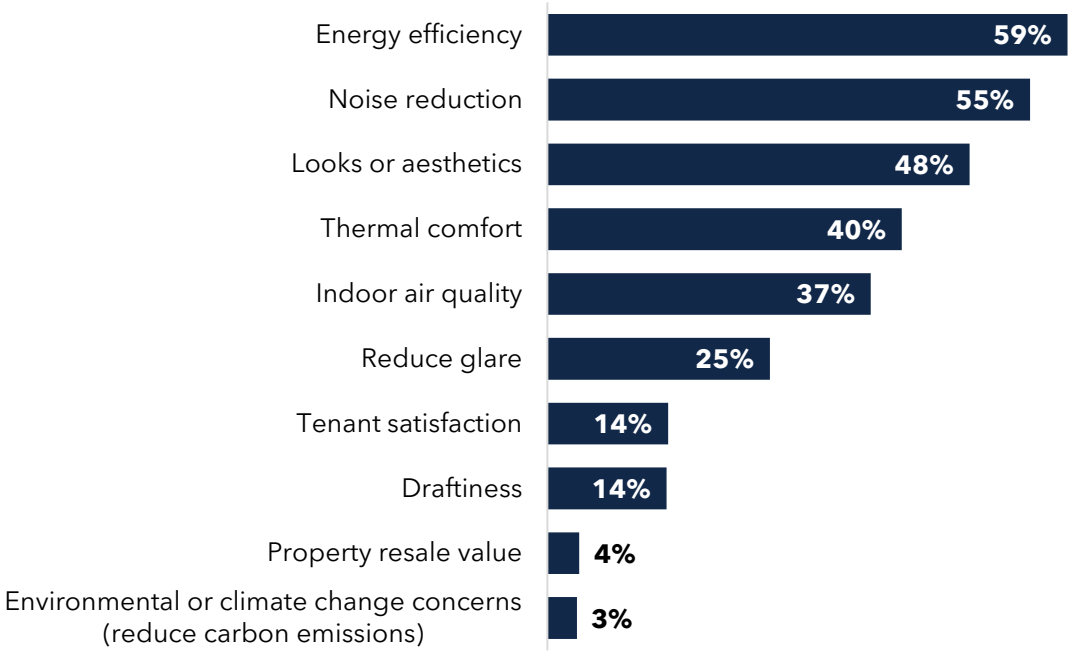


Source: CalMTA CRAWS Building Owner and Property Manager Survey Q C2: "Which aspects of window performance do you receive negative feedback or complaints about? Select all that apply" (n=39). Results rounded to the nearest percentage.

6.8.2 Motivations to upgrade

Surveyed building owners/managers were asked to rank their top reasons (up to three) for why they would consider upgrading or replacing windows in their buildings. Figure 18 summarizes the most selected motivators. Overall, 59% of commercial building owners/managers identified energy efficiency among the top motivating factors, followed by noise reduction (55%), and looks or aesthetics (48%).

Figure 18. Top Motivators to Upgrade



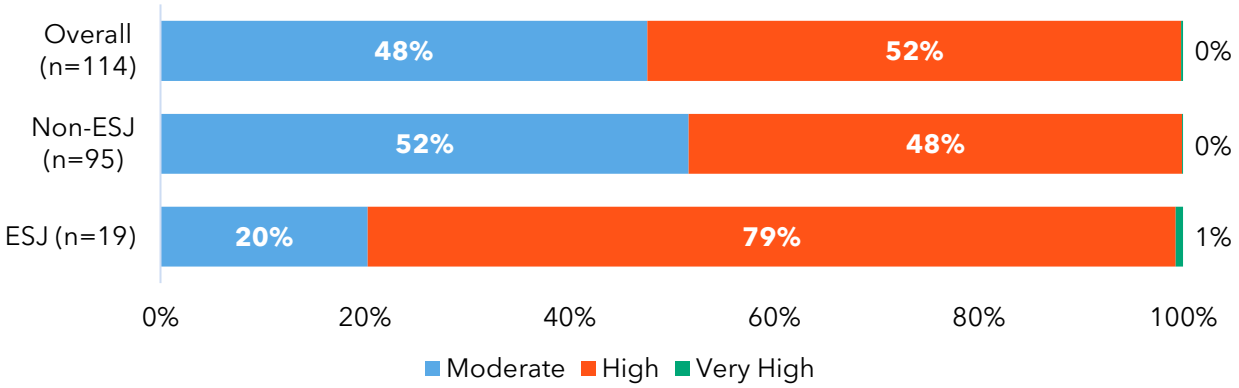
Source: CalMTA CRAWS Building Owner and Property Manager Survey Q C3: "If you were to upgrade or replace any of the windows in your building(s), what would you say are the most important reasons that you would consider doing so? Please rank up to three reasons, where #1 is the most important and #3 is the third-most important. "(n=114) Results rounded to the nearest percentage.

6.8.3 Perceived importance of efficient windows

When asked to rate the importance of efficient windows in reducing energy costs in their buildings, 52% of owners/managers rated the importance of efficient windows as important (Figure 19). Very few building owners or managers reported it was of *very high importance,* while none rated it as *very low importance*. The survey found that building owners/managers with buildings in ESJ communities rated the importance of efficient windows higher than those with buildings in non-ESJ communities: 80% of building owners/managers in ESJ communities rated the importance of efficient windows highly, compared to only 48% of those in non-ESJ communities.[82]

[82] ESJ sample size was small (n=19). Therefore, this finding should be considered directional.

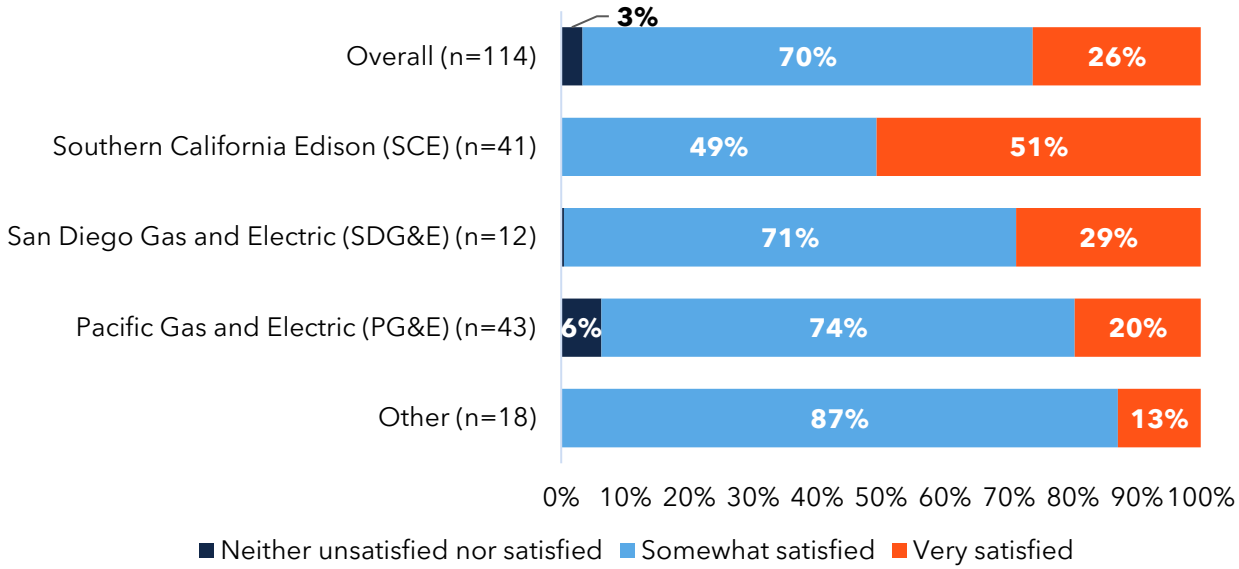
Figure 19. Importance of Efficient Windows



Source: CalMTA CRAWS Building Owner and Property Manager Survey Q C4: "How would you rate the importance of efficient windows to reducing energy costs in your buildings? (n=114). Results rounded to the nearest percentage. Note: Results are for directional purposes only, given the small n-value of ESJ responses (n=19).

Surveyed building owners/managers also rated their satisfaction with their current windows. As shown in Figure 20, 96% of commercial building owners/managers said they were *somewhat* or *very satisfied* with the performance of the windows in their buildings.

Figure 20. Satisfaction with Window Performance



Source: CalMTA CRAWS Building Owner and Property Manager Survey Q C5: "Overall, how satisfied are you with the performance of the windows in your building(s)?" (n=114). Results rounded to the nearest percentage. Note: "Somewhat unsatisfied" and "Very unsatisfied" were response options, but no respondents selected them.

6.9 Awareness and perceptions of efficient window solutions

6.9.1 Familiarity with CSW and VIG

During the literature review, CalMTA found that CSW and VIG are referred to by different names in the market. Table 27 provides a list of secondary window manufacturers identified in a recent market report and VIG manufacturers identified by a consulting firm.[83] To highlight the fact that secondary windows are often referred to by different terms, the table provides the product description according to the manufacturer.

Table 27. Manufacturers of Secondary Windows and VIG

Manufacturer	Product description	Type	Market (Residential or Commercial)
Allied Window	Storm Windows	Secondary Window	Both
Alpen	Secondary Window	Secondary Window	Both
Chosen	Insulating Pane	Secondary Window	Both
Cityproof	Interior Windows	Secondary Window	Commercial
Climate Seal	Storm Windows	Secondary Window	Both
Innerglass	Interior and Exterior Storm Windows	Secondary Window	Both
Inovues	Glazing Retrofit System	Secondary Window	Commercial
Larson	Interior and Exterior Storm Windows	Secondary Window	Both
Indow	Storm Window Inserts	Secondary Window	Both
Magnetite	Interior Secondary Glazing Panel	Secondary Window	Both
Maine Glass	Interior Insulating Windows	Secondary Window	Commercial
QuantaPanel	Storm Window	Secondary Window	Both
Renovate by Berkowitz	Window Retrofit	Secondary Window	Commercial
Thermolite	Secondary Interior Window Systems	Secondary Window	Commercial

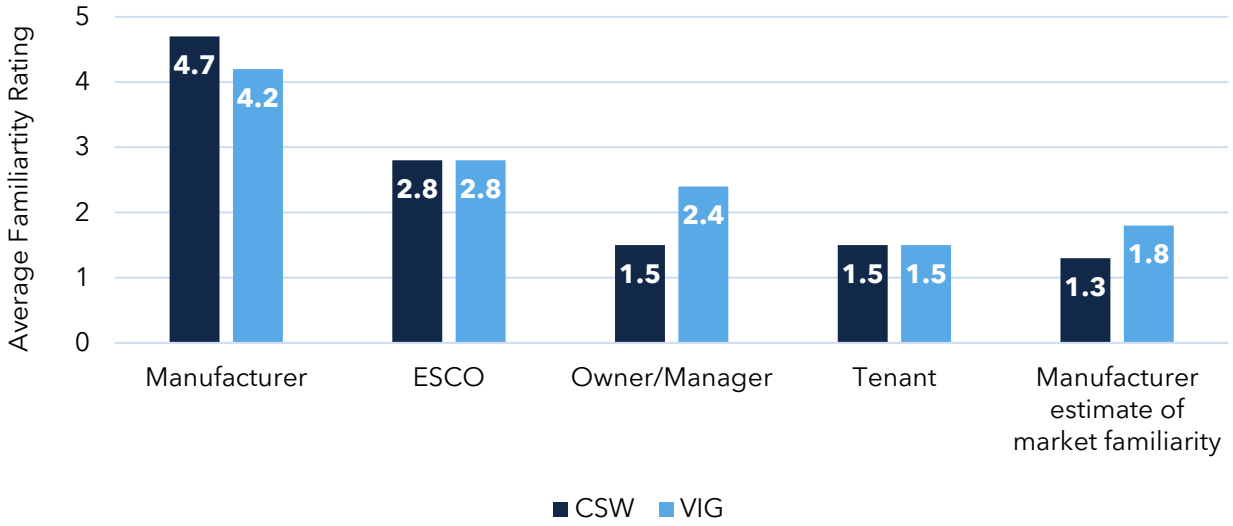
[83] Evergreen Economics. 2020. *Commercial Window Attachments: Secondary Window Market Characterization*. Prepared for NEEA.

Manufacturer	Product description	Type	Market (Residential or Commercial)
Wausau Window	Interior Accessory Windows	Secondary Window	Commercial
Wex Energy	Windowskins	Secondary Window	Both
FINEO by AGC	Vaccum insulating glazing	VIG	
LandGlass	Vacuum glass	VIG	Both
LuxWall	Enthermal	VIG	Both
Nippon Sheet Glass (NSG)	Insulight Therm/Architectural glazing	VIG	Both
Vitro Architectural Glass	VacuMax Vacuum Insulating Glass	VIG	Both

To gauge familiarity with CSW and VIG, CalMTA asked questions about awareness in the survey with building owners and managers and in interviews with manufacturers and ESCOs.

Manufacturers demonstrated the highest level of familiarity with both CSW and VIG technologies, followed by energy service companies (ESCOs). On a scale of 1 to 5, where 1 is *not at all familiar* and 5 is *very familiar*, manufacturers reported high familiarity with CSW, averaging 4.7. Their familiarity with VIG was slightly lower, averaging 4.2. ESCOs, building owners/managers, and tenants all reported lower familiarity with CSW and VIG technology, as shown in Figure 21. Manufacturers uniformly reported that awareness among end users and distributors of CSW and VIG technologies is limited. Figure 21 shows self-reported familiarity with each technology by market actor type, alongside manufacturer-estimated familiarity for the market as a whole.

Figure 21. Self-Reported Familiarity with CSW and VIG by Market Actor Type

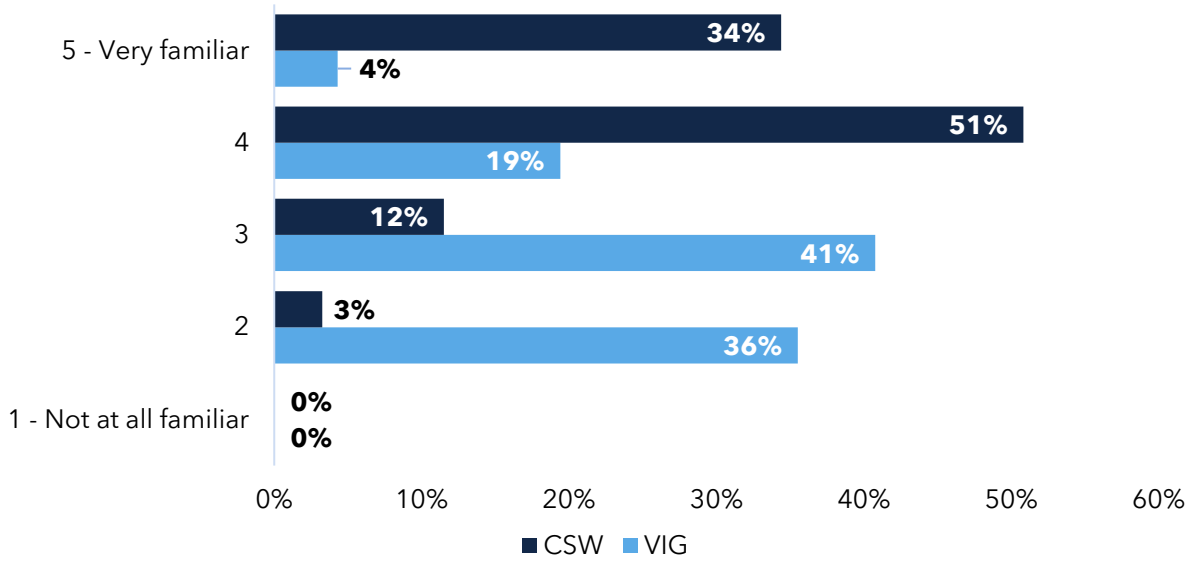


Source: CalMTA Manufacturer interviews (n = 6), ESCO interviews (n = 5), owner/manager interviews (n = 8, and tenant interviews (n = 6). "On a scale from 1 to 5 where 1 is not familiar at all and 5 is very familiar, how would you describe your level of familiarity with Commercial Secondary Window (CSW) technology? " and "On a scale from 1 to 5 where 1 is not familiar at all and 5 is very familiar, how would you describe your level of familiarity with Vacuum Insulated Glass (VIG) technology?"

The survey of building owners/managers provided a description of CSW and VIG and asked respondents if they were familiar with the technology. Eighty-five percent of commercial building owners/managers said they were at least somewhat familiar with CSW (a rating of 4 or 5, with 5 being *very familiar*).

Building owners/managers were far less familiar with VIG; only 23% responded that they were somewhat or very familiar with the technology. As shown in Figure 22, just 4% of commercial building owners/managers reported being very familiar with VIG prior to the survey. Forty-one percent of building owners/managers rated their familiarity a "3" and 36% rated it a "2" on a 5-point scale, where 1 meant *not at all familiar* and 5 meant *very familiar*. No respondents reported *not at all familiar* with CSW or VIG.

Figure 22. Familiarity with CSW and VIG Among Commercial Building Owners and Managers



Source: CalMTA CRAWS Building Owner and Property Manager Survey D1: "Prior to this survey, how familiar were you with CSW?" (n=114) and D11: "Prior to this survey, how familiar were you with VIG?" (n=114)

In the in-depth interviews CalMTA conducted with building owners and property managers, familiarity with the potential benefits, drawbacks, and installation processes for both CSW and VIG was generally low. Five of the eight interviewed respondents had never heard of CSW, and only two stated they had any level of familiarity. Of the two that had some level of familiarity, one said they had heard that CSW could help improve safety and internal comfort, while the other said the installation process was quick, and labor was less expensive than full window replacement.

Specifically, for VIG, five respondents said they had little to no awareness. One respondent was very familiar with VIG because they had installed the technology and praised its abilities to combat glare, reduce noise, and increase thermal comfort. Further, the respondent noted that if they had known about VIG prior to upgrading their hospital buildings, they would have elected to use VIG rather than double-pane window replacement. The lack of awareness is evident in the fact that the two respondents who had undergone window replacements regretted that their contractors did not provide alternative options to double pane, with one stating, "I have not heard anything about either CSW or VIG. They were not presented or mentioned by our third-party contractor."

Additionally, both commercial-tenant building owners interviewed reported no familiarity with CSW; however, both were familiar with VIG, one had installed it in the building where they operate their business and the other had it installed in their home. Both highlighted the ease of installation and emphasized that the benefits of VIG justified the cost.

To assess ESCO perspectives on demand, CalMTA asked ESCOs how they perceived their clients' awareness of the value proposition of CSW and VIG, as well as any barriers to adoption of these

technologies. Interview respondents rated both market and end-user familiarity with CSW as *very low*, with three out of four ESCOs rating their familiarity at 1 or 2 on a 5-point scale, and one estimating awareness among specialized trades as slightly higher at 2 or 3. All four respondents characterized awareness as limited. One noted that many installation contractors default to simpler solutions like window film, despite their lower performance benefits compared to CSW.

Interview respondents also emphasized that most building owners and customers are unaware of CSW as an alternative to full window replacement. One interviewee observed that architects and suppliers tend to promote full replacements, which discourages owners from pursuing a window upgrade project due to cost and complexity. Another noted that contractors often fail to educate end users about these technologies. In total, three respondents cited factors that contribute to low awareness, highlighting the need for broader education and outreach to increase CSW adoption.[84]

6.9.2 Perceptions of CSW and VIG

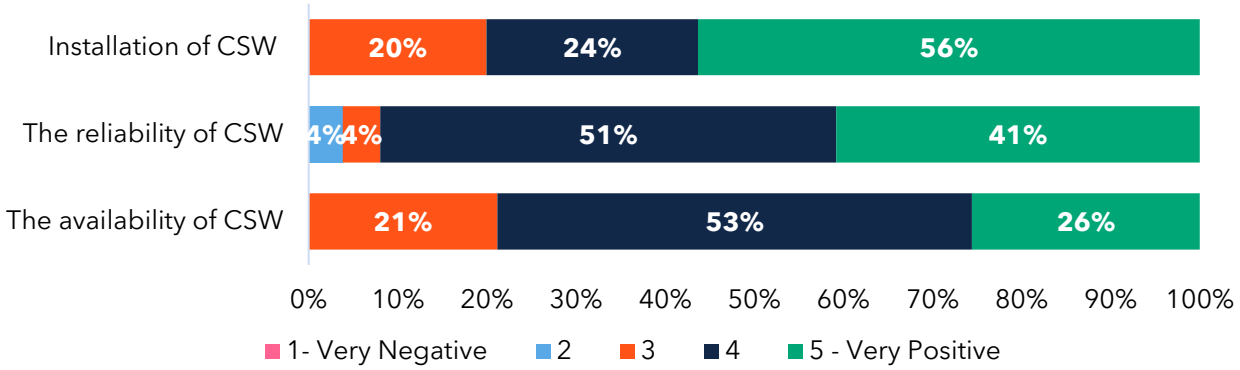
To assess manufacturer perspectives on demand, CalMTA asked respondents to discuss their familiarity with CSW and VIG, how they perceived their customers' awareness of the value proposition of these technologies, and any barriers to adoption they saw.

When asked about the benefits of CSW, all manufacturers interviewed cited its high energy efficiency, soundproofing, increased comfort, and the ease and non-disruptive nature of installation. When asked the same question about VIG, all manufacturers cited its high energy efficiency; two cited the lightness of the glass.

To assess market readiness for advanced window technologies, the survey asked building owners and managers about their perception of CSW and VIG solutions (Figure 23). Commercial building owners/managers who reported being familiar with CSW (a rating of 4 or 5) reported a positive impression of the availability (79%), reliability (92%), and installation (80%) of CSW.

[84] Interview responses were mixed on installer familiarity with CSW. Both installer respondents (n=2) rated their familiarity as *high* or *very high* (a 4 or 5 on a 5-point scale), while one installer mentioned that CSW building owners and property managers are well versed in technology.

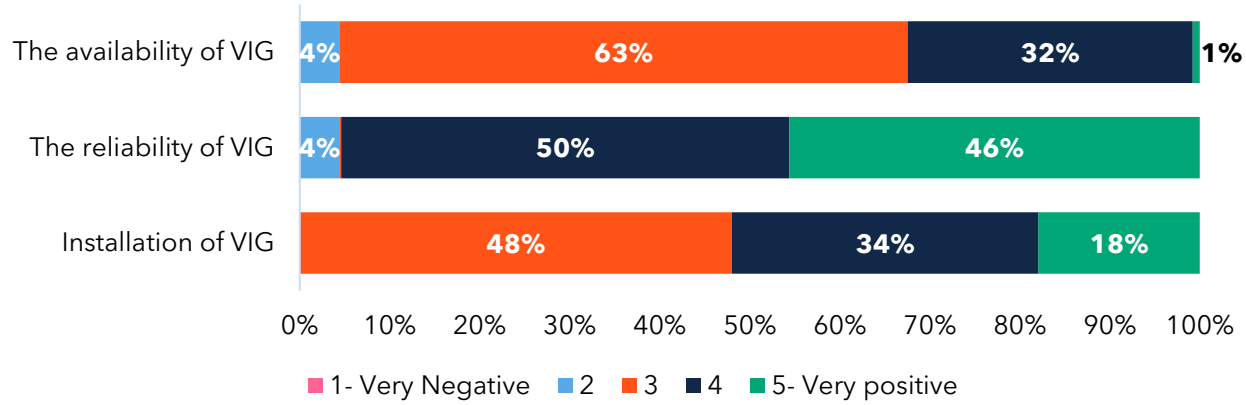
Figure 23. Building Owner and Property Manager Perceptions of CSW



Source: CalMTA CRAWS Building Owner and Property Manager Survey Q D4: "How would you rate your impression of each of the following:" (n=104). This was a follow-up question asked only of respondents who reported being familiar with CSW. Results rounded to the nearest percentage. Results may not sum to 100 due to rounding.

As shown in Figure 24, building owners/managers' perceptions of VIG were less positive than their perceptions of CSW in terms of installation (52% rating positive or very positive) and availability (33% rating positive or very positive). However, perceptions of VIG reliability were similar to CSW (96% rating "positive or very positive").

Figure 24. Building Owner and Property Manager Perceptions of VIG



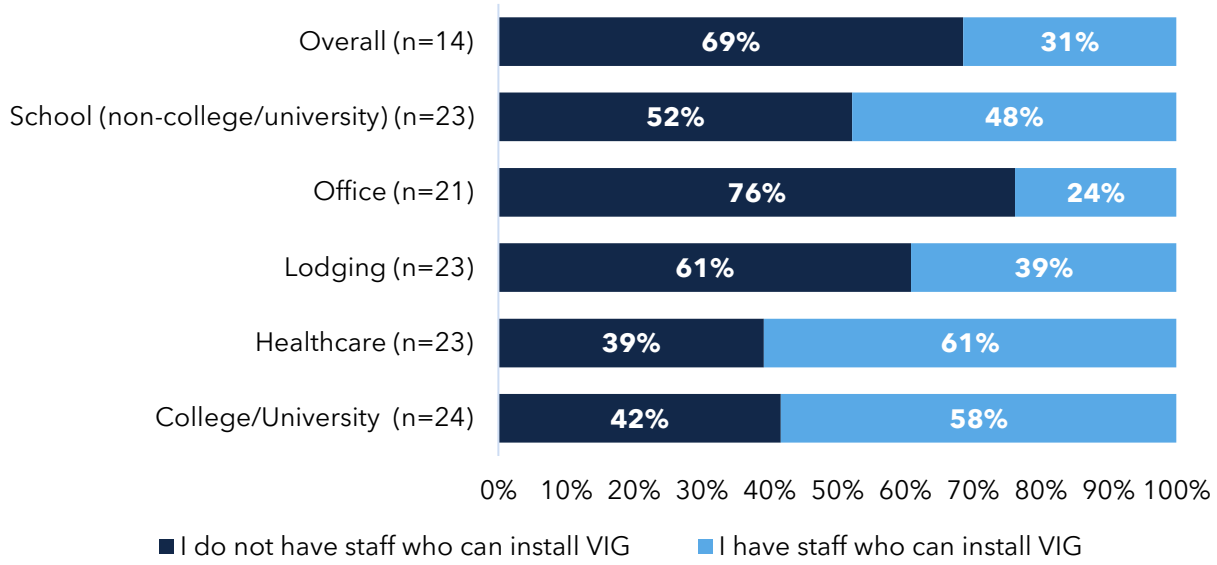
Source: CalMTA CRAWS Building Owner and Property Manager Survey Q D14: "How would you rate your impression of each of the following:" (n=24). This was a follow-up question asked only of respondents who reported being familiar with VIG. Results may not sum to 100% due to rounding.

6.9.3 Workforce capacity

To better understand workforce capacity and the availability of skilled staff, the survey asked commercial building owners/managers whether they employ personnel qualified to install CSW

solutions.[85] Overall, 31% of commercial building owners/managers reported having on-site staff capable of installing CSW (Figure 25). However, in the university and healthcare segments, 58% and 61% of building owners/managers, respectively, indicated they have qualified installation staff.

Figure 25. Ability to Install CSW by Building Type

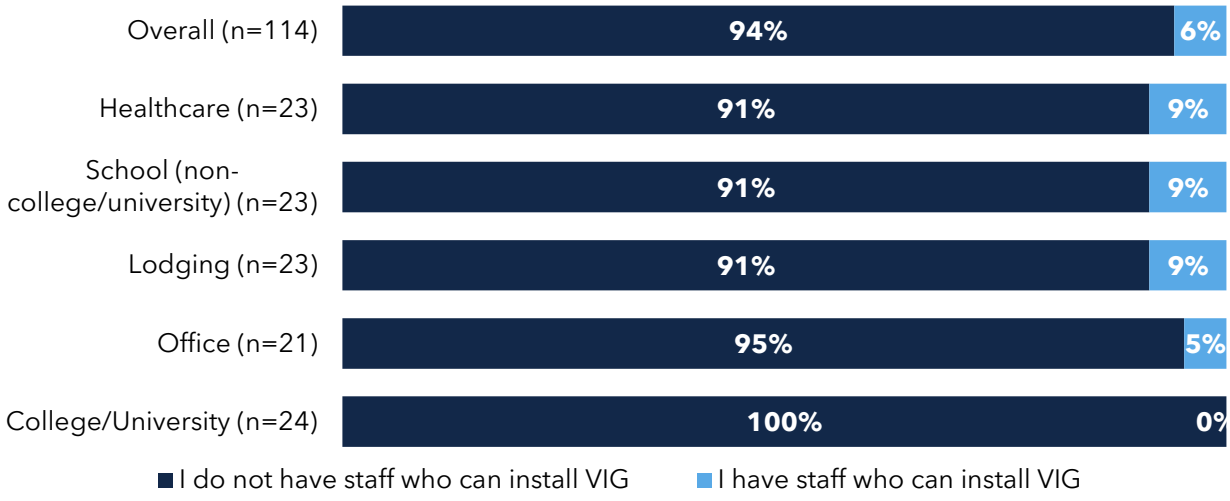


Source: CalMTA CRAWS Building Owner and Property Manager Survey Q D2: "Do the buildings you own or manage employ any staff who are able to install CSW?" (n=114). Results may not sum to 100 due to rounding.

In contrast to CSW, only 6% of commercial building owners/managers reported having staff capable of installing VIG (Figure 26). Across building types, VIG installation capability was virtually minimal or nonexistent. Only 9% of healthcare, lodging, and school building owners/managers reported having staff capable of installing VIG.

[85] The survey did not describe the qualifications required to install CSW solutions.

Figure 26. Ability to Install VIG by Building Type



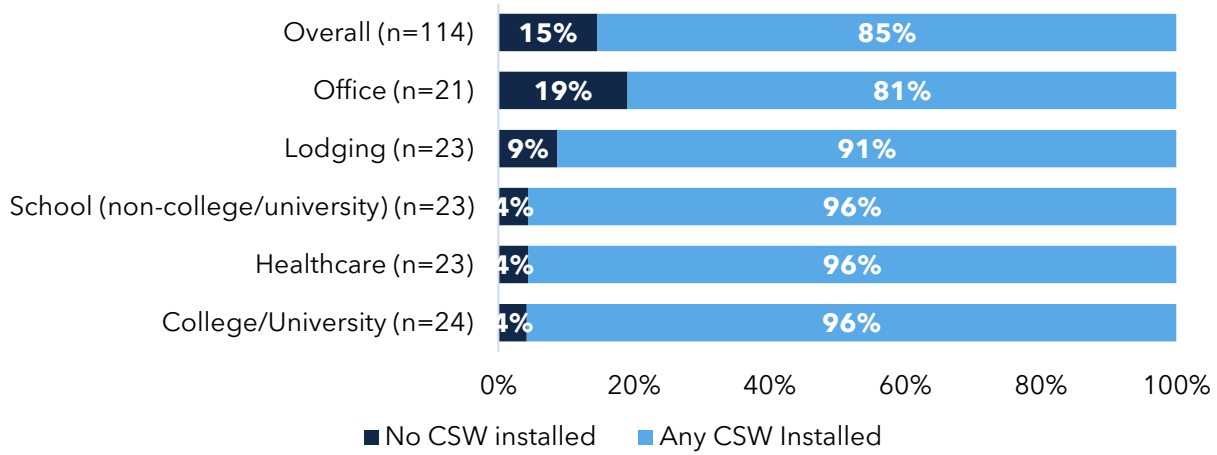
Source: CalMTA CRAWS Building Owner and Property Manager Survey Q D12: "Do the buildings you own or manage employ any staff who are able to install VIG?" (n=114). Results rounded to the nearest percentage.

6.9.4 Prevalence of CSW and VIG

The survey examined the presence of CSW and VIG across commercial building owners/managers. Eighty-five percent of commercial building owners/managers indicated having one or more CSW installed in at least one of their buildings (Figure 27). The proportion of respondents who reported having one or more CSW installed was especially high (96%) in the healthcare, school, and college building segments. However, the reported prevalence of CSW should be interpreted cautiously.

Prior to being asked about the presence of CSW and VIG windows in their buildings, respondents were provided with descriptions of the technologies and asked about their level of familiarity with the technology. Although familiarity was high, these findings are not consistent with findings from qualitative interviews or secondary research, which suggest that awareness and prevalence of CSW and VIG are quite low. Thus, actual awareness and prevalence levels are likely lower than reported by survey respondents. This could be due to participant misunderstanding stemming from the fact that CSW are often confused with storm windows.

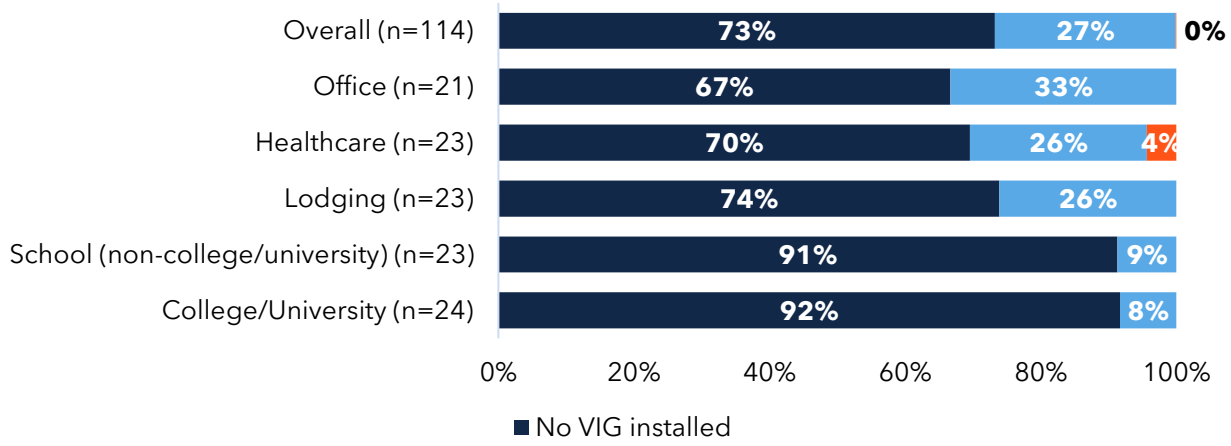
Figure 27. Building Owners and Managers Reporting One or More CSW Installed, by Building Type



Source: CalMTA CRAWS Building Owner and Property Manager Survey Q D6: "To your knowledge, are any CSW installed in any of your buildings?" (n=114). Results rounded to the nearest percentage.[86]

As shown in Figure 28, while commercial building owners/managers reported that CSW has been installed in at least some buildings across all market segments, VIG remains far less common. Only 27% of commercial building owners/managers reported any VIG installations. These numbers should also be interpreted with caution, given the limited number of estimated VIG installations to date.

Figure 28. Building Owners and Managers Reporting One or More VIG Installed, by Building Type



Source: CalMTA CRAWS Building Owner and Property Manager Survey Q D16: "To your knowledge, are any VIG installed in any of your buildings?" (n=114). Results rounded to the nearest percentage.

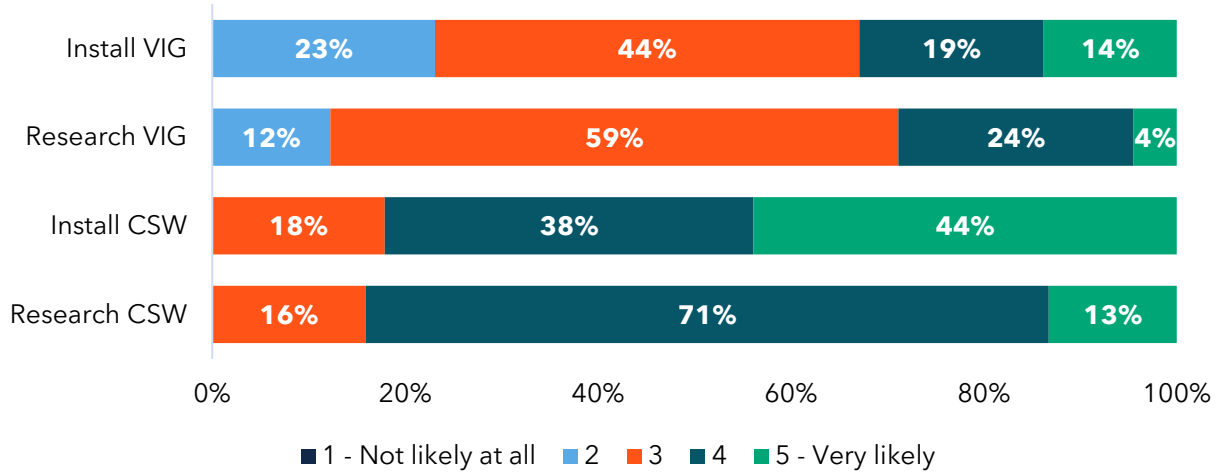
[86] CalMTA cannot report the percentage of actual square footage of buildings with CSW installed. The survey respondents reported the presence of CSW and VIG, but not the installed square footage.

6.10 Likelihood of adoption

6.10.1 Likelihood to research and install CSW or VIG in the future

The survey asked commercial building owners and managers how likely they would be to research and install CSW or VIG for future window upgrades or replacements. As shown in Figure 29, respondents were more likely to install and research CSW than VIG. Eighty-four percent of commercial building owners/managers responded that they were *likely* or *very likely* to research CSW, while 82% of commercial building owners/managers responded they were *likely* or *very likely* to install CSW. In contrast, only 29% of commercial building owners/managers responded that they are *likely* or *very likely* to research VIG (this figure differs slightly from the values shown in the chart due to rounding), while 33% responded that they are *likely* or *very likely* to install VIG.

Figure 29. Likelihood to Research and Install CSW and VIG



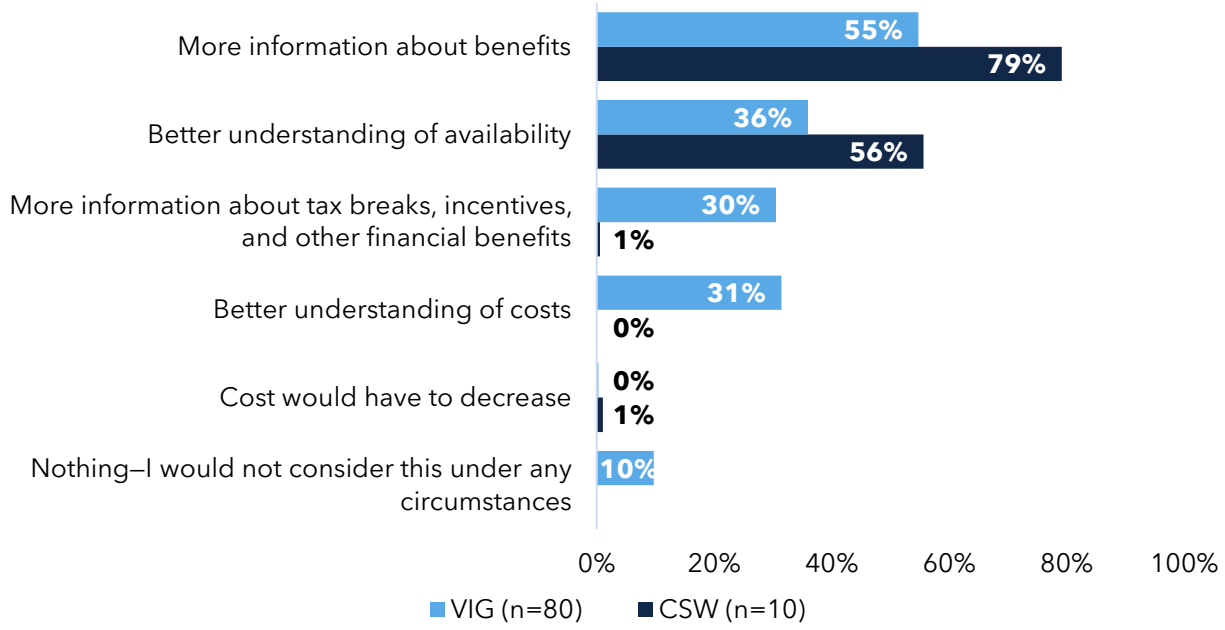
Source: CalMTA CRAWS Building Owner and Property Manager Survey Q E1: "Assuming you needed to replace or upgrade windows in one or more of your buildings, how likely would you be to research CSW on a scale of 1-5, where 1 is "Not at all likely" and 5 is "very likely"?" (n=114) & Q E2: "Assuming you needed to replace or upgrade windows in one or more of your buildings, how likely would you be to install CSW (with the level of understanding you have now)?" (n=114) & Q E3: "Assuming you needed to replace or upgrade windows in one or more of your buildings, how likely would you be to research VIG on a scale of 1-5, where 1 is "Not at all likely" and 5 is "very likely"?" (n=114) & Q E4 "Assuming you needed to replace or upgrade windows in one or more of your buildings, how likely would you be to install VIG (with the level of understanding you have now)?" (n=114). Results rounded to the nearest percentage. Results may not sum to 100% due to rounding.

6.10.2 Preferences and motivators in selecting window alternatives

To understand preferences for alternative window solutions, commercial building owners/managers who indicated a low likelihood of researching CSW or VIG (ratings of 1 to 3 on a scale of 1 to 5, where 1 is *not at all likely* and 5 is *very likely*) were asked which type of windows they might choose instead of CSW or VIG. All (100%) commercial building owners/managers within this subset stated that they would install double-pane windows instead of CSW, and 97% would install double-pane windows instead of VIG. This finding was consistent for all building types.

To explore potential drivers of adoption, commercial building owners/managers within the subset indicating low likelihood of installing CSW or VIG were asked what factors might motivate them to consider installing CSW or VIG in their buildings. As shown in Figure 30, 55% of commercial building owners/managers responded that learning more about the benefits of VIG would be the top motivation, while 79% of commercial building owners/managers said the same for CSW. This was followed by motivation through a better understanding of VIG availability (36%) and costs (31%), while owners/managers considering CSW were more likely to be motivated by having a better understanding of availability (56%).

Figure 30. Motivators of Future CSW and VIG Installation



*Source: CalMTA CRAWS Building Owner and Property Manager Survey Q E6: "What would motivate you to consider **installing** CSW in your building(s)? Select all that apply" (n=10) & Q E8: "What would motivate you to consider installing VIG in your building(s)? Select all that apply" (n=80). This question was asked only of respondents who indicated low likelihood of **installing** CSW or VIG (1-3 on a scale of 1 to 5, where 1 is "not at all likely" and 5 is "very likely). Results rounded to the nearest percentage. N-values are unweighted.*

6.11 Barriers to adoption

CalMTA identified barriers to CSW and VIG adoption through a combination of primary and secondary research.

A literature review identified several factors that have hindered market actors from embracing and pursuing secondary window solutions. Many barriers to adoption stem from a lack of awareness or knowledge regarding one or more aspects of CSW or VIG window solutions or the

installation process.[87] Capacity constraints and limited training opportunities for installers raise concerns about installation time and required expertise. Uncertainties remain around the service life and performance of VIG, especially regarding durability and condensation issues. Additionally, the high initial cost and perceived risks of newer or less familiar products often lead decision makers towards conventional alternatives.

6.11.1 Building owners and managers survey – barriers to CSW or VIG upgrade selection

The survey asked commercial building owners and managers to rank the top factors (up to three) that would prevent them from selecting CSW or VIG for window upgrade projects. As shown in Figure 31, 64% of commercial building owners/managers ranked a lack of information as the most important barrier preventing them from selecting CSW or VIG for window upgrade projects. Concerns about performance (43%) and concerns about durability or maintenance (39%) were also cited as major barriers.

[87] Energy Solutions. 2024. Commercial Windows Market Study and Measure Package Development. Prepared for CalNEXT.

[87] Evergreen Economics. 2020. Commercial Window Attachments: Secondary Window Market Characterization. Prepared for NEEA.

[87] NREL. 2022. *Pathway to Zero Energy Windows: Advancing Technologies and Market Adoption*. Prepared for the U.S. Department of Energy. April 2022. https://research-hub.nrel.gov/en/publications/pathway-to-zero-energy-windows-advancing-technologies-and-market-/

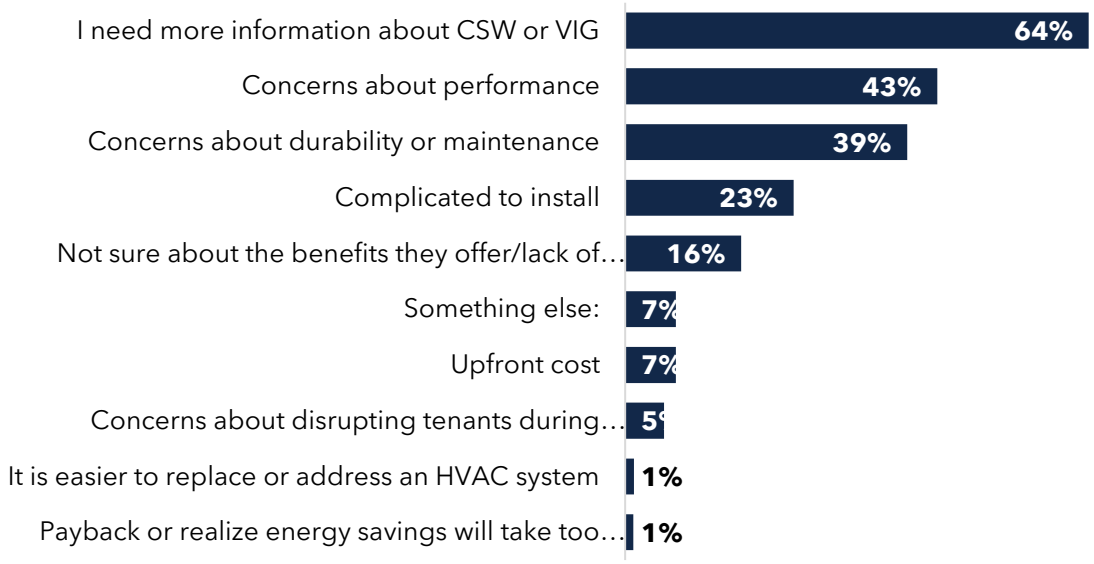
[87] Navigant Consulting. 2018. Commercial Windows Attachment (SGS) Initiative. Prepared for NEEA.

[87] SPR Consulting. 2023. Innovative and Cost-Effective Solutions to Improve Building Envelope Performance.

[87] Navigant Consulting. 2018. Commercial Windows Attachment (SGS) Initiative. Prepared for NEEA. https://neea.org/wp-content/uploads/2025/03/commercial-window-attachments-sgs-phase-1-research.pdf

[87] Energy 350. 2023. Commercial Secondary Windows Field Observations and Decision-Maker Interviews Report. Prepared for NEEA.

Figure 31. Top-Ranked Barriers to VIG or CSW Replacement or Upgrade



Source: CalMTA CRAWS Building Owner and Property Manager Survey Q F1: "What factors, if any, would prevent you from selecting CSW or VIG as a replacement or upgrade solution to your window needs? Please rank up to three factors, where #1 is the most important and #3 is the third-most important." (n=114). Results rounded to the nearest percentage.

6.11.2 Manufacturer interviews – barriers to CSW and VIG manufacturing and sales

CalMTA interviewed five manufacturers and asked about barriers negatively affecting the manufacturing and sale of these technologies for either CSW or VIG. One said that VIG faces difficulties due to the immaturity of U.S. manufacturing capacity. Interestingly, five of six manufacturers said that tariffs and economic uncertainty are negatively affecting their business but did not associate this disruption with a negative impact on manufacturing or sales capacity. One said that tariffs will slow the North American adoption of VIG manufactured in China, while three indicated tariffs are likely to increase the cost of raw materials.

When asked why a customer might decide not to buy CSW, manufacturers responded with a variety of reasons, including economic uncertainty, inability of the technology to meet a customer's needs, potential cost perceptions, and the presence of competing initiatives vying for retrofit funds. When asked the same question about VIG, all six manufacturers mentioned cost as a reason customers might decide not to purchase.

When asked how these barriers to adoption could be mitigated, two manufacturers mentioned government incentives. One said that an interior solution that does not change building aesthetics could allay some customer concerns.

6.11.3 ESCOs interviews – barriers to CSW and VIG sales

In CalMTA's interviews with ESCOs, cost was a key barrier, cited by two respondents. One noted that windows typically do not sell unless the out-of-pocket expense is low, and that utility incentives or state subsidies are often essential to make projects financially feasible. Another respondent pointed to broader market trends, stating that since 2023, permit applications for new buildings have declined by over one-third in many California cities. This respondent tied window retrofit activity to necessity, code compliance, and available financing.

ESCOs consistently cited cost as the primary barrier to VIG adoption. All four respondents indicated that budget limitations often prevent customers from moving forward with VIG projects. Two respondents noted that windows are usually considered a lower-priority upgrade, especially when there are competing renovation needs (e.g., roofing and HVAC). Unless there is a visible failure (e.g., leaks) or an insurance-driven replacement, VIG is often deprioritized in tight budgets. One respondent mentioned that even when customers understand the benefits, operational impacts and budget trade-offs can still derail the decision to move forward. Three out of four respondents reported positive or neutral perceptions of CSW and VIG reliability, especially when the products are installed by reputable contractors. One respondent had only received positive feedback, while another said that reliability concerns are rarely mentioned. One expressed skepticism, citing broader issues, such as maintenance costs and insufficient program funding, rather than problems with the products themselves.

When discussing efficient window solutions more broadly, cost again emerged as the most cited barrier (two of four respondents), particularly when projects require substantial out-of-pocket spending or lack access to long-term financing. Two respondents also mentioned operational and scheduling constraints, especially for sites like schools, where installation timelines are limited. One respondent raised concerns about product lead times and sourcing delays, while another emphasized the lack of consistent incentives and the need for more prescriptive rebate structures rather than custom ones.

Finally, one respondent highlighted the lack of customer education pertaining to CSW and VIG technologies, describing them as poorly understood and often perceived as a luxury. Additional concerns included the perception of tenant disruption during installation and skepticism about ROI claims due to limited or unclear market data.

6.11.4 Building owners and managers interviews – barriers to CSW and VIG adoption

Building owners and managers mentioned that the primary barriers inhibiting decision makers from pursuing window upgrades are cost related. Cost concerns, including both initial costs (labor, materials, and installation), and the opportunity cost of replacing windows for the energy savings they might experience, were explicitly mentioned by four of the six who had not addressed their window inventory. Another barrier mentioned by two respondents who operate medical centers was the time and disruption that come with major building upgrades, which is magnified in hospital settings where patients are treated. The one commercial-tenant business

owner who had VIG installed in their home stated that they would consider VIG for the commercial building if the cost was reasonable.

6.11.5 Tenants interviews – barriers to CSW and VIG sales

When asked about any barriers they perceived to the adoption of CSW and VIG, interviewed tenants highlighted the issue of decision-making authority. None of the tenants own the buildings where their businesses operate and therefore cannot independently implement upgrades. While some tenants can submit requests to landlords, the final decision typically lies with the property owner. This limits tenants' ability to pursue energy efficiency improvements, even if they are interested.

Other potential barriers emerged from these interviews regarding concerns around the cost of the products and installation. One tenant noted that both product and labor costs must be factored into the decision-making process. Additionally, the needs of businesses play a role in adopting these technologies. One tenant stated that window upgrades were not necessary for their building, suggesting that awareness of the benefits or urgency of such improvements may vary across tenants.

These insights suggest that ownership, financial considerations, awareness of benefits, and the needs of the business are tenant-perceived factors that influence the adoption of advanced window technologies in commercial settings.

Among surveyed commercial building owners/managers, lack of information was the top-ranked barrier (64%) to selecting CSW and VIG for a retrofit project, followed by concerns about performance (43%).

Manufacturers also highlighted limited customer awareness, particularly around the benefits and applications of CSW and VIG, as well as operational disruptions and scheduling constraints tied to installation. Tenants raised issues around decision-making authority, noting that even when they are interested in energy upgrades, the final decisions rest with property owners.

7 Supply-side characteristics

7.1 Key findings

- Interview responses from across groups (manufacturers, building owners and managers, and ESCOs) described a fragmented but interconnected network of market actors, with architects, contractors, glaziers, and general contractors commonly mentioned as influential in decision-making and delivery.
- Distribution channels for CSW and VIG products are diverse. Manufacturers distribute products directly to end users, as well as via contractors, glaziers, ESCOs, and manufacturer rep groups.

- A central, unifying theme is widespread concern over supply chain instability—tariffs on Chinese imports, geopolitical conflicts, and unpredictable lead times were repeatedly cited as major risks by manufacturers and ESCOs. These challenges complicate project planning and inflate costs, with some respondents noting extreme delays for imported products.
- Respondents expressed cautious optimism about emerging product trends such as electrochromic glass, solar-integrated windows, aerogels, and smart window technologies, though most of these remain costly or technically unproven for large-scale adoption.
- Window upgrades, particularly CSW and VIG, are rarely pursued as standalone projects. ESCOs consistently package these with other upgrades (HVAC, lighting, solar) to improve ROI and project feasibility.

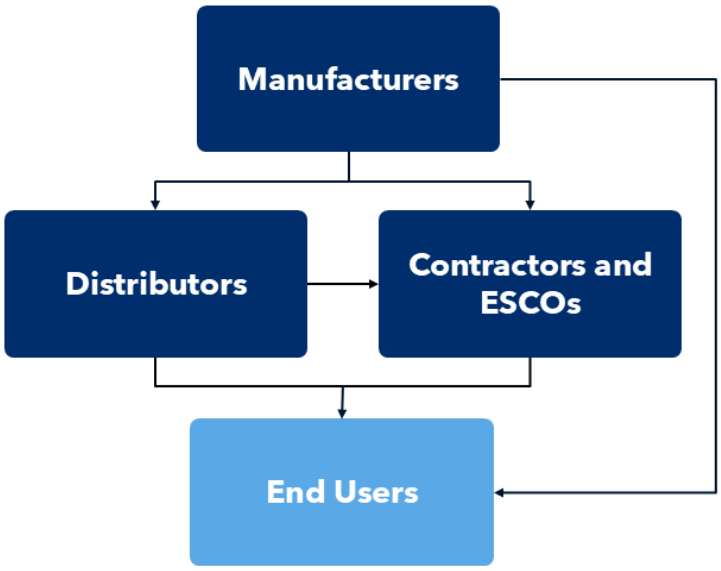
7.2 Supply chain map

Based on CalMTA's interviews with CSW and VIG manufacturers, the supply chain for these technologies can vary substantially from project to project depending on size, end-user familiarity, and existing connections between the manufacturer, distributor, ESCO, and contractor or decision maker.

End users can take many paths to purchase a window. If an established line of communication and trust exists between a manufacturer and a building owner, manufacturers may provide windows directly. Otherwise, the manufacturer will provide windows via one or more intermediaries, which may include distributors, ESCOs, or installation contractors.

Figure 32 maps the CSW supply chain, which is well-established. In contrast, CalMTA's interviews with manufacturers found that the VIG supply chain is still nascent in the U.S.

Figure 32.Commercial Secondary Window Supply Chain



7.3 Supply chain market actors and market channels

The NEEA study defined market actors as having either primary or secondary roles. The primary actors include the following:[88]

- **Manufacturers** are primary actors; they manufacture and provide customized and standard solutions for windows. It is not uncommon for customers to interact directly with manufacturers. This helps in identifying the individual project needs.
- **Architects** often consult with general contractors but may recommend secondary windows.
- **Installers** are usually general contractors or glazers who work with all market actors in the building retrofit or window upgrade process.
- **Building owners and managers** are the individuals or groups who make decisions on projects for the buildings they own or manage.

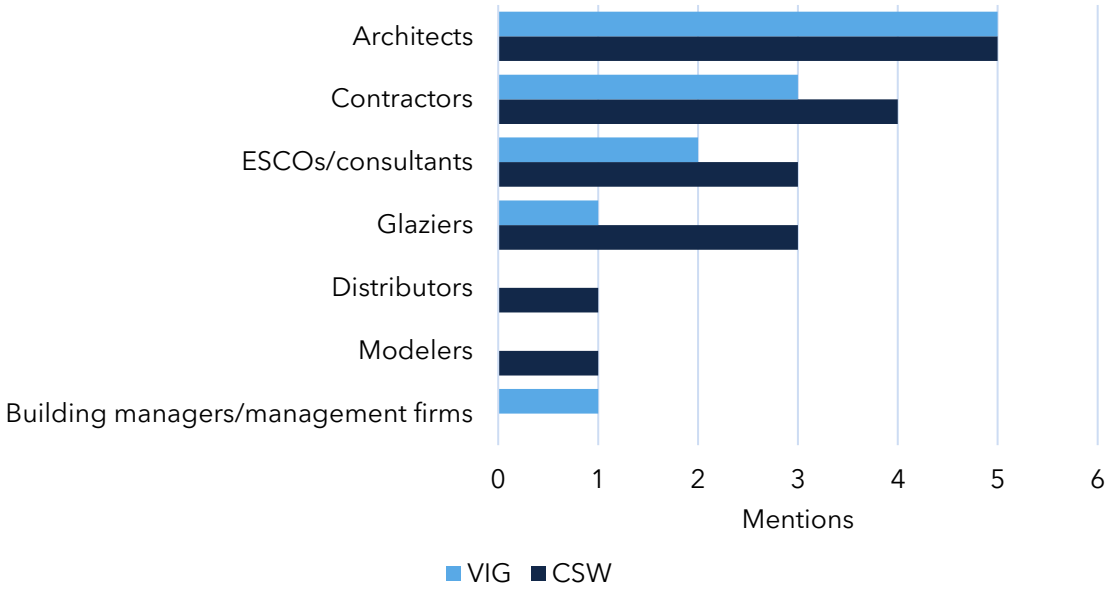
Secondary market actors provide support for the primary market actors:

- **Distributors** may offer different products. The NEEA study indicates that large manufacturers generally tend to engage distributors/dealers.
- **ESCOs** identify, specify, and manage energy efficiency projects that enable buildings to save energy and costs.

[88] Evergreen Economics. 2020. Commercial Window Attachments: Secondary Window Market Characterization. Prepared for NEEA.

In interviews, CalMTA gathered manufacturers' perspectives on the supply side of the market, asking them to identify key market actors and distribution channels they view as most influential in the window solutions market (Figure 33). Every manufacturer who responded to this question mentioned architects; no manufacturers considered modelers or distributors to be influential actors in the VIG market.

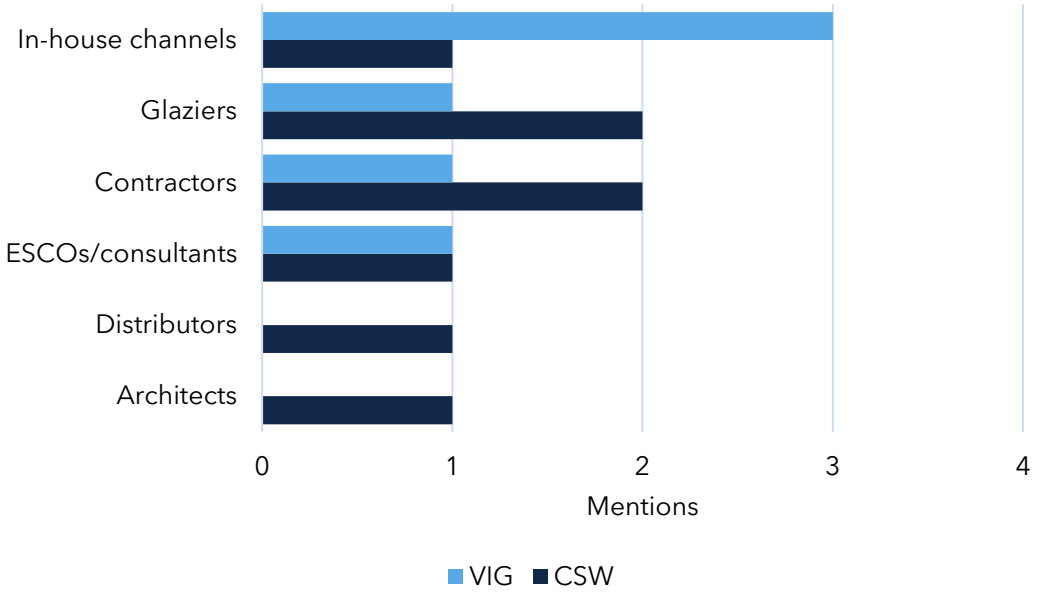
Figure 33. Manufacturers of VIG or CSW Identification of Key Market Actors



Source: CalMTA Manufacturer interviews Q D2: "Who are the key market actors that contribute to the sale, distribution, and installation of CSW solutions?" and Q D5: "Who are the key market actors that contribute to the sale, distribution, and installation of VIG solutions?" (n = 5)

Manufacturers also described the distribution channels commonly used for CSW and VIG products (Figure 34). They cited a variety of channels for CSW products, with glaziers and contractors each mentioned twice, and other channels mentioned once each. For VIG, three of five interviewees said that large manufacturers typically maintain in-house distribution channels.

Figure 34. Identification of Key Distribution Channels



Source: Manufacturer interviews Q D3: "What are the primary distribution channels for CSW equipment?" and Q D6: "What are the primary distribution channels for VIG equipment?" (n = 5)

ESCOs described a diverse network of actors in the window solutions market, including contractors, glazing subcontractors (mentioned as responsible for installation), design-build contractors, architects, and other ESCOs (mentioned as influencing decisions during early project phases). They explained that equipment selection is guided by technical, financial, and legal factors. One respondent outlined a detailed vetting they use to assess manufacturers—including reviewing their history, warranties, service coverage, and verifying they have a U.S.-based presence. Others described a collaborative approach with engineers, installers, and architects to evaluate technical fit and constructability. ROI remains central, with one noting that decisions are "almost always ROI based." ESCOs select installers based on a mix of trusted relationships and competitive bidding. One firm relies on a general contractor they regularly work with, rather than selecting window installers directly. Others prioritize past performance and proven reliability. Two respondents use RFPs or bidding processes, evaluating price, availability, and capacity. One respondent also mentioned a commitment to engaging diverse businesses.

ESCO projects involving CSW or VIG technologies are usually part of larger building upgrade packages. All three ESCO respondents who addressed this question cited HVAC and lighting as standard components, while two noted that adding controls, roofing, and envelope improvements is a common way to boost overall performance. Two respondents also mentioned pairing projects with renewable technologies such as solar panels, battery storage, and EV chargers, while one highlighted mechanical upgrades like motor replacements and variable-speed drives. Another mentioned solar film as a less disruptive, more cost-effective alternative to full window replacement.

7.4 Supply chain challenges

In interviews with manufacturers and ESCOs, supply chain challenges emerged as a continuing theme. When asked about trends affecting the supply chain for efficient window solutions, three of six manufacturers identified tariffs or the implications of escalating conflicts between the U.S. and China in current tariff negotiations. One explained that interest in high-efficiency technology is rising in the European Union and that their relationships with stakeholders there is moving much faster than those with U.S. firms because they are more supportive of energy-efficient technology and have higher efficiency standards in general than the U.S. Another said that construction is slowing down, causing contractors to diversify their project pipelines, typically by refocusing on the retrofit market; this manufacturer also mentioned that utilities and contractors are increasingly emphasizing the benefits of envelope retrofits and secondary windows, driving up demand for their products. Finally, a manufacturer of custom CSW solutions for historic buildings reported observing increased interest in adaptive reuse (i.e., conversion of office spaces to housing) and in historic preservation.

All respondents mentioned that supply chain challenges are a concern, reflecting broader issues across the building materials sector. Tariffs, especially on materials from China and Mexico, were cited by all four ESCOs who answered this question. Respondents described tariffs as chaotic and unpredictable, with some taking effect just hours before the interview. One respondent also mentioned logistical issues, such as high shipping costs and long lead times, which led to project delays or reductions in scope when materials were unavailable. One firm has tried to manage risk by buying in bulk and negotiating with vendors.

7.5 Lead times

The team asked manufacturers to estimate the lead times for their products and received a wide range of answers, from two to four weeks at the shortest to twelve to fourteen weeks at the longest (for a custom CSW manufacturer). Median lead time is five weeks for the lower bounds provided by interviewees and seven weeks using the upper bounds.

7.6 Emerging Technologies

CalMTA asked manufacturers about emerging technologies that were exciting or worrying and received a wide array of responses with no overlap. The only emerging technology that was mentioned as *exciting* more than once was windows that harvest energy via photovoltaics (PV). Manufacturers also discussed aerogel insulation, the application of a low-E coating that also produces heat, innovations in applied film products, and smart windows. One manufacturer said that VIG itself was an exciting emerging technology. When asked about *worrying* emerging technologies, four manufacturers had no response. One expressed worry at the lack of research and development

> "Any solution that's not taking both performance and weight into account is worrying. Adding additional weight to a façade just amplifies the complexity of the project."
>
> -CSW Manufacturer

funding (not technology, but rather the lack of exploration into new technologies), and one said that they were worried about any technology that does not take both performance and weight into account. This manufacturer also expressed worry over the longevity of VIG products, especially their steel components.

Respondents representing ESCOs expressed cautious optimism about emerging technologies. Two ESCO interviewees highlighted interest in electrochromic glass, including VIEWGLASS,® which offers on-demand tinting, but noted its high cost and the need for full lifecycle evaluation before broader adoption. Another respondent was most excited about the shift toward electrification and decarbonization, particularly the move from fossil fuel systems to electric HVAC solutions. One respondent did not have specific technologies they were excited about. Instead, they focused on upgrading legacy systems with improved versions of existing technologies like lighting, HVAC, solar, and batteries.

8 Costs and benefits

8.1 Key findings

- Among the three CSW manufacturers who provided price points for their products, two were less expensive per square foot than the average low-E double-pane window.
- VIG manufacturers were only able to provide speculative price points, but both agreed that once manufacturing capability is mature, VIG will have a similar price point to standard double-pane windows.
- Three of six ESCOs asserted that CSW and VIG projects are more expensive than traditional window replacements, with one calling the difference "outrageous," though one noted the potential long-term value if paired with energy savings and lifecycle performance. This opinion contrasts starkly with the affordable market price and supposed ease of installation of CSW technology highlighted by manufacturers and indicates an informational asymmetry between manufacturers and ESCOs regarding costs.
- While non-energy benefits such as thermal comfort and noise reduction were appealing to building owners, several emphasized that these benefits alone were insufficient to justify a window upgrade. Projects had to demonstrate tangible energy cost savings and good ROI to be considered viable.
- Tenants who could speak to benefits cited aesthetics, noise reduction, and leak prevention. However, most declined to discuss the issues related to cost and financing knowledge and recommend that we speak with property owners or window installers, underscoring their limited role in capital improvement decisions.

8.2 Price points

CSW and VIG products are highly customized, which makes reliable price data limited and often inconsistent across available sources. To estimate price ranges, CalMTA relied on information from field studies, case studies, pilot projects, industry experts, and public retail pricing when available. CalMTA was unable to secure reliable cost data for standard commercial windows.

For CSW, we found an average installed cost of approximately $40 per square foot.[89,90,91,92] CalMTA's interview with an industry expert, along with pilot study data, indicates VIG prices range from $25 to $100 per square foot. Table 28 provides average costs per square foot for VIG and CSW.

Table 28. Average Installed Cost of CSW and VIG

Category	Average Installed Cost	Notes
Typical CSW	$32 - $44/ sq ft[93]	The average cost is based on various sources, including manufacturer retail prices, industry reports, and a California school case study, and represents a range.
Typical VIG	$25–$100/ sq ft[94]	The VIG average cost is an estimate based on a market expert interview.

Sources: CSW Cost: AERC (2023); Indow (2025); NEEA (2023); CalMTA, Madison Elementary Field Test (2025). VIG: CalMTA personal interview, Nov. 6, 2025.

8.3 ESCO perspective on CSW and VIG

CalMTA asked ESCOs about the costs of advanced window solution projects compared to traditional window replacements. All three respondents who answered this question indicated that installation costs of CSW and VIG technologies are greater than traditional window replacements. One respondent acknowledged the premium but emphasized potential long-term value through better lifecycle performance and energy savings. Still, the perceived high upfront cost remains a major obstacle, especially without stronger incentives. This conflicts with statements from some manufacturers that CSW are roughly as affordable as standard double-

[89] Attachments Energy Rating Council. 2023. CSW Technical Factsheet. May 2023.https://aercenergyrating.org/wp-content/uploads/2023/05/CSW-Technical-Factsheet.pdf

[90] Indow Windows. (n.d.). Commercial window inserts.https://indowwindows.com/products/commercial-window-inserts

[91] Field study site at Madison Elementary in the Madera Unified School District CalMTA (2025)

[92] Northwest Energy Efficiency Alliance. 2023. Commercial Secondary Windows field test (Report No. E23-341). Energy 350. December 18, 2023. https://neea.org/wp-content/uploads/2025/03/Commercial-Secondary-Windows-Field-Study.pdf

[93] We have provided a range for the CSW costs. Some sources include installation and unit costs, while other sources available offer solely unit costs. For example, AERC mentions CSW installed cost being as "little as" $32/sq ft including material and installation, Indow quotes unit cost at $44/sq ft ($40/sq ft for bulk pricing), and a NEEA field study cites an average installed cost of $38.57/sq ft across six installation projects.

[94] CalMTA personal interview November 6, 2025.

pane windows and indicates a disconnect between perceived and actual cost of CSW among manufacturers and ESCOs. This may reflect the following issues:

- Lack of awareness or transparency around actual pricing
- Mistrust or outdated assumptions among purchasers
- Additional costs related to installation or supply chain that are not accounted for by manufacturers

8.4 Building owners and managers' perspectives on CSW and VIG

CalMTA asked decision makers about the cost considerations that would impact their decisions to upgrade their buildings, specifically their windows. None of the respondents know how much CSW or VIG might cost, but most (five out of eight) stated that access to public funding (such as utility rebates or federal tax incentives) was essential to any project. In the absence of public funding, window upgrades, which are already generally viewed as a lower priority compared to other needs, become an afterthought. Other avenues to funding include donations and private financing. One respondent noted that while they relied on some donations for retrofit projects, they only covered a fraction of the cost. Four respondents said that they would seek private financing through loans or company capital funds, but only if public financing was unavailable, and usually only in emergency situations.

> "Often these types of projects are not the highest priority. Unless something is broken or we are forced to replace it, these projects get pushed aside."
>
> -School building manager

Respondents in the interview identified several non-energy benefits as primary motivating factors to seek out window upgrades, including increased thermal comfort, noise reduction, and improved air quality. However, several respondents noted that while non-energy benefits are good, they ultimately only matter if their performance can be quantified by energy cost savings. One university administrator noted that "non-energy benefits are more of a luxury, or secondary, to how much money we will save." Additionally, one commercial building owner noted that limited availability of VIG products could influence decision-making, as window replacements are often time-sensitive and need to be completed quickly.

8.5 Commercial tenant perspective on CSW and VIG

CalMTA asked commercial tenants if they had any awareness of the cost and benefit considerations that would impact the likelihood of their buildings undergoing window upgrades. Due to low familiarity with the specified technology and inability to make building upgrade decisions, most tenants were unable to provide detailed input on cost or benefit considerations.

No tenants provided answers about the benefits of CSW. One tenant mentioned that VIG helped with noise reduction, leak prevention, and improved aesthetics.

When asked more generally about the benefits of efficient windows, two tenants had a clear understanding that installing advanced window technologies would likely reduce operational expenses. One tenant noted that better insulation and energy efficiency would help lower costs and have even encouraged the building owner to pursue upgrades. Another tenant confidently stated that operational costs would "go down, no question," and believed installation would not extensively disrupt business operations, estimating a one-day installation period.

These responses suggest that while some tenants recognize the long-term financial benefits of building upgrades, there is limited awareness or discussion around specific technologies. This reflects the broader trend of tenants not being primary decision makers for capital improvements.

8.6 Financing

This section summarizes interview insights on financing for window upgrades. Manufacturers generally reported low awareness of or involvement with financing, noting that customers usually secure funding independently. ESCOs observed that financing is limited but gradually improving through state programs and green lenders. While improving, ESCOs noted that available financing typically supports only those projects with strong returns. Building owners emphasized that public incentives like rebates and tax credits are essential to build momentum in the market.

8.6.1 Financing insights from market actor interviews

Manufacturers

CalMTA asked manufacturers for information about financing mechanisms utilized by their customers. Four of six manufacturers said they were not aware of any financing mechanisms that their customers use for CSW, and all six stated they were not aware of any for VIG. Of the two that were familiar with such mechanisms for CSW projects, one mentioned traditional equipment leasing, construction loans, and "energy as a service" or "pay-for-performance" contracts where customers pay for retrofits in installments rather than up front; the other mentioned commercial property assessed clean energy programs and equipment lenders.

> "Our assumption is that a sophisticated commercial building owner has their own line of credit."
>
> -CSW Manufacturer

When asked whether they have any concerns about financing for CSW projects, five of six stated they had none. The remaining manufacturers indicated their concerns include low occupancy rates reducing available capital, the value of real estate assets, and the ability of commercial building owners to secure loans (a concern which is exacerbated for commercial building owners in ESJ areas).

ESCOs

CalMTA asked ESCOs about their experiences with helping customers finance advanced window solution projects. Respondents indicated that financing for window upgrades is limited but beginning to improve. One noted that none of the 600-plus projects they had completed annually

since 2007 used third-party energy financing. However, they highlighted a new state-subsidized program that includes windows and stated they had two projects that might use it. Others reported offering flexible internal financing solutions, with one firm noting that it can act as the bank by delaying invoices and applying a finance charge. Another respondent described working with green banks, utility incentives, and lenders to help finance retrofits, demonstrating that public-private financing partnerships are a viable pathway.

Still, financing remains rarely used by most customers and is typically limited to nonprofits or budget-constrained organizations. One respondent asserted grants and incentives are more commonly used, with low-cost financing mainly appealing to clients lacking capital.

Views on financing concerns varied. One ESCO respondent mentioned the topic arises "every day," highlighting capital access as a frequent barrier. Another noted that it is rarely discussed, as their clients seldom use financing. A third explained that financing can improve strong projects but will not justify those with poor ROI. Overall, ESCOs discussed financing as a tool to support viable projects rather than a solution for uneconomic ones.

Attachment A: Weighting Methodology

To ensure that survey results accurately represent the building stock in California, weights were developed at building type level using population data from publicly available sources (ComStock/CBECS).[95] Each building type is assigned a single, unique weight that is applied uniformly across all respondents within a given building type, treating each respondent equally within building types.

$$Weight\ for\ Building\ Type_b = \frac{Population\ Square\ Footage\ of\ Building\ Type_b}{\sum Buildings_{bi} \times Square\ Footage_{bi}}$$

Where:

Population Square Footage of Building Type$_b$ =Total Population square footage of the building type owned or managed by respondent$_i$

Buildings$_{bi}$ = Number of buildings owned or managed by respondent$_i$

Square Footage$_{bi}$ = Average Square Footage of Buildings Owned or managed by Respondent$_i$ of Building Type$_b$

Post stratification weighting is applied so that the survey responses are normalized to the targeted population, which CalMTA defined as specific building types in California's building stock, reflecting the relative share of the building types in the targeted population rather than the distribution in the sample.[96] This was necessary because the raw survey data overrepresents building types that make up a smaller percentage of the population share of the California building stock (colleges/schools) and underrepresents building types that account for a larger share (offices, non-college schools).

[95] CBECS and Comstock were used to develop the square footage for population

[96] The building segmentation is described in Section 2.2, Target market, and includes College/University, Healthcare, Lodging, Office, School (non-College/University)

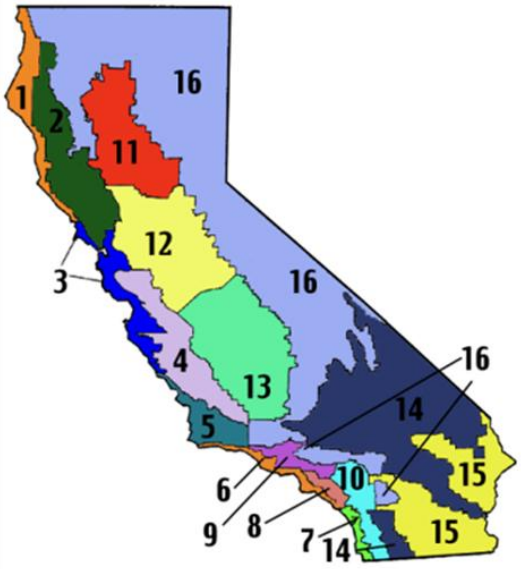
Attachment B: Zip Code and Climate Zone Mapping

CalMTA classified survey respondents by climate zone and regions. To identify the climate zone for the survey sample, we applied the California Energy Commission (CEC) mapping of zip code to California Building Climate Zones.[97]

CalMTA then developed broader definitions of climate regions for the survey sample by mapping the CEC climate zones to regions, as identified by the CPUC Impact Evaluation of Water Heating Measures report.[98] These climate regions include the following (also depicted in Figure 35):

1. Coastal Climate Region: Includes CEC climate zones 1, 2, 3, 4, 5, 6, 7, and 16.
2. Inland Climate Region: Includes climate zones 8, 9, 10, 11, 12, 13, 14, and 15.

Figure 35. CEC Climate Zones



Source: DNV. 2019. Impact Evaluation of Water Heating Measures. Retrieved from https://www.calmac.org/publications/CPUC_Group_A_Report_Water_Heating_PY_2019_Final_CALMAC.pdf

[97] https://www.energy.ca.gov/media/3560

[98] DNV. 2019. *Impact Evaluation of Water Heating Measures*. Retrieved from https://www.calmac.org/publications/CPUC_Group_A_Report_Water_Heating_PY_2019_Final_CALMAC.pdf

Attachment C: Research Instruments

CalMTA CRAWS Building Owner/Manager Online Survey

CalMTA CRAWS Interview Guides:

- CRAWS Tenant + Business Owner Interview Guide
- CRAWS ESCO Guide
- CRAWS Installer Guide
- CRAWS Manufacturer Guide
- CRAWS MUSH Interview Guide