Title

Are Deep Energy Retrofits in Commercial Buildings Including Window Upgrades?

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Are Commercial Deep Energy Retrofits Including Window Upgrades?

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ABSTRACT

U.S. Commercial buildings account for about 20% of total U.S. energy consumption. Because the thermal performance of windows significantly affects building energy efficiency and HVAC system performance, best practice guidance often includes window and envelope improvements in conjunction with HVAC upgrades to optimize energy use and improve occupant comfort. It is an open question, however, regarding how often these best practices are implemented in the field. This paper aims to address that gap by conducting a literature review and a series of interviews with commercial building auditing and management professionals to explore the factors that drive window retrofits in commercial buildings. The paper explores a range of case studies from deep energy retrofits across the globe, comparing projects with and without window retrofits. The primary goals of this review are to: (1) provide data from real-world case studies illustrating the role of windows in deep energy renovations and HVAC upgrades, (2) conduct retrofit cost analyses for windows and high-performance HVAC systems and (3) offer insights into how window upgrade decisions are made and when they are implemented as part of deep energy retrofits. Most of the retrofit studies focused exclusively on high performance HVAC upgrades without considering how window upgrades might further enhance the overall energy efficiency of commercial buildings. Interviews with building industry experts shed light on the key factors influencing deep energy retrofit decisions and what factors tip the scales in favor of including window measures with more comprehensive retrofit projects.

INTRODUCTION

Of all the building envelope components – roofs, walls, floors, and windows – thermal transfers through windows consistently account for a disproportionate share of building heating and cooling loads as well as occupant comfort complaints. For a prototypical medium-sized office building, windows will make up about 12% of the envelope area, on average, but will be responsible for over 50% of the thermal transfers through the envelope.[1] About 40% of 5.9 million U.S. commercial

[1] Based on a 2024 Berkeley Lab UA analysis for a prototypical 53,000 ft^2 3-story office building built to the ASHRAE standard 90.1-2022, with 33% window-to-wall area, simulated in the heating dominated IECC Climate Zone 5.

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buildings have inherently poor insulating single-pane windows and about 60% of all commercial windows having unimproved glass that is not low emissivity (low-e) (EIA 2021). Energy-efficient heating ventilation and air-conditioning (HVAC) equipment works best when paired with tight and efficient envelopes. In older buildings with poorly sealed and leaky envelopes, window retrofits can help manage and reduce heating and cooling loads. This can potentially reduce HVAC size requirements, improve operational efficiency, extend equipment lifespan, and improve occupant comfort, thermal resilience, and noise insulation. This would suggest that window retrofits would be included in deep energy retrofits that include HVAC upgrades; however, it is an open question as to how often envelope and HVAC upgrades are paired. To address this question, this study conducts a literature review and a series of interviews with commercial building auditing and management professionals to assess the current retrofit market and explore factors that drive commercial building window retrofit decisions and successful implementations.

BACKGROUND

Despite the recognized thermal and air-leakage issue with windows, market research would suggest that relatively few commercial windows are replaced or retrofit each year, with only an estimated 14% of all existing commercial fenestration having been installed as a retrofit. Figure 1 shows the fenestration installed by vintage for retrofit versus new construction applications (Guidehouse 2021).

Figure 1 Commercial building installed fenestration by building vintage ("Construction" refers to fenestration remains from the original construction).

Commercial Window Retrofit Technologies

There are several technologies and approaches that can be taken to improve the thermal efficiency of a commercial[2] window system. ANSI/ASHRAE/IES 100-2024 (2024) provides commercial building guidance on how to achieve energy efficient existing buildings through energy benchmarking, auditing, and retrofits, where retrofit measures are prioritized based on their overall benefit-cost ratio or savings-to-investment ratio. ASHRAE 100 lists window retrofit recommendations as part of its *Informative Appendix H Energy Efficiency Measures,* and includes the following measures:

- "Replace single-pane and leaky windows with thermal/operable windows to minimize cooling and heating loss.
- Install exterior shading, such as blinds or awnings, to cut down on heat loss and reduce heat gain.

[2] This paper includes large multifamily buildings as part of the analysis to more broadly examine a range of commercial real estate auditing practices and window system retrofit applications.

- Install storm windows and multiple glazed windows.
- Use tinted or reflective glazing or energy control/solar window films.
- Replace existing fenestration (toplighting and/or sidelighting) with dual-glazed low-e glass wherever possible to reduce thermal gain.
- weatherization and air-sealing improvements." (ASHRAE 2024)

Both DOE and the U.S. General Services Administration's (GSA) Technology Proving Ground project have field validated and demonstrated the performance of these retrofit measures in both heating- and cooling-dominated climate zones in multiple commercial building types. Table 1 characterizes the technologies tested and the associated study findings.

Table 1. DOE and GSA Window Retrofit Case Studies

Technology	Building Type and Location	Baseline Description	Findings
Exterior Low-e Storm Windows[(a)]	Multifamily (100 units) storm window replacement in Philadelphia, PA	Single-pane, wood-frame windows; old storm windows	• 18% reduction in overall home heating load • 10% reduction in overall home air infiltration
Liquid-applied absorbing solar-control film [(b)]	Government/ office in St Louis, MO	double-glazed window (with no low-e coating)	• Up to 29% HVAC energy savings in warm climates • Cost-effective for single-pane clear windows but not double-pane bronze windows
Low-e window films [(c)]	Government/ office in Ogden, UT and Dallas, TX	Clear single-pane window	• Average of 29% in M&V perimeter HVAC savings (single-pane clear windows) • Average of 25% in modeled perimeter energy savings • 2-6 year payback
Lightweight quad-pane windows[(d)]	Government/ office in Denver, CO	Double-pane windows	• 24% more energy savings than double-pane windows • 1-6 year payback for new construction and window replacements
Ultralight Window Insulation Panels[(e)]	Government/ office, Eau-Claire, WI	Double-pane with clear glass with anodized aluminum frame	• 3-6% modeled HVAC savings • Payback periods >15 years • Reduced rate of cooling in perimeter rooms by 28%
Interior Non-Glass Secondary Window Attachments[(f)]	Historic office building application in Seattle, Washington (2022)	Single pane wood-framed historic facade	• Frame-attached interior panels nearly eliminated (i.e., >90% reduction) air leakage and reduced outdoor noise by 17dB on tested window • >50% improvement U-value of window with all attachments 95% for windows with air-conditioning units

(a) EERE (2013)
(b) Curcija et al. (2014)
(c) Curcija et al. (2017)
(d) Kiatreungwattana, K and L Simpson (2021)
(e) Myer et al (2024)
(f) Cort, K and E Louie (2022)

STUDY APPROACH

This study is based on a literature review of commercial deep energy retrofit case studies and window retrofit field validation studies as well as surveys and interviews conducted with building management professionals to gather information on building energy auditing practices and retrofit decisions. Because window retrofits can lower heating and cooling loads, the literature review focuses on the interaction of window upgrades and downsizing HVAC systems. It explores case studies from energy audits, DOE's Better Buildings Challenge program, and geothermal programs, comparing projects with and without window retrofits. The review also includes international perspectives, outside the United States, and examine academic research investigating deep energy retrofits. Key goals include evaluating the cost and performance implications of window upgrades on HVAC systems and comparing real-world experiences with academic studies to inform future renovation strategies.

To evaluate the influence of energy audits and auditing practices on window retrofit decisions, a combined PNNL (Pacific Northwest National Laboratory) and LBNL (Lawrence Berkeley National Laboratory) research team conducted an analysis based on a series of surveys and workshops with stakeholders in the auditing industry in 2024. Because the overall consensus of participants in these workshops was that energy auditing practices seldomly focus on window performance and upgrades, it was followed up with a series of interviews with professionals involved in commercial building retrofit and remodeling activities to better identify and characterize the factors influencing decisions to upgrade windows. An exerted effort was made to interview asset managers who had successfully implemented window upgrades in commercial building settings to better understand what factors led to the success of these window upgrade projects.

LITERATURE REVIEW

This study conducted a literature review of both academic research and real-world case studies to assess how window retrofits can help in downsizing high performance HVAC systems in commercial buildings. A total of over 100 sources, including academic papers, reports, and real-word case studies, were reviewed. Of these, 24 were identified as including both HVAC and window retrofits. Table 2 provides selected findings and characteristics from case studies.

Table 2. U.S. Deep Energy Retrofit Case Studies Including Window Retrofits

Technology	Building Type and Location	Baseline Description	Findings
Triple Pane Window Replacement	Multifamily (250 units) in MA	1978 clear glass windows	In total, the deep energy retrofits reduced energy intensity by 54% with $148K in annual operating savings.[(a)]
Window Replacement (double pane low-e)	Multifamily (senior living) sites in MA and UT.	Single-pane windows	5 case studies with overall impacts from deep energy retrofits reduced energy intensity from 20-60%, on average. Brighton, MA site improved east- and west-facing units from overheating. [(a)]
Window Replacement (ENERGY STAR)	Multifamily (affordable) in CA, NY, NM, WA	Single-pane windows	5 case studies with overall impacts from deep energy retrofits reduced energy intensity by 20-25% on average. [(a)]
Resealing Windows	Hotel (6,700 m^2) in GA	Double pane	In total, deep energy retrofits reduced energy intensity by 22.5%.[(a)]
Double-pane low-e window upgrade	Office, Mental health service building in CA	Unspecified	Part of broader study including simulations, laboratory testing, and field demonstration of Zero Net Energy packages with heating savings from 22-25% and cooling savings of approximately 60%.[(b)]
Secondary Window Attachments	5 Office Buildings in Pacific Northwest	Single-pane clear glass windows	Interior secondary window attachments installed in 5 office buildings yielding average annual energy savings ranging from 7-11%, reducing air-infiltration an average 7% and noise reduction of 7 dB measured after application of secondary windows. [(c)]

(a) DOE Better Buildings Solution Center: Showcase Projects Solutions Search (https://betterbuildingssolutioncenter.energy.gov/solutions)
(b) Regnier, et al. (2023)
(c) NEEA (2023)

In recent years there has been an increase in interest and field studies demonstrating the benefits of geothermal heat pumps provide, which often have the potential to dramatically reduce overall HVAC costs. Geothermal installations can be planning-intense and costly endeavors, however, especially in a space-constrained existing building retrofit application. One issue that is often encountered in existing building retrofits is that the poorly insulated building envelopes lead to high and variable energy load needs, which can be challenging for geothermal systems and drive-up equipment and borefield sizing and drilling needs, which drives up costs. Improving the envelope performance could reduce infiltration and heating/cooling loads of the building; thus, one it would seem reasonable that these retrofit measures would be considered in combination with one another.

To evaluate whether or not envelope and window retrofits were considered as part of geothermal retrofits, a literature of review of commercial building projects referencing geothermal system retrofits was completed. Fourteen existing commercial building deep energy retrofit case studies were reviewed that involved high performance HVAC technologies. Of the 14 studies, only 3 studies focused specifically on geothermal systems while the remaining studies considered either packaged (air-source), hybrid (duel-fuel), or packaged window HVAC. The two studies that explicitly factor in the impact of window performance on sizing implications for high performance HVAC retrofits are focused on multifamily buildings in cold climate zones in northern Europe (Niemelä et al. 2017; Neubert et al 2024).

Window replacement and field measures of energy savings were included in 14 of the U.S. studies; however, only one study of secondary window attachments delineated the energy savings impact of the window upgrades from total impacts of the more comprehensive set of energy-savings measures. Most of the existing deep energy retrofits included a combination of envelope sealing and window upgrades, lighting retrofits, and HVAC replacement. The majority of the U.S. studies were pulled from the DOE Better Buildings Solution Center database and most of the window upgrades focused on replacing existing windows with low-e double-pane windows in multifamily buildings. Many of these combined window and HVAC studies were in multifamily buildings where each unit was retrofit with a ductless window HVAC units and window upgrades ranged from modest re-sealing retrofits to high-efficiency triple-pane replacement windows.

COST ESTIMATES

The costs and return on investment for both HVAC and window projects vary widely by project and region. While energy savings are highest in cold regions for both HVAC and window upgrades, the costs and payback period on the investment for high-efficiency HVAC are typically lower in warm regions. For example, in one study that focused on packaged HVAC systems, the median simple payback period was 10 years in warmer regions and over 20 years in the colder regions (Nadel and Perry 2020). Based on RSMeans 2020, the incremental costs to upgrade from a conventional packaged HVAC unit to a high-efficiency packaged HVAC unit were estimated to be about $292/ton (Gordian 2020). A 2019 study on high performance HVAC retrofit strategies for multifamily buildings provided the cost estimates relative to conventional packaged systems ranged from $5/s.f. to $20/s.f. ($.5/m^2 to $1.9/m^2) conditioned floor area (Steven Winter 2019).

Proposed window replacement retrofit measures in the New York City Local Law 87 Dataset of Energy Audits submitted from 2012 to 2018 were analyzed for characteristics of estimated implementation cost, savings performance, coincidence with proposed HVAC replacement projects, and building type (see Figure 2). The Local Law 87 requirements primarily pertain to multifamily building stock rather than commercial properties, and within the 2012 through 2018 public data multifamily properties were approximately 70% of energy audits submitted and about 80% of proposed window replacement projects, while commercial properties represented under 25% of submitted audits and under 8% of proposed window replacement retrofits. Summary plots of the NYC LL87 energy audit window project data are shown in Figure 2 and the plots on the left side are zoomed in on the right side. The window replacement projects distinguished between those paired with proposed HVAC replacement retrofits and not paired with HVAC replacements. While the retrofit projects in the NYC energy audit dataset are only suggested projects and do not represent implemented projects, many of the submitted window replacement projects have long simple payback timeframes, seen in Figure 2, and may not be implemented on the merit of energy savings alone.

SURVEYS AND INTERVIEWS

To more accurately characterize the full spectrum of window upgrade options in the market and the business opportunities for upgrades for commercial buildings a combined PNNL and LBNL research team assembled a Technical Advisory Committee (TAC) of stakeholders in the industry and completed market analyses in a 2024 report.[3] The team also completed a series of follow-up interviews with professionals involved with commercial building retrofit and remodeling activities to better identify and characterize the factors influencing decisions to upgrade windows. Because commercial building window upgrades are rarely implemented, an exerted effort was made to interview asset managers who had successfully implemented window upgrades in commercial building settings to better understand what factors led to the success of these window upgrade projects.

The PNNL/LBNL research team met with approximately 25 building management staff who have been involved with

[3] TAC workshop and interview summaries described in unpublished PNNL/LBNL 2024 report, *Commercial Secondary Energy Auditing Market Assessment for Commercial Buildings (and How Assessments Influence Window Upgrade Decision).*

window retrofit upgrade assessments, planning, and/or implementations. Table 3 lists the organizations participating in interviews, surveys, and/or workshops by category of business. Information gathered from all participants is summarized below, based on their responses to a survey and/or discussions in teleconference meetings. Most of the buildings that were covered by these professionals included medium-large sized office buildings; however, k-12 schools and high education facilities were also covered and identified as candidate buildings with high needs for upgrades.

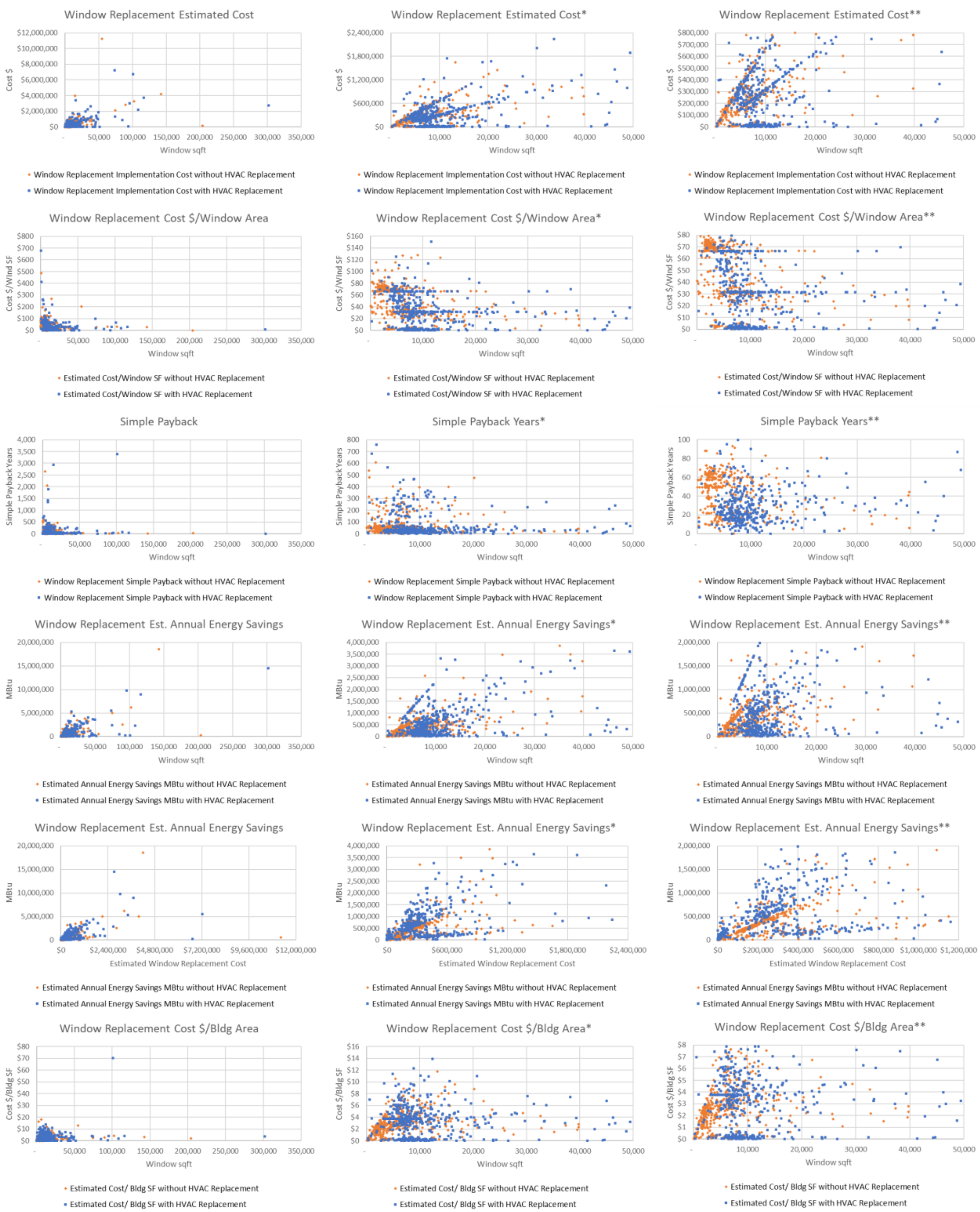

Figure 2. Window Replacement Estimated Cost Data from Dataset of Energy Audits Submitted between 2012 and 2018 for New York City Local Law 87 (the asterisks denote the plots on the righthand side are reduced axis range views of the plots on the left).

Building Assessments, Audits, & Tools

A series of questions were asked about building auditing practices. Consistent in the TAC meetings and follow-up interviews on the topics, most respondents indicated that they completed building assessments and energy audits on a regular basis; however, window performance was rarely a focus of these audits. When window upgrades were considered, they typically were limited to surface applied film technologies and rarely considered secondary window systems or automated shading. Organizations are not typically considering secondary co-benefits of window improvements such as equipment downsizing or lower infiltration, as part of the initial audit; however, once a decision to retrofit is made, secondary benefits such as improved occupant, sound insulation, and glare reduction were identified as valued benefits associated window retrofit upgrades. Respondents mentioned the need for simpler "rule of thumb" types of tools to help evaluate and integrate peak demand and secondary benefits into commercial building assessments. Most respondents indicated that they utilized some form of commercially available or publicly available tools for building energy assessments and data collection/analysis; however, customized spreadsheets, developed in-house, were the most commonly used tools for both data collection and analysis. Several consultants mentioned that façade consultants, who really understand commercial building facades and know how to navigate the risks involved in improving this building component, may not be affordable for many property customers.

Key Drivers and Retrofit Decision Making

Building professionals interviewed prioritized a list of factors to determine their "level of importance" with regard to influencing window upgrade decisions. From this list, the cost effectiveness of the technology and the existence of resource-efficiency or building performance goals were considered "very important" factors that influenced window upgrade decisions. The parameters and holding period under which this cost-effectiveness was determined varied depending on the project and the ownership outlook. In general, building owners with a longer time horizon and planned "holding period" for the asset, were more likely to consider building envelope retrofits, including windows. Often, the repositioning of a building for a new leasing arrangement also was considered "fairly important" to a window upgrade decision and non-energy benefits, such as noise and visual aesthetics may play a more significant role than energy, depending on the property. Utility and government program rebates and incentives were rarely considered as an important part of window upgrades because the timing often would not align with the project and the effort to justify securing the rebates and/or incentives was often deemed "more trouble than it was worth." Some exceptions were noted in New York and New England where commercial building retrofit requirements and incentives have been in place for several years.

Key Takeaways and Opportunities

Based on the feedback from building managers who had successfully implemented window upgrades, there appeared to be three factors that make a window retrofit happen in privately held assets, universities, and federal facilities:

1) The **Building Owner** must be motivated *beyond simple energy payback or ROI*, such as building performance concerns, LEED certification, or regional building programs. These higher performance goals were often associated with high value properties that had the best chance of reaping the benefits (in terms of higher occupancy and leasing rates) of these window improvements. These improvements might also provide a competitive advantage in a competitive commercial real estate market.
2) The **Building Management/Manager** needs to be *proactive and empowered* to seek out solutions/consultation to comprehensively address building issues and explore retrofits.
3) There needs to be a *proactive* **Building Systems Consultant** who can move them beyond the "Like for Like" replacement model and look for whole building solutions, which opens them up to window retrofits and improved systems.

Public schools and municipal buildings were also positively influenced by the above factors; however, these institutions were also largely constrained by regional political environment and their ability to raise funds through public bonds.

Table 3. Workshop and Interview Participants

Organization Type	Organization
Architecture - Engineering/ ESCO (energy service companies)	• **ARUP** (Global Design-Engineering Consultant) • **Avido Solutions** Energy Engineering • **Bright Power** (Building Energy Consultant) • **RWDI Consulting Engineers** (Building Performance Consultant) • **NGS** (Window Consultant and Films Manufacturer) • **Servidyne** (Building Energy Consultant) • **TRC Engineering** (Global Engineering Consultant with building energy department)
Real Estate Management Companies	• **CBRE** (Global property management company) • **JLL** (Global Property Management company) • **Orchard Commercial** (California property management, including office buildings) • **Room & Board** (Minneapolis, MN headquartered company with properties throughout U.S.) • **Tishman Speyer** (Global Property Management company)
Building Management Staff and Consultancies	• **PNNL Operations Team** • **FEDS** (Facility Energy Decision System) **Modeling Consultant** • **GRITS (**Sustainability Project Management Platform) • **Sustainability Pittsburgh**
Schools, Universities, Medical Centers & Municipals	• **Adams Five Star Schools**, Colorado • **Boston Medical Center,** Massachusetts • **Dane County Municipal Building**, Wisconsin • **Madera School District**, California • **Seattle Public Schools**, Washington • **University of Pittsburgh**, Pennsylvania

CONCLUSIONS AND RECOMMENDATIONS

Our review of the literature, market data, and building stakeholder surveys and interviews indicate that commercial building deep energy retrofits rarely include window upgrades. Most of the retrofit studies examined in this paper focused exclusively on high performance HVAC retrofits without considering how window upgrades might further enhance the overall energy efficiency of commercial buildings. Building audit and management professionals confirmed that building assessments typically consider envelope and window performance as a fixed measure and rarely consider window upgrades as a retrofit option. Nevertheless, many commercial building stakeholders have carried out successful window upgrades, and several notable factors and market trends indicate increasing opportunities for commercial building window retrofits such as an increasing focus on energy efficient and resilient asset management and regional building efficiency programs. Additionally, the non-energy impacts associated with many window upgrades, including noise insulation and occupant comfort, were notable drivers for window retrofits in high-value and urban markets such as NYC, San Francisco, and Boston.

In all cases, building stakeholders indicated that the cost-effectiveness and ROI on energy-efficiency measures played an important role in retrofit decisions and that the ROI on window measures could be improved with an acceptance of longer payback periods and lower cost retrofits. It was also noted that well-tested, quick-payback technologies such as window films would often rise to the top because of this ROI factor and that more demonstrations and field validation studies of other window retrofit technologies could help inform retrofit decisions.

In regions where utilities and local jurisdictions are supporting envelope retrofit measures with pilots and demonstrations, more window retrofits are being completed and the economies of scale and ROIs on window projects appear to be improving. As interest in geothermal and other high performance HVAC technologies increases, there is a need for more research and field studies to validate HVAC cost reductions and operational improvements from window and envelope retrofits. Additional tools, resources, and field studies to validate the full value proposition of window upgrades could help inform the commercial building retrofit market and accelerate higher performance window upgrades.

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