ESTCP
Cost and Performance Report

(EW-201252)

Demonstration Program for Low-Cost, High-Energy-Saving Dynamic Windows

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14. ABSTRACT
As an addition to previous related ESTCP contract, View proposes to demonstrate an innovative, pre-commercial product and installation process for dynamic windows, called "Dynamic In-Fill". A Dynamic In-Fill system is one where a dual-pane insulated glass unit (IGU) is mounted to the inside of the existing window and frame, without removing the original windows (see figure 1A). This approach cuts the total cost of a dynamic window upgrade by 2x, while maintaining most of the energy-savings, peak-load reduction and life cycle benefits of a traditional dynamic window retrofit. In fact, the cost of a Dynamic In-Fill installation will be less than traditional window retrofits with standard low-e glass.

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ACRONYMS AND ABBREVIATIONS

°F	degree(s) Fahrenheit
ASHRAE	American Society of Heating, Refrigerating and Air Conditioning Engineers
BLCCA	Bridge Life-Cycle Cost Analysis
Btu	British thermal unit
CAPEX	capital expenditure(s)
CCR	Criteria Change Request
DOAS	dedicated outdoor air system
DoD	U.S. Department of Defense
DOE	U.S. Department of Energy
ECM	energy/water conservation measure
EIA	U.S. Energy Information Administration
EO	Executive Order
ESCO	energy service company
ESPC	Energy Savings Performance Contract
ESTCP	Environmental Security Technology Certification Program
EUI	energy usage intensity
FAR	Federal Acquisition Regulation
ft	foot/feet
GHG	greenhouse gas
GSA	General Services Administration
hr	hour(s)
HVAC	heating, ventilation, and air conditioning
IGU	insulated glass unit
kBtu	kilo-British thermal unit(s)
kWh	kilowatt hour(s)
LBNL	Lawrence Berkeley National Laboratory
LEED	Leadership in Energy and Environmental Design
low-e	low emissivity
NIST	National Institute of Standards and Technology
OPEX	operating expenditure(s)

ROI	return on investment
SHGC	solar heat gain coefficient
SIR	savings-to-investment ratio
sqft	square foot/feet
T_{VIS}	visible light transmittance
UFC	Unified Facilities Criteria
UFGS	Unified Facilities Guide Specification
yr(s)	year(s)

ACKNOWLEDGEMENTS

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We would like to acknowledge the fantastic team at National War College for their support and enthusiasm in this project. We would like to particularly thank Colonel Mark “Bulldog” Pizzo, U.S. Marine Corps (retired) for ensuring everything went smoothly. Additional thanks go to the experienced and professional subcontractors who contributed to the successful completion of this project. In addition to their work, the subcontractors created a safe, clean environment for both the project team and the building occupants who continued to work onsite throughout all phases of the project.

A final thanks goes to ESTCP for their vision of bringing forth technologies that will provide both energy security and a more sustainable future for our military infrastructure.

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EXECUTIVE SUMMARY

ENERGY PROBLEM

Inefficient windows in buildings represent one of the biggest energy problems in the military today. Facilities consume 30% of all U.S. Department of Defense (DoD) energy demand (DoD 2016). This massive energy footprint costs taxpayers billions of dollars each year and impacts DoD mission assurance by straining fragile public electricity grids.

In the United States, >50% of building energy is used for cooling, heating, and lighting (DOE 2015), all of which are directly impacted by windows. The thermal envelope impacts about 56% of total commercial energy consumption. Windows are considered to be the "Achilles' heel" of the building envelope, as they allow unwanted solar heat to enter during the summer via radiation and conduction, increasing cooling energy requirements and peak loads, and allowing internal heat to escape during the winter, increasing season heating. Beyond negative energy impacts, current windows allow glare, which reduces occupant comfort; over-use of window blinds; and the over-use of artificial lighting energy.

OBJECTIVES OF THE DEMONSTRATION

Electrochromic, or 'dynamic' glass, represents a promising technology for the reduction of energy use in DoD buildings. Dynamic glass windows are manufactured with an electrochromic coating enabling them to electronically change their visual and solar heat gain characteristics. A previous Environmental Security Technology Certification Program (ESTCP) project demonstrated the capability of dynamic glass for meaningful whole-building energy savings that included heating, ventilation, and air conditioning (HVAC) savings of 29% and potential artificial lighting savings of up to 62% (NREL 2015, ESTCP 2014). However, the installation of dynamic glass required full demolition and replacement of the existing windows. This level of construction activity involved high construction expenses and the displacement of occupants, adding to the final financial cost of the project.

An alternate installation method, termed 'Dynamic In-Fill,' may offer a method for reducing deployment costs while retaining the energy and non-energy benefits of dynamic glass. Dynamic in-fill is a method of installing an additional, non-structural window unit interior to the existing window. It adds insulative glass and air layers plus it enables the glass to actively change its performance in response to the environment or user preferences. It does not require demolition of the original window or displacement of occupants in operational facilities. In this way, Dynamic In-Fill has the potential to remove these primary barriers to adoption of dynamic windows for DoD installations, while increasing the viability of this window technology with traditional Energy Savings Performance Contracts (ESPCs). If broadly adopted, this technology could reduce global DoD facility energy consumption by up to 10% with total facilities peak load reductions of up to 25%. Such reductions broadly implemented could ease existing strain on the national grid. Overall, this technology addresses two of DoD's three key installation energy goals: (1) reduce energy usage/intensity and (2) improve energy security.

In addition to energy savings, one of the major economic benefits of dynamic windows is the possible capital savings and maintenance savings from downsizing HVAC systems that is enabled by the reduced heating and cooling peak-load with installed Dynamic In-Fill windows. The full-scale field data generated in this demonstration project and subsequent calibrated model allowed the team to quantify and validate this reduction in HVAC capacity, enabling the building designers to downsize future HVAC systems without risk.

TECHNOLOGY DESCRIPTION

Electrochromic glass is a window material that darkens when a voltage is applied to the glass. This darkening of the glass reduces the transmission of visible and infrared sunlight. When this glass is used in a typical double-paned window, it helps to reduce the heat load in a building that comes from solar irradiance.

By controlling the voltage, a dynamic glass glazing assembly can vary its solar heat gain coefficient (SHGC) from 0.46 to 0.09. This indicates that the transmitted radiant solar heat varies between approximately 46% to about 9% of the incident solar radiation. Likewise, the electrochromic device can vary its visible light transmission from 58% transmission to just 3% total light transmission. In addition, intermediate tint states can be selected to optimize performance of the windows throughout the day.

DEMONSTRATION SCOPE

The purpose of this project was to demonstrate the energy and capital savings enabled by View, Inc.'s dynamic windows by performing a limited-scope retrofit at the National War College in Washington, D.C. Over the course of the project, the team developed a detailed energy-model for the demonstration site, with and without dynamic windows. The team then installed monitoring equipment in the demonstration site and performed baseline energy measurements. This data was then used to calibrate the baseline energy models and extrapolate energy consumption over an annual period. That extrapolated energy model was verified against measured building energy consumption.

The team then retrofitted 58 existing windows with Dynamic In-Fill glass units while the building remained occupied and operational. The installation took less than one month and was followed by months of energy and occupant monitoring. These results were used to further refine the energy models and the modeled results were annualized to determine the total annual impact of Dynamic In-Fill windows. From this data, total lifecycle cost, energy savings, and greenhouse gas (GHG) reductions relative to upgrading to state-of-the-art low emissivity (low-e) windows at the host site were quantified.

DEMONSTRATION RESULTS

The project demonstrated a reduction in HVAC energy consumption of 6,900 kilowatt hours (kWh) or 6% compared to the existing windows baseline. Peak HVAC loads were reduced by 23% allowing for significant HVAC system downsizing and cost savings during their next maintenance cycle. Additionally, the daily peak cooling requirement shifted from 1 p.m. (typical of existing DoD buildings) to approximately 5 p.m., allowing off-occupancy, tapered conditioning.

The reduced peak loads and load shift allowed for better system balancing (hot versus cold offices) for the entire building. Office temperatures were cooler when under direct sunlight. Visual analysis showed an elimination or reduction in the use of blinds and shades and more natural daylight within the offices.

IMPLEMENTATION ISSUES

Overall, the installation was completed in a timely manner and on budget. All performance objectives were met, and the host site staff and visitors have been enthusiastic and pleased with the impact on comfort in the building.

Most implementation and data collection issues were related to the renovation of the demonstration site. Due to the limitation of the existing panel layout in the building, the measured lighting energy and HVAC energy were combined in the collected data, which made it impractical to calibrate the lighting and HVAC energy separately. Second, the existing HVAC zoning and distribution system did not correlate 1:1 with the demonstration areas. Some energy exchange between treated and untreated spaces was likely, but unaddressed in the calculations.

One issue unrelated to the project site was occupant training and expectation management. While the demonstration project team conducted a basic training and operational overview of dynamic glass for the occupants, initially many of the test subjects expressed frustration with the transition time or confusion regarding transition logic. Better training protocols are recommended for future installations.

This project has created awareness and, most importantly, confidence with installing dynamic glass across many DoD installations. Several high-ranking officials have visited the site and have been exposed to this novel dynamic glass system.

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1.0 INTRODUCTION

1.1 OBJECTIVE OF THE DEMONSTRATION

In Environmental Security Technology Certification Program (ESTCP) demonstration project EW-201252 (ESTCP 2014), the project team installed replacement electrochromic glass (also termed dynamic glass) windows in a small office building. The project was able to demonstrate heating, ventilation, and air conditioning (HVAC) energy savings, lighting energy savings, and user preference for dynamic glass over traditional systems. However, the demolition of the existing windows and their replacement with dynamic glass windows was both costly and disruptive to the occupants. For those reasons, dynamic glass' applicability to the existing DoD building stock is limited to those requiring deep renovation or energy efficiency upgrades.

For those reasons, the goal of this project was to develop a new installation method to address the cost and disruption barriers. The project team developed a non-structural insulated glass unit, a 'Dynamic In-Fill' unit, and proposed to install and monitor its performance in an operational setting with reduced cost and minimal impact on the occupants.

Specifically, the project aimed to validate the performance and lifecycle cost benefits of a dynamic window system with a 50% lower installed cost. It was also anticipated that the installation and deployment exercise would generate the data and insights needed to create awareness and acceptance of the technology. The project was intended to facilitate future technology transfer across all DoD building stock, while providing a direct benefit to the host base in terms of reduced energy consumption, reduced lifecycle cost, and improved occupant comfort. The intended outcomes of this demonstration were twofold: first, the deployment of a 50% lower cost dynamic glass installation method compatible for use in a broad range of existing and historic buildings. Second, the project aimed to validate the performance, comfort, and lifecycle cost benefits of dynamic windows in an operational environment.

1.2 REGULATORY DRIVERS

Two important Federal mandates are addressed by this technology:

1.2.1 Executive Order (EO) 13693, Planning for Federal Sustainability in the Next Decade

This EO proposes to cut the Federal Government's greenhouse gas (GHG) emissions by 40% over the next decade from 2008 levels and increase the share of electricity the Federal Government consumes from renewable sources to 30%. The EO outlines a number of measures to make the Federal Government's operations more sustainable. By participating in the Federal Green Challenge, facilities are provided with technical support, networking opportunities, and tools to assist with tracking progress toward the EO directives.

1.2.2 Sustainability Rule for Procurement (FAR 2017) under the Federal Acquisition Regulations (FARs)

The DoD, the General Services Administration (GSA), and the National Aeronautics and Space Administration (NASA) recently issued a joint interim rule that requires all new construction to reduce energy use by 30% compared to the existing standard. For major renovations, buildings must reduce their energy use by 20% below their 2003 pre-renovation baseline. The new rule also requires increased use of natural daylight in all new and renovated buildings. Previous research programs and studies by the Department of Energy (DOE) Building Technology Program and Lawrence Berkeley National Laboratory (LBNL) indicate that dynamic glass may be a valuable solution to address these Federal regulations. For example, the studies indicate that dynamic glass can reduce building cooling loads by >10% while also allowing more daylight into the workplace, additionally reducing lighting energy costs (LBNL 2006, Dariush et al. 2006, DOE 2016).

1.2.3 Antiterrorism Standards

Dynamic glass technology is compliant with Unified Facilities Criteria (UFC) 4-010-01.[1] Specifically, the completed ESTCP project demonstrated compliance with UFC directives including "DoD Minimum Antiterrorism Standoff Distances for Buildings (FOUO)" (4-010-02)[2] and to the updated requirements applying to "New Construction" and "Existing Buildings." Also, there are currently four Criteria Change Requests (CCRs) that have been submitted with regard to the use of chromogenic (dynamic glass). These include:

1. Unified Facilities Guide Specification (UFGS) 08 51 13 Aluminum Windows (CCR submitted 2014-07-09 17:06 UTC)
2. UFGS 08 60 45 Skylights and Translucent Panels (CCR submitted 2014-07-09 17:22 UTC)
3. UFGS 08 81 00 Glazing (CCR submitted 2014-07-09 17:38 UTC)
4. UFC 3-101-01 Architecture (CCR submitted 2014-07-24 19:33 UTC)

Third-party certification of View Dynamic Glass (View, Inc.) windows was completed as part of this project and can be found in the prior ESTCP project report (ESTCP 2014).

[1] UFC 4-010-01 DoD Minimum Antiterrorism Standards for Buildings, with Change 1, https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/ufc-4-010-01.
[2] UFC 4-010-02 DoD Minimum Antiterrorism Standoff Distances for Buildings (FOUO), https://www.wbdg.org/ffc/dod/unified-facilities-criteria-ufc/ufc-4-010-02.

2.0 TECHNOLOGY DESCRIPTION

2.1 TECHNOLOGY OVERVIEW

Electrochromic glass is a window material that darkens when a voltage is applied to the glass. This darkening of the glass reduces the transmission of visible and infrared sunlight. When this glass is used in a typical double-paned window, it helps reduce the heat load in a building that comes from solar irradiance.

The electrochromic device, applied to a single glass surface, is formed via a stack of five thin coatings applied to the inner surface of the outer pane of glass in an insulated glass unit (IGU). To darken the window, low voltage direct current (<5 volts [V]) is applied, driving ions from one layer of the coating to the next, causing the stack to change tint and also to absorb light and heat. Reversing the voltage reverses the flow of ions. This also reverses the effect and transitions the stack back to a clear state (Korgel 2013).

By controlling the voltage, a dynamic glass glazing assembly can vary its solar heat gain coefficient (SHGC) from 0.46 to 0.09. This indicates that the transmitted radiant solar heat varies between approximately 46% to about 9% of the incident solar radiation. Likewise, the electrochromic device can vary its visible light transmission from 58% transmission to just 3% total light transmission. In addition, intermediate tint states can be selected to optimize performance of the windows throughout the day.

Figure 1 plots the transmitted light levels across the visible and non-visible spectrum for several common glazing products. Solarban® and Solarban® 70XL are the commercial names for very common low emissivity (low-e) glass products from the PPG glass company.[3,4] They represent typical performance curves for the general class of low-e glass materials. The performance curves for View Dynamic Glass are given for the four available tint states. It can be observed that the infrared spectrum, representing about 50% of the sun's transmitted heat) is significantly attenuated by dynamic glass in Tints 2, 3, and 4. All of the relevant insulated glass performance parameters can be found in Table 1.

[3] http://www.vitroglazings.com/en-US/Glass/Products/Low-E-Glass/SOLARBAN-Solar-Control-Low-e/SOLARBAN-60-Glass.aspx.
[4] http://www.vitroglazings.com/en-US/Glass/Products/Low-E-Glass/SOLARBAN-Solar-Control-Low-e/SOLARBAN-70XL-Glass.aspx.

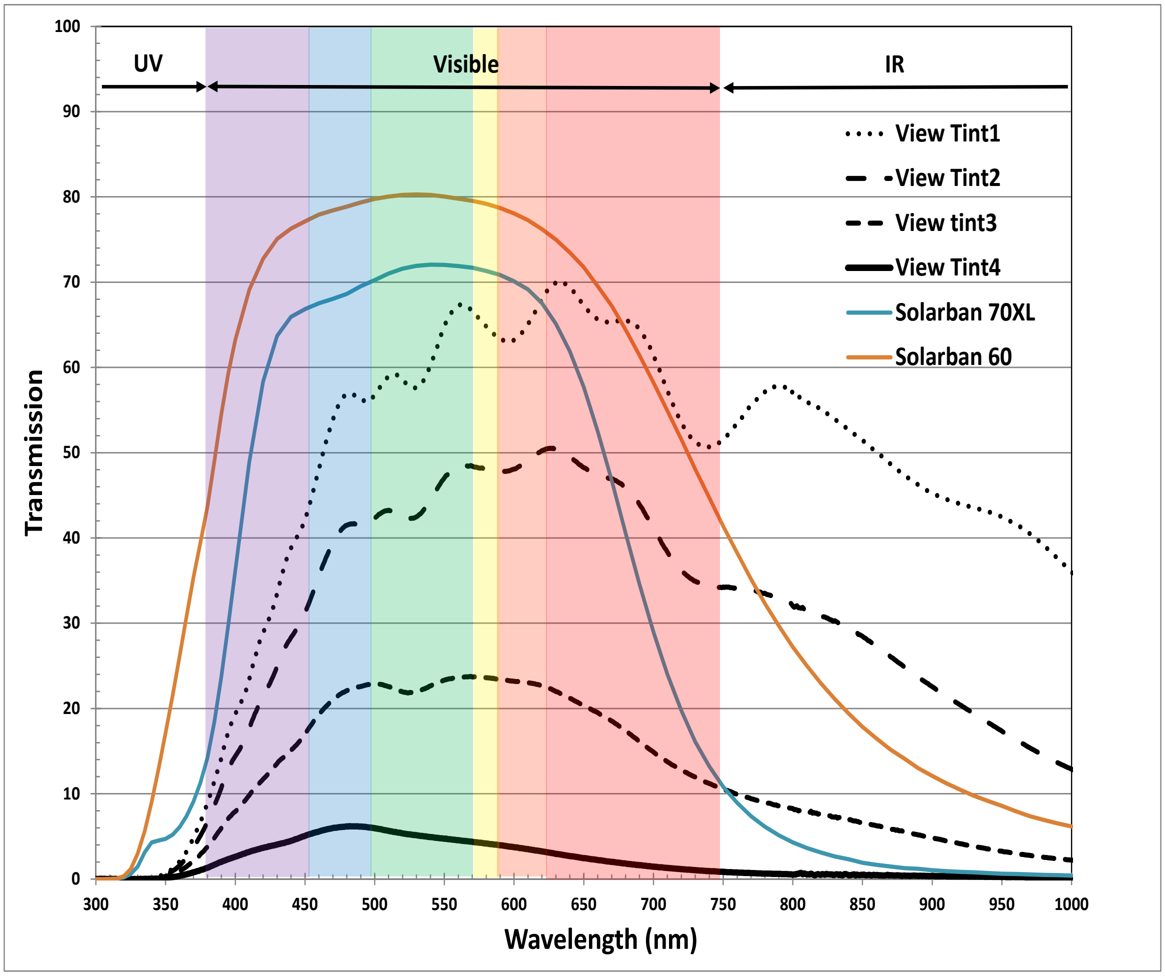


Figure 1. Electrochromic Window Configuration and Optical Characteristics Plotted Against Low-e Glass Examples

Table 1. View Dynamic Window Performance Characteristics (including intermediate states)[5]

Tint Level	Transmittance (%)			Reflectance (%)			U-value	SHGC
	Visible	Ultraviolet (UV)	Solar	Visible Out	Visible In	Solar Out		
Tint 1	58	3	37	18	20	18	0.29	0.46
Tint 2	40	2	21	12	19	12	0.29	0.26
Tint 3	20	1	8	8	17	11	0.29	0.16
Tint 4	3	0	1	7	17	11	0.29	0.09

[5] View, Inc. website, http://viewglass.com/assets/pdfs/igu-data-sheet-us.pdf (accessed February 2017).

For commercial installation and use, the electrochromic-coated glass is packaged as a traditional IGU for use in windows. IGUs are sealed combinations of two or more lites of glass separated by a hermetically sealed space. A spacer is used to separate the lites. There is a primary seal between the spacer and the lites; this forms the hermetical seal. View, Inc. (View) uses a traditional industry best practices including a Polyisobutane (PIB) adhesive for the primary seal. The gap from the spacer to the edge of the glass is filled with the secondary seal. For this seal, View uses a silicone rubber structural material. View fills the hermetically sealed space between the lites with 90% argon gas. These IGUs are shipped to customers to be installed directly into the facade framing (in the case of large commercial building) or they can be mounted in a unitized element for installation later as in mid- or high-rise commercial office building applications.

Figure 2 illustrates how the visible light transmission and the solar heat gain are reduced as the glass darkens.

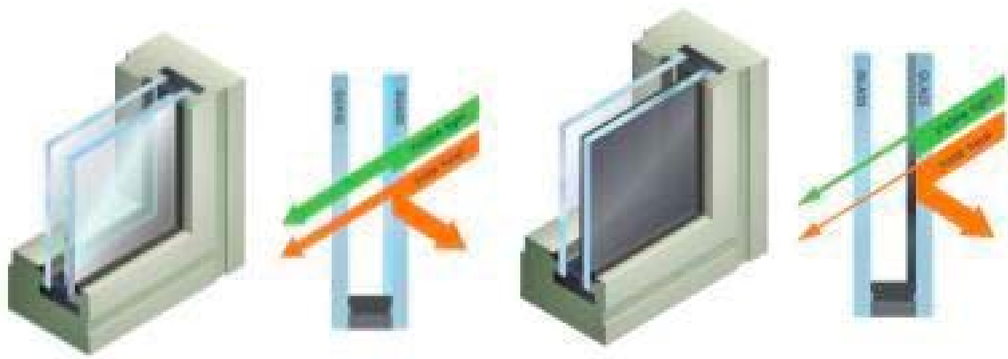


Figure 2. Cutaway View of an Electrochromic Window in the "Tint 1 - Clear" (left) and "Tint 4 -Dark" (right) States

This commercially-available IGU is also suitable for major renovations where the façade will be reconstructed with new glazing and possibly frames. For renovation projects were the existing glass is not being replaced, an alternate solution needs to be developed.

2.1.1 Energy Consumption

Total energy consumption by these windows is negligible (1,800 square feet [sqft] of glass uses less power than a 60-watt light bulb). All energy calculations in this proposal include this small energy consumption.

2.1.2 Impact on Leadership in Energy and Environmental Design (LEED) and American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Requirements

Use of dynamic glass is explicitly recognized and accepted by the current ASHRAE Standards. ASHRAE 90.1–2016[6] describes the specific treatment of dynamic glass in determining project compliance either by the prescriptive or performance paths. With technology/product acceptance

[6] ANSI/ASHRAE/IES Standard 90.1-2016 Energy Standard for Buildings Except Low-Rise Residential Buildings, https://www.energycodes.gov/resource-center/training-courses/ansiashraeies-standard-901-2016.

ensured, dynamic glass is a preferred project component based upon its energy performance and code-required savings objectives. When used in a new construction or renovation project, it can have a beneficial energy impact of 5–20% total building energy savings. That incremental savings can be crucial to making a project compliant with the current standard.

Beyond minimum code requirements, the use of dynamic glass can often offset other capital-intensive building elements required for high-performance or LEED-certified design, as required for Federal new construction and deep renovations. As an example, the promotion of ample daylighting (75% of floor area)[7] drives larger window area and often requires the use of expensive external shades, louvers, or light shelves. Or, in the case of hospital settings, operable shades are often encapsulated within the insulated glass unit to minimize the chance of infection-prone materials. Dynamic glass eliminates these measures with a single solid-state solution delivered at a lower net first cost.

2.2 TECHNOLOGY DEVELOPMENT

This demonstration project is the first full-scale deployment of the dynamic glass technology packaged in a form designed to be compatible with buildings that keep their existing glass in place. Termed a 'Dynamic In-Fill' product, it sits inside the existing building envelope in the existing window pocket. Figure 3 shows a cross-section of a building envelope with the addition of the Dynamic In-Fill product. As shown in Figure 3A, the electrochromic device is applied to the inner surface of the outer pane of glass in the double-pane IGU. This is then in-set and securely mounted to the existing window frame system. The system is designed to prevent condensation by allowing a small amount of air to circulate between the IGU and the original window pane.

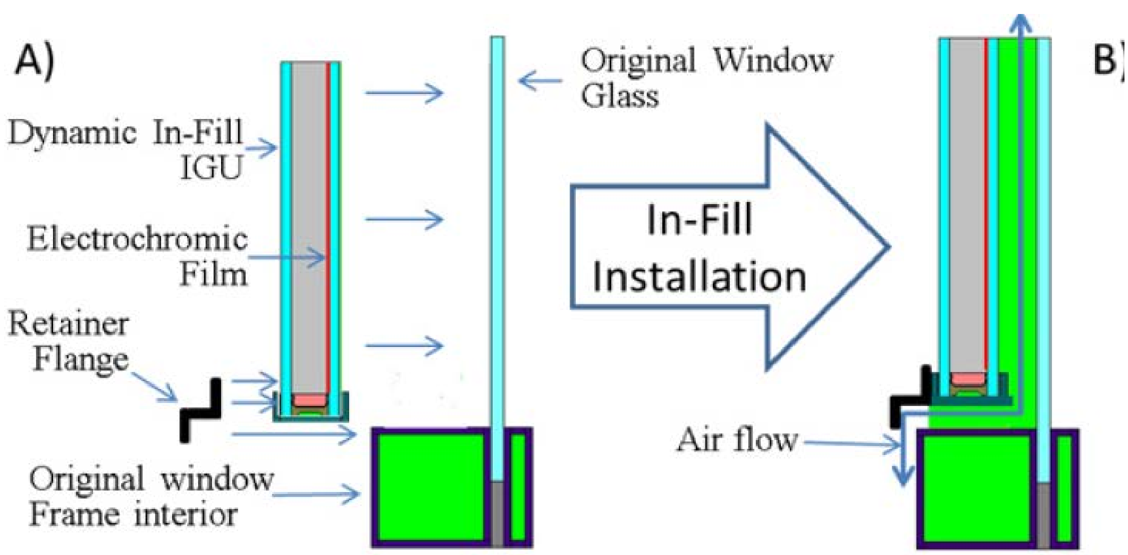


Figure 3. Dynamic In-fill Product

Figure 3A – prior to installation, the infill component is sized to the available window. Figure 3B – the complete system showing the proximity of the surfaces and designed venting path.

[7] LEED Standard requirement EQ8, www.usgbc.org/credits/eq8.

2.2.1 Applications of the Technology

This technology is applicable to virtually all of the existing DoD building stock, specifically cost-effective envelope retrofits for the thousands of buildings that currently feature aging, inefficient windows. This technology is particularly high-value in deep renovation situations, where the windows and HVAC systems are already slated for replacement/upgrade. In those situations, the enabled capital avoidance of refreshed HVAC systems can often completely offset the increased cost of the dynamic windows, generating all of the benefits demonstrated here at no net additional cost. This technology has already generated enthusiasm among the DoD installation energy managers who were approached during this project, and who visited the host site to see the technology in action.

2.3 ADVANTAGES AND LIMITATIONS OF THE TECHNOLOGY

2.3.1 Alternative Technologies

Windows technology today represents a compromise of the DoD's energy efficiency and workplace performance. Clear, double-pane IGUs provide thermal insulation and natural lighting, reducing interior heating and artificial lighting. However, these IGUs allow significant unwanted solar heat gain to enter the building, increasing the size and consumption of HVAC systems due to a higher cooling load. Tinted and reflective IGUs provide thermal insulation and block solar heat gain, reducing cooling and heating, but they also block natural light, increasing lighting requirements inside. Modern low-e IGUs attempt to balance these extremes by blocking some solar heat gain while allowing for natural light to pass. However, low-e IGUs are still a compromise striking a single performance value for both summer and winter conditions for the life of the product, which leads to significant annual lighting and heating energy consumption. Further, these static low-e IGUs do not control glare, therefore requiring the use of blinds and limiting the use of daylighting. Typical practice leads to blinds that are often left in the closed position all day, significantly exacerbating lighting energy consumption beyond what building managers intend or budget for. Dynamic glass is a technical response to these issues, designed to maximize daylight, energy efficiency, and comfort in response to the outdoor conditions.

2.3.2 Advantages and Limitations of Dynamic Windows Compared to Low-E Windows

<u>Advantages:</u> There are significant benefits of dynamic glass compared to low-e windows:

1. *Cuts solar heat by 75% in the summer:* Dynamic glass has an SHGC that can be tuned as low as 0.09 in the summer compared to 0.38 for a typical static low-e window. Dynamic windows can cut solar heat gain by approximately 75%, thereby reducing the cooling load on peak days and throughout the cooling season. For installations with older generation clear glass, the current SHGC may be as a high as 0.60, allowing for greater potential savings.
2. *Increases solar heat by 33% in the winter:* With an SHGC that can be tuned as high as 0.46 (versus the 0.38 for typical low-e glass), dynamic windows can allow 33% more passive solar heating than static low-e, reducing heating load in the winter.

3. *Reduces whole-building peak-load:* Replacing existing clear glass with low-e glass can reduce a buildings peak load by approximately 20%. Use of dynamic glass can double this benefit to a 20+% peak load reduction. This peak load reduction can result in smaller, less expensive replacement HVAC systems during renovation cycles.
4. *Reduces transmitted light by 95%:* With a visible light transmittance (T_{vis}) that can be tuned as low as 3%, dynamic windows can reduce the incoming light by 95% below low-e (T_{vis} ~70%). This light mitigation can prevent glare and visual discomfort in a variety of working environments. It also has the secondary benefit of improving occupant comfort without compromising outdoor views lost via the use of blinds and shades.
5. *Significantly improves daylighting:* With shade-free operation and T_{vis} that can be tuned as high as 58%, dynamic windows can allow for higher average daylight use over low-e with blinds, thereby reducing artificial lighting energy. Analysis of multiple office building in various settings has revealed that typical natural light levels are 2–3 times higher (a 100–200% increase) for workspaces with dynamic glass versus blinds and shades.
6. *Greater lifecycle cost savings*: Through a combination of reduced energy consumption and reduced capital and maintenance costs, the total lifecycle cost savings can be up to 300% higher than those realized with low-e in an equivalent building.

<u>Limitations:</u> The limitations of dynamic windows compared to low-e are minor and have been minimized through an engineering approach that reduces materials and labor required for installation. The limitations include the following:

1. *Higher up-front cost*: The installed cost of dynamic windows is 50% higher than a comparable low-e system. However, this cost is easily offset by the reduction in HVAC capital expenditure (CAPEX), elimination of replacement blinds and their maintenance, and lifetime energy savings. For many installations, dynamic windows can be installed with a net cost at or below the cost of renovation with traditional low-e windows.
2. *Slightly more complicated installation*: Dynamic windows require low-voltage wiring and control systems, but do not require a licensed high-voltage electrician for installation. This wiring is akin to installing data network or alarm cables in the building and can be achieved at costs of $2–$5/sqft of window area.
3. *Single pane size limitation of 5 feet (ft) x 10 ft* – Today, maximum dynamic glass dimensions are 5 ft x 10 ft. While traditional glass can be produced in larger formats, the 5 ft x 10 ft maximum size addresses 90% of the existing glass market. It also represents nearly 100% of the existing DoD building stock.

3.0 TEST DESIGN

3.1 PROJECT OBJECTIVES

The goal of this project is to demonstrate that Dynamic In-Fill windows can provide the same performance benefits as traditional dynamic window retrofits, but at dramatically lower cost and with minimal operational disruptions. The project demonstrates this new product in an operational environment at a DoD facility of sufficient scale to validate its performance and cost benefits for future DoD deployment and the minimally disruptive nature of the installation process. To accomplish this, the team collected both quantitative and qualitative data addressing each of the following key project objectives:

1. Install Dynamic In-Fill windows, in collaboration with a Federal energy service company (ESCO), in an operational DoD facility, with minimal occupant disruption.
2. Monitor HVAC and lighting energy consumption, as well as occupant comfort, for a period of 12 months before and 12 months after installation of Dynamic In-Fill windows.
3. Quantify the energy-, cost-, peak-load-, and GHG-savings; the payback; and savings-to-investment ratio (SIR) for Dynamic In-Fill windows and quantify the capital equipment savings enabled for future HVAC upgrades.
4. Create energy/water conservation measure (ECM) definitions and metrics for Dynamic In-Fill windows and work with ESCOs to integrate them into their ESPC ECM portfolios. Launch first ESPC-financed Dynamic In-Fill project.
5. Using an experimentally validated energy model, estimate total cost, energy and GHG savings potential across DoD's building stock (with consideration for relevant metrics such as building type and climate zone).
6. Engage DoD users to understand and meet acceptance requirements for Dynamic In-Fill windows (including regulatory requirements), create awareness, and accelerate the adoption of the Dynamic In-Fill system.

3.2 BASELINE CHARACTERIZATION

3.2.1 Baseline Energy Models

The goal of this study is to quantify and document the energy savings incurred by replacing the existing single-pane glass with high-performance Dynamic In-Fill glass. Due to the lack of measured historical energy consumption data, an energy calibration approach was adopted by following the steps below:

- Sub-meters were installed on the entire second floor of the building to monitor electrical receptacle, lighting, and HVAC energy at the panel level for a period of about two weeks while the floor experienced school-in-session occupancy.

- A calibrated energy model for the second floor was developed to match the two-week metered conditions (post-installation period of Dynamic In-Fill glass) in OpenStudio®[8] (FAR 2017). Additional information includes drawings provided by the college, and window control and modeling strategies provided by View. The baseline model (pre-installation period of Dynamic In-Fill glass) was then obtained by modifying the window properties of the calibrated model to match existing windows.
- A comparative analysis was conducted by comparing the energy consumption of the baseline model and the calibrated model for spaces that experienced the window retrofit to determine the energy savings from Dynamic In-Fill glass.

3.2.2 Energy Model Calibration

In order to estimate the energy savings from installing View Dynamic Glass, an energy model representing the building operation after the window retrofit was developed and calibrated to measured data over a period of about two weeks. Constrained by the existing panel layout and HVAC thermal zone definition, it was very difficult to measure the energy usage only in spaces where the window retrofit took place. Taking into account the flexibility of parsing out the energy usage for the retrofitted spaces in the energy model, the scope for the onsite sub-metering as well as the calibrated model was expanded to the entire second floor. In developing the calibrated energy model for the case with View Dynamic Glass, the following steps were taken:

- Metered data was collected for September 2–16, 2015.
- An energy model (the calibrated model) was built for the second floor of the National War College to match the construction and mechanical design as shown on the drawings provided by college personnel.
- View Dynamic Glass was modeled in the calibrated model with an overall U-value (including framing effect) of 0.35 British thermal units (Btu)/sqft/hr/°F and two tint states, with its clear state having an SHGC of 0.28 and tint state of 0.18. Under View's guidance, the glass was modeled to tint when the solar incidence level on the glass >25 Btu/sqft/hr.
- The energy model's lighting and individual electrical receptacle energy were calibrated to match the metered data, completing the energy model calibration.

3.2.3 Energy Model Detailed Description:

A one-story building was modeled to represent the second floor of the National War College (floor plan shown in Figure 4). Its floor construction was defined as adiabatic to prevent heat transfer with the ground because, in reality, the second floor is not in direct contact with the ground and the vertical heat transfer between floors is minimal assuming all spaces are conditioned to similar temperature set-points.

[8] OpenStudio energy modeling software, https://www.openstudio.net/.

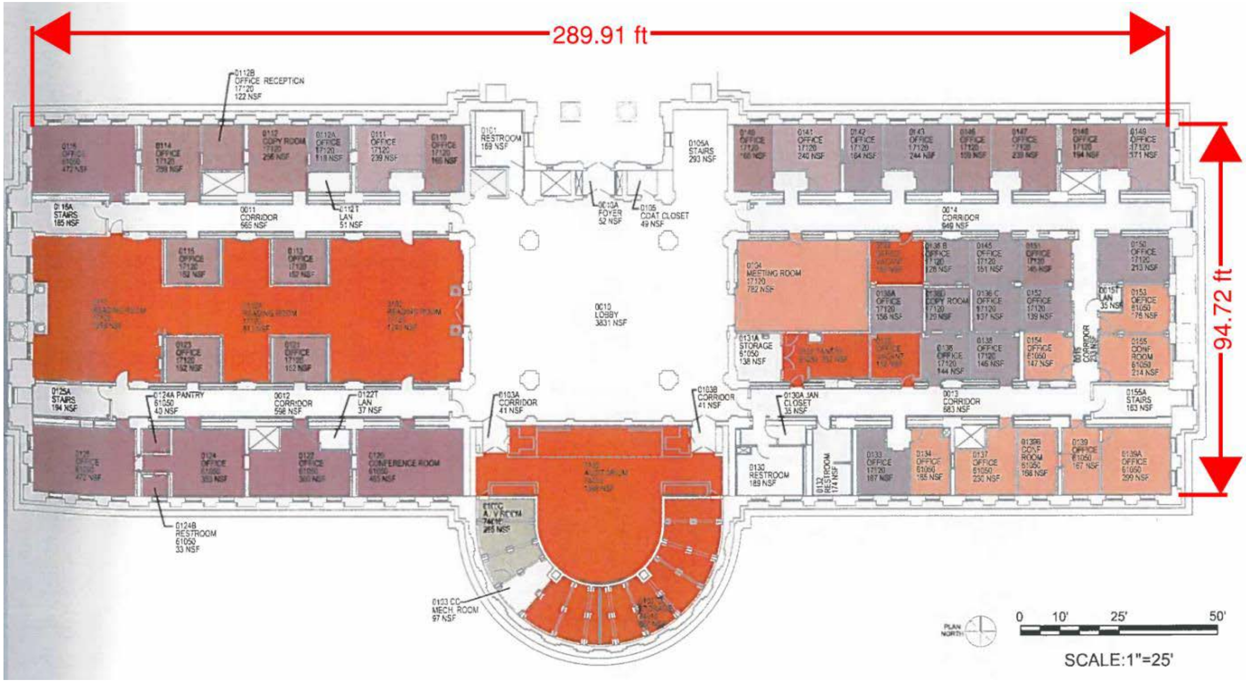


Figure 4. National War College, Floor Plan, Second Floor

Screenshots of the geometry of the energy model are shown in Figure 5. The window-to-wall ratio was estimated to be 40%. The primary HVAC system type for the site is fan coil units with dedicated outdoor air systems (DOAS). A rooftop chiller and an electric resistant water heater supply chilled water and hot water, respectively, to the fan coil units.

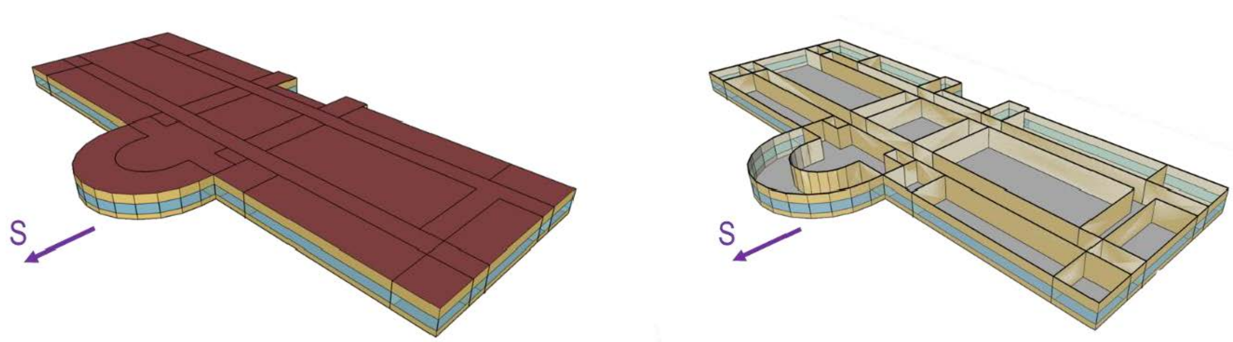
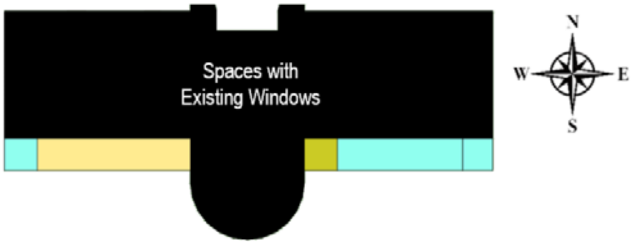


Figure 5. Baseline Energy Model Created in the OpenStudio Software

3.2.4 Energy Model Calibration Results

The calibrated lighting and receptacle inputs are listed in Figure 6. Although the calibration was conducted for the whole second floor model, shown below are only inputs for spaces that experienced the window retrofit because only these spaces are analyzed in the following energy performance assessment.



Space Type	Office	Seminar	Support
Massing Color			
Area/person [SF/p]	200	20	100
Lighting [W/SF]	1.1	1.3	0.9
Receptacle [W/SF]	0.64	0.4	0.07
Thermostat Cooling [°F]	75°F occupied, 80°F setback		
Thermostat Heating [°F]	70°F occupied, 60°F setback		

Figure 6. Calibrated Inputs for Space with View Dynamic Glass

Due to the limitation of the existing panel layout (Figure 7 and Table 2) in the building, the measured lighting energy and HVAC energy were combined in the collected data, which made it impractical to calibrate the lighting and HVAC energy separately.

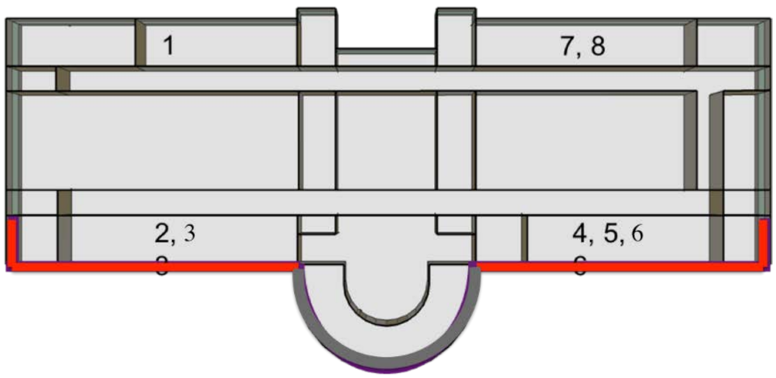


Figure 7. Calibration Panel Locations

Table 2. Corresponding Panel Identifiers and Load Type for Panel Locations Described in Figure 7

#	Panel	Location	Type	Load Type
1	RIN-2A2	NW	Hobo	Lighting or HVAC
2	RIN-2A1	SW	Hobo	Lighting or HVAC
3	CIN-2A1	SW	Dent	Plug Load
4	RIN-2B1	SE	Dent	Lighting or HVAC
5	RIN-2B1	SE	Hobo	Lighting or HVAC
6	CIN-2B1	SE	Hobo	Plug Load
7	R1N-2B2	NE	Dent	Lighting or HVAC
8	C1N-2B2	NE	Hobo	Plug Load

With reasonable assumptions of the mechanical equipment efficiencies and schedules (using data from similar building types and vintages in the Washington, D.C. area), the lighting power density was then adjusted to achieve similar combined energy consumption of HVAC and lighting as the measured data. The modeled receptacle energy matches up to the measured data within a reasonable error range (<4%).

Most important, the combined calibrated building energy model—one that considers HVAC, lighting, and all miscellaneous receptacle energy consumption—was very well correlated to the actual usage (Figure 8). Modeled consumption was a 97% of actuals over a one-year (yr) period. This is a superior correlation (<4% discrepancy).

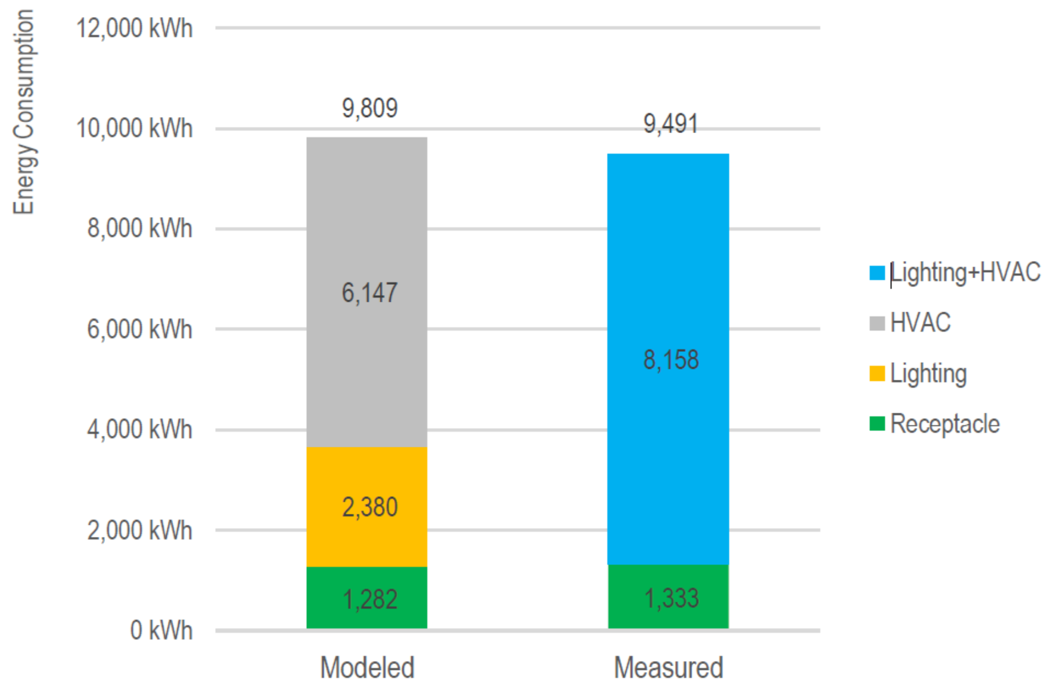


Figure 8. Energy Consumption for the Calibration Period of September 2–September 16, 2015 (modeled versus measured)

3.3 DYNAMIC IN-FILL SYSTEM DESIGN AND INSTALLATION:

3.3.1 Preparation

One major consideration for the project completion and success was the review and approval of the regional historical society. Following the submission of the proposal, including project photos and design drawings, by the National War College team, the project was given approval. Because the Dynamic In-Fill preserves the existing framing and glass of the exterior façade, it was deemed that the renovation would not diminish the historical significance of the building.

All windows within the project scope (second floor south, east, and west) were measured, and any special requirements beyond window and IGU parameters were identified. An installation schedule was established with the facilities operations teams to coordinate installation between semesters and scheduled classes. As a result, all of the installation was completed in less than two weeks in December 2014.

3.3.2 Balance of Systems Installation:

The first step of Dynamic In-Fill window installation does not involve the window units, but instead installation of the components of the wired network that controls the dynamic glass. Power and control cables of the IGU (drop cables) were installed above the windows in the existing ceiling plenum created by a standard drop ceiling design. In addition to the installation of drop cables, window controllers (the electronic components used to regulate power transmission and send control signals to specific IGUs) were also mounted in the ceiling plenum. Figures 9 and 10 depict installation of these perimeter network components. An overview of the cable and window controller physical attributes and installation instructions can be found here: http://viewglass.com/assets/pdfs/bos-cables-overview-guide.pdf.[9]

Figure 9. Available Space for Dynamic Glass System Components in the Existing Ceiling Plenum

Figure 10. Installation of Dynamic Glass System Components in the Existing Ceiling Plenum

[9] View Dynamic Glass window controller and drop cable installation guide, http://viewglass.com/assets/pdfs/bos-cables-overview-guide.pdf (accessed February 2017).

Next, the central trunk cables were laid out in the central corridors in order to transmit power and information to the perimeter components (Figure 11). Similar to the drop cables and window controllers, these were installed into the existing ceiling plenum without disruption to the existing conditions in the ceiling or occupied spaces. An overview of the trunk cable physical attributes and installation instructions can be found here: http://viewglass.com/assets/pdfs/trunk-line-installation-guide.pdf.

Figure 11. Central Trunk Cables Laid Out in Central Corridors

For the View Dynamic Glass system, power and logic are delivered via a centrally-located control panel (Figure 12). This unit is a single cabinet with dimensions of 20 inches x 26 inches x 9 inches deep. The control panel was located in the existing second floor electrical closet (adjacent to the fire alarm system control panel). An overview of the control panel physical attributes and installation instructions can be found here: http://viewglass.com/assets/pdfs/control-panel-installation-guide.pdf

Figure 12. Control Panel (with power supply and network controller) Installed

3.3.3 Dynamic In-Fill Installation:

Dynamic IGUs were fabricated by View, including 6-millimeter (mm) middle and interior glass, and integrated into fixed aluminum windows designed for a flush fit with the existing windows. The final configuration of the existing window and the Dynamic In-Fill is shown in Figure 13.

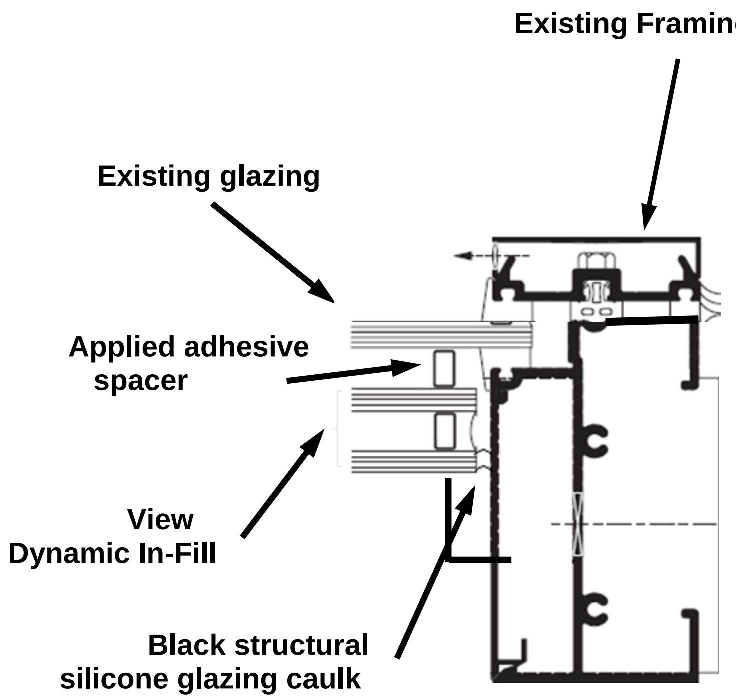


Figure 13. Configuration of a Typical Dynamic In-Fill Unit

Completed Dynamic In-Fill units were delivered to the site for installation via a multistep process. Installation was conducted in a fully operational facility. The only requirement was that the room in which Dynamic In-Fill installation was occurring be unoccupied at the time. As a result, installation was conducted across the entire project site during a single break in the class schedule between teaching semesters.

The first step for Dynamic In-Fill installation was to mount a perimeter spacer to a dynamic glass IGU. The surface of the glass was cleaned and prepped prior to spacer installation (see Figure 14).

Figure 14. Perimeter Spacer/Seal was Applied at Site

Next, a vacuum pump was situated to create a vacuum adjacent to the existing glass for a given window unit (Figure 15). The seal-prepped IGU was placed into the existing window pocket with the vacuum pump in place. The IGU was pressed to create a tight seal with the existing glass. Once the IGU was settled into a stable position, the vacuum pump was engaged to evacuate the cavity between the existing glass unit and the Dynamic In-Fill unit. This step in the process removed air, moisture, and any foreign material.

Figure 15. Desiccated Vacuum Seal is Created

Once the air cavity between the existing glass and the Dynamic In-Fill unit was drawn down to a low-density, low-moisture condition, the port for the vacuum was withdrawn and the seal fully closed. The Dynamic In-Fill unit was stable, held in place by both negative air pressure and by the adhesive in the external perimeter seal.

The installed unit was then finished with a perimeter of rectangular profile aluminum framing with a finish matching the existing frame. In the case of the demonstration project, all framing had a traditional architectural ‘bronze’ finish. Figures 16–18 show the finished retrofitted windows. This process was repeated for all 58 window units within the project scope.

Figure 16. Interior Frame Being Installed and Sealed

Figure 17. Glass Appearance as Commissioned – during Tint Transitioning

Figure 18. Glass Appearance as Commissioned – Fully Tinted

3.4 PERFORMANCE OBJECTIVE OUTCOMES

Many of the targeted performance objectives were met (Table 3), including lifecycle cost, occupant comfort, and awareness. The building peak load was reduced by 23%, missing the 25% total reduction target. Similarly, Annual Energy Savings objectives and lifecycle GHG reduction objectives were well below targets. The primary reason for missing the energy/GHG targets stemmed from the existing HVAC system for the building. The HVAC zones were not compatible with the demonstration areas so that, during typical operation, the HVAC system was meeting the needs of treated and untreated spaces simultaneously. As a result, the operational savings were approximately 1/3 of what was anticipated. Those operational figures directly correlated to underperformance of lifetime GHG reductions.

Table 3. Summary of Performance Objectives Versus Measured Results

Performance Objective	Metric	Success Criteria	Results
Quantitative Performance Objectives			
Annual HVAC/Lighting Energy Usage	Energy intensity (kWh/sqft)	>15% annual energy savings over existing glass	6% annual energy reduction
Building Peak Load	Peak power intensity (kWh/sqft)	>25% peak energy reduction over existing glass	23% peak load reduction
Lifecycle GHG Emissions	Metric tons carbon dioxide (CO_2) via complete lifecycle analysis (LCA)	>24% savings over existing	8% GHG reduction
Lifecycle cost	Dollars spent	50% lower installed cost versus dynamic glass replacement	2x savings over dynamic glass replacement
Qualitative Performance Objectives			
Occupant Comfort	Likert-type survey results plus real time data	Statistically significant gains in comfort	Lower glass temps and gain. Similar comfort due to occupant displacement from glass.
User Awareness and Acceptance	Survey results and reactions	Statistically significant gains in satisfaction	High adoption and satisfaction with site facilities management and occupants

In future projects, both the site and the scope of the retrofit project should be carefully matched with regard to HVAC zoning. Ideally, the entire façade of the building should be retrofitted with a Dynamic In-Fill system and the HVAC system should be reduced and balanced to the new design. If this is not possible (as with limited scope retrofit projects, e.g., an enclosed courtyard), the project team should take considerable care to match the zoning to the project scope so there is not unneeded cooling impacting the overall performance objectives.

4.0 PERFORMANCE ASSESSMENT

A baseline model was created by modifying the calibrated model described in the earlier sections. In all non-glass aspects (physical design, system components, operational conditions), the baseline model was held constant to the calibrated model. The only difference between the two calibrated models was that for the baseline, View Dynamic Glass was replaced with a window construction that reflected that of the previously existing glass. The baseline glass was given the performance parameters of an overall U-value of 0.53 and an SHGC of 0.53, consistent with the approximate performance of the existing glass.

Both the baseline model and the calibrated model were then simulated for the whole year using the typical meteorological year 3 (TMY3) weather data for Washington, D.C. The energy consumption data for office spaces and classrooms that were within the scope of the demonstration projects (those with the Dynamic In-Fill retrofit) were extracted from both models and compared against each other to quantify the savings from installing the Dynamic In-Fill system. Figure 19 shows the estimated monthly and annual energy savings from the recent installation of View Dynamic Glass in the National War College.

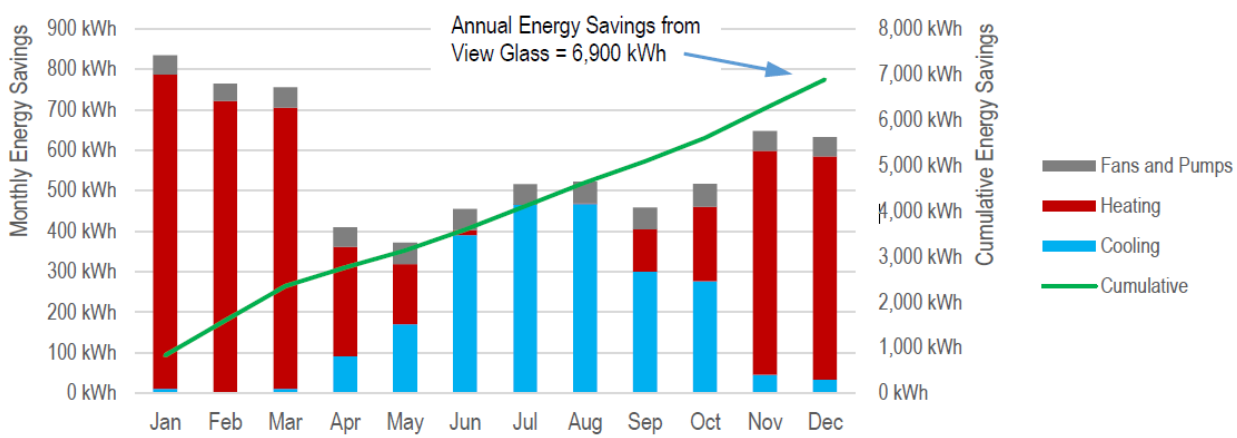


Figure 19. Estimated Energy Savings from View Dynamic Glass by Month

Annual energy savings for the second-floor south façade were 6,900 kWh, equivalent to about 6.0% of the annual HVAC energy consumed by the retrofitted spaces. From an energy usage intensity (EUI) perspective, the Dynamic In-Fill system saved these spaces about 5.6 kilo-British thermal units (kBtu)/sqft/yr as shown in Figure 20. The extremely high heating energy is caused by the inefficient electric resistance reheat. Being in the denominator of the percent calculation, this high heating energy base is the main cause of the seemingly low relative savings of 6.0%.

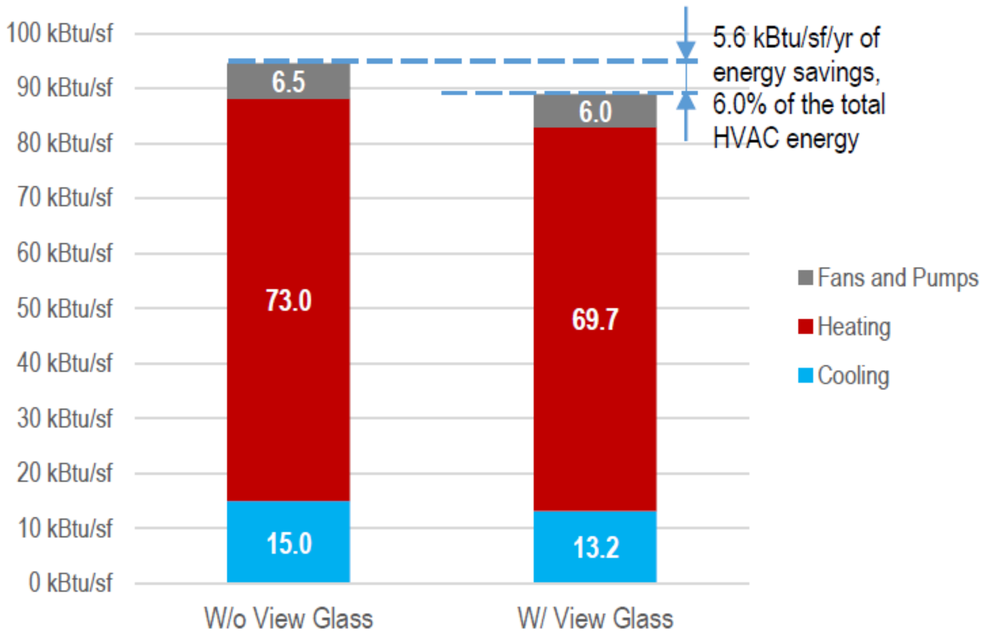


Figure 20. HVAC EUI Savings from Dynamic In-Fill Glass

4.1 PEAK LOAD IMPACT

The Dynamic In-Fill glass system is intended to tint during peak cooling load periods, thereby blocking unwanted solar radiation and yielding savings in peak load cooling energy use. This also results in reduced HVAC equipment sizing as well as system simplicity when compared to traditional glazing solutions.

Figure 21 compares the peak cooling load of a typical office where Dynamic In-Fill glass was installed as compared to its estimated peak cooling load prior to the window retrofit. By switching from the baseline glass to View Dynamic Glass, the total peak cooling load and the solar heat addition at the cooling peak period were reduced by 23% and 67%, respectively. It can also be noted that the peak cooling time was shifted from 1 p.m., when the thermal mass in the wall had not been saturated by the high outdoor temperature and solar radiation (surface conduction heat addition is very low), to 5 p.m. after the full benefit of thermal mass had been harvested. This shift indicates a co-benefit between high thermal mass constructions and View Dynamic Glass in the effort of peak cooling load reduction.

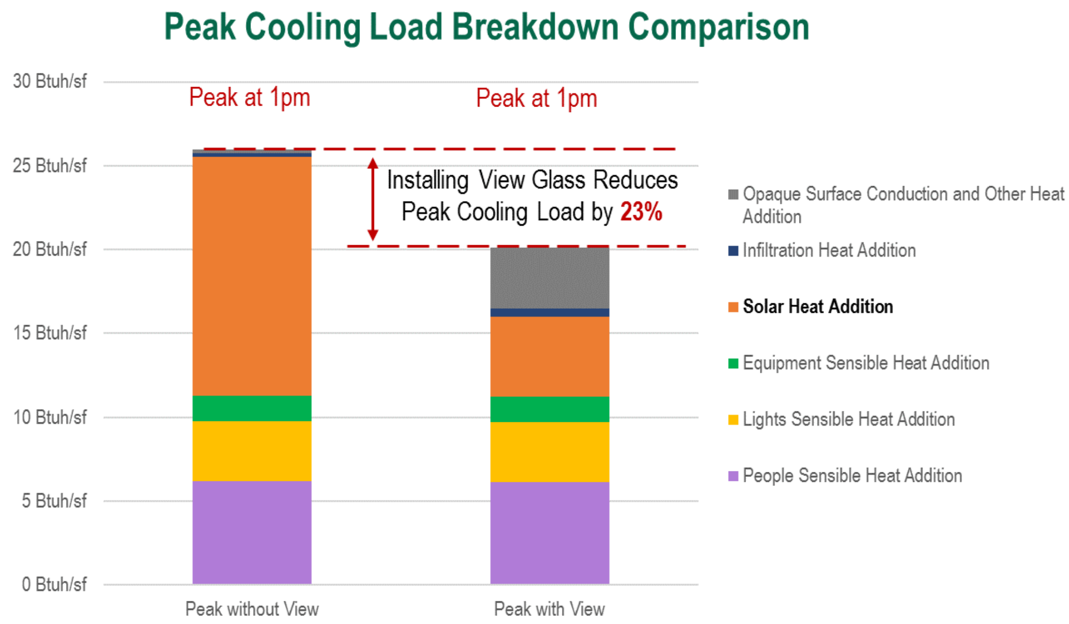


Figure 21. Peak Cooling Load Breakdown Comparison

The implications of the peak cooling benefits are multiple. First, the size and complexity of the required HVAC system is reduced by approximately 23%. While the current demonstration installation did not need or plan for an HVAC refresh or retrofit, that replacement system could be downsized for considerable financial savings when it does occur. A previous demonstration project by View at Marine Corps Air Station (MCAS) Miramar[10] saw similar downsizing opportunities for a building that was planning for an HVAC refresh in the near future. When that scheduled upgrade took place, the replacement HVAC was 20+% smaller and less expensive.

A second implication to energy cost and consumption was the time shift of the peak cooling requirement. By shifting the load to off-peak hours, buildings can shave time-of-use costs associated with peak usage times. Further, because the peak cooling requirement coincides with the end of the work day, the facility may avoid the cost (and associated GHG emissions) of cooling for a fully occupied facility. As found by the analysis, the time shifted peak occurred at 5 p.m. for the Dynamic In-Fill system offices. This was due to the thermal saturation of the historic brick façade and not associated with the heat rejection limits of the dynamic glass. Better heat rejecting opaque envelope (e.g., high albedo stucco) could shift that peak later into the evening or further reduce its severity.

4.2 ADDITIONAL RESULTS

Additional findings of the project demonstration energy analysis include the following highlights:

- Installing View glass reduces HVAC energy throughout the year.
- Relative annual HVAC energy savings is 6.0%.

[10] https://viewglass.com/portfolio/marine-corps-air-station/.

- The overall EUI savings is 5.6 kBtu/sqft.
- High heating energy is due to the very inefficient electric resistance reheat.
- The Dynamic In-Fill system reduced the asymmetric heating/cooling along the building. The conditioning system was better balanced for higher comfort.
- Additional energy savings may be harvested if the system is coupled with good daylighting design.

4.3 OCCUPANT COMFORT

In addition to the demonstration's primary objective of assessing energy savings, the project and site also offered an opportunity to compare the comfort of similar spaces with and without the Dynamic In-Fill glazing. The definition of comfort defined by ASHRAE Standard 55 was used (ANSI/ASHRAE 2013), with site measurements of air temperature, humidity, and radiant surface temperatures taken. Surface temperatures were determined through use of infrared photography (using a FLIR® D60 camera). The ASHRAE Standard 55 comfort analysis found similar results between spaces with and without View glass.

For the pair of rooms that had similar direct solar exposure (233 and 133), the View glass had a 10°F lower interior glass surface temperature than the traditional glass pane, (85°F versus 95°F). As expected, both rooms had the same frame temperature of approximately 100°F. While the lower window temperature does impact occupant comfort, at the seating location 6 ft from the window, the air temperature and floor/ceiling/wall temperatures dominated and resulted in the predicted percent dissatisfied being calculated as the same at 5%. The air temperatures in these two rooms were also the same, which suggests similar radiant temperatures since the same air temperature setpoints were in use.

It was observed that the blind position was different, with the louver blinds fully dropped in the traditional glazing room but half open in the View glass space. This is as expected with the electrochromic glazing offering glare control without blind use.

5.0 COST ASSESSMENT

5.1 ASSUMPTIONS FOR COST PROJECTIONS

In addition to developing models to predict the energy and GHG benefits of dynamic glass technology, the project team also developed an empirically-derived economic model to assess the deployment costs and benefits for the installation site and for other similar DoD buildings. For this, several assumptions about expected project costs were made to include the following:

Glass (IGU) Costs: These costs were the total cost from the glass vendor. For the low-e baseline, this includes glass material cost only. For the dynamic scenario, the glass cost includes the dynamic IGU, associated electrical components, and commissioning.

Shading Costs: Glare control blinds are assumed to be an installation requirement on low-e replacement windows, but not dynamic windows. Cost for the installed blackout shades was researched and assumed to be $15/sqft. The additional wooden, horizontal louvers were assumed to be $40/sqft. The assumed average usable lifetime of blinds is 10 yrs, with maintenance cost of $0.15/sqft/yr. The use of both blackout shades and premium wooden louvers is atypical of mainstream commercial offices and existing government facilities. In typical spaces, existing blinds are likely narrow, metal horizontal blinds or non-metal vertical blinds. These can have lower replacement costs on the order of $10–$15/sqft installed. For offices with roller shades, costs are slightly higher: approximately $20/sqft for manual shades and up to $40/sqft for motorized shades.

HVAC Costs: For the present installation, cost calculations were based on the existing DOAS plus fan coil unit system. Estimated service life for the system is 20 yrs and the cost for end-of-life replacement is approximately $2,100/ton.

For the building stock HVAC costs, a more general approach was adopted. Depending on the type of HVAC system selected, the installed cost, system life, and maintenance cycle can vary widely. Because of the wide variety of solutions in place in the current DoD building stock, the project team needed to simplify the approach and to select a reasonable set of costs and equipment lifetimes. For this, the project team drew on an internal library of 100+ reviewed energy models and the informed input from multiple principals at a leading mechanical, electrical, and plumbing (MEP) firm (Integral Group[11]). It was determined that the assumed average usable lifetime of a typical HVAC system is 15 yrs. (This estimate is deemed conservative. HVAC maintenance costs were assumed to be 1% of system cost. It is worth noting that the model assumed the estimated service life of the equipment versus the actual or observed service life of the HVAC equipment. Tabulating benefits beyond the recommended best practices is inappropriate and represents a reasonable, if conservative, estimate. Using anticipated equipment lifetimes is also consistent with how the service life of the glazing system was estimated [30 yrs versus 50+ yrs typical actual service of glass].) It was also assumed that any future HVAC upgrades would be downsized to the revised and proper peak-load requirement for the building for a given window condition (for either dynamic or low-e windows).

[11] http://www.integralgroup.com/.

In calculating the total costs for the demonstration project, it was assumed that an HVAC replacement was eminent due to the end the existing unit's serviceable life. This assumption was verified as accurate by the base facilities team.

Building Lifetime: It was assumed that each site has a remaining service life of 30+ yrs and the full benefits of glazing and HVAC upgrades will be realized for one refresh cycle.

Energy: Energy results were derived directly from the validated EnergyPlus™ whole building model. Total savings due to efficiency gains were calculated by multiplying energy savings (kWh) by actual Washington, D.C. utility rates ($/kWh) (U.S. Department of Labor 2018). For broader energy cost projections, the project team used regional energy costs obtained from the U.S. Energy Information Administration (EIA). For the second quarter 2017, the U.S. national average cost of commercial electricity was $0.104/kWh. Regional prices ranged from the lows in the West South Central ($0.0844/kWh) and South Atlantic ($0.0942/kWh), to moderate costs East North Central ($0.1016/kWh) and East South Central ($0.1050/kWh), to the upper range in regions of New England ($0.1496/kWh) and Pacific Contiguous ($0.1233/kWh) (EIA 2018) (Note: Alaska and Hawaii are exceptionally higher rates at $0.2357/kWh average).

It was assumed that energy costs will increase 2% annually. This is consistent with nationally recognized energy prediction models.

Electrical Labor Costs: Electrical labor cost for wiring dynamic glass balance of system (BOS) components throughout the façade and bringing power to the control box was calculated using the RSMeans® construction labor reference guide and actual quotations/bids from mechanical contractors and engineering firms for other dynamic glass installations.

5.2 COST ANALYSIS

All cost assessments were done using simple payback and SIR over a 30-yr period using the National Institute of Standards and Technology (NIST) Bridge Life-Cycle Cost Analysis (BLCCA) process (NIST Handbook 135 [DOE 1996]). Using the measured data and energy models, the team projected the future potential energy and cost savings (including future capital and maintenance costs from HVAC and blinds replacements) from the use of dynamic windows as compared to traditional low-e glazing at each site.

The model includes an analysis based on a simple return on investment (ROI)/payback and the total realized benefits over a 30-yr lifecycle. Each analysis was broken into two categories of expenditures: CAPEX, which captures all first-time costs/savings including the HVAC system and peripheral components retrofit cost, and window shades/blinds costs.

Also broken out is the second category of Operating expenditures (OPEX), which is a total of all reoccurring expenses/savings impacted by the efficiency measure on an annual basis. OPEX captures the costs associated with energy consumption, HVAC maintenance, and window shades/blinds maintenance. A description of each line item and section are listed in the tables below, along with any stated assumptions. All assumptions on glazing, materials, equipment, labor, utility rates, etc. were gathered by industry standard reference sources such as the RSMeans construction cost guide and actual quotations/bids from mechanical contractors and engineering firms.

5.3 COST ANALYSIS AND COMPARISON

As noted in Section 4, Dynamic In-Fill glass has a measurable impact on annual energy and peak load reduction, which results in: (1) energy costs and demand charge savings, (2) capital equipment cost savings (e.g., HVAC downsizing and elimination of blinds/shades), and (3) maintenance cost savings (e.g., from HVAC and blinds). The economic impact of retrofitting with View Dynamic Glass was compared to retrofitting with low-e glass, both with dimmable lights. Table 4 shows the "first costs" of integrating dynamic windows as part of a modest energy efficiency or modernization retrofit.

Table 4. Capital First Costs (and lifetime costs) Plus Annual (and lifetime) Operational Savings, Including Lifetime Total Cost of Ownership.

All costs normalized to sqft glass.

Capital First Costs (30-yr Lifetime Capital Costs) for Retrofits		
Component	**Low-e Glass System**	**Dynamic Glass System**
IGU ($/sqft glazing)	$20 ($20)	$40 ($40)
Window Frame ($/sqft glazing)	$30 ($30)	$10 ($10)
Installation Labor ($/sqft glazing)	$25 ($25)	$10 ($10)
Low Voltage Labor ($/sqft glazing)	$0 ($0)	$2 ($2)
HVAC Capex Cost ($/floor sqft)	$21 ($32)	$17 ($26)
Shading Capex Cost ($/sqft)	$15 ($45)	$0 ($0)
Total Net Capital First (Lifetime) Costs ($/sqft glazing)	$112 ($152)	$79 ($88)
%-Increase	NA	-30% (-42%)
Annual (Lifetime) Operational Expenses		
Element	**Low-E Glass System**	**Dynamic Glass System**
Energy Consumption ($/floor sqft /yr)	$1.64	$1.54
HVAC Maintenance ($/ floor sqft/yr)	$0.13	$0.11
Shading Maint. ($/glazing sqft/yr)	$0.15	$0
Total Annual (Lifetime) Cost ($/sqft)	$1.92 ($58)	$1.64 ($49)
%-savings		15% savings
Lifetime Total Cost of Ownership ($/glazing sqft)	**$215**	**$141**

For this example, based on market data for typical horizontal metal blinds, installed shading costs are assumed to be $15/sqft with a typical replacement cycle of 10 yrs. This is not representative of the National War College installation, which had a premium, dual-blind solution installed at the time of the demonstration project.

Table 5 shows the overall economic analysis for this site for the first year. As shown, there are multiple potential savings from the use of dynamic glass. In terms of capital and operational savings, the use of dynamic glass saves $82,000 in HVAC equipment up-front, plus an additional $82,000 for future HVAC replacements during the lifetime of the windows (assumed to occur every 20 yrs) and $30,000 savings on HVAC maintenance during this same period. Dynamic glass also results in $27,000 in up-front savings for shading attachments, plus an additional $54,000 savings on future shading replacement during the lifetime of the windows (assumed to occur every 10 yrs) and $9,000 savings on shades maintenance during this same period. Finally, the use of dynamic glass saves approximately $1,100 in electricity/yr, or $33,000 in electricity savings over the lifetime of the windows. Overall, dynamic windows results in a $222,000 lifetime ROI (see Table 6).

Table 5. Year 1 CAPEX and OPEX Comparison Between Upgrading with View Dynamic Windows Versus State-of-the-art Low-e Windows

Low-e versus View Dynamic Glass			
Façade package	Low-e	Dynamic	
Glass	1,500 sqft	1,500 sqft	
Internal shading	Manual blinds + horizontal louvers	None	
Exterior shading	None	None	
Dimmable lights	Yes	Yes	
First Time Costs (CAPEX)	**Low-e ($)**	**Dynamic ($)**	**Difference (Savings)**
Glass installed cost	112.5K	90K	(22.5K)
Electrical labor	-	3K	3K
HVAC	176K	143K	(33K)
Internal shades	22.5K	-	(22.5K)
External shading			
Total CAPEX	**$311K**	**$236K**	**($75K)**
Annual Operating Costs (OPEX)	**($)**	**($)**	**Difference (Savings)**
Energy consumption	18K	16.9K	(1.1K)
HVAC maintenance	1.4K	1.2K	(0.2K)
Shading maintenance	0.3K	-	(0.3K)
Total OPEX	**$19.7K**	**$18.1K**	**($1.6K)**

*Assumptions

Low-e glass cost	$20/sqft glass cost; $75/sqft installed cost
View Dynamic Glass cost	$40/sqft glass cost; $60/sqft installed cost
Electrical labor (dynamic only)	$2.00/sqft

HVAC savings	7.0 ton reduction @ $1,600/sqft
HVAC CFM reduction	4,669 CFM; $4.08/CFM
HVAC related components	23% reduction from baseline of $12/sqft of perimeter area
Energy consumption savings	6% from baseline energy consumption
HVAC maintenance	1.0%/yr of HVAC cost
Internal shades	$15.00/glazing sqft
External shades	None
Shading maintenance	$0.15/glazing sqft/yr

Table 6 depicts the output of a standard NIST BLCCA analysis for this site. Year 1 SIR is 0.83, with a payback of less than 3 yrs. The 30-yr SIR is 2.46, with a total lifetime cost savings of $222,000. This case study recognizes that View windows and state-of-the-art low-e windows both have an expected lifetime of 30 yrs, as does the National War College facility.

Table 6. NIST BLCCA Cost Analysis and 30-yr Savings-to-investment Analysis

Dynamic vs Low-E	**Years**				
	1	**5**	**10**	**20**	**30**
Initial Investment (Windows) ($k)	**90**	**90**	**90**	**90**	**90**
Other Capex Savings ($k)	72	72	72	144	144
Energy Savings ($k)	1.1	5.5	11	22	33
Maintenance Savings ($k)	1.5	7.5	15	30	45
Total Savings ($k)	**74.6**	**85**	**98**	**196**	**222**
Savings/Investment	0.83	0.94	1.08	2.18	2.46
Payback	**6 Years**				

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6.0 IMPLEMENTATION ISSUES AND LESSONS LEARNED

At the center of this technology's successful demonstration is its full compatibility with modern construction practices and delivery channels. The innovation of an active coating is delivered in a novel, cost-effective form that is acceptable to construction trades, facilities operators, and historical societies. Further, the energy-saving and comfort benefits apply to a broad spectrum of DoD building types and locations. However, these intrinsic technology advantages can create multiple project hurdles.

6.1 PROCUREMENT AND INSTALLATION

With regard to the demonstration project, there were no procurement or installation issues. View Dynamic Glass is positioned as a smart glass product designed for purchase and installation by DoD-qualified glazing subcontractors and low voltage subcontractors, as were used for this project.

For future installations, it should be noted that the subcontractors control the product markup and installation pricing. As a result, costs can vary based on country region and the familiarity of the contractor with the product. This potential issue can be mitigated through active training and education of installers.

Further, because View Dynamic Glass is procured by the glazier and not the government directly, it is not currently listed on the GSA Purchasing Schedule. If needed, View Dynamic Glass can be added to the Purchasing Schedule in the future.

6.2 STRUCTURAL LOAD

There were no structural load issues with the demonstration project. View Dynamic Glass weighs approximately the same as traditional low-e insulated glass units (approximately 4 pounds/sqft). However, for future renovation and retrofit projects where single pane glass is being added to, the additional skin load can potentially be an issue (as would complete renovation with any dual-pane low-e or dynamic windows). As such, in renovation projects where single pane glass is in place, the project team should include a structural engineer in early discussions.

6.3 WINDOW OPERABILITY

For this demonstration project, no operable windows were present. For historic buildings, operable windows are commonplace and could be incompatible with the present solution. Operable windows had been in place for decades, with employees accustomed to their presence and flexibility.

If operable windows are present, the change of window operator type should be considered as a potential objection in future installations. Although there are positive energy benefits, occupants tend to reject the loss of operability and can weigh that against the energy and comfort benefits of dynamic glass. When possible, replacement dynamic glass windows should match the prior operation type. Note that View dynamic windows are available in operable, as well as inoperable, formats.

6.4 OCCUPANT TRAINING

From this project, the team learned that occupant training is a key element of project commissioning and should be included as a project milestone in any installation. Following the successful completion of this project, the project team feels that this may be the most important milestone for successful adoption.

The basis of the training should be to set expectations on glass tint transition time. The glass is designed to predictively tint and clear to maximize comfort. This is a gradual process that may occur infrequently throughout the day. However, occupants expected the glass to transition quickly and often in response to non-comfort or energy conditions. If occupant expectations are not aligned with glass purpose and performance, it may be rejected as a technology due to a misunderstanding.

It is recommended that future project teams share key features and benefits of dynamic glass with building occupants both before and after the product installation. Occupants should also be encouraged to participate in satisfaction surveys designed to improve the behavior algorithm for that project site.

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