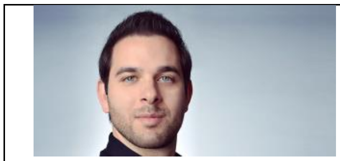
ADAPTABLE GLAZING SHIELDS

Pushing the Envelope of Facade and Window Retrofits



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ABSTRACT

Today, about 40% of all buildings in the U.S. still have single-pane windows, and ~70% of the existing building stock is estimated to suffer from under-performing facades. Experts project that 20-40% of the total energy savings in buildings—the #1 end users of energy—to be from windows and building envelopes. Thus, the demand for energy-efficiency facade and window retrofits/upgrades is estimated to grow rapidly over the coming years due to the rapid adoption of energy-efficiency regulations for existing buildings, which in turn, are influencing the real-estate market.

The problem is that window replacement is a highly intrusive and costly solution that is often carried out only when the windows reach the end of their service-life and must be replaced. Additionally, most glazing systems—including the current ones—are designed with little consideration (if any) given to their inevitable retrofit during the service-life of the building. Thus, most facade and window retrofit practices are often considered not feasible as well due to the associated complexity, building and business disruption, and long payback period.

This paper presents the concept of Inovues' patent-pending, external window upgrade system and non-intrusive facade retrofit method. The technology provides a cost-effective and sustainable solution for upgrading the old/inefficient, single- or double-glazed curtainwalls to high-performing double- or triple-glazed systems without requiring any replacement or causing building or business disruption. A case study using Lever House in NYC is presented, which is one of several performed to analyze the visual impact, thermal performance, payback, and ROI. The results showed an improvement of over 50% in the total system U-Factor; over 250% increase in condensation resistance; ~15% improvement in thermal comfort in the perimeter areas; nearly 20% energy savings; and ~85% shorter payback period (compared to replacement) with ~300% ROI over the estimated 20-25 year service-life of the system.

KEYWORDS

Facade, curtainwall, glass, retrofit, energy efficiency, adaptability, case study

INTRODUCTION

In the United States—the second largest energy consumer and greenhouse gas emitter in the world after China—most GHG emissions come from energy consumption and production (84% in 2014), and carbon dioxide makes up the majority of these emissions (92% in 2014) (Enerdata 2016; EIA 2016). According to Architecture 2030 (2013), the building sector alone is responsible for almost half of all energy consumption (47.6%) and CO2 emissions (44.6%), outperforming both industry and transportation. Globally, similar percentages (40%) were found in both developed and developing countries (UNEP 2009).

Today, 30+ U.S. cities have set bold emissions reduction targets of 80% or higher by the year 2050 or earlier (WWF 2015). Many of them have started issuing stringent mandates and ambitious action plans that target the energy efficiency of the existing building stock. The reason is that most existing buildings would need to become nearly 40% more energy efficient for cities to achieve their overall 80% reduction target (Long 2011). Meeting this goal means many existing buildings would require deep energy retrofits over the coming years with measures that address all building systems, including the building envelope. Some experts estimate that nearly half of the existing building stock in the U.S., about 150 billion ft^2, will need to be renovated over the next 30 years (Holness 2008). Currently, the majority of the commercial building stock is ready for retrofit due to being over 20 years old (ESB 2009; EIA 2015).

Taking that into consideration, several reports have highlighted that 20-40% of the total energy savings in buildings is projected to be from windows and building envelopes (IEA 2013; Habibzadeh 2015; Apte and Arasteh 2006). Up until the 1980s, windows and curtainwalls were mainly single-glazed with frameworks that had no thermal breaks, leading to a significant heat loss in the winter and heat gain in the summer, and as a result, higher energy consumption. Today, about 40% of all commercial and multifamily residential buildings in the U.S. still have single-pane windows, and most of the remaining 60% have early/low-performing double-pane window systems that lack significantly in performance compared to the current glazing technologies and building and energy code requirements (DOE 2017; EIA 2016; Schiff 2014; Apte and Arasteh 2006). Some estimates indicate that about 70% of the existing building stock suffer from underperforming facades (Fig. 1) (Enclos 2013).

Therefore, the demand for energy-efficiency façade and window retrofits/upgrades is estimated to grow rapidly over the coming years due to the rapid adoption of energy-efficiency regulations for existing buildings, which in turn, are impacting and influencing the real estate market. For example, New York City highlighted in the recent "One city: Built to Last" action plan that all single-pane windows will need to be replaced, and they announced that they are going to invest $1 billion to retrofit 3,000 city-owned buildings to lead by example (NYC 2016b; NYC 2016c). According to Navigant Research, the building envelope energy-efficiency market in the U.S. has been showing an impressive growth with 60% increase since 2011, reaching $15 billion in 2016 (Navigant 2016).

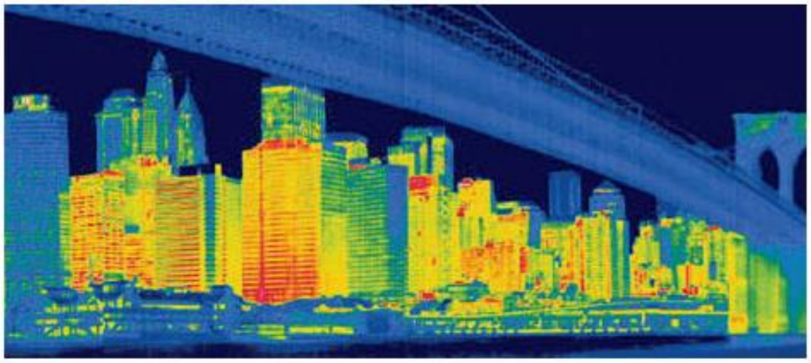


Figure 1: A thermal infrared image showing the heat loss from New York City buildings. Photo by Tyrone Turner/National Geographic (Chambers 2009).

BACKGROUND

Despite the steady and fast growth over the past few years and the projected increase in demand in the future, the building envelope energy-efficiency market is still considered a largely untapped segment with a huge gap between its profitable potential and the reality (UNEP FI 2014). Facade retrofit activities in general and window replacement, in particular, are widely considered a major undertaking that is most likely carried out only when the component is due for replacement—i.e., not earlier as a pure energy saving measure (IEA 2015). One of the main reasons behind such perception is the extended payback periods (50-100 years) that are much longer than the average 3.6 years associated with typical energy efficiency retrofits, like indoor lighting, which render investments in the building envelope as too risky (McGraw-Hill 2011).

Most facade and window retrofit solutions available today include intrusive measures that require the disruption of building uses and business operations for extended periods of time, which increases the overall cost dramatically, and in turn, the payback period. Thus, current retrofit practices are often considered not feasible by most owners and tenants. In many cases, all or major parts of the existing facade and glazing systems would need to be ripped out and replaced with new ones simply because upgrading the critical and under-performing parts, like the glass infill panels or the seals, is just too complex (Fig. 2) (Patterson 2012). In addition, given the destructive nature of these practices, they normally result in a significant amount of construction-related waste and unused materials that need to be shipped to landfills, which increases shipping and labor costs, and in turn, results in a longer payback period. Further, most retrofit solutions utilize complex systems that are associated with complex installation methods. They often require an entirely new and customized system-design for each building, which in turn limits scalability and increases upfront costs.

Therefore, most conventional retrofit methods are considered unsustainable practices—economically and environmentally. Building owners often ignore them due to the associated complexity, building and business disruption, and long payback period. However, given that the service life of most glazing systems is far shorter than that of the whole building (20-30 vs. 50-100 yrs.), retrofitting building windows and curtainwalls—something that is not deliberately considered in their original design, including the current systems—is an inevitable event during the much longer service life of the building.

Recently, a few low-cost and less disruptive window-retrofit practices have been developed and showed some gain in energy efficiency, including interior supplemental vision panels, low-e window films, and low-e storm windows. However, many drawbacks prevent them from being widely adopted by most buildings. Storm windows, which are the only exterior retrofit option available, are a temporary and impractical solution that generally do not work with curtainwalls and cannot be used on high-rise buildings. They are more suitable for single windows in punched openings, particularly for houses and low-rise residential. Moreover, they typically change the appearance of the original window and interfere with its operation, which in turn, limits their adoption.

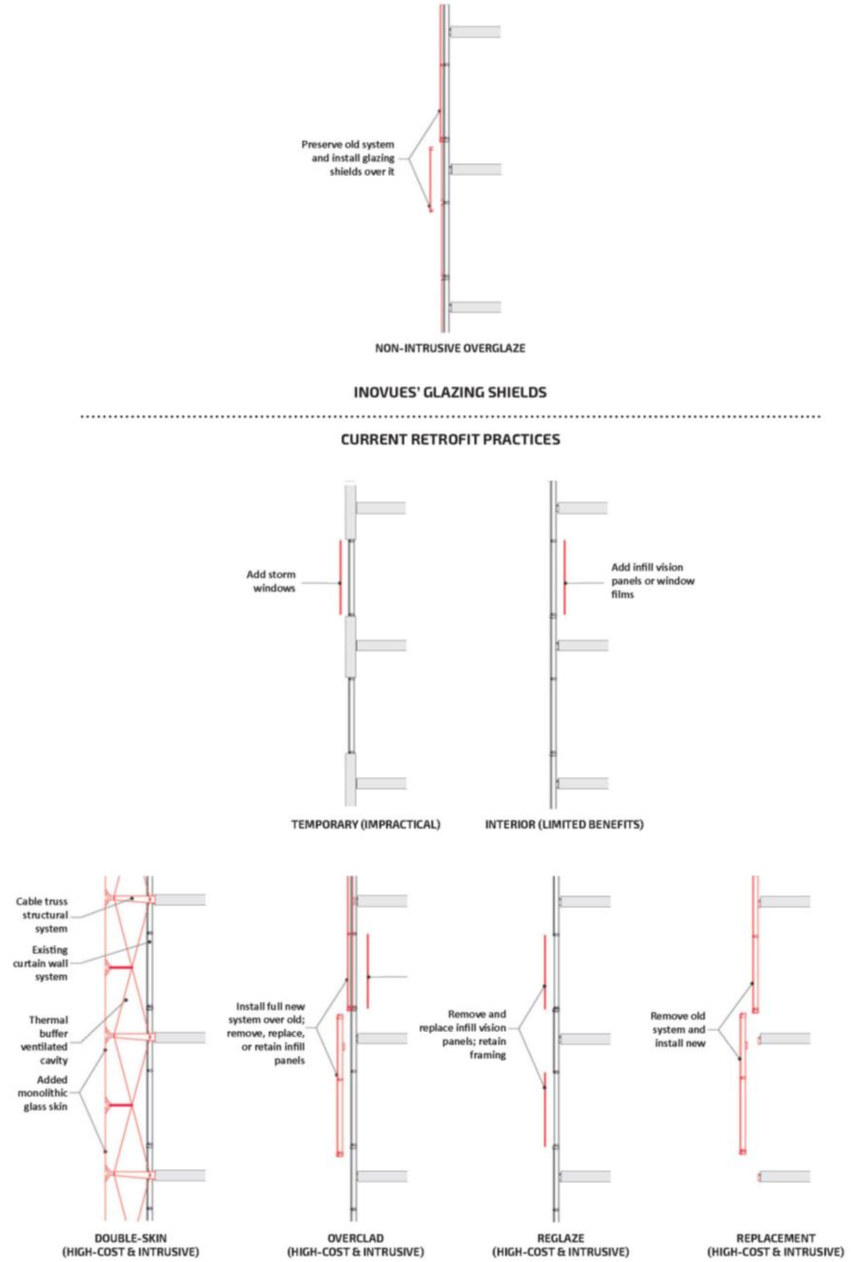


Figure 2: Wall section diagrams comparing Inovues' non-disruptive retrofit method to other conventional facade and glazing retrofit practices (Diagram by the author based on: Enclos 2012)

The interior supplemental vision panels, on the other hand, also interfere with operable windows; they are not compatible with some glazing systems; and they often fail to alleviate the performance deficiencies and thermal bridging in the frames, particularly in curtainwalls. In addition, there is a risk when they are installed behind tinted glass, particularly if not heat-strengthened, that the original glass could overheat and break (thermal stress breakage) due to having the newly-formed air gap and the low-e glass of the new panel on the inside and not on the outside. Also, if the existing glazing system is not weather tight, air and moisture may leak through the original seals into the newly-formed air gap, in some applications, and increase the risk of condensation.

Another interior application is the use of low-e window films, which also do not address the performance deficiencies and thermal bridging in the frames—they mainly improve the thermal transmittance (U-Factor) of the glazing infill panels only. Thus, they do not improve the overall thermal performance of the original window system as much as other solutions. Also, they are generally prone to scratches, have a relatively short warranty period, and are only effective on windows without condensation (Wright 2014). There are also applications that significantly alter the optical properties of the glazing infill panels to a point that makes them unpractical as vision panels. Other Retrofit options compromise the historic characteristics or the architectural identity of the building, which prevents them from being adopted by a significant number of properties, particularly those designated as historic landmarks.

Further, it is worth noting that all interior applications do not provide the benefits typically associated with an exterior retrofit—they only offer interior, energy-related benefits. For example, they cannot protect the original glazing systems, address the performance deficiencies that are related to their seals, or extend their service life to delay/avoid their replacement. Also, they cannot offer features to enhance the exterior image of the building if the owner is interested in a facade retrofit for aesthetic purposes. In fact, aesthetic improvement (image update) and performance/failure remediation (durability) were found to be the 1st and 3rd drivers respectively for façade and window interventions according to a market survey by researchers at the University of Southern California (Martinez and Patterson 2013). That is why interior retrofit solutions often face the "split-incentive” barrier with building owners—an issue that is impacting the adoption rate of many energy retrofit solutions and slowing the overall impact of energy efficiency on the existing building stock. The reason for the split incentive barrier is in part because most energy-efficiency retrofit solutions often fail to provide significant economic benefits to building owners who are typically responsible for the upfront costs of energy retrofits, while the tenants—who often pay the energy bills—end up capturing the energy savings.

Therefore, there is a growing need in the largely untapped building envelope energy-efficiency market for next-generation window and curtainwall retrofit solutions that are not only cost-effective and non-disruptive but also able to offer several economic, energy and non-energy related benefits to both owners and tenants—which is necessary to allow new technologies to reach a high level of market penetration, and in turn, promote a faster transformation into a sustainable future.

ADAPTABLE GLAZING SHIELDS

An external window-upgrade system “glazing shield” and a non-intrusive facade retrofit method are being developed. The objective is to provide a cost-effect and sustainable solution for upgrading the inefficient single- or double-pane windows and curtainwalls to high-performing double- or triple-pane systems without having to replace or alter any of their original parts and without causing disruption to the building or the occupants. The glazing shield system comprises a support spacer and a unitized panel (Fig. 3). The anchor-like support spacer is made up of smaller assemblies (individual sides) and is mounted directly on the existing glazing system in a non-intrusive and non-destructive installation method using structural adhesives. The unitized panel is mounted on the support spacer, trapping a volume of air between the infill panel of the original glazing system and the unitized panel of the glazing shield.

The adaptable design and highly compact and lightweight nature of the glazing shield (<1” thk., ~3.5lb/ft^2) allows it to work with most old and current, framed or frameless-looking glazing systems as an exterior or interior attachment. When used as an exterior retrofit solution, the system results in a new insulating weather barrier that preserves the original window/curtainwall and improves its thermal insulation properties between 40-55% (simulations), sound insulation properties by about 50% (10+ STC pts, 4+ OITC pts, estimates), and condensation resistance by over 240% (simulations). The new weather barrier would also alleviate most of the performance deficiencies in the original window/curtainwall system without compromising its structural integrity. By utilizing a very minimal frame—compared to a full window/curtainwall—the average weight of the glazing shield with a ¼” laminated glass would be almost half the weight of a typical 1" IGU with two ¼” glass lites (6.5lb/ft^2).

It is worth noting that in most old and current windows and curtainwalls, the metal frame members often maintain their structural integrity beyond the standard service life of the overall system. Additionally, most glazing systems are typically designed with relatively high safety factors for static and dynamic loads, which is due in part to the limitation in structural simulations with regards to accurately determining the behavior of materials in real life conditions while accounting for any non-factored loads or shortcomings during construction. Moreover, most systems often end up being specified with standard size structural parts and fasteners that are likely to be higher than what is required by the structural calculations. Thus, most glazing systems end up being inefficient with excessive structural capacity beyond needed, making it feasible for the original window or curtainwall to carry the additional light load of the glazing shield. Taking that into consideration, the glazing shields would use only a fraction of the remaining structural capacity in the existing system, which could be determined by a structural field test. A similar application that takes advantage of the excessive structural capacity and is already being used with curtainwalls is the addition of an interior supplemental vision panel (monolithic and IGUs), which is typically supported by the horizontal frame member only.

In terms of performance, the glazing shield system utilizes a thermally-broken attachment that helps create a highly-insulating weather barrier, which significantly improves the overall performance of the original window. The system also incorporates multiple air, water, and moisture barriers that prevent any leakage to the newly-formed, non-permanently sealed air gap. The new seals also cover the existing ones that might not be performing well, which helps mitigate the deficiencies in the performance of the original framework. Additionally, the panel of the glazing shield utilizes multiple desiccant elements, permanent and removable, including a silicone foam with desiccant pre-fill. These desiccant elements would help remove any residual moisture in the air and reduce the risk of condensation and volatile fogging that might form on the surfaces adjacent to the newly-formed air gap.

Further, the glazing shield utilizes a unique locking mechanism that retains the panel in place without requiring any drilling or mechanical fasteners. In addition, the flexible weather-tight joints provide enough tolerance for installation and allow the glazing shields to adapt easily to movements in curtainwall panels—which tend to be very minimal in the glazing shields because they are directly attached to the original infill panels, and thus, they already move together with them as the panels move. Also, the glazing shield system incorporates a flexible rubber gasket around the perimeter of each unit. The gasket would provide a flexible joint between the adjacent units, allowing them to adapt individually to the movement of their associated original infill panels.

The installation is typically performed in two stages. After the original glass is cleaned, the four pre-assembled sides of the support spacer are individually attached to the original glazing infill panel using structural adhesives—a proven material in the glazing industry for similar applications since the 1980s. The second stage is mounting the pre-fabricated unitized panel on the support spacer after the original glass is re-cleaned, creating an insulated air gap between the original glazing system and the glazing shield.

In addition to the lightweight nature of the system, splitting the glazing shield into two separate components allows for a relatively easier and manageable method of installation on site. In many cases, the lightweight glazing shields could be installed using the existing window cleaning platforms or facade access systems (BMUs) without the need for additional scaffolds or custom installation platforms. The split system also makes it feasible to utilize structural adhesives in the field. So, by attaching the 1.5" wide individual sides of the support spacer first, the adhesive will be allowed to fully cure before it is stressed with the load of the panels.

Further, it is worth noting that separating the unitized panel from the support spacer allows it to be non-permanently fixed to the existing glazing system, which makes it easily replaceable/upgradeable if needed. This feature enables building facades and windows to become resilient by allowing them to be easily retrofitted when the need arises. Moreover, given the relatively short payback period of this retrofit, existing buildings will be able to continuously incorporate the latest technologies without the need to rip off all or parts of their original facades or glazing systems every time. For example, cutting-edge technologies like vacuum insulated glazing, dynamic glazing, vision photovoltaic, and media facades would be available for existing buildings by incorporating these technologies in a self-sufficient, mount-and-play panel that replaces the old one without the need for an entirely new facade or window system.

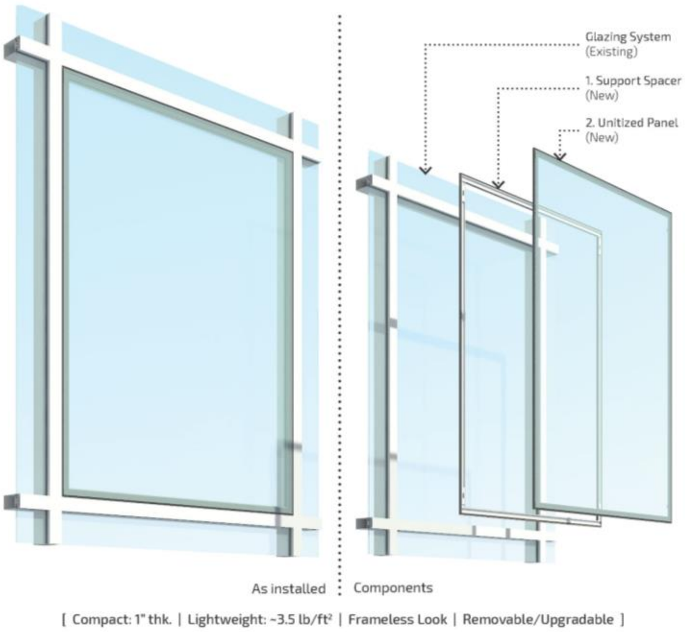


Figure 3: A 3D image showing the primary components and the split structure of the glazing shield system (Image by the author).

METHOD

Several before-and-after system-based and building-based analysis studies were performed on different glazing systems and existing buildings to analyze the overall impact and feasibility of the glazing shields. This includes visual impact, thermal performance, energy savings, and simple payback and return on investment (ROI).

SYSTEM-BASED STUDIES

Before-and-after thermal analysis studies were performed on the following types of glazing systems, which represent a wide range of existing buildings:

- Case 1: Stick Curtainwall System (Fig. 12, 15, and 16)
  Single glazed using 6mm (¼”) monolithic clear glass panels. The aluminum framing utilizes a dry seal with pressure plates and cover caps, and the system is not thermally broken.
- Case 2: Unitized Curtainwall System (Fig. 13)
  A 4-sided structural silicone glazing system (SSG) using 25.4mm (1”) insulated glass units (IGU) with two 6mm (¼”) monolithic clear glass.
- Case 3: Single Fixed Window System (Punched Opening) (Fig. 14)
  Single glazed using 6mm (¼”) monolithic clear glass panels. The aluminum framing utilizes a dry seal with pressure plates and cover caps, and the system is not thermally broken.

The following intervention scenarios were simulated and compared against a baseline model to show the difference in performance (Fig. 4):

- Baseline Model: Existing system
- Opt 1: Existing + glazing shield with aluminum profiles.
- Opt 1a: Existing + glazing shield with ~75% uPVC profiles.
- Opt 2: Existing + glazing shield with ~75% uPVC profiles + 2 coats (7mm) of clear thermal insulation paint on caps.
- Opt 3: Existing + glazing shield with uPVC profiles + 12.5mm deep, additional 1.2mm thk. aluminum tube (fake cap) with a double sided structural adhesive tape.

The simulations were performed per the standards of the National Fenestration Rating Council (NFRC) for certifying glazing products using THERM 7.5 and Window 7.5 by Lawrence Berkley National Laboratory (LBNL). By using the NFRC guidelines, the results can be compared against other NFRC certified glazing systems. Also, the percentage of improvement can be used as a reference or a starting point to estimate the improvement in thermal performance of similar glazing systems that fall under the same family of the ones that were simulated.

Note: The glazing shields simulated in these studies utilized a monolithic laminated glass with a pyrolytic low-e coating (hard coat) on surface #2 of the laminate (Fig. 15).

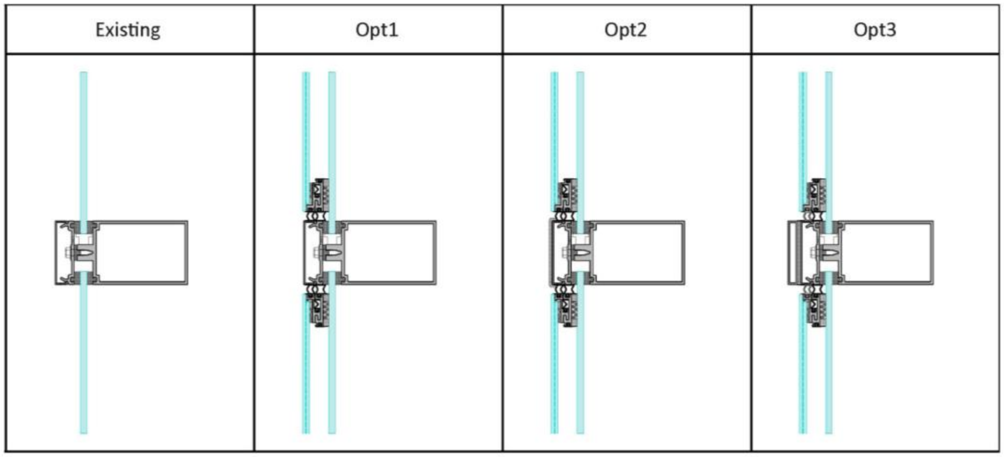


Figure 4: Case 1 stick curtainwall details at a typical horizontal meeting rail showing the existing and the proposed intervention scenarios with glazing shields—early concept (Image by the author).

PARTIAL BUILDING-BASED STUDIES

Partial, building-based analysis studies were performed to examine the impact of the glazing shields on a 5-meter deep perimeter zone (16.4 ft) at several buildings in both heating and cooling dominated climates. The studies analyzed the impact of the shields from several aspects, including energy consumption, indoor environmental quality, and cost and payback. Comfen 5 by (LBNL) was used to model and simulate the scenarios, which were repeated for the four elevations of each building to highlight the differences in impact each scenario has relative to the orientation.

In addition to simulating a baseline model, the primary intervention scenarios outlined above in the system-based studies were simulated twice with curtainwall systems. One set was simulated with the glazing shields applied to the vision and spandrel panels, and the other set with them applied only to the vision panels.

Notes Regarding the Simulation Process:

- Input values in Comfen that are related to the characteristics and the performance of the curtainwall as a system were derived from the results of the system-based case studies outlined above.
- The maximum allowable U-Factor for frame members in Comfen is 6.2 W/m2-K (1.1 Btu/h-ft2-F). Thus, all frame U-Factor values above the maximum value were normalized to align the baseline value of the system with the maximum allowable value in Comfen. However, this does not impact the outcome because it is a comparative and benchmarking process.
- Comfen's location-based labor and material cost adjustment factor was neglected to achieve neutral results (Fig. 17).
- Given that this is a benchmarking and a relative comparison process against a baseline model, Comfen generic values with regards to the HVAC and lighting systems were used for all scenarios.
- It is worth noting that there is no context input in Comfen, so the results do not take into consideration the impact of context shading on solar irradiation.
- Given that energy modeling in Comfen represents only a 5-meter deep perimeter area, the percentage of the total building energy savings will be smaller—estimated to be no less than 1/3 of perimeter savings (Curcija et al., 2017).
- The following are the estimated individual unit costs that represent each intervention option as shown in Fig. 17:
  Opt 1: \$20/ft^2
  Opt 1a: \$20.19/ft^2
  Opt 2: \$20.6/ft^2
  Opt 3: \$21.5/ft^2

FULL BUILDING-BASED STUDIES

Full, building-based analysis studies were also performed to examine the impact of glazing shields on the whole building. Parametric energy models were built for each building to simulate a baseline scenario that resembles the current conditions of the facades and the primary intervention scenarios highlighted above. The simulation results of the intervention options were then benchmarked against the results of the baseline scenario to calculate the total estimated percentage of reduction in energy consumption. The percentage of energy reduction was then used with the actual reported source energy use intensity (EUI) to calculate the total estimated energy savings and simple payback period and ROI as shown in Fig. 19 for example.

In addition to simulating a baseline model, the primary intervention scenarios outlined above in the system-based studies were simulated twice with curtainwall systems (similar to the partial building-based studies). One set was simulated with the glazing shields applied to the vision and spandrel panels, and the other set with them applied only to the vision panels.

The parametric energy model was built using Rhinoceros 3d along with the Honeybee plug-in for Grasshopper, and the simulations were performed using the EnergyPlus engine by the U.S. Department of Energy (DOE). To ensure the results were accurate, each scenario model was simulated twice; once directly through the Honeybee plug-in in Rhino 3D, and once through the OpenStudio platform, which is developed by the National Renewable Energy Lab (NREL). The results between the two platforms were almost identical (only about 0.3% off).

The purpose of the full building-based studies was to simulate the impact of the facades on the total energy consumption of the building. Thus, the parameters that were considered variables between the scenarios were only those related to the characteristics of the facade and glazing systems. Taking that into consideration and given that this is a comparative/benchmarking process against a baseline scenario, the energy model focused primarily on the attributes of the building envelope to simplify the process. Therefore, a standard HVAC system was used in all scenarios and each floor was modeled as a single zone except for the mechanical floors.

Context shading was taken into consideration in these studies by modeling the primary adjacent buildings that were more likely to drop shadows on the buildings throughout the day as shown in Fig. 18 for example.

LEVER HOUSE – CASE STUDY

KEY ATTRIBUTES

- Designed by Gordon Bunshaft of SOM, and built in 1952 (Fig. 5).
- 2nd curtainwall building in New York City.
- Designated as a New York City landmark in 1982 and was added to the National Register of Historic Places in 1983.
- The building went through a facade retrofit, also by SOM, between 1998-2001.
- The curtainwall system is till single-glazed.
- The property features a roof-top window-washing gondola.
- The energy use intensity (EUI) of this building is more than 94% of similar properties (Fig. 7).

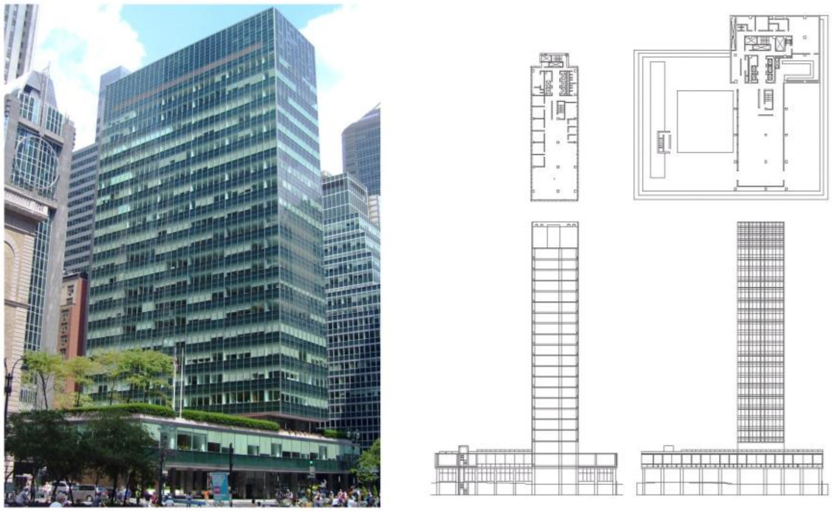


Figure 5: Lever House in NYC (Left) (Source: Wikimedia Commons). Lever House building plans and sections (Right) (Source: www.quondam.com/21/217ki01.gif.)

FACADE TYPOLOGY

An early type of metal stick curtainwall system with expressed horizontal and vertical frames that are not thermally broken. The curtainwall is made up of vision and spandrel panels that are single glazed (clear ¼” heat strengthened glass) (Fig. 6).

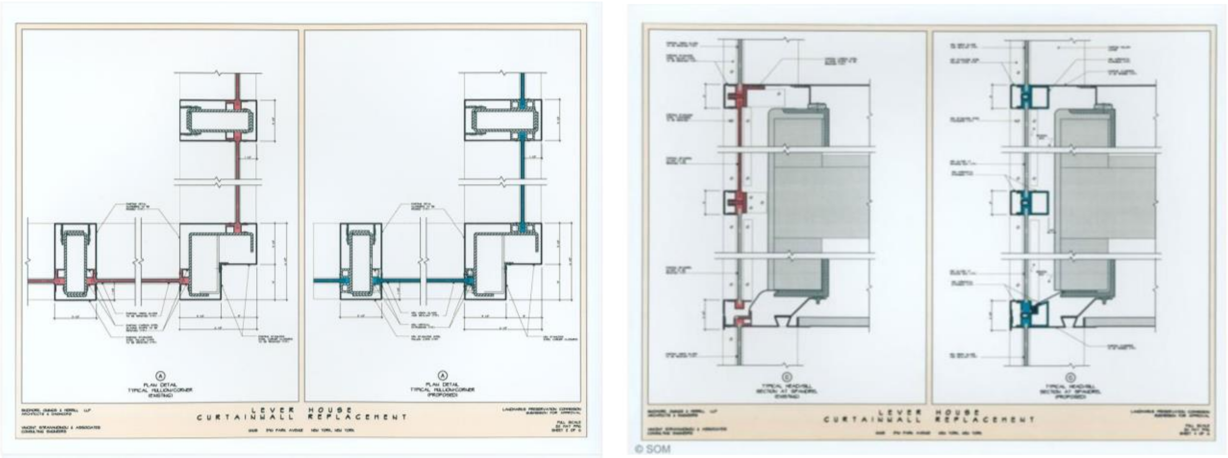
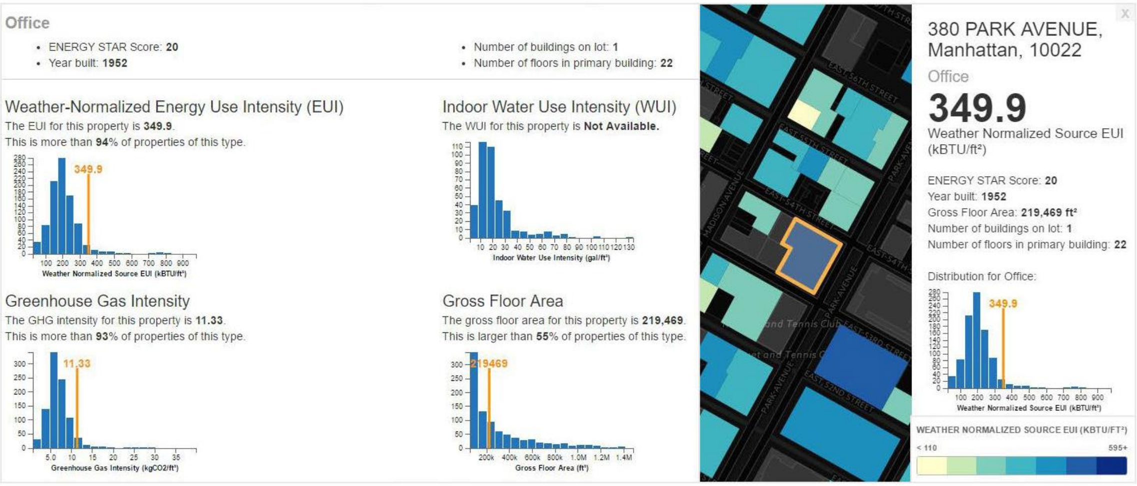


Figure 6: Lever House curtainwall details before and after the restoration job by SOM—horizontal details of typical mullions (Left) and vertical details of typical horizontal meeting rails (right). (Image courtesy of SOM).

THE POTENTIAL OF REQUIRING A FACADE RETROFIT IN THE NEAR FUTURE

According to New York City Energy & Water Performance Map, the energy use intensity of the building is more than 94% of other properties of similar type, and the greenhouse gas intensity is more than 93% of similar properties. In 2013, the building's source EUI was 345.8 kBtu/ft^2 and in 2014 was 349.9 kBtu/ft^2 (Fig. 7) (NYC 2016). Thus, it is projected that the building will be required to perform an energy efficiency retrofit in the near future to improve its performance by about 40%. This due to the new energy consumption and carbon emissions reduction targets that were introduced in the 2014 action plan "One City: Built to Last" by the mayor's office and its associated energy efficiency laws and regulations that target the existing building stock. To achieve this, the building envelope, in particular, needs to be addressed due to the significant impact of the single-glazed and non-thermally broken curtainwall on the energy consumption of this all-glass building.

Further, although Lever House is designated as a historic landmark—a status that used to allow a building in New York City to be exempt from complying with energy conservation codes and requirements—it was clear that the new action plan will target all existing buildings, including those designated as historic (NYC 2016b). Thus, retrofitting historic building facades is likely to become even more challenging because it needs to meet the stringent requirements of the continuously improving energy codes while complying with preservation guidelines.



Office

- ENERGY STAR Score: **20**
- Year built: **1952**
- Number of buildings on lot: **1**
- Number of floors in primary building: **22**

Weather-Normalized Energy Use Intensity (EUI)

The EUI for this property is **349.9**.
This is more than **94%** of properties of this type.

Indoor Water Use Intensity (WUI)

The WUI for this property is **Not Available.**

Greenhouse Gas Intensity

The GHG intensity for this property is **11.33**.
This is more than **93%** of properties of this type.

Gross Floor Area

The gross floor area for this property is **219,469**.
This is larger than **55%** of properties of this type.

380 PARK AVENUE,
Manhattan, 10022

Office

349.9

Weather Normalized Source EUI (kBTU/ft²)

ENERGY STAR Score: **20**
Year built: **1952**
Gross Floor Area: **219,469 ft²**
Number of buildings on lot: **1**
Number of floors in primary building: **22**

Distribution for Office:

Figure 7: The Energy Use Intensity of Lever House in 2014 as reported in the NYC Energy & Water Benchmarking Map (Image by the author—source: NYC 2016).

RETROFITTING LEVER HOUSE WITH GLAZING SHIELDS

One of the objectives of this case study is to illustrate the limited impact of glazing shields on the architectural identity of Lever House (Fig. 8, 9, 10, and 11). This retrofit method can preserve the historic characteristics of the building, unlike the intrusive and destructive facade retrofit solutions. Another objective is to show that this economically feasible and environmentally friendly retrofit method can significantly improve the performance of the original facade and the overall energy efficiency of the building, offering comparative performance results to new replacement systems. Also, it is worth noting that the window-washing gondola of this 1952 building, which operates around the parapet wall on tracks, could make it possible to install the glazing shields without the need for additional scaffolds or custom installation platforms due to the lightweight nature of the panels. This in turn could result in a shorter payback period and a better ROI.

Note: Given that this is a before-and-after comparative process, and in order to take advantage of this case study and use it as a starting point or a benchmark for other buildings with similar façade systems, the curtainwall analyzed in this case study is not an exact replica of the one at Lever House. Instead, the curtainwall illustrated in Case 1 in the system based studies above was used, which shares the primary attributes of the curtainwall system at Lever House.

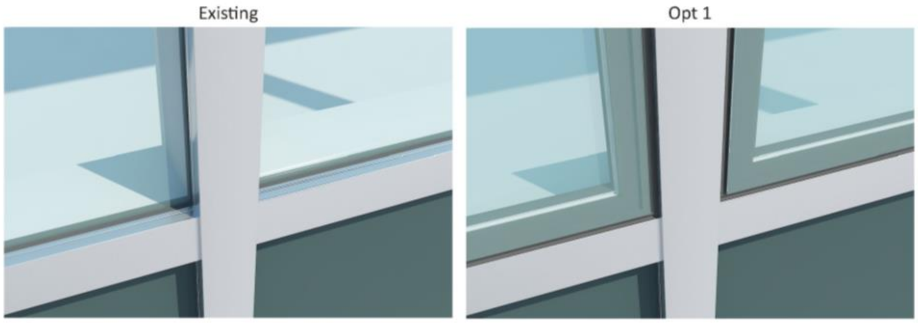


Figure 8: Close-up 3d images of a typical curtainwall joint at Lever House showing the existing and the proposed option 1 scenario with glazing shields on the vision panels only (Image by the author).

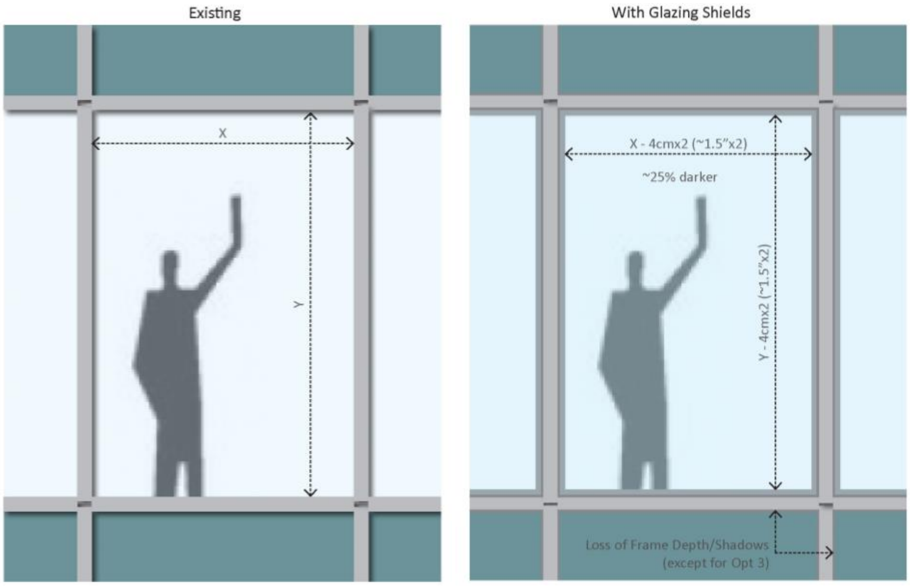


Figure 9: 2d elevation diagrams showing the visual impact of the glazing shields on a curtainwall system with exposed frames similar to the one at Lever House (Image by the author).

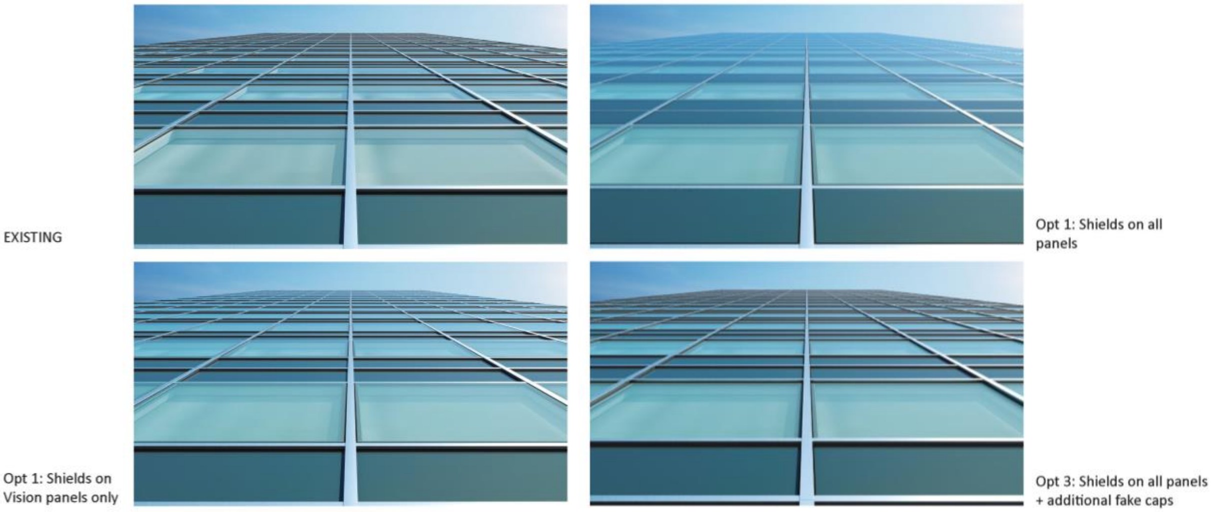
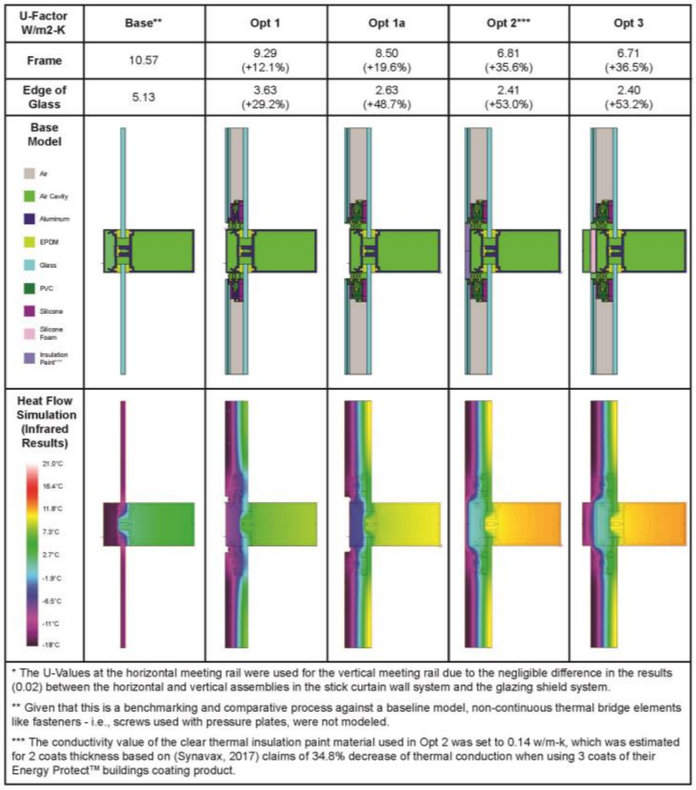


Figure 10: 3d rendered views of a partial facade at Lever House showing the existing and the proposed scenarios with glazing shields (Image by the author).

Figure 11: A partial facade view of Lever House showing the existing curtainwall (Left) and Opt 1 intervention scenario (right). (Image courtesy of SOM, edited by the author)

DATA



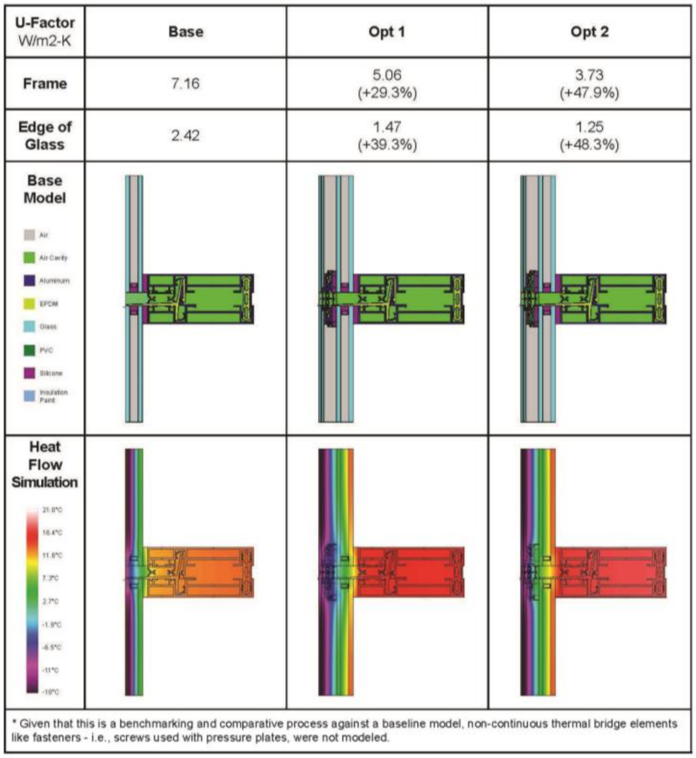
U-Factor W/m2-K	Base**	Opt 1	Opt 1a	Opt 2***	Opt 3
Frame	10.57	9.29 (+12.1%)	8.50 (+19.6%)	6.81 (+35.6%)	6.71 (+36.5%)
Edge of Glass	5.13	3.63 (+29.2%)	2.63 (+48.7%)	2.41 (+53.0%)	2.40 (+53.2%)

* The U-Values at the horizontal meeting rail were used for the vertical meeting rail due to the negligible difference in the results (0.02) between the horizontal and vertical assemblies in the stick curtain wall system and the glazing shield system.

** Given that this is a benchmarking and comparative process against a baseline model, non-continuous thermal bridge elements like fasteners - i.e., screws used with pressure plates, were not modeled.

*** The conductivity value of the clear thermal insulation paint material used in Opt 2 was set to 0.14 w/m-k, which was estimated for 2 coats thickness based on (Synavax, 2017) claims of 34.8% decrease of thermal conduction when using 3 coats of their Energy Protect™ buildings coating product.

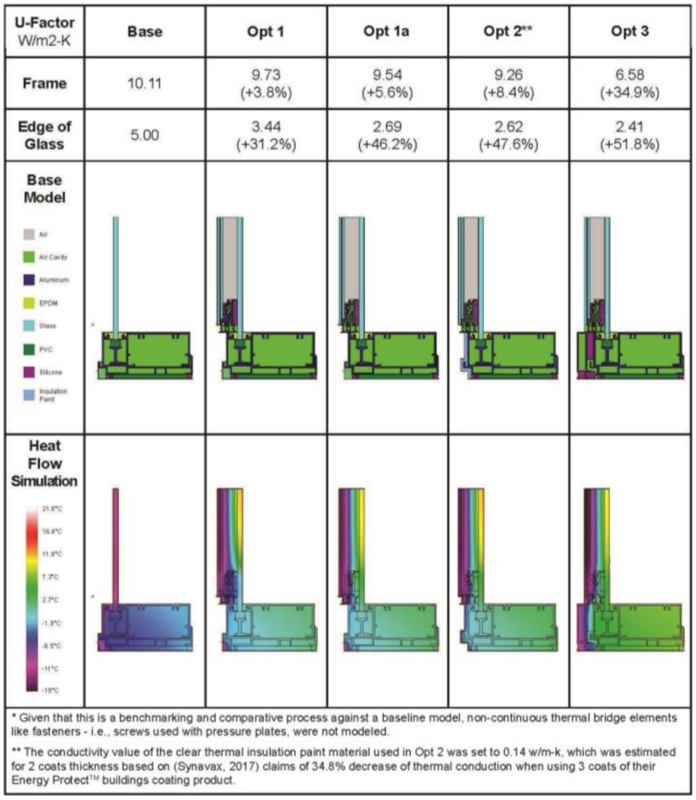
Figure 12: Thermal simulations at the horizontal meeting rail of Case 1 system showing the impact of each intervention scenario on the frame and edge of the glass U-Factor (Image by the author).



U-Factor W/m2-K	Base	Opt 1	Opt 2
Frame	7.16	5.06 (+29.3%)	3.73 (+47.9%)
Edge of Glass	2.42	1.47 (+39.3%)	1.25 (+48.3%)

* Given that this is a benchmarking and comparative process against a baseline model, non-continuous thermal bridge elements like fasteners - i.e., screws used with pressure plates, were not modeled.

Figure 13: Thermal simulations at the horizontal meeting rail of Case 2 system showing the impact of each intervention scenario on the frame and edge of the glass U-Factor (Image by the author).



U-Factor W/m2-K	Base	Opt 1	Opt 1a	Opt 2**	Opt 3
Frame	10.11	9.73 (+3.8%)	9.54 (+5.6%)	9.26 (+8.4%)	6.58 (+34.9%)
Edge of Glass	5.00	3.44 (+31.2%)	2.69 (+46.2%)	2.62 (+47.6%)	2.41 (+51.8%)

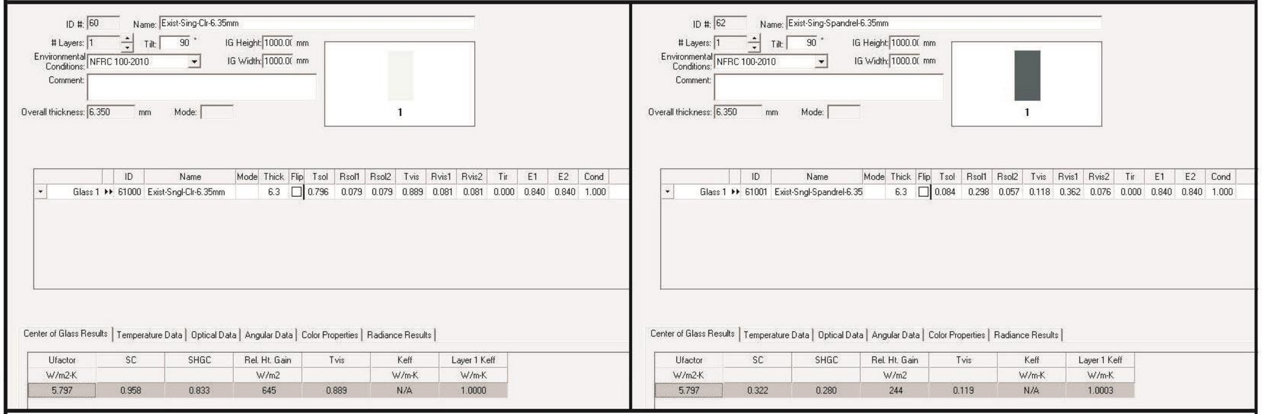
* Given that this is a benchmarking and comparative process against a baseline model, non-continuous thermal bridge elements like fasteners - i.e., screws used with pressure plates, were not modeled.

** The conductivity value of the clear thermal insulation paint material used in Opt 2 was set to 0.14 w/m-k, which was estimated for 2 coats thickness based on (Synavax, 2017) claims of 34.8% decrease of thermal conduction when using 3 coats of their Energy Protect™ buildings coating product.

Figure 14: Thermal simulations at the horizontal meeting rail of Case 3 system showing the impact of each intervention scenario on the frame and edge of the glass U-Factor (Image by the author).

Baseline (Left: Vision, Right: Spandrel)

CoG U-Factor: 5.80 W/m2-k



ID #: 60
Name: Exist-Sing-Clr-6.35mm
Layers: 1
Tilt: 90 °
IG Height: 1000.0(mm
IG Width: 1000.0(mm
Environmental Conditions: NFRC 100-2010
Comment:
Overall thickness: 6.350 mm
Mode:

		ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond
Glass 1	▸▸	61000	Exist-Sngl-Clr-6.35mm		6.3	☐	0.796	0.079	0.079	0.889	0.081	0.081	0.000	0.840	0.840	1.000

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff
W/m2-K			W/m2		W/m-K	W/m-K
5.797	0.958	0.833	645	0.889	N/A	1.0000

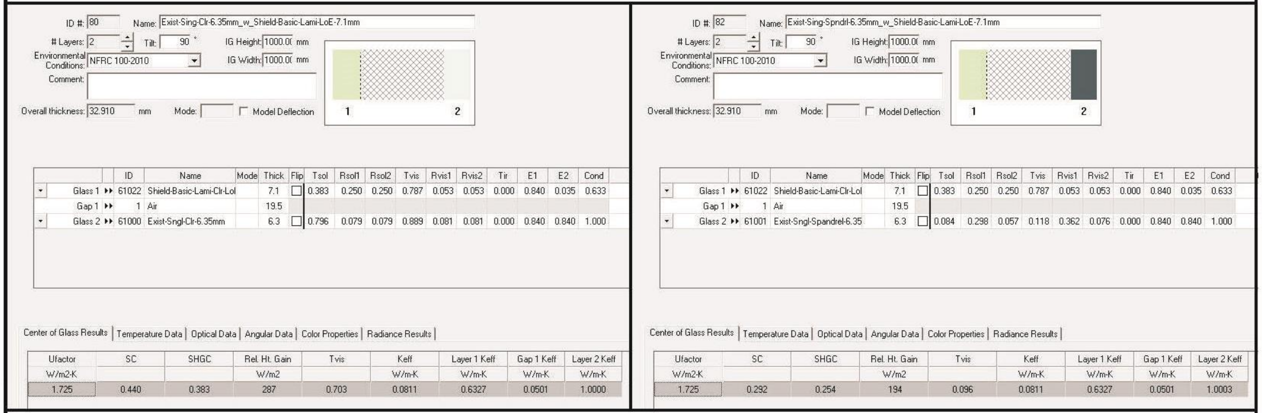
ID #: 62
Name: Exist-Sing-Spandrel-6.35mm
Layers: 1
Tilt: 90 °
IG Height: 1000.0(mm
IG Width: 1000.0(mm
Environmental Conditions: NFRC 100-2010
Comment:
Overall thickness: 6.350 mm
Mode:

		ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond
Glass 1	▸▸	61001	Exist-Sngl-Spandrel-6.35		6.3	☐	0.084	0.298	0.057	0.118	0.362	0.076	0.000	0.840	0.840	1.000

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff
W/m2-K			W/m2		W/m-K	W/m-K
5.797	0.322	0.280	244	0.119	N/A	1.0003

Opt 1 (Left: Vision, Right: Spandrel)

CoG U-Factor: 1.73 W/m2-k (+70.2%)



ID #: 80
Name: Exist-Sing-Clr-6.35mm_w_Shield-Basic-Lami-LoE-7.1mm
Layers: 2
Tilt: 90 °
IG Height: 1000.0(mm
IG Width: 1000.0(mm
Environmental Conditions: NFRC 100-2010
Comment:
Overall thickness: 32.910 mm
Mode:
☐ Model Deflection

		ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond
Glass 1	▸▸	61022	Shield-Basic-Lami-Clr-Lol		7.1	☐	0.383	0.250	0.250	0.787	0.053	0.053	0.000	0.840	0.035	0.633
Gap 1	▸▸	1	Air		19.5											
Glass 2	▸▸	61000	Exist-Sngl-Clr-6.35mm		6.3	☐	0.796	0.079	0.079	0.889	0.081	0.081	0.000	0.840	0.840	1.000

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
1.725	0.440	0.383	287	0.703	0.0811	0.6327	0.0501	1.0000

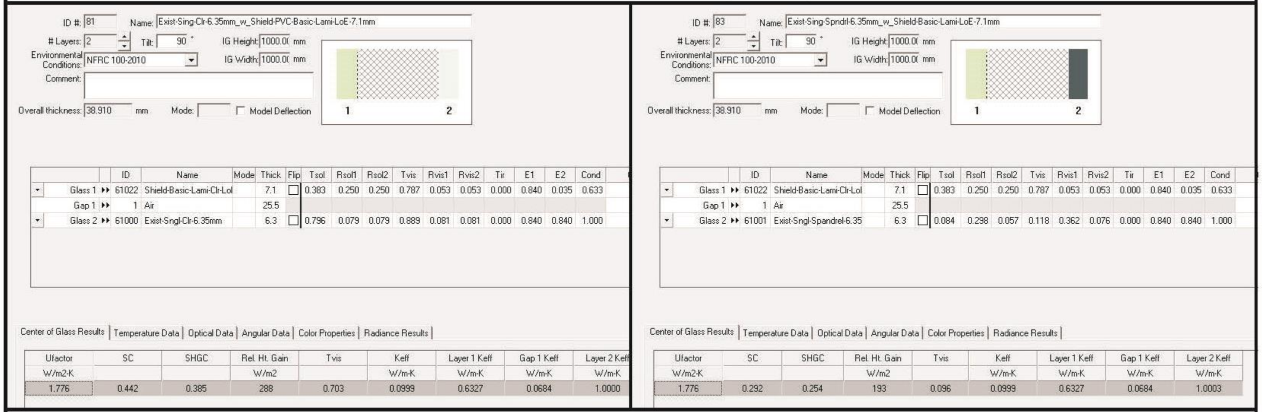
ID #: 82
Name: Exist-Sing-Spndrl-6.35mm_w_Shield-Basic-Lami-LoE-7.1mm
Layers: 2
Tilt: 90 °
IG Height: 1000.0(mm
IG Width: 1000.0(mm
Environmental Conditions: NFRC 100-2010
Comment:
Overall thickness: 32.910 mm
Mode:
☐ Model Deflection

		ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond
Glass 1	▸▸	61022	Shield-Basic-Lami-Clr-Lol		7.1	☐	0.383	0.250	0.250	0.787	0.053	0.053	0.000	0.840	0.035	0.633
Gap 1	▸▸	1	Air		19.5											
Glass 2	▸▸	61001	Exist-Sngl-Spandrel-6.35		6.3	☐	0.084	0.298	0.057	0.118	0.362	0.076	0.000	0.840	0.840	1.000

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
1.725	0.292	0.254	194	0.096	0.0811	0.6327	0.0501	1.0003

Opt 1a (Left: Vision, Right: Spandrel)

CoG U-Factor: 1.78 W/m2-k (+69.3%)



ID #: 81
Name: Exist-Sing-Clr-6.35mm_w_Shield-PVC-Basic-Lami-LoE-7.1mm
Layers: 2
Tilt: 90 °
IG Height: 1000.0(mm
IG Width: 1000.0(mm
Environmental Conditions: NFRC 100-2010
Comment:
Overall thickness: 38.910 mm
Mode:
☐ Model Deflection

		ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond
Glass 1	▸▸	61022	Shield-Basic-Lami-Clr-Lol		7.1	☐	0.383	0.250	0.250	0.787	0.053	0.053	0.000	0.840	0.035	0.633
Gap 1	▸▸	1	Air		25.5											
Glass 2	▸▸	61000	Exist-Sngl-Clr-6.35mm		6.3	☐	0.796	0.079	0.079	0.889	0.081	0.081	0.000	0.840	0.840	1.000

Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
1.776	0.442	0.385	288	0.703	0.0999	0.6327	0.0684	1.0000

ID #: 83
Name: Exist-Sing-Spndrl-6.35mm_w_Shield-Basic-Lami-LoE-7.1mm
Layers: 2
Tilt: 90 °
IG Height: 1000.0(mm
IG Width: 1000.0(mm
Environmental Conditions: NFRC 100-2010
Comment:
Overall thickness: 38.910 mm
Mode:
☐ Model Deflection

		ID	Name	Mode	Thick	Flip	Tsol	Rsol1	Rsol2	Tvis	Rvis1	Rvis2	Tir	E1	E2	Cond
Glass 1	▸▸	61022	Shield-Basic-Lami-Clr-Lol		7.1	☐	0.383	0.250	0.250	0.787	0.053	0.053	0.000	0.840	0.035	0.633
Gap 1	▸▸	1	Air		25.5											
Glass 2	▸▸	61001	Exist-Sngl-Spandrel-6.35		6.3	☐	0.084	0.298	0.057	0.118	0.362	0.076	0.000	0.840	0.840	1.000

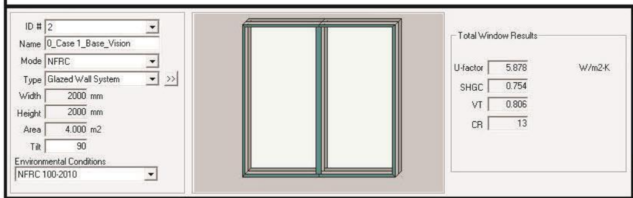
Ufactor	SC	SHGC	Rel. Ht. Gain	Tvis	Keff	Layer 1 Keff	Gap 1 Keff	Layer 2 Keff
W/m2-K			W/m2		W/m-K	W/m-K	W/m-K	W/m-K
1.776	0.292	0.254	193	0.096	0.0999	0.6327	0.0684	1.0003

* Opt 2 and 3 use the same glazing infill panel of Opt 1a.

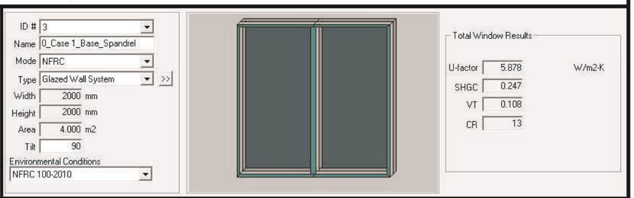
Figure 15: Glazing infill panel and center of glass (CoG) performance for Case 1 intervention scenarios (Image by the author).

Baseline (Left: Vision, Right: Spandrel)

U-Factor: 5.88 W/m2-k, CR: 13


ID # 2
Name 0_Case 1_Base_Vision
Mode NFRC
Type Glazed Wall System
Width 2000 mm
Height 2000 mm
Area 4.000 m2
Tilt 90
Environmental Conditions
NFRC 100-2010

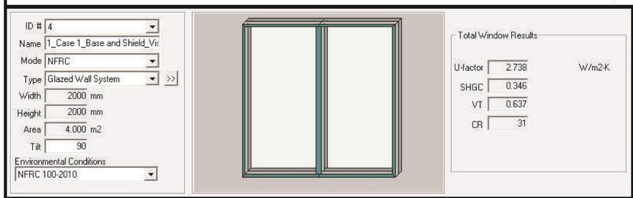
Total Window Results
U-factor 5.878 W/m2-K
SHGC 0.754
VT 0.806
CR 13


ID # 3
Name 0_Case 1_Base_Spandrel
Mode NFRC
Type Glazed Wall System
Width 2000 mm
Height 2000 mm
Area 4.000 m2
Tilt 90
Environmental Conditions
NFRC 100-2010

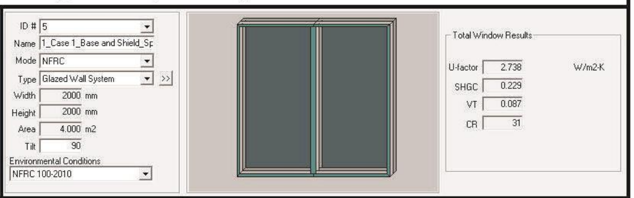
Total Window Results
U-factor 5.878 W/m2-K
SHGC 0.247
VT 0.108
CR 13

Opt 1 (Left: Vision, Right: Spandrel)

U-Factor: 2.74 W/m2-k (+53.4%), CR: 31 (+238.5%)


ID # 4
Name 1_Case 1_Base and Shield_Vi
Mode NFRC
Type Glazed Wall System
Width 2000 mm
Height 2000 mm
Area 4.000 m2
Tilt 90
Environmental Conditions
NFRC 100-2010

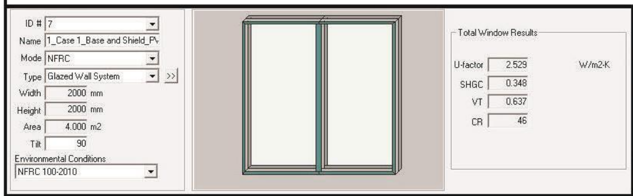
Total Window Results
U-factor 2.738 W/m2-K
SHGC 0.346
VT 0.637
CR 31


ID # 5
Name 1_Case 1_Base and Shield_Sp
Mode NFRC
Type Glazed Wall System
Width 2000 mm
Height 2000 mm
Area 4.000 m2
Tilt 90
Environmental Conditions
NFRC 100-2010

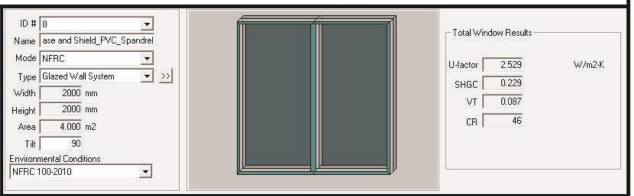
Total Window Results
U-factor 2.738 W/m2-K
SHGC 0.229
VT 0.087
CR 31

Opt 1a (Left: Vision, Right: Spandrel)

U-Factor: 2.53 W/m2-k (+57.0%), CR: 45 (+346.2%)


ID # 7
Name 1_Case 1_Base and Shield_P
Mode NFRC
Type Glazed Wall System
Width 2000 mm
Height 2000 mm
Area 4.000 m2
Tilt 90
Environmental Conditions
NFRC 100-2010

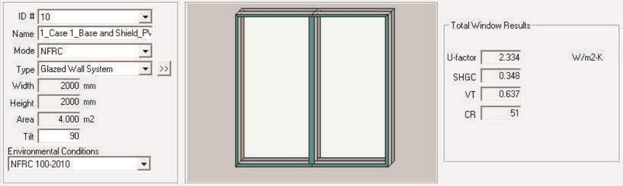
Total Window Results
U-factor 2.529 W/m2-K
SHGC 0.348
VT 0.637
CR 46


ID # 8
Name ase and Shield_PVC_Spandrel
Mode NFRC
Type Glazed Wall System
Width 2000 mm
Height 2000 mm
Area 4.000 m2
Tilt 90
Environmental Conditions
NFRC 100-2010

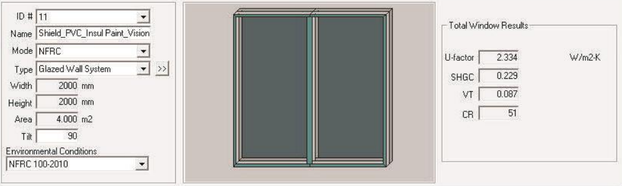
Total Window Results
U-factor 2.529 W/m2-K
SHGC 0.229
VT 0.087
CR 46

Opt 2 (Left: Vision, Right: Spandrel)

U-Factor: 2.33 W/m2-k (+60.4%), CR: 51 (+392.3%)


ID # 10
Name 1_Case 1_Base and Shield_P
Mode NFRC
Type Glazed Wall System
Width 2000 mm
Height 2000 mm
Area 4.000 m2
Tilt 90
Environmental Conditions
NFRC 100-2010

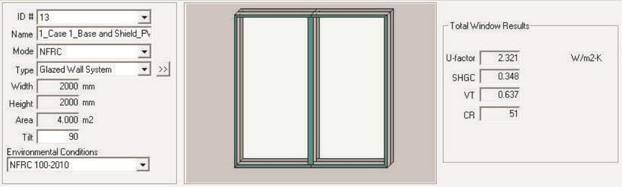
Total Window Results
U-factor 2.334 W/m2-K
SHGC 0.348
VT 0.637
CR 51


ID # 11
Name Shield_PVC_Insul Paint_Vision
Mode NFRC
Type Glazed Wall System
Width 2000 mm
Height 2000 mm
Area 4.000 m2
Tilt 90
Environmental Conditions
NFRC 100-2010

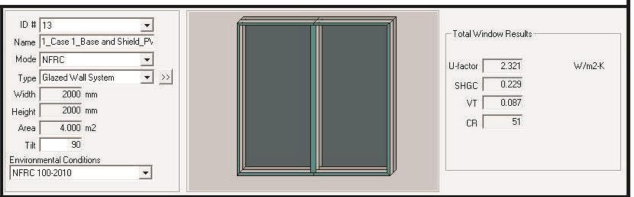
Total Window Results
U-factor 2.334 W/m2-K
SHGC 0.229
VT 0.087
CR 51

Opt 3 (Left: Vision, Right: Spandrel)

U-Factor: 2.32 W/m2-k (+60.5%), CR: 51 (+392.3%)


ID # 13
Name 1_Case 1_Base and Shield_P
Mode NFRC
Type Glazed Wall System
Width 2000 mm
Height 2000 mm
Area 4.000 m2
Tilt 90
Environmental Conditions
NFRC 100-2010

Total Window Results
U-factor 2.321 W/m2-K
SHGC 0.348
VT 0.637
CR 51


ID # 13
Name 1_Case 1_Base and Shield_P
Mode NFRC
Type Glazed Wall System
Width 2000 mm
Height 2000 mm
Area 4.000 m2
Tilt 90
Environmental Conditions
NFRC 100-2010

Total Window Results
U-factor 2.321 W/m2-K
SHGC 0.229
VT 0.087
CR 51

- U-factor: Heat Transfer Coefficient. The smaller the value the better, which means lower rate of heat flow.
- SHGC (Solar Heat Gain Coefficient): Ranges between 0-1. High values signifies high solar heat gain and low value low SHG.
- VT (Visible Transmittance): The amount of visible light transmitted through the glazing. Ranges between 0-1. High values, high VT.
- CR (Condensation Resistance): Ranges between 0-100. The higher the value, the better the condensation resistance.

Figure 16: Total thermal performance of Case 1 glazing system for each intervention scenario (Image by the author).

ID	Name	O	W...	#	Gla:
0	N_Existing	N	1.0	3	Sing
1	N_w/ Shield	N	1.0	3	Cas
2	N_w/ Shield_PVC	N	1.0	3	Cas
3	N_w/ Shield_PVC_Paint	N	1.0	3	Cas
4	N_w/ Shield_PVC_Cap	N	1.0	3	Cas
5	N_w/ Shield_Vision only	N	1.0	3	Cas
6	S_Existing	S	1.0	3	Sing
7	S_w/ Shield	S	1.0	3	Cas
8	S_w/ Shield_PVC	S	1.0	3	Cas
9	S_w/ Shield_PVC_Paint	S	1.0	3	Cas
10	S_w/ Shield_PVC_Cap	S	1.0	3	Cas
11	S_w/ Shield_Vision only	S	1.0	3	Cas
12	E_Existing	E	1.0	3	Sing
13	E_w/ Shield	E	1.0	3	Cas
14	E_w/ Shield_PVC	E	1.0	3	Cas
15	E_w/ Shield_PVC_Paint	E	1.0	3	Cas
16	E_w/ Shield_PVC_Cap	E	1.0	3	Cas
17	E_w/ Shield_Vision only	E	1.0	3	Cas
18	W_Existing	W	1.0	3	Sing
19	W_w/ Shield	W	1.0	3	Cas
20	W_w/ Shield_PVC	W	1.0	3	Cas
21	W_w/ Shield_PVC_Paint	W	1.0	3	Cas
22	W_w/ Shield_PVC_Cap	W	1.0	3	Cas
23	W_w/ Shield_Vision only	W	1.0	3	Cas

Geometry and Materials

Height: 3.75 m
Width: 5.25 m
Depth: 5 m
Floor Area: 26.25 m2
Orient.: North
Wall: Default (from Project Prop.)

Environment

Lighting Control: None
Natural Ventilation: ☐
HVAC Economizer: None
Lighting Load: 10.76 W/m2
Equipment Load: 8.07 W/m2
people: 1 people

	Baseline Model Cost (Existing)	Opt 1 Cost (w/ Shield)	Opt 1a Cost (w/ Shield_PVC)	Opt 2 Cost (w/ Shield_PVC_Paint)	Opt 3 Cost (w/ Shield_PVC_Cap)	Opt 4 Cost (w/ Shield_Vision only)
Frame:	$0.00	$0.00	$0.00	$127.15	$317.87	$0.00
Glazing System:	$0.00	$2,260.42	$2,281.90	$2,281.90	$2,282.01	$2,260.42
Shading System:	$0.00	$0.00	$0.00	$0.00	$0.00	$0.00
Spandrels:	$0.00	$2,002.88	$2,021.25	$2,021.25	$2,021.08	$0.00
Total:	**$0.00**	**$4,263.30**	**$4,303.15**	**$4,430.29**	**$4,620.96**	**$2,260.42**
Total (Adjusted):	**$0.00**	**$4,263.30**	**$4,303.15**	**$4,430.29**	**$4,620.96**	**$2,260.42**

ID	Total Energy (MJ/m	Peak Demand Gas (	Peak Gas Date	Peak Demand Elec.	Peak Elec. Date	Heating (MJ/m2-yr	Cooling (MJ/m2-yr)	Lighting (MJ/m2-yr	Fans (MJ/m2-yr)	Avg. Daylight Illum	Avg. Discomfort Gl:	Avg. Thermal Comf	CO2 emissions (kg/
1	492.45	152.55	JAN 23 06:15 AM	61.63	JUL 13 04:00 PM	83.06	145.58	122.08	141.73	348.03	6.14	84.74%	48.62
2	496.30	177.92	FEB 6 06:15 AM	61.49	JUL 13 04:00 PM	86.46	146.26	122.08	141.51	348.03	6.14	84.58%	48.85
3	494.94	145.14	FEB 9 06:15 AM	61.46	JUL 13 04:00 PM	84.86	146.56	122.08	141.44	348.03	6.14	84.63%	48.79
4	494.27	144.68	FEB 9 06:15 AM	61.40	JUL 13 04:00 PM	84.59	146.50	121.85	141.33	348.30	6.14	84.64%	48.73
5	537.48	163.85	FEB 6 06:30 AM	59.31	JUL 13 04:00 PM	158.08	121.20	122.08	136.12	348.03	6.14	80.96%	49.24
6	859.60	219.24	FEB 6 06:15 AM	100.93	AUG 25 10:00 AM	136.57	315.67	122.08	285.28	1,752.56	7.85	80.68%	85.35
7	566.64	152.11	FEB 27 06:15 AM	71.06	AUG 25 10:00 AM	16.74	253.72	122.08	174.10	1,308.41	7.34	89.27%	60.42
8	566.75	143.63	JAN 23 06:15 AM	70.81	AUG 25 10:00 AM	18.05	252.95	122.08	173.68	1,308.41	7.34	89.16%	60.36
9	566.85	141.57	JAN 23 06:15 AM	70.79	AUG 25 10:00 AM	17.51	253.61	122.08	173.64	1,308.41	7.34	89.20%	60.40
10	566.29	140.70	JAN 23 06:15 AM	70.72	AUG 25 10:00 AM	17.40	253.54	121.85	173.51	1,309.06	7.34	89.20%	60.34
11	536.20	154.20	DEC 26 06:15 AM	67.51	AUG 25 10:00 AM	51.64	201.41	122.08	161.07	1,308.41	7.34	86.69%	55.14
12	943.30	237.05	FEB 6 06:15 AM	99.59	JUL 13 08:30 AM	250.99	233.88	122.08	336.35	779.65	8.00	76.33%	87.93
13	580.08	152.08	FEB 6 06:15 AM	73.68	JUL 17 08:15 AM	51.67	198.25	122.08	208.08	580.70	7.44	85.82%	59.89
14	582.59	151.99	FEB 6 06:15 AM	73.21	JUL 17 08:15 AM	54.57	198.43	122.08	207.51	580.70	7.44	85.63%	60.00
15	581.63	152.02	FEB 6 06:15 AM	73.23	JUL 17 08:15 AM	53.29	198.81	122.08	207.45	580.70	7.44	85.69%	59.97
16	580.96	151.83	FEB 6 06:15 AM	73.15	JUL 17 08:15 AM	53.06	198.74	121.85	207.31	581.07	7.44	85.69%	59.91
17	595.98	175.19	FEB 6 06:15 AM	69.04	JUL 17 08:15 AM	118.35	162.90	122.08	192.65	580.70	7.44	82.22%	57.83
18	1,002.20	236.79	FEB 6 06:15 AM	124.12	JUL 20 04:15 PM	163.77	337.51	122.08	378.85	1,593.46	7.96	79.45%	99.25
19	633.97	163.03	FEB 7 06:15 AM	85.81	JUL 20 04:15 PM	24.13	264.86	122.08	222.91	1,191.35	7.43	88.44%	67.29
20	634.47	166.05	FEB 7 06:15 AM	85.55	JUL 20 04:15 PM	26.11	264.16	122.08	222.12	1,191.35	7.43	88.25%	67.23
21	634.42	164.56	FEB 7 06:15 AM	85.53	JUL 20 04:15 PM	25.33	264.83	122.08	222.19	1,191.35	7.43	88.31%	67.27
22	633.72	164.02	FEB 7 06:15 AM	85.46	JUL 20 04:15 PM	25.18	264.72	121.85	221.97	1,191.93	7.43	88.31%	67.20

Figure 17: Overview of the basic input values in Comfen and the simulation results of all the intervention scenarios for each elevation of Lever House (Image by the author).

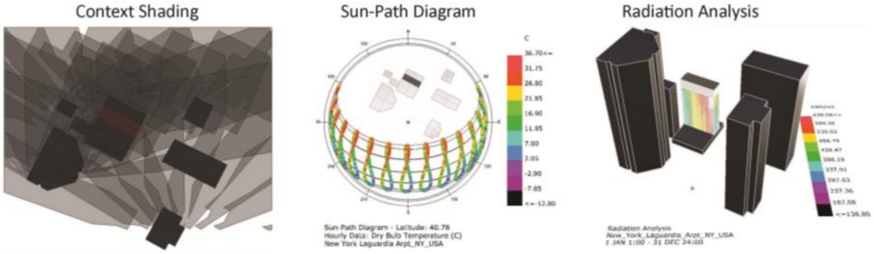
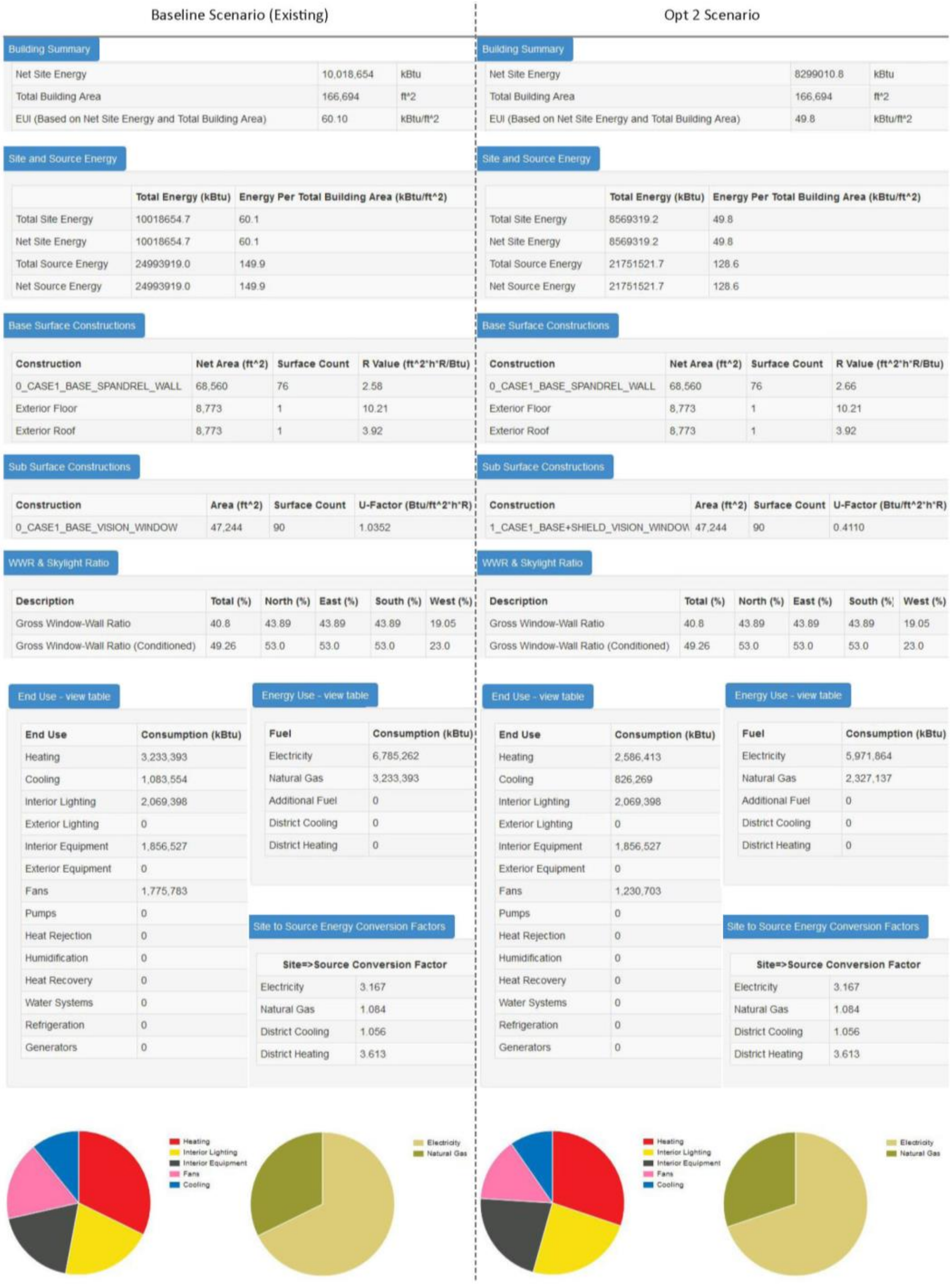


Figure 18: Context shading, sun path, and radiation analysis diagrams for Lever House, which were simulated as part of the energy model (Image by the author).



Baseline Scenario (Existing)

Building Summary

Net Site Energy	10,018,654	kBtu
Total Building Area	166,694	ft^2
EUI (Based on Net Site Energy and Total Building Area)	60.10	kBtu/ft^2

Site and Source Energy

	Total Energy (kBtu)	Energy Per Total Building Area (kBtu/ft^2)
Total Site Energy	10018654.7	60.1
Net Site Energy	10018654.7	60.1
Total Source Energy	24993919.0	149.9
Net Source Energy	24993919.0	149.9

Base Surface Constructions

Construction	Net Area (ft^2)	Surface Count	R Value (ft^2*h*R/Btu)
0_CASE1_BASE_SPANDREL_WALL	68,560	76	2.58
Exterior Floor	8,773	1	10.21
Exterior Roof	8,773	1	3.92

Sub Surface Constructions

Construction	Area (ft^2)	Surface Count	U-Factor (Btu/ft^2*h*R)
0_CASE1_BASE_VISION_WINDOW	47,244	90	1.0352

WWR & Skylight Ratio

Description	Total (%)	North (%)	East (%)	South (%)	West (%)
Gross Window-Wall Ratio	40.8	43.89	43.89	43.89	19.05
Gross Window-Wall Ratio (Conditioned)	49.26	53.0	53.0	53.0	23.0

End Use - view table

End Use	Consumption (kBtu)
Heating	3,233,393
Cooling	1,083,554
Interior Lighting	2,069,398
Exterior Lighting	0
Interior Equipment	1,856,527
Exterior Equipment	0
Fans	1,775,783
Pumps	0
Heat Rejection	0
Humidification	0
Heat Recovery	0
Water Systems	0
Refrigeration	0
Generators	0

Energy Use - view table

Fuel	Consumption (kBtu)
Electricity	6,785,262
Natural Gas	3,233,393
Additional Fuel	0
District Cooling	0
District Heating	0

Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613

Opt 2 Scenario

Building Summary

Net Site Energy	8299010.8	kBtu
Total Building Area	166,694	ft^2
EUI (Based on Net Site Energy and Total Building Area)	49.8	kBtu/ft^2

Site and Source Energy

	Total Energy (kBtu)	Energy Per Total Building Area (kBtu/ft^2)
Total Site Energy	8569319.2	49.8
Net Site Energy	8569319.2	49.8
Total Source Energy	21751521.7	128.6
Net Source Energy	21751521.7	128.6

Base Surface Constructions

Construction	Net Area (ft^2)	Surface Count	R Value (ft^2*h*R/Btu)
0_CASE1_BASE_SPANDREL_WALL	68,560	76	2.66
Exterior Floor	8,773	1	10.21
Exterior Roof	8,773	1	3.92

Sub Surface Constructions

Construction	Area (ft^2)	Surface Count	U-Factor (Btu/ft^2*h*R)
1_CASE1_BASE+SHIELD_VISION_WINDOV	47,244	90	0.4110

WWR & Skylight Ratio

Description	Total (%)	North (%)	East (%)	South (%)	West (%)
Gross Window-Wall Ratio	40.8	43.89	43.89	43.89	19.05
Gross Window-Wall Ratio (Conditioned)	49.26	53.0	53.0	53.0	23.0

End Use - view table

End Use	Consumption (kBtu)
Heating	2,586,413
Cooling	826,269
Interior Lighting	2,069,398
Exterior Lighting	0
Interior Equipment	1,856,527
Exterior Equipment	0
Fans	1,230,703
Pumps	0
Heat Rejection	0
Humidification	0
Heat Recovery	0
Water Systems	0
Refrigeration	0
Generators	0

Energy Use - view table

Fuel	Consumption (kBtu)
Electricity	5,971,864
Natural Gas	2,327,137
Additional Fuel	0
District Cooling	0
District Heating	0

Site to Source Energy Conversion Factors

	Site=>Source Conversion Factor
Electricity	3.167
Natural Gas	1.084
District Cooling	1.056
District Heating	3.613

Figure 19: OpenStudio energy model simulation results for Lever House—baseline scenario (left) and Opt 2 intervention scenario (right).

EXPLANATION

SUMMARY OF THE SYSTEM-BASED SIMULATION RESULTS AT LEVER HOUSE

- Opt 1 improved the thermal transmittance (U-Factor) of the curtainwall system by 53.4% and the condensation resistance (CR) by 238.5%.
- Opt 1a improved the thermal transmittance (U-Factor) of the curtainwall system by 57% and the condensation resistance (CR) by 346.2%.
- Opt 2 improved the thermal transmittance (U-Factor) of the curtainwall system by 60.4% and the condensation resistance (CR) by 392.3%.
- Opt 3 improved the thermal transmittance (U-Factor) of the curtainwall system by 60.5% and the condensation resistance (CR) by 392.3%.

SUMMARY OF THE PARTIAL BUILDING-BASED SIMULATION RESULTS AT LEVER HOUSE

- All intervention scenarios reduced the total energy consumption and Co2 emissions at the perimeter area zones by more than one-third and energy costs by around 30%.
- All intervention scenarios reduced peak electricity and natural gas demand between 23-34%.
- All intervention scenarios improved thermal comfort between 9-14% and reduced average glare discomfort by nearly 10%.
- All intervention scenarios provided more than 100% ROI (from energy savings only) by the end of the estimated 20-25 year service life of the glazing shields.
- All scenarios reduced the average daylight illuminance levels by about 25%. However, even on the north side of the building, which normally receives less daylight in the Northern hemisphere, the average levels remained around 450 lux, which is within the recommended range (300-500 lux) for detailed office work (FIG. 17).

SUMMARY OF THE FULL BUILDING-BASED SIMULATION RESULTS AT LEVER HOUSE

The total energy savings, simple payback period, and ROI results shown in this section are related to the Opt 2 scenario with the glazing shields installed on the vision panels only.

By comparing the simulation results of this scenario to the simulation results of the baseline scenario (Fig. 19), the following percentages were found:

- Total site energy use intensity (EUI) was reduced by 17.1%
- Electricity consumption was reduced by 12%
- Natural gas consumption was reduced by 28%

By using the site-to-source conversion rates in (Fig. 19), the actual site EUI and energy uses were calculated based on the reported source EUI for Lever House in 2014 (Fig. 7), which is 350 kBtu/ft^2/yr as follows:

{X * 3.167} + {Y * 1.084} = 350 kBtu/ft2/yr
where:
X: electricity
Y: natural gas
Percentage of electricity use to the total energy consumption in the baseline scenario = 67.73%
Percentage of natural gas use to the total energy consumption in the baseline scenario = 32.27%
=> X = 2.1 Y
=> {2.1 Y * 3.167} + {Y * 1.084} = 350
=> Y = 45.25 kBtu/ft2/yr
=> X = 95.03 kBtu/ft2/yr
=> Actual site EUI = 140.28 kBtu/ft^2/yr

=> Actual estimated reduction in electricity consumption = 95.03 * 12% = 11.4 kBtu/ft^2/yr
=> Actual estimated reduction in natural gas consumption = 45.25 * 28% = 12.67 kBtu/ft^2/yr
=> Actual estimated reduction in site EUI = 24.07 kBtu/ft^2/yr

=> Total building energy reduction annually for the tower portion is:

24.07 kBtu/ft^2/yr * 166,694 ft^2 (total floor area - Fig. 19) = 4,012,325 kBtu
=> Electricity (47.36%) = 1,900,237 kBtu / 3.412 (conversion rate) = 556,928 kWh
=> Natural Gas (52.64%) = 2,112,088 kBtu / 100 (conversion rate) = 21,121 therms

According to the U.S. Bureau of Labor Statistics (BLS 2017):
The average price of 1 kWh of electricity in NYC in 2017 = 19.4 cents
The average price of 1 therm of utility (piped) gas in NYC in 2017 = $1.130
=> Annual savings on Electricity = $108,044
=> Annual savings on Natural Gas = $23,867
=> Total Estimated Annual Energy Savings = $131,911

Simple Payback Period & ROI:
Total vision panels area = 47,244 ft^2
Total frame area = 10,422 ft^2 (47,244 vision + 68,560 spandrel = 115,804 ft2 * 0.09 ft^2 exposed frame area per 1 ft^2 of Lever House CW).
=> The total initial cost = $960,109 {$953,856 (glazing shields on vision panels only = 47,244 * $20.19) + $6,253 (thermal insulation paint on all frames = 10,422 ft2 * $0.6)}
=> The simple payback period from energy savings only = $960,109 / $131,911 = 7.3 years
=> The estimated return on investment over the typical 20-25 year service life of glazing shields:
Over 20 years: 20 / 7.3 = 274%
Over 25 years: 25 / 7.3 = 343%

CONCLUSION AND FUTURE WORK

The purpose of this paper is to present the concept of a patent-pending, external window upgrade system and non-intrusive facade retrofit method. The technology would work with most types of windows and curtainwalls and provides a cost-effective solution to be adopted by the majority of the existing building stock. The paper analyzed the impact of the glazing shields on the thermal performance of different glazing systems, and a case study using Lever House in New York City illustrated their impact on the visual appearance and overall energy performance of the building. The study also analyzed the economic feasibility of this facade retrofit solution by calculating the estimated energy savings, simple payback period, and ROI.

The system-based simulation results showed that using the glazing shields can improve the insulation properties (total system U-Factor) of single-pane window systems by over 50% and improve their condensation resistance by over 240%. The building-based simulation results for Lever House in New York City showed that adding the glazing shields to the exterior of the vision panels only along with 2 coats of thermal insulation paint on caps can reduce heating energy consumption by about 28% and cooling energy consumption by about 12%. As a result, savings on energy bills is estimated to be nearly 20% per year and the simple payback period is projected to be ~85% shorter than that in window replacement, offering ~300% ROI over the estimated 20-25 year service life of the glazing shields.

With regards to future work, we are currently in the process of building a number of prototypes and mockups to validate the performance of the glazing shields per industry standards at an independent testing facility. We plan to test the glazing shields for condensation resistance through accelerated weathering; air, water, and structural performance; and dynamic water penetration under a 130mph wind pressure, which in turn, will allow us to test how effective is the locking mechanism in keeping the panels in place under high wind pressures. Some of the standard tests that we will conduct include the ASTM E 2190 Standard Specification for Insulating Glass Unit Performance and Evaluation, the ASTM E 283 Air Infiltration Test, the ASTM E 331 Static Water Penetration Test, the ASTM E 330 Structural Performance Test, and the AAMA 501.1 Dynamic Water Penetration Test.

The performance mockups will also help us analyze the visual impact in the real world and test the installation method in the field. This in turn will enable us to determine the required installation time and the ideal cleaning process to ensure both the original and new glass surfaces that will be adjacent to the newly formed air gap are clean when the panels are installed.

Future work also includes validating the concept of the second generation—the adaptive glazing shields—which would support 3rd party active/smart window technologies like electrochromic/dynamic glazing in a self-sufficient manner for the first time using the latest clear photovoltaic (vision PV) coating technologies. The future mount-and-play, cleantech panels would make it economically feasible for existing buildings to enjoy many further benefits through automation and in an environmentally sustainable manner.

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