

Shell Upgrades: A Key Step for Deep Retrofits?

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ABSTRACT

Upgrading commercial buildings often involves replacing the lighting and mechanical systems, but what about the building envelope? Code improvements affect the energy performance of new buildings with only modest effects on existing commercial buildings, most of which were built decades ago. As cities and states throughout the country increasingly use benchmarking data to identify and encourage building upgrades needed to meet climate change mitigation objectives, program administrators and building owners are taking another look at opportunities associated with building shell upgrades for existing buildings.

The energy consumption of commercial buildings is well documented, as are the opportunities to improve performance through upgrades to mechanical, shell, domestic hot water, and control systems. Many of these benefits remain unrealized because of constraints on investment, concerns about tenant disruption, split incentives, and competing demands for attention. Poor performing window systems are common among these buildings, and often among the last of the major systems to be upgraded. In the Northwest, program administrators are promoting window attachments as a lower cost, less intrusive solution.

Introduction

Challenges executing deep retrofits in existing commercial buildings are well documented as program and policy research continues to find substantial opportunity and technically feasible projects that fail to move forward because of the economic and human challenges involved (Amann et. al 2005, Granade et. al 2009, Higgins 2011, RMI 2012). As cities and states throughout the country are increasingly using benchmarking data to identify and encourage building upgrades required to meet climate change mitigation objectives, program administrators and building owners are taking another look at opportunities associated with building shell upgrades.

Existing buildings lag new construction in the adoption of efficient technologies, as they are largely excluded from the requirements of new building code compliance (Kwatra and Essig, 2014). These older commercial buildings are likely to be occupied for decades and represent a tremendous opportunity for meaningful reduction of energy consumption consistent with state and local targets for greenhouse gas emissions reduction. Given the number of these buildings and the need to permanently reduce the energy consumption associated with them, program designers and policy advocates are increasingly identifying the need to upgrade the performance of these buildings.

For decades, energy efficiency professionals have advocated for comprehensive “whole building” approaches for commercial buildings—acknowledging that addressing multiple systems optimizes overall energy performance and can potentially reduce future capital expenditures through downsized mechanical equipment. Programs supporting deep retrofits are often cast as custom or comprehensive and enable a variety of measures to be included—

avoiding prescriptive measures that may or may not work for a given project. The costs for these upgrades are typically borne by owners and investors in commercial real estate, who are often reluctant to spend money on upgrades that primarily affect energy costs paid for by building tenants. This classic split incentive barrier can be difficult to overcome when framed in energy costs and savings alone. Market research and program experience has found that emphasizing complimentary non-energy benefits helps overcome the split incentive barrier (RMI 2012, Vrabel 2018). If an upgrade can lead to improvements that are desirable to tenants—for example, a more comfortable space, reduced noise, or the status associated with a “green” or sustainable building space—upgrades can lead to higher occupancy and longer lease terms. Even when these non-energy benefits are identified and likely, the disruption and cost of shell improvements (typically windows, insulation, or façade improvement) mean that only a small portion of the energy savings potential associated with comprehensive building upgrades are ever realized.

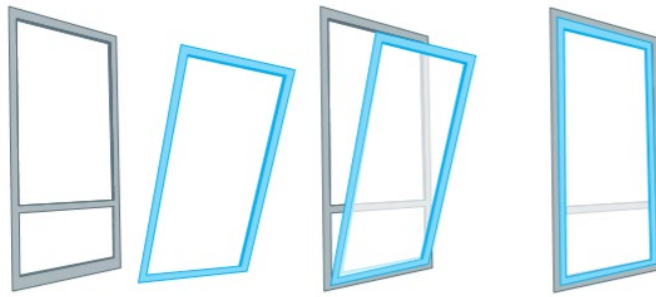
Within this dynamic, shell upgrades are typically the last type of upgrade considered, even though they can result in reduced mechanical and lighting system loads if they are completed first and incorporate daylighting and envelope improvements. Integrated design approaches prioritize considering the interactive effects of multiple building systems, including shell performance, in whole building upgrades. Nevertheless, shell upgrades of existing buildings are rare. They are expensive, complex, and often not tackled until window and façade systems are failing. The Northwest Energy Efficiency Alliance (NEEA) sponsored research into the dynamics of this market as they relate to commercial secondary windows (Moran et. al. 2021). This paper presents the results of that research in the context of previous research into commercial building upgrades.

Commercial Secondary Windows

Commercial secondary windows (CSW) are window units with one or more transparent panes in a frame that attaches to the interior or exterior of existing windows without replacing the original glass or frame. This creates an insulating pocket of air between the existing and new secondary window. Some products also incorporate low-e glass to reduce radiative heat loss and further improve insulating performance. Secondary windows are sometimes referred to by other names in the market such as interior storm windows, interior storms, insulating panels or inserts, and secondary glazing systems. These terms all describe similar products.

Secondary window systems are customized to fit a building’s existing window openings. CSW products are customizable, and manufacturers offer products with a wide array of features that encompass window operability, interior vs exterior mounting, different installation and sealing methods, and framing materials—all of which enable the product to match the variety of window configurations in existing buildings. Secondary window attachments have been available for many years and are commonly used for security purposes in government buildings. With the recent establishment of the Attachments Energy Rating Council (AERC), CSW products are emerging that establish efficiency and comfort benefits at a lower cost than full window replacement. The product category is evolving rapidly with technology innovations like active windows, light directing films, and suspended films.

Figure 1: Illustration of Interior Secondary Window Installation



To support its efforts to promote CSW and engage the commercial building market, NEEA sponsored targeted market research to better understand the nuance and factors behind decisions to upgrade the shell of an existing commercial building. This research included several activities that together provide a picture of a complex market in which decision-makers balance multiple competing priorities when considering solutions for under-performing windows. The research activities sought to:

- Understand the decision-making process that accompanies envelope improvement in existing buildings.
- Assess awareness among the key market actors expected to be involved in selecting window products.
- Explore and confirm key scenarios for which CSW might be a viable solution, including hypothesized opportunities related to major building retrofits, historic buildings, and to address tenant needs.¹

Opportunities

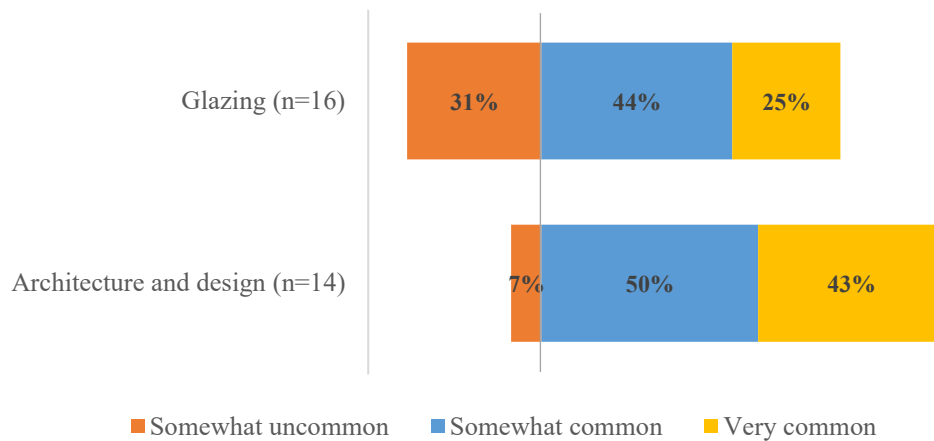
Shell upgrades require mitigating a nuanced set of market barriers. The mix of opportunities and barriers could be different for each building, as could the relative power of any specific factor. While there are numerous potential building stock-related opportunities, there are also substantial market-based barriers. Market barriers tend to prevent shell improvements generally and apply to CSW products. (Table 1)

There are two sets of primary opportunities: stock-related opportunities and market-related opportunities, each with different leverage points. CSW will be most attractive in projects where both building stock features *and* market drivers are working towards product selection. Stock-related opportunities reflect the vintage and construction characteristics of the building and the condition of the windows. First, the window performance issues must be identified. Surprisingly, the surveyed glazing contractors were less likely to report finding window performance issues in existing buildings relative to surveyed architects. This could reflect their different roles—architects are often brought in to upgrade existing buildings, while glaziers tend to focus on new construction or repair. (Figure 2).

Figure 2: Prevalence of Window Performance Issues in Existing Buildings

¹ The NEEA team included a scenario in which window attachments would be considered as part of an HVAC upgrade as a means of tightening the building envelope. HVAC and other mechanical upgrades did not emerge as a project scenario in discussions with key market actors. Additional research could shed light on the prospect that shell improvements could be tied to HVAC replacement.

Glazing contractors less likely to report window performance issues are very common in existing buildings



The building stock opportunities presented in Table 1 tend to be specific to windows and are likely necessary conditions for any CSW project. However, these conditions are not sufficient *on their own* to trigger an investment in CSW, or shell improvements generally.

Table 1: Building Stock and Market Based Opportunities and Barriers

Building Stock Features	
Opportunities • Historic buildings • “Ribbon” windows • Single pane glass • Intact framing • Vintage (pre-1990) • Punched opening windows	Barriers • Additional requirements/complexity associated with historic preservation • Building height (for external mounting) • Structural concerns about weight • Curtain wall construction
Market and Decision Drivers	
Opportunities • Tenant complaints about comfort • Owner occupied • Institutional owner (long time horizon)	Barriers • Inertia • Information gaps • High cost of solutions • Low awareness of solutions • Multiple decision-makers • Concerns about liability

Market-related opportunities present different challenges, many of which are associated with human behavior and decision-making. This market research indicates that inertia is likely the single biggest market related barrier as interviewees universally reported the tendency for owners to wait until windows have failed before taking action. At that point, a building would no longer be an appropriate candidate for CSW, as the existing windows need to have proper sealing, be intact, and free of rot. A building in this condition could participate in comprehensive

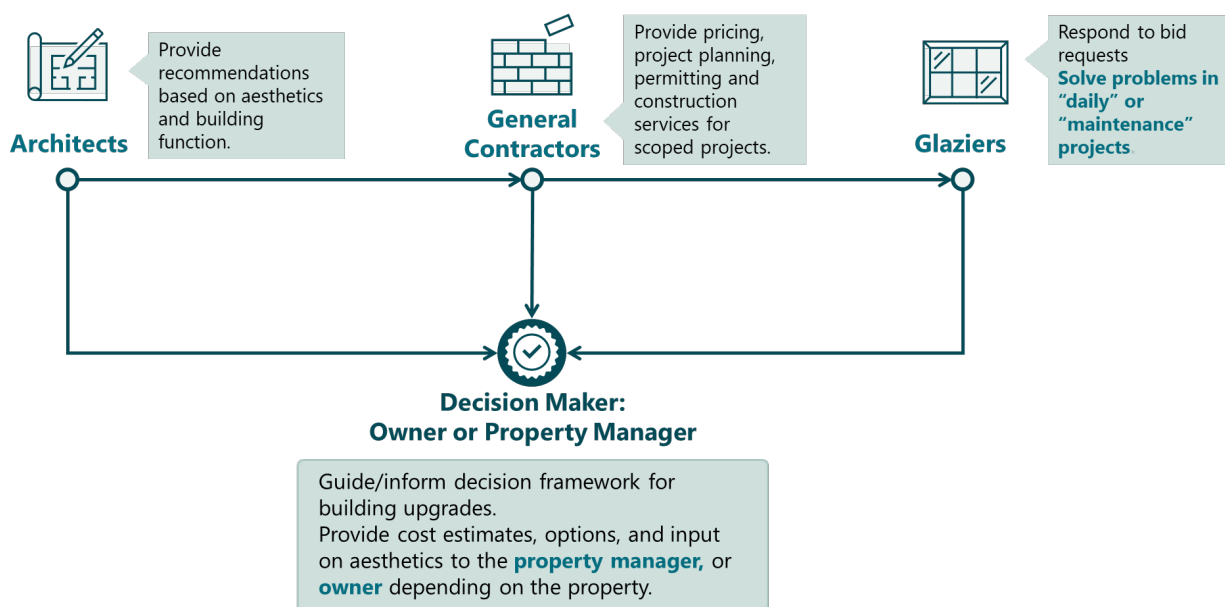
“whole building” programs to maximize the efficiency of the post-retrofit mechanical and lighting systems.

Decision Making Process

The decision-making process for commercial buildings, and especially shell upgrades is exceedingly complicated, involving multiple professionals, substantial investment, and disruption for both tenants and neighbors. Understanding how window upgrades typically occur provides insight into alternatives. Professionals involved in shell and window project scoping include architects, who would be involved in any project that requires a permit, and glaziers, who often respond to specific bid requests. All market actors report striving for satisfied occupants and a happy client (typically the building owner) and will protect their professional reputation by recommending the highest quality solution.

The team diagrammed the relationship between the primary actors (Figure 3).

Figure 3: Decision Making Relationships



Architects are expected to provide input and recommendation for product choices for windows. Architects are generally involved in products requiring a permit—property management companies and landlords without an in-house architect will engage them for ideas and product recommendations.

General contractors are typically selected by the owner or property manager and will work closely with an architect on projects that require a permit or with glazing subcontractors on window specific work. According to property managers, general contractors will also suggest alternative approaches or products if they think it will save their client money or hassle, or if a project budget is limited.

Glaziers (window installers/contractors) typically respond to bid requests. Property management companies often have existing relationships with trusted glazing firms. When a project is scoped, they will contact these professionals for pricing and timing information.

“Speed is king,” said one property manager, “unless we are doing the entire building... that

requires more planning, and we can be more selective.” Note that Figure 3 includes a description with bolded text associated with “daily” or “maintenance” work. In focus group discussions, several glaziers distinguished their firms from glazing firms that provided smaller, ad hoc service work and repair.

Property managers determine who needs to inform the options provided to the building owner. This could include contacting an HVAC, glazing, general contractor or similar. The property manager obtains bids, outlines different scenarios (including costs, expected payback, and effects on tenants) and presents this information to the building owner. *“If something has a quick payback, it’s a no-brainer; if the upgrade addresses common areas and lowers the common area maintenance (CAM) costs, everyone absorbs the costs and experiences the benefits.”* CAM costs are associated with atriums, parking lots, and lobbies—tying upgrades to these types of opportunities can make it easier to justify glazing investments. Property management contacts are closer to the experience of those occupying their buildings and offered more detail about common issues they most associate with existing windows, reflecting the numerous non-energy benefits associated with high performing windows. Existing window performance issues include:

- **Operability.** Tenant requests for operability include complaints about windows that are “stuck” open or closed. Operability is viewed as an attractive attribute of historic building windows.
- **Noise.** Tenants are likely to complain about noise in downtown areas or in buildings near highways or railroads.
- **Drafts.** Tenants will complain if they experience drafts, which can indicate that either seals have failed, or inefficient single pane glass is present which can create convection loops that are felt as drafts next to the cold glass.
- **Solar heat gain.** Issues associated with the sun include heat buildup as well as glare.
- **Security.** Property managers also field concerns about safety, including broken glass, vandalism, and perceived risk.

Of the performance issues identified here, all but operability are directly improved by installation of CSW.

Tenants. Depending on the purpose of the upgrade and existing contractual relationships, tenants may also be involved in the decision-making process. If tenants are paying for the improvement (either because it’s a negotiated tenant improvement project, or because it’s something important to their business such as special storefront glass for a retail or restaurant space), then tenants will often pay for the design and only get approval as required from the building management or ownership.

Not all of these roles will be involved in every project or decision process. Deep retrofit projects will likely involve all these roles, whereas smaller projects focused on addressing specific poor performing windows may only involve the building owner/occupant and a local contractor. Energy Service Company (ESCO) interviews provided another perspective, noting that envelope measures are rarely incorporated in their commercial projects because of the long energy savings payback. Because secondary windows are less expensive than full reglazing, payback will be faster; however overcoming inertia and taking action before windows have failed remains a challenge. Building owners may decide to move forward if there are ancillary benefits that would offset the investment (for example, improved building integrity, or improved

property value). This can be different for institutional customers with longer time frames and more favorable economics for envelope improvements.

Two primary barriers to CSW adoption emerged from research into this decision-making process. One relates to current market conditions and the other to information gaps.

1. **Glaziers are extremely busy and do not usually promote projects among otherwise reluctant building representatives.** Glaziers report they do not tend to solicit work or identify solutions for those that have not requested a bid. Thus, the buildings in an inertia state—that could benefit from CSW but are not asking for solutions—are unlikely to be identified. Glaziers report that their proposals need to reflect the specification framed in the bid, limiting their ability to propose different solutions.
2. **Informational gaps are numerous and reflect the concerns of each market actor.** Glaziers offered myriad specific questions about CSW products in focus group conversations, many of which reflected concerns about liability, cleaning requirements, and the extent to which CSW would meet bid-specified performance requirements. Architect questions focused more on visual and operational impacts to buildings and generally limited viable applications to historic buildings and those with low profile window construction. Property management contacts had questions about pricing and how to obtain the products.

Other Barriers

This research also reaffirmed that awareness of options and benefits remains low among those that might consider opportunities to improve the overall performance of existing commercial buildings—a well-documented barrier to robust upgrades (Kwatra and Essig, 2014). Building owners and managers turn to the trades and design professionals for recommendations, so lack of awareness among these professionals means that options are simply never considered. This is the case for CSW products. While CSW solutions are not appropriate for every building, without awareness, they will not be in the decision set provided when a building requires renovation.

There is very low awareness of CSW among key market actors, particularly for standard (non-historic) vintage commercial buildings.

- **Architects, glaziers, and property managers are largely unaware of CSW products, particularly for non-historic buildings.** The awareness of CSW among market actors is generally centered on historic buildings, which have restrictions on alterations to exterior features. Most had not specified or seen CSW installed in “normal” commercial buildings. Secondary windows are generally associated with residential storm windows.
- **Architects reported the highest level of awareness but expressed concerns about recommending these products.** Architects indicated a higher level of awareness of CSW options and a likeliness to consider these products, however two-thirds of them had never recommended, installed, or purchased these products and focus group discussions indicated this openness may be limited to historic buildings, where choices are more limited.
- **Property management contacts had almost no exposure to CSW solutions.** The two contacts reporting they had used secondary windows both described unique historic building applications. Those managing more traditional commercial building portfolios

expressed surprise, and interest, in options to attach additional glass to existing window framing.

Awareness is a powerful barrier, and linked closely to other barriers, all of which need to be mitigated on some level to overcome inertia and disrupt standard practice. Table 2 provides findings associated with the primary barriers for CSW.

Table 2: Barriers and Research Findings Map

Lack of awareness	
Barrier	Findings
Supply side	There is clearly an opportunity to improve overall awareness among those that specify and install window products. Glazier awareness was largely limited to historic building applications. Manufacturers are more aware of these solutions—secondary window product manufacturers can provide examples of successful projects.
Demand side	Low awareness among property managers and reluctance to address shell measures prior to failure are both affecting demand. This is less about demand for CSW specifically and more about demand for upgrading the building envelope systems in the absence of pressure to act. Energy efficiency will not be sufficient motivation—this outcome will need to be paired with improvements in sound transmission and thermal comfort, glare, or property value to get the attention of building owners.

Gaps in information and expertise	
Barrier	Findings
Insufficient installer knowledge to sell	These barriers are closely related, and all emerged organically in interviews. We recommend approaching these barriers holistically by providing detailed information on product options, prices, installation, and performance to glaziers. Window replacement and repair contracting is a specialized trade, and these contacts require specific, detailed information to bid products. Their questions about installation practices, liability, and product options are not necessarily separate issues—this information is needed to recommend and successfully complete CSW work. It is important to note that energy savings is not the top priority in product specification. They track U-value, solar heat gain, and NFRC ratings, but also focus on sound, aesthetics, and water infiltration. AERC ratings are not yet widely available or understood.
Lack of supply side installation expertise	
Missing proof of performance in Northwest buildings	

High relative cost	
Barrier	Findings

Inertia	The “relative cost” in this scenario refers to the option of doing nothing. Indeed, the expense of addressing shell improvements means that many owners choose to do nothing until glazing systems are failing, after which they are inappropriate for CSW. This is likely the single biggest demand side barrier and is likely to be overcome on a building-by-building level, through customized solutions provided at the right time.
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Lack of product differentiation	
Barrier	Findings
Lack of market signal or label to distinguish high performance product.	This barrier was not assessed directly; however, it is important to note that introducing performance differentiation when basic awareness is low could reduce confidence in the overall product category. The questions the research team fielded from market actors indicate that answering fundamental product-level questions will be needed prior to introducing elements of differentiation. If labeling provides specific performance ratings (on sound transmission, solar heat gain, U-value) of <u>combined systems</u> (primary and secondary glass) it could potentially serve both purposes (increased awareness and confidence while also differentiating).

Putting it Together: Creating Market Demand

Many of the recommendations below are related to increasing awareness, which is a key activity associated with ultimate success engaging with the commercial building market generally. While lighting and mechanical projects have natural trigger points associated with equipment failure or obsolescence, shell improvements have historically occurred at a much lower rate (Bloch et. al 2012, Navigant Consulting, Inc. 2012). Even in custom or comprehensive program designs that encourage, or at least enable, assessment of shell opportunities, these projects are rare. If meeting energy efficiency and greenhouse gas emissions reductions requires tackling deep retrofits of commercial buildings, programs and market interveners will need to pay more attention to the specific challenges associated with upgrading building shell attributes.

Advocates will need to launch creative, ***aggressive efforts to spread information and increase awareness*** of shell improvements that do not require extensive building renovation, like CSW. Developing materials that provide clear, technically accurate answers to the most frequently asked questions can overcome initial skepticism. Messaging that creates urgency for assessing window performance prior to obvious failure could encourage CSW installation that increases efficiency and extends the life of existing windows. Demonstration projects provide an opportunity for building representatives and design professionals to see and touch products prior to including them in project specifications. Partnering with industry organizations improves credibility and taps into existing market relationships. Building relationships with property management companies is also important as these contacts have sway with building owners and are often intermediaries between design professionals and the owners. In interviews these contacts expressed surprise and interest in a product that could improve window performance

without the associated disruption to tenants and immediately began asking follow up questions about permit requirements and delivery timelines.

Encouraging shell improvements will also require ***building and maintaining credible relationships*** with architects, glaziers, and mechanical, electrical and plumbing (MEP) contractors. These professionals are involved in major retrofit projects in which buildings undergo multiple system upgrades—screening these buildings for window and shell performance issues that could lead to more integrated design. For specific products (like CSW) it is important to have a product representative position themselves as a one-stop resource for questions on products and performance. Our research showed substantial, but surmountable, initial skepticism to CSW and having a “face of the product” who can credibly answer technical and product level questions would help build trust.

Building contact and stock analysis activities will likely be needed to ***identify high propensity buildings***. Shell solutions like CSW are not appropriate for all buildings—any building in which windows are already failing, for example, would require new windows. In the Northwest, stock data are collected via periodic Commercial Building Stock Assessments. This data, when combined with vintage and owner information from tax assessor data (or benchmarking results from areas with commercial building benchmarking ordinances) can help programs home in on buildings with a moderate propensity to have issues with window performance. However, these data are not sufficient. Fully leveraging the information will likely require mapping to building management context. This is a long-term investment in market mapping that will support myriad efforts to promote comprehensive commercial building upgrades. A concentrated effort to build out contact lists, build on relationships with the Building Owners and Managers Association (BOMA²) and similar trade groups like International Facilities Management Association (IFMA), will likely be required.

For CSW products, high propensity buildings include:

- **Historic buildings.** The most obvious application for glaziers and architects is associated with buildings that have restrictions that would prevent replacement. Among property managers who had installed any type of secondary glazing in commercial buildings, experience was limited to historic buildings.
- **Buildings with substantial direct sun exposure.** The heat gain in these buildings can create thermal discomfort that triggers a search for affordable solutions.
- **Older non-historic buildings.** Older buildings with single pane glass emerged as buildings likely to benefit from window rehabilitation and replacement. When pushed for precise vintage cutoff dates, contacts referred to buildings from the 1980s or earlier. However, glaziers and architects both cautioned that these older glazing systems often have performance problems that would prevent CSW installations—most commonly framing failures and water infiltration.
- **Where safety and security are prioritized.** Glaziers report that bullet-or blast-proof windows are increasingly specified and that ground floor operable windows are sometimes screwed shut to improve building security. Secondary windows could provide additional security in both scenarios. Perceived increases in vandalism and window damage have made property managers more sensitive to upgrades that can reduce the susceptibility of their buildings to damage. Blast proofing is often a requirement for government buildings. To the extent CSW are positioned as a solution for blast proofing

² Building Owners and Managers Association <https://www.boma.org/>

retrofits, they could be specified for these buildings, although specialized designs to meet test standards may be required.

- **Occupied multifamily or office buildings.** The prospect of upgrading windows without disrupting tenants or waiting until space is unoccupied had previously been documented as a benefit of secondary windows and was confirmed again in interviews with property managers. Because they can be installed in occupied space, property managers agreed that CSW could provide a cheaper and less invasive solution than window replacement.

Concerns

While there are many options for building demand and encouraging comprehensive building upgrades, it is important to acknowledge and address the concerns of market actors. Broadly, these concerns fell into three categories: liability, client satisfaction, and installation requirements.

Liability. The single biggest concern glaziers expressed related to perceived liability. As the professional responsible for the performance of the overall glazing system, glaziers are compelled to recommend products that they are confident in. Their professional reputations depend on satisfied customers and high-quality work and are concerned that they might be accepting responsibility for the CSW and the existing window, even if they do not change the existing window.³ Glaziers expressed concerns about “band-aid” solutions like secondary windows, which could create unforeseen failures they would be responsible for.

What about the cost relative to replacement?

CSW manufacturers highlight the low cost of secondary windows relative to a full replacement, in some cases 25% of the total cost including installation and avoided disposal costs, but glaziers and architects are less certain. In focus groups, these market actors often brought up concerns over the uncertainty about exact pricing comparisons between the two options. For market actors to recommend CSW, they will likely need more information about cost differences.

Client/tenant satisfaction. All three market actor groups want happy clients and satisfied tenants. Architects were concerned that CSW could result in client complaints about aesthetics or reduced operability. Glaziers offered examples of client satisfaction with new, high performing windows as evidence that their customers might not be as happy with CSW. Property managers generally offered more pragmatic opinions, noting that if the product made sense and they were convinced it would work for their buildings they would consider it.

Installation. Glaziers had numerous questions associated with the installation process. They asked about cleaning requirements, time required to install, and if installation required special training. Property managers identified an opportunity to avoid soft costs associated with permitting, disposal, and street closures that often accompany replacement, and asked

about installation options.

³Include warranty details as part of an information campaign to address concerns and in frequently asked questions among market actors.

Conclusions

Comprehensive “deep” retrofits of commercial buildings are likely needed to meet greenhouse gas emissions reduction goals. These projects have historically been challenging—requiring a mix of technical expertise, market credibility and the confluence of multiple drivers. This paper discusses the results of market research specifically focused on secondary window attachment products, but the lessons learned apply to many potential shell improvement projects. Efforts to promote these projects will require concerted, long-term investment in building relationships and credibility, working directly with design professionals to mitigate barriers and align solutions to their professional concerns. Intentional screening and prospecting, technical assistance, robust warranties, and demonstration projects will be required. While product costs and resulting savings are still being verified in the Northwest, CSW products have a larger profile in areas of the country with more extreme weather, including the Midwest and the Northeast.

References

- Amann, J., and E. Mendelsohn. 2005. Comprehensive Commercial Retrofit Programs: A Review of Activity and Opportunities. ACEEE Report Number A052.
- Bloch, C., J. Hampton, J. P. Salmon, B. Davis, J. Hummer, and B. Barkett. 2012. Existing Facilities Program Market Characterization and Assessment Report. Prepared for New York State Energy Research and Development Authority. Boulder, CO: Navigant Consulting, Inc
- Granade, H.C., J. Creyts, A. Derkach, P. Farese, and S. Nyquist. 2009. Unlocking Energy Efficiency in the U.S. Economy. McKinsey & Company.
http://www.greenbuildinglawblog.com/uploads/file/mckinseyUS_energy_efficiency_full_report.pdf
- Higgins, C. 2011. A Search for Deep Energy Savings. Prepared for Northwest Energy Efficiency Alliance. New Buildings Institute. https://newbuildings.org/wp-content/uploads/2015/11/NEEA_Meta_Report_Deep_Savings_NBI_Final81520111.pdf
- Kwatra, S. and C. Essig. 2014. *The Promise and Potential of Comprehensive Commercial Building Retrofit Programs*. ACEEE. aceee.org/research-report/A1402.
- Moran, D., J. Hessels and A. Starkey. 2021. Commercial Secondary Window Program Development Research. Prepared for Northwest Energy Efficiency Alliance.
<https://neea.org/resources/commercial-secondary-window-program-development-research>
- Navigant Consulting Inc. 2012. Commercial and Industrial Energy Efficiency Retrofit Custom Programs Portfolio Evaluation Final Report. Prepared for Puget Sound Energy.
https://conduitnw.org/_layouts/Conduit/FileHandler.ashx?RID=772
- Lyles, M., C. Higgins, J. Jennings, R. Cochrane. 2012. A Search for Deep Energy Savings. In Proceedings of Summer Study on Energy Efficiency in Buildings. Pacific Grove, California. ACEEE.
- Rocky Mountain Institute (RMI). 2012. RetroFit Depot Guide to Building the Case for Deep Energy Retrofits. https://rmi.org/wp-content/uploads/2017/04/Pathways-to-Zero_Bldg-Case-for-Deep-Retrofits_Report_2012.pdf
- Vrabel, Katie. 2018. Beyond the Dollar Sign – Non-Energy Benefits to Energy Efficiency. Waypoint Energy. <https://www.waypoint-energy.com/post/beyond-the-dollar-sign-non-energy-benefits-to-energy-efficiency>