Each decade commercial building energy efficiency improves with the deployment of new technologies and the adoption of eco-conscious design. The challenge is how to reduce energy consumption of the aging building stock with an acceptable return on investment (ROI). The average age of a U.S. commercial building is 53 years and approximately 75% of the U.S. building stock was built prior to 2000. A high percentage of these buildings have a site Energy Use Intensity (EUI) greater than 131 kBtu per square foot with heating, cooling, and ventilation accounting for 78% percent of the EUI. A major contributor to the high EUI are thermally inefficient single-pane windows with non-thermally broken frames.

The status quo for addressing poor performing windows and high utility bills has been to do nothing and live with the problem, or fully replace the window or façade systems with new windows. Reglazing the building with dual-pane, high performance windows can have a measurable, positive effect on the building's energy efficiency, but the operating payback is typically fifteen to thirty years due to the limited thermal performance improvement coupled with the high capital cost to replace the entire window system. The replacement rate for single pane windows is only 1.5% per year according to the U.S. Department of Energy (DOE) because the energy payback period is not financially attractive and tenant disruption or displacement can be challenging and costly.

Sustainix Enthermal™ is a novel glazing approach that offers a path forward. The cavity between the two panes of glass is fully evacuated, creating a vacuum space that significantly reduces window u-factor by eliminating convective heat transfer, reducing conductive heat transfer, and reducing solar radiation through the incorporation of a high-performance low-emissivity (Low-E) coating in the cavity. As shown in *Figure 1*, Enthermal vacuum insulated glass (VIG) reduces building solar heat gain by up to 60% and heat loss by up to 45%. Enthermal has a center of glass (COG) u-factor of 0.049 Btu/hr-ft^2-°F compared to full window replacement technology, double pane insulating glass with a Low-E coating and argon gas in the cavity, COG u-factor of 0.25 Btu/hr-ft^2-°F, an 80% improvement. This leads to material energy savings and emissions reductions from improved building envelope efficiency.

A unique feature of Enthermal is the slim, 8-mm unit profile, which affords the option to replace only the glass in a single pane or double pane window system and reduces reglazing CapEx cost by up to fifty percent compared to full window replacement.

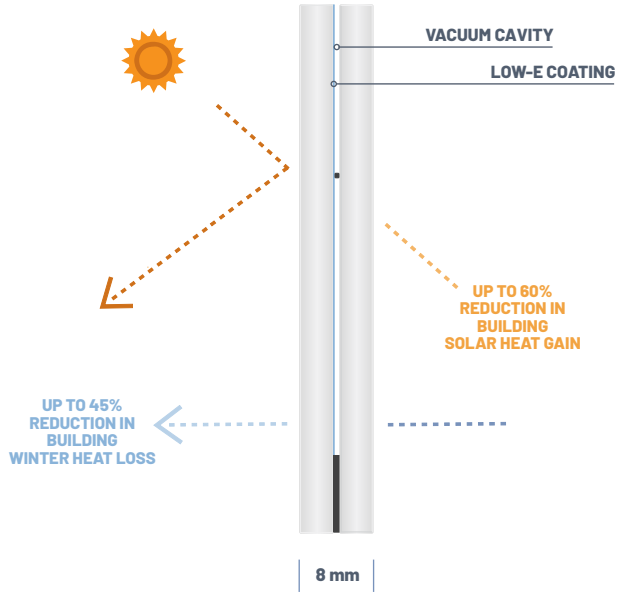

Figure 1: Enthermal Vacuum Insulated Glass

GLASS-ONLY RETROFITS

The only viable glazing option for improving an older building's envelope energy efficiency has been to remove the existing glass and frame system and replace it with a new window system. Retrofitting single pane clear windows isn't possible without a thin profile alternative. Enthermal's thin 8-mm profile changes this dynamic by enabling the retention of existing frames with the addition of new gaskets and/or inserts to fill the frame pocket. Its significant u-factor gains compensate for the limited u-factor performance of the existing frames, resulting in a window system that outperforms a double pane unit with a high-performance Low-E coating, argon gas in the cavity, and new thermally broken frames.

> *"Office buildings from the mid-20th century offer significant opportunities for increasing value and reducing environmental impact through energy-efficient retrofits.[1]"*
>
> *- American Institute of Architects*

1. American Institute of Architects (AIA), "Renovate, retrofit, reuse: Uncovering the hidden value in America's existing building stock;" Katharine Logan; 2019; http://content.aia.org/sites/default/files/2019-07/.

Company field research shows a high percentage of buildings constructed between 1950 and 2000 have frames that are viable for an Enthermal glass-only retrofit. The Enthermal retrofit procedure is performed by local glazier from inside the building avoiding the need for exterior

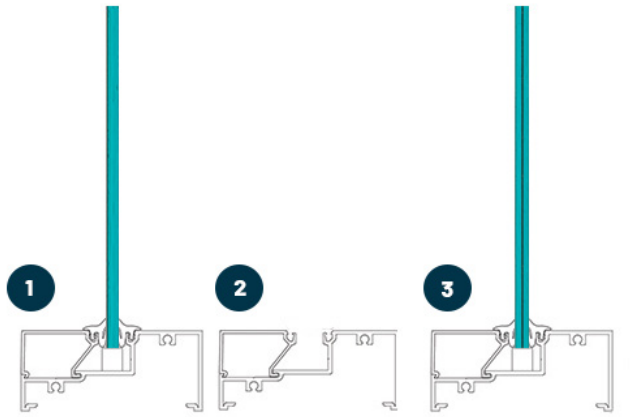

Figure 2: Enthermal Glass-Only Retrofit Procedure

cranes or scaffolding, and is faster and less disruptive to the occupants, compared with a full window replacement. *Figure 2* and the following glazing sequence detail the three simple steps for an Enthermal glass-only retrofit.

1. **Remove Existing Glazing:** Remove weather seal caulking, inner zipper gaskets, lower sash or frame cover, setting blocks, single pane glass, and outer zipper gaskets.

2. **Clean and Repair Frame:** Remove excess weather seal caulking, clean the frame pocket cavity, tighten frame mounting if required, and weather strip air infiltration areas.

3. **Install Enthermal Glazing:** Install new high-durability outer zipper gaskets, insert Enthermal unit into the frame cavity with optional U-channel gasket, install new setting blocks, re-install the sash or frame cover, install new high-durability inner zipper gaskets, apply new weather sealing caulk, and finally clean the frame and glass.

The Enthermal glass-only retrofit typically takes less than thirty minutes to complete per glazing, which significantly reduces tenant disruption and avoids tenant displacement, a major reason poor performing windows are not being replaced.

The capital cost required for an Enthermal glass-only retrofit is significantly lower than for full window replacement. The glass-only retrofit eliminates numerous costly steps associated with a full glazing replacement - engineering design; glazing demolition; glazing opening repair; glazing opening abatement, if required; cost of thermally broken frames; and increased shipping weight. The building modeled in this case study has 53,769 ft^2 of floor space and a 35% Window to Wall Ratio (WWR). The full glazing replacement capital cost was $1,756,176 ($150.00 per ft^2 of glazing) versus the Enthermal glass-only retrofit of $750,478 ($64.10 per ft^2 of glazing), a 57% reduction. The whole building energy model definition and key parameters, energy savings, and ROI calculations are covered in the following sections. In addition to energy savings, the Enthermal retrofit qualifies for the Internal Revenue Service (IRS) 179D Energy Efficient Buildings Tax Deduction (179D) and may qualify for federal and state rehabilitation tax credits (RTCs) that materially reduce the capital expenses.

STUDY APPROACH

As a case study, Energetics Consulting Engineers, LLC conducted a whole building energy analysis to understand the impact of an Enthermal glass-only retrofit versus a double pane window with a Low-E coating full replacement relative to the existing single pane windows. The whole building energy modeling offers a detailed examination of an entire building's systems and its key parameters, including heating and cooling, pumps and ventilation, lighting, plug and process loads, occupancy schedules, and the envelope.

MODELED BUILDING

A commercial office building in New York City (NYC) was modeled for 2024 energy consumption, energy costs, and operating CO_2e emissions to highlight the value of an Enthermal glass-only retrofit. An 11-story, class B building with strip windows was modeled at 35% WWR as shown in *Figure 3*. The building has a floor area of 53,769 ft^2 with each floor being 100 feet by 50 feet with a 20-foot by 10-foot core. The glazing area was 11,708 ft^2 with an average unit glazing opening size of 6.00 feet by 3.95 feet.

The model parameters were selected from pre-1980 buildings with whole building site EUI of 131 kBtu per ft^2. Heating was modeled with a gas-fired boiler with 78% gross seasonal efficiency. Cooling was modeled with a chiller having a

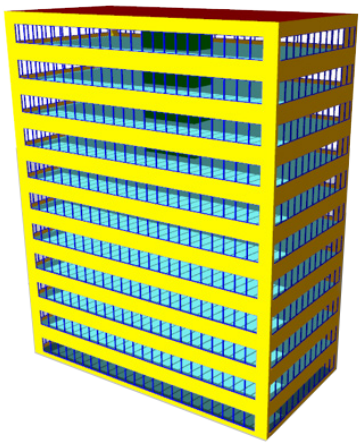

Figure 3: Modeled Class B Office Building

seasonal COP of 2.78. Mechanical ventilation was modeled at 0.55 W/cfm for supply fans, and 0.42 W/cfm for extract fans, the minimum flow rate was set at 40%, and motor efficiency was 85%. These ventilation values accounted for 20% of duct losses in the HVAC system. The occupancy schedule was 6:00 AM to 10:00 PM Monday through Friday, with half occupancy on Saturday, and no occupancy on Sunday. Occupancy sensible gains (people density) were modeled at 0.433 W/ft^2, plug loads were 0.9 W/ft^2, and ambient lighting loads were 0.98 W/ft^2.

The following building u-values (Btu/hr-ft^2-°F) were used in the model: external walls (0.332), roof (0.103), and windows varied by glazing type. The opaque envelope air infiltration was 1.835 cfm/ft^2, existing glazing air infiltration was 3.0 cfm/ft^2 based on field data for single pane windows, and the Enthermal glass-only retrofit and high-performance double pane full replacement were 0.40 cfm/ft^2. The glass-only retrofit infiltration reduction is due to new high durability gaskets, weatherstripping, and weather seal caulking. Model scenarios were run at varying window air infiltration levels, and the energy impact was limited due to the overall energy inefficiency of the building and low WWR.

GLAZING OPTIONS AND PERFORMANCE

This study compares three glazing options - keep the existing windows (single pane clear glass); glass-only retrofit with Enthermal (vacuum cavity containing a Low-E coating); and full glazing replacement (high performance (HP) double pane insulating glass unit with argon gas and a Low-E coating mounted in a new frame). The same triple silver Low-E coating, 63% visible light transmission, and 0.25 SHGC, were used for the full replacement and Enthermal retrofit configurations. COG, Edge of Glass (EOG), frame areas, and u-values were used to calculate total window performance using Windows 7.8 and THERM. The existing windows have a non-thermally broken frame (NTBF), the full window replacement uses a thermally broken frame (TBF) with a single isolation bar, and the glass-only retrofit used the same NTBF as the existing window *Table 1* details the u-values for each glazing type and method.

Glazing Type	Glazing Method	u-Value (Btu/hr-ft^2-°F)		
		Frame	COG	Total Window
Single Pane Clear	Existing Glazing	1.320	1.036	1.058
HP Double Pane	Full Replacement	0.850	0.234	0.329
Enthermal	Glass-Only Retrofit	1.320	0.049	0.245

Table 1: Glazing System Performance

Due to the ultra-low Enthermal COG or vision area u-value, Enthermal significantly outperforms HP double pane windows. The total window u-value is negatively impacted by the poor NTBF u-value, but not COG.

Another significant benefit of the Enthermal glass-only retrofit is the impact on interior glass surface temperatures. Single pane glazing can lead to extreme interior glass surface temperatures in winter and summer. Radiant energy from interior glass surfaces adversely affects occupants' comfort, and HVAC systems are often designed to mitigate such cold or hot layers near the windows. The higher the summer and the lower the winter interior temperatures, the higher the HVAC operational and capital costs. *Table 2* details interior glass surface temperatures in winter and summer for the three glazing options. For the analysis, the ambient exterior winter temperature was 32° F with a winter interior space temperature of 68° F, and the ambient exterior summer temperature was 86° F with an interior space temperature of 77° F.

Season	Outside Temperature	Single Pane Clear	HP Double Pane	Enthermal
Winter	32° F	41.9° F	62.5° F	66.7° F
Summer	86° F	87.8° F	88.4° F	81.0° F

Table 2: Interior Glass Surface Temperature

Interior surface temperatures for Enthermal were found to be much closer to the interior ambient conditions compared to other glazing types. The improved interior glass temperature decreases operating costs (e.g. operation and maintenance of the HVAC for cold and hot layers) and increases occupant comfort.

Enthermal glass-only retrofits have lower embodied carbon than full glass and frame replacement. Enthermal embodied carbon (LCA A1-A3) is 4.6 kg per ft^2 versus a full frame replacement's embodied carbon of 17.7 kg per ft^2, comprised of 4.8 kg per ft^2 for a new HP double pane unit and 12.9 kg per ft^2 for a new aluminum frame. Enthermal has 74% less embodied carbon.

BUILDING ENERGY CONSUMPTION AND CARBON GENERATION

The study assessed HVAC energy consumption broken down by heating, cooling, and auxiliary (fans and pumps). Equipment energy draw (e.g. plug loads) and ambient lighting energy draw were held constant irrespective of glazing. Operational CO_2e emission reductions were calculated using carbon intensities specified by the NYC Department of Buildings (electricity CO_2e at 0.288962 kg/kWh and natural gas CO_2e at 0.18122 kg/kWh). *Table 3* shows annualized energy use and HVAC-related operating carbon emissions for the glazing options.

ENERGY AND CARBON EMISSION SAVINGS

The annual energy and carbon savings were computed using current NYC utility rates based on Con Edison bills and NYSERDA published data, $0.254 per kWh for electricity and $1.91 per therm for natural gas. *Table 4* shows annualized energy savings in kWh, percent reduction in HVAC energy, energy saving in dollars ($), energy savings per ft^2 of floor space, and reduction in operating carbon emissions per ft^2 of floor space.

Savings and emission reductions for the re-glazing projects were as follows: doing nothing with a single pane clear building meant an annual energy expense of $332,411 and annual emissions of 492 metric tons CO_2e versus the full replacement option annual energy expense of $243,069 and annual emissions of 337 metric tons CO_2e versus the Enthermal glass only retrofit option annual energy expense of $238,606 and annual emissions of 328 metric tons CO_2e.

REGLAZING INCENTIVES

There are several rehabilitation incentives available to property owners who are considering reglazing an existing building including IRS 179D, IRS 26 U.S. Code 47 Rehabilitation Tax Credit (RTC), and State Rehabilitation Tax Credits (SRTC). Older buildings with single pane windows like the one in this case study can benefit significantly from such support in lowering the capital cost required for reglazing as shown in *Table 5*.

IRS 179D: 179D is a permanent program intended to lower the barrier for property owners to implement energy efficiency improvements such as lighting, HVAC, and the building envelope for existing buildings and new

Glazing Type	Heating (Therm)	Cooling (kWh)	Auxiliary (kWh)	Total HVAC (kWh)	HVAC Emissions (kg CO_2e)	Building EUI (kBtu/ft^2/yr)
Single Pane Clear	37,285	281,268	272,291	1,646,001	357,929	131
HP Double Pane	19,779	167,866	170,398	917,798	202,768	86
Enthermal	18,536	164,728	165,664	873,501	193,893	83

Table 3: Glazing Annual Energy Consumption and Operating Carbon Emissions

Glazing Option	Heating Savings (Therm)	Cooling Savings (kWh)	Auxiliary Savings (kWh)	Energy Savings (kWh)	HVAC Energy Savings (%)	Energy Savings ($)	Energy Savings ($/$ft^2$)	Emissions Savings (kg CO_2e/ft^2)
HP Double Pane (Full Replacement)	17,505	113,402	101,893	728,203	44%	$89,342	$1.66	2.89
Enthermal (Glass-Only Retrofit)	18,749	116,540	106,627	772,500	47%	$93,805	$1.74	3.05

Table 4: HVAC Energy and Emissions Savings

construction. The deduction is available for commercial entities (e.g. corporation, s-corporation, etc.), and tax-exempt and nonprofit entities (e.g. federal, state or local government buildings).

For existing buildings like the one in this study, the deduction is determined per the following requirements: (1) $2.83 per ft^2 of floor space for whole building EUI improvement of at least 25%; (2) increase of $0.11 per ft^2 of floor space for each additional percentage point of EUI improvement above 25%; and (3) up to a maximum of $5.65 per ft^2 of floor space if EUI improvements are 50% or higher. The taxpayer must substantiate energy savings for the whole building and satisfy defined requirements. The Enthermal glass-only retrofit can realize a 179D tax deduction of $4.11 per ft^2 of floor space.

IRS RTC: The RTC was created to facilitate the rehabilitation of historic buildings and has leveraged over $116 billion to preserve more than 47,000 properties. The National Park Service (NPS) and IRS administer these programs in partnership with State Historic Preservation Offices (SHPOs). Older buildings with single pane windows may already be designated as historic (e.g. located within a historic district, which covers much of Manhattan). Alternatively, such buildings may qualify for historic designation through an established process with the NPS.

Reglazing qualifies as rehabilitation and Enthermal's ability to fit into existing window frames improves the prospects for approval by municipal entities that govern preservation of historic structures. Tax credits apply to "qualified rehabilitated buildings" and equate to 20% of qualified rehabilitation expenditures (QRE). QREs are defined as any amount chargeable to a capital account, that is incurred by a taxpayer for a property where depreciation is allowed under IRC 168. The ratable share of the rehabilitation credit is determined each year over a 5-year period. The Enthermal glass-only retrofit can realize a 20% tax credit of $135,408, inclusive of fees to establish historical status.

State RTC: State-level RTCs are available in 37 states, including New York. Owners of income-producing properties that have been approved to receive the 20% federal RTC can additionally claim an SRTC if the property is located in a qualifying census tract. To qualify for the 20% credit, the placed-in-service date must be after January 1, 2010, and the total QREs cannot exceed $5.0 million. For the 30% credit, the placed-in-service date must be after January 1, 2022, and the total QREs cannot exceed $2.5 million. The federal-level RTC application is sufficient for New York state-level benefits. Other states' RTC policies vary in terms of quantity and ability to layer on top of the federal RTCs. For this case study, an Enthermal glass-only retrofit can realize a 20% SRTC of $135,408 or a 30% SRTC of $219,451, inclusive of fees to establish historical status.

GLAZING ROI SUMMARY

Property owner ROI was calculated as total glazing costs divided by total energy and HVAC maintenance savings on an annual basis. Capital costs comprised engineering services, project management, demolition and installation labor, glazing materials, shipping, overhead expenses, and channel profit based on the NYC market for the type of building modeled, as detailed earlier in the case study. Tenant displacement costs were not included in the comparative analysis.

Table 6 details glazing ROI versus the base case and cascading incentive – IRS 179D only; IRS RTC only (20%); SRTC only (30%); IRS 179D plus IRS RTC (20%); IRS RTC plus SRTC (30%); and IRS 179D plus IRS RTC (20%) plus SRTC (30%). HVAC maintenance savings of $0.18 per ft^2 relate to 43% lower

Tax Incentives	Tax Incentive Optionality						
Enthermal Retrofit CapEx	$736,504	$736,504	$736,504	$736,504	$736,504	$736,504	$736,504
IRS 179D Deduction (Post Tax)		($70,632)		($70,632)			($70,632)
IRS RTC				($135,408)		($135,408)	($135,408)
State RTC					($219,451)	($219,451)	($219,451)
Enthermal Retrofit CapEx – with Incentives	$736,504	$665,872	$601,096	$530,464	$517,053	$381,645	$311,013

Table 5: Available Tax Deductions and Credits

Tax Incentives		Tax Incentive Optionality						
IRS 179D Deduction (post tax)			✓		✓			✓
IRS RTC				✓	✓		✓	✓
State RTC						✓	✓	✓
Glazing Options	**Heating Source**	**Glazing ROI (%)**						
Enthermal Glass-Only Retrofit	Natural Gas	13.8%	15.2%	16.9%	19.1%	19.6%	26.6%	32.5%
HP Double Pane Full Replacement	Natural Gas	5.5%	5.5%	6.7%	7.0%	7.8%	10.6%	11.4%
Enthermal Glass-Only Retrofit	Fuel Oil	16.5%	18.3%	20.3%	22.9%	23.6%	31.9%	39.0%
HP Double Pane Full Replacement	Fuel Oil	6.5%	6.5%	8.0%	8.4%	9.3%	12.7%	13.7%
Enthermal Glass-Only Retrofit	Steam	19.9%	22.0%	24.4%	27.6%	28.4%	38.5%	47.0%
HP Double Pane Full Replacement	Steam	7.9%	7.9%	9.7%	10.2%	11.3%	15.3%	16.5%

Table 6: Glazing Project Return On Investment (ROI)

peak loads and less HVAC daily variation due to improved interior glazing surface temperatures with Enthermal.

Fuel Oil #2 and District Steam energy sources were considered as alternatives to heating via natural gas. These energy sources are more expensive than natural gas on a per-kBtu-basis in New York City. The ROI for glass-only retrofits with Enthermal improved when the building heating was with Fuel Oil #2 or District Steam.

Owner ROI for Enthermal glass-only retrofits was found to be materially higher (2X to 3X) than HP double pane full replacements. The much higher ROI is driven by higher energy savings coupled with up to fifty percent (50%) lower capital costs. IRS 179D, IRS RTCs, and State RTCs further improve the ROI. Additional ROI increases can be achieved with reduction or avoidance of carbon tax penalties such as NYC LL97, BERDO, etc. or energy reduction rebates from utility companies.

CONCLUSION

Sustainix's Enthermal VIG offers property owners a compelling new glazing option to reduce HVAC energy consumption and costs compared to existing single pane glazing by up to 47% per year, lower operating carbon emissions by 3.1 kg per ft^2 per year, reduce embodied carbon by 13.1 kg per ft^2 of glazing surface area (compared to HP double pane), improve occupant comfort by raising the glass surface temperature up to 25° F in winter, and realize a 2.5X increase in glazing ROI.

The Enthermal retrofit solution delivers a higher ROI with significantly less embodied carbon than traditional full replacements due to lower capital costs, higher energy savings, and lower HVAC maintenance costs, while significantly reducing tenant disruption. The glazing ROI is further enhanced by offsetting capital costs with the IRS 179D tax deduction, IRS rehabilitation tax credit, state-level rehabilitation tax credit, and combinations thereof.

Sustainix Enthermal Glass-Only Retrofit Owner Benefits

- **60% reduction in solar heat gain**
- **45% improvement in heat loss**
- **43% lower HVAC peak and running loads**
- **$1.74 per ft^2 energy savings**
- **3.05 kg per ft^2 lower operating carbon emissions**
- **75% lower embodied carbon than full replacement**
- **Improved glass surface temperatures (occupant comfort)**
- **Minimal tenant disruption and no displacement**
- **High capital ROI 13.8% to 32.5% (incentive dependent)**