ADVANCED
BUILDING SKINS

10-11 October 2016, Bern, Switzerland

Advanced Building Skins

11th Conference on Advanced Building Skins

10-11 October 2016, Bern, Switzerland

ISBN: 978-3-98120539-8

Advanced Building Skins GmbH
Hostettstr. 30
CH-6062 Wilen (Sarnen)
Switzerland

VAT: CHE-383.284.931

Tel: +41 41 508 7036
info@abs.green

Folded-BISC:
a parametric design approach to building integrated solar collectors

Simone Giostra Lawrence Blough
Department of Architecture and Urban Studies, Politecnico di Milano, Italy
simone.giostra@polimi.it
Department of Architecture, Pratt Institute, New York
lblough@pratt.edu

Abstract

The paper discusses an innovative multi-functional façade system with building-integrated solar collectors (BISC) that generates on-site renewable energy, is highly energy efficient, and produces a new vocabulary for sustainable construction. The work includes a preliminary evaluation of the system applied to a double-skin unitized curtain wall for a re-cladding project on a high-rise building in New York City.

The study presents a workflow implementing the latest digital parametric tools, pairing environmental analysis with geometric form finding, so that factors such as solar irradiation, sun angle and sun shading inform a novel and differential façade system tailored to its environment and orientation.

Preliminary energy analysis shows approximately 48.5% energy savings, resulting from both the interactive effects of individual energy conservation measures, sun control, and the production of electricity from façade integrated photovoltaics, fulfilling the target of a net-zero lighting retrofit for a Class-A office building.

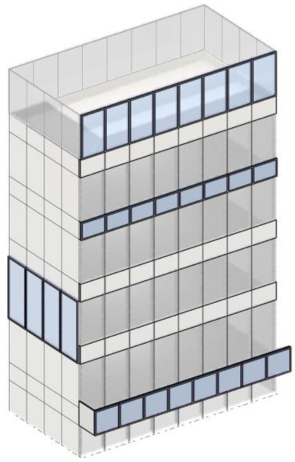
Keywords: on-site renewables; folded surfaces; parametric design; form-finding; envelope retrofit; multi-functional façade

1. Introduction

Following new regulations mandating strict energy performance requirements and a steep increase in energy costs, most buildings will be retrofitted in the near future to significantly reduce energy demand. As photovoltaic and solar thermal collectors are being increasingly integrated into buildings (Fig. 1), it becomes imperative for urban planners and architects to provide greater solar energy potential in buildings, maintaining good daylighting levels, while decreasing associated heat loss in wintertime and minimizing overshadowing.

Traditionally used on roofs, an emerging market for solar collectors integrated in façades is growing in Europe with promising results. In the contest of highly populated urban areas, façade applications of solar collectors provide more available surface area, particularly in tall buildings where roof area is limited, reducing the risks for solar thermal panels to overheat in the summer months, while still producing a high yearly solar fraction. Façade applications have greater value than roof applications because collectors are often integrated with semi-rigid insulation providing added thermal performance for retrofits at no added cost. In addition to energy cost savings, vertical applications of solar collectors may contribute to survivability through on-site energy production and increased thermal performance, creating a resilient building stock, particularly in disaster-prone coastal cities.

However, high costs and lack of architectural quality characterizing existing building integrations are two major reasons for the low adoption of the technology. Virtually all solar collectors on the market consist of functional assemblies of contrasting components mounted with basic metal framing onto the building. Issues of visual appearance and integration with standard building materials and components must be taken in consideration, as well as geometric optimization of the envelop in order to maximize solar potential and overall efficiency of the collectors in both retrofits and new construction.



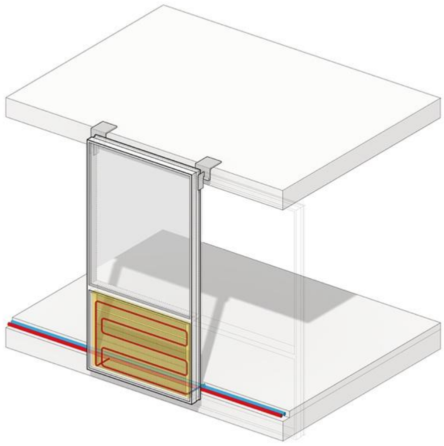


Figure 1: Opportunities for integration of solar collectors Figure 2: Concept for a BIST façade system by the authors

2. Method

2.1 Geometric characterization of building envelope

This study is based in part on previous research –conducted by the authors and supported by the Architecture School at Pratt Institute in New York– on a cost effective, low maintenance BIST façade system, integrated to a unitized glazed flat plate panel application for use as both an over-clad system for retrofits and a façade assembly for new construction and expected to generate an R-value up to 16 and up to 50% of yearly DHW (Fig. 2).

Previous research also investigated the energy implications of tessellating a building surface by applying different periodic tridimensional tiling to the geometry of a generic facade (Fig. 3). The study included approximately 30 geometric variations of the facade's geometry, with a constant size and number of apertures, floor-to-floor distance, latitude and orientation of the building. Most importantly, the dimensional range of panel components resulting from geometric manipulation is compatible to conventional unitized curtain wall systems as defined by industry standards and building code in New York City.

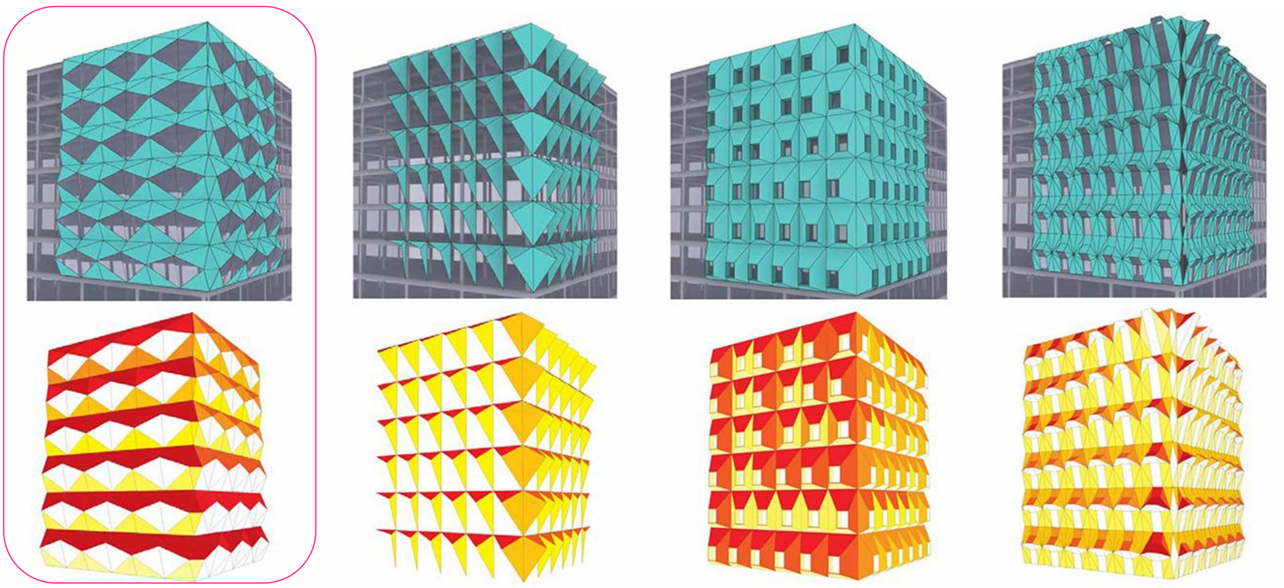


Figure 3: Tessellation studies of a building surface and corresponding solar radiation analysis

Solar radiation and daylight analysis show distinctive characteristics for each model, in terms of ability to block excess solar radiation from entering the building while maintaining an appropriate level of daylighting, and potential for on-site energy generation by replacing specific panel components with solar collectors. The overall effect of folding the facade to form tassels with distinct size and tilt is to produce panel units that are specialized to perform one or more specific tasks.

For the purpose of evaluating the energy implications of a folded-BISC facade applied to an existing high-rise building in New York City, a specific geometry presenting a large differentiation in solar radiation values was selected (Fig. 4).

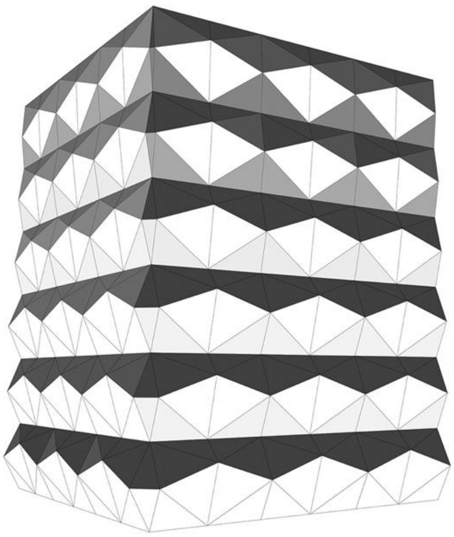


Figure 4: Selected tessellation with differentiation in radiation values

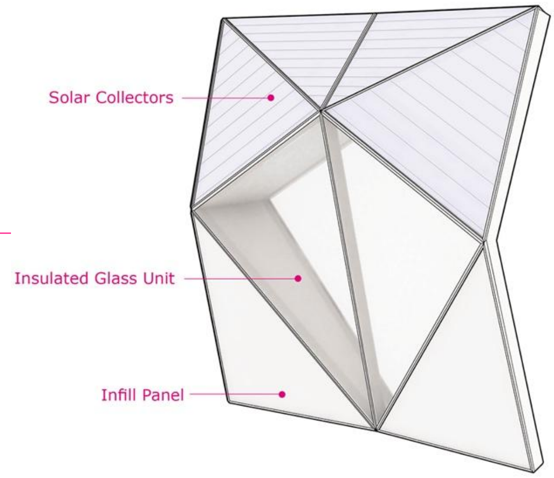


Figure 5: Functional description of panel unit

2.2 Functional description of panel units

Based on solar radiation potential and daylighting requirements, the façade elements include combinations of vision glass with folded opaque and perforated metal panels –for sun control and light emission– along with integrated photovoltaic or solar thermal collectors, for on-site electricity and heat production (Fig. 5).

The system also integrates all functions pertaining to building enclosures, including waterproofing, pressure equalization, thermal insulation, expansion/contraction and vapor transfer, structural support, and wind load resistance, within one component. This approach avoids redundancies and interferences created by traditional solar panels mounted on existing enclosures and foresees a new generation of integrated solar collectors for building cladding systems.

In contrast to discrete components, which are best suited for upgrades in individual residential units, the proposed system targets comprehensive refurbishment of multi-unit buildings and new construction. Both types offer unique advantages, including the economy of scale that comes with large surfaces, the high efficiency of fully integrated design, and the comprehensive approach offered by a newly designed envelope system.

2.3 Site selection and analysis

New York City is one of the most favorable markets in NY State for solar energy due to high energy costs and access to sunlight. The Met Life building (formerly Pan Am) has been chosen for an exemplar application of the proposed system due to its iconic presence within the skyline of the City and its unique siting, exposing the building’s east, south and west facades to large amounts of solar radiation for most of the daytime throughout the year (Fig. 6).

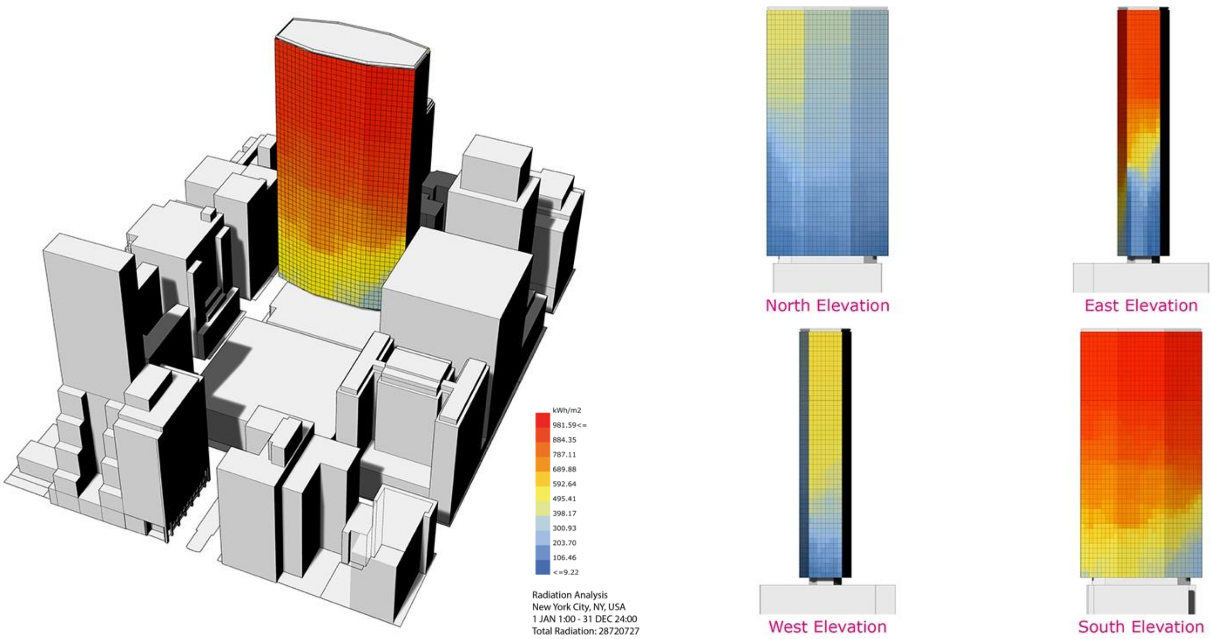


Figure 6: Yearly solar radiation analysis of the Met Life building in New York, NY

The building also presents distinctive vertical folds along the south-west and north-east facades, allowing for greater variation in solar exposure within a single facade. Finally, the building's ageing curtain wall is in urgent need of repair and it has been a *cause célèbre* arousing controversy within the architectural community in the city as of late.

In accordance with the urban grid of Manhattan and the general configuration of the island, the Met Life building's main facades are oriented toward the south-west and the north-east, while the narrow lateral facades are oriented toward the north-west and the south-east. Due to the height of the building relative to its immediate neighbors, solar radiation on the upper half of the south-west facade is unobstructed by overshadowing, while yearly solar analysis shows a rich pattern of radiation intensity levels across the lower half of the same facade. Similar patterns appear over the lateral elevations, although with comparably lower intensity values. The north-east elevation is only minimally exposed to direct radiation, mostly in the early morning hours during the summer.

2.4 Parametric optimization of the facade

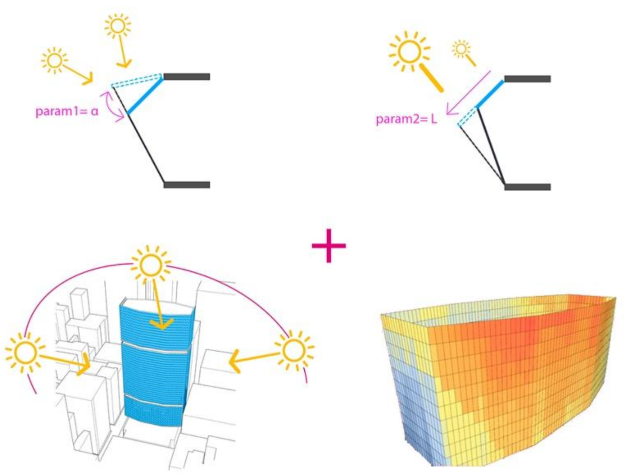
The following geometric modifications were applied to the tridimensional tessellated surface model previously discussed:

- Tilt α (param1): solar collector modules are tilted based on yearly average sun angle related to each orientation, so as to maximize energy production while becoming more effective as shading devices
- Length L (param2): solar collectors size increases in areas where yearly radiation is most intense and therefore payback time is shorter; larger collectors also reduce heat gain (Fig. 7)

A customized algorithm controls geometric properties for each panel component across the entire envelope. The combination of local sun angle (param1) and solar radiation value (param2) controls the gradual shifting of the front vertex upward and outward, adjusting solar collector's size and tilt in order to increase energy output and reduce excessive radiation in the building's interior (Fig. 8).

The folded geometry of the façade allows for continual modification of the panel type to optimize performance relative to sun angle. In this way, areas of the façade can be tuned parametrically to south, west and east facing exposures. South facing modules are the most outwardly angled creating shade pockets reducing glare and heat gain. Additionally, the top surface is positioned closer to the horizon to collect solar energy when the sun is highest in the sky. West and East facing modules are flatter because overhead shading is not effective for low angled sunlight. The top surface approaches the vertical position to collect solar energy when the sun is lower in the sky and reduces the amount of vision glass for sun control.

Addressing the specifics of the site, the building façade geometry not only responds to sun angle but is also adapted to consider overshadowing from adjacent buildings. Where the bottom third of the tower's south façade is in shadow, the cladding has more glass and the solar collectors are replaced with metal panels. A similar strategy is deployed on the north façade creating a differential expression based on site parameters.



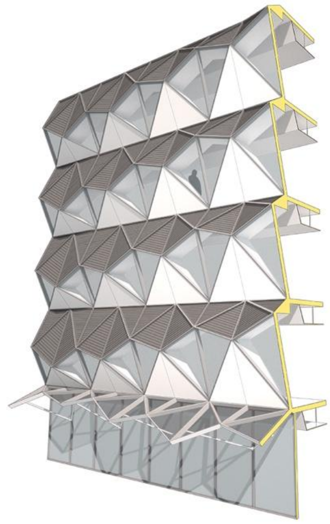


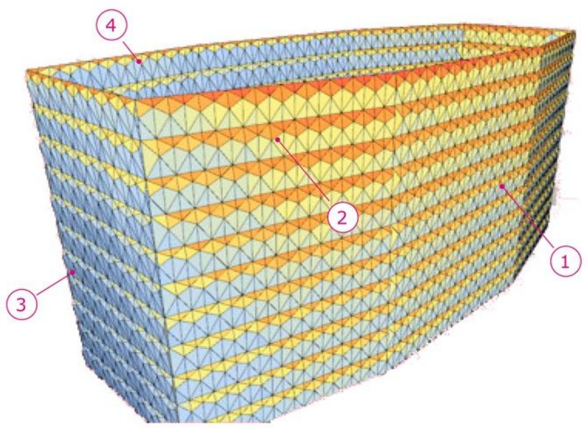
Figure 7: Parameterization of façade geometry

Figure 8: Differentiation of façade modules

2.5 Infill panel allocation

Additional solar analysis of the optimized geometry (Fig. 9) help identifying solar collectors that are under-utilized, which are then replaced by dummy panels. Similarly, lower solid panels that show low solar radiation are replaced by perforated panels, in order to increase daylighting accessibility. In areas that show no direct solar exposure -typically on the north facade -lower panels are replaced entirely by glass panels (Fig. 10).

The initial optimization of the building façade geometry is therefore complemented by ad-hoc allocation of appropriate panel types, based on acceptable efficiency thresholds in energy production of solar collectors and desired levels of daylighting in the building interiors. The differentiated approach to panel's material and function is predicated on the assumption that current unitized curtain wall framing is capable of accommodating different infill panel materials and equipment -including electrical wiring and balance of system- without substantial modification to base components.



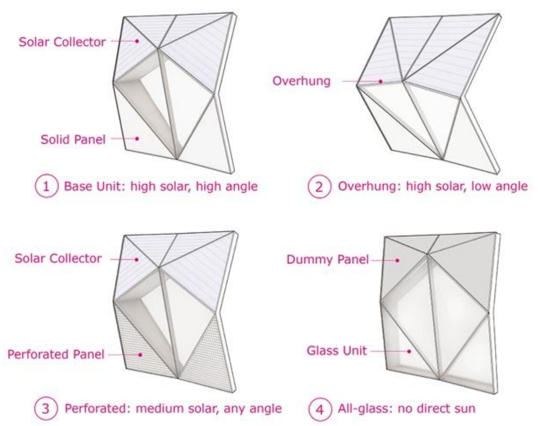


Figure 9: Solar analysis of the optimized geometry

Figure 10: Infill panel allocation and unit types

3. Results and Discussion

Electric lighting is the most significant energy user in office buildings if primary instead of site energy is considered. In the US every kWh saved on lighting is three times more effective than a kWh saved on heating (Source: *Sustainable Engineering Lab*). Retrofitting the buildings electric lighting, combined with daylighting controls and geometric glare mitigation, allow the project to save over 40% of the lighting energy previously used (Fig. 11). Based on simulations of energy produced by the PV panels integrated to the façade (Fig. 12), the primary target of a net-lighting building has therefore been exceeded by a large margin.

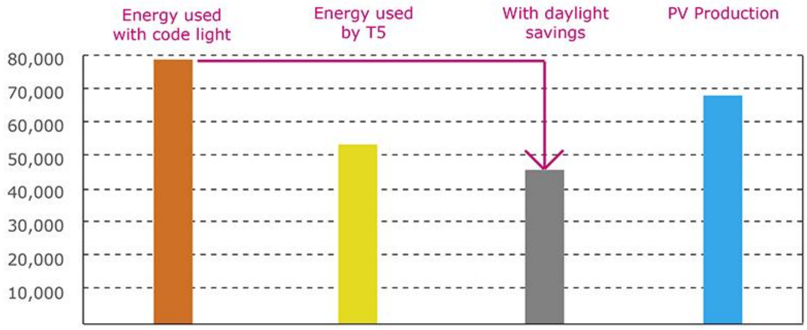


Figure 11: Impact of facade on electric lighting energy use (kWh)

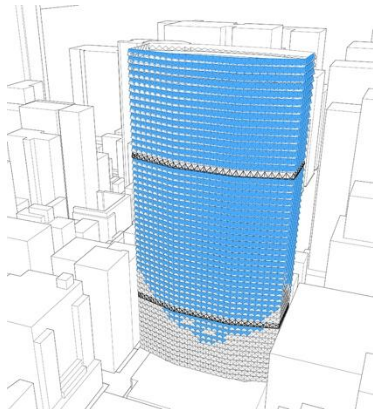


Figure 12: Pattern of solar collectors

Preliminary analysis of daylight performance on the south facade of a typical floor of the building were conducted without additional shading devices on: 1) existing conditions, 2) a code replacement facade, and 3) the proposed folded-BISC facade (Fig. 13). The proposed system shows substantial improvements in the quality of daylight, particularly in areas where the simulation of existing conditions show higher than valuable amounts of light. Interestingly, the additional shading effect of the solar collectors does not reduce daylight autonomy values outside the building core area.

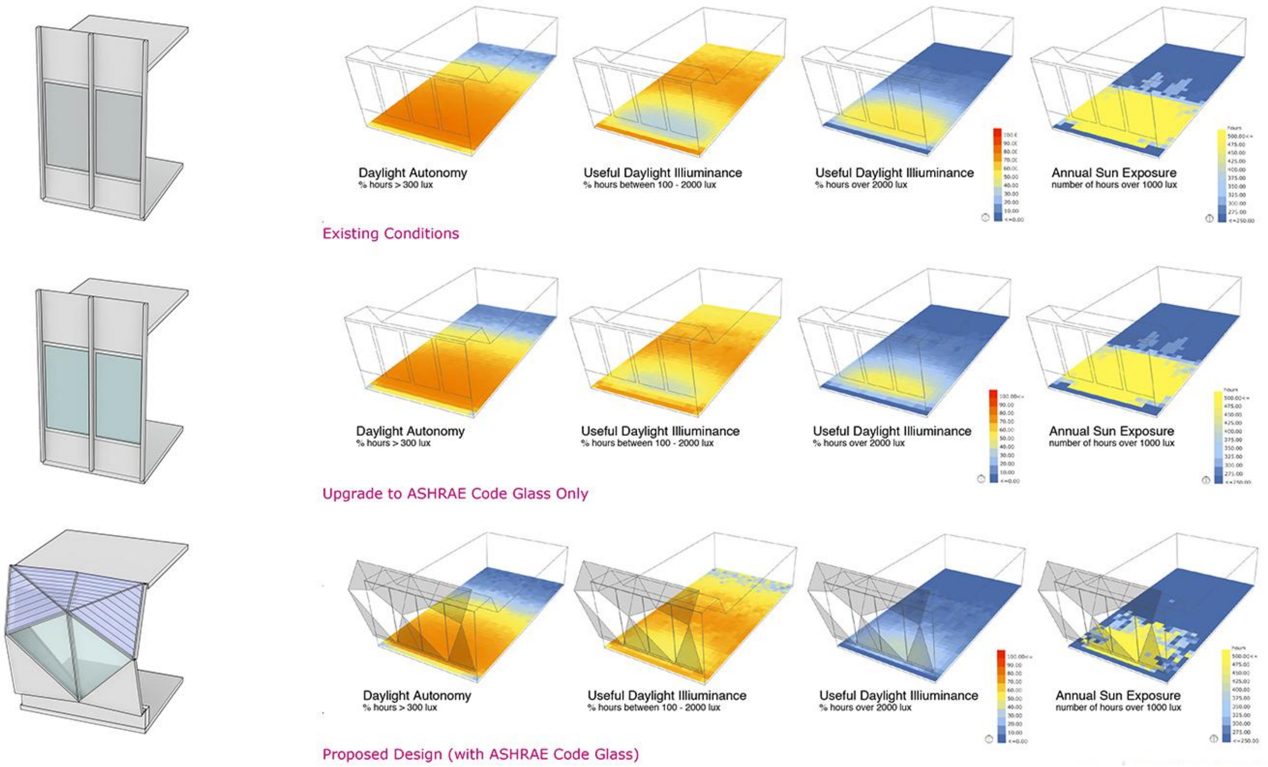


Figure 13: Preliminary analysis of daylight performance on the south facade of a typical floor of the building

The additional layer of enclosure provided by the double-skin system significantly increases the exterior wall's thermal resistance, decreasing associated heat loss in wintertime. Both reduced heat gains from electric lighting and the shading effects from the new façade's geometry and opaque elements reduce cooling energy by nearly a third. The total impact of the facade addition and associated lighting retrofit is approximately 48.5% energy savings. These savings are the result of both the interactive effects of individual energy conservation measures and the production of electricity from the facade integrated photovoltaics (Fig. 14, 15).

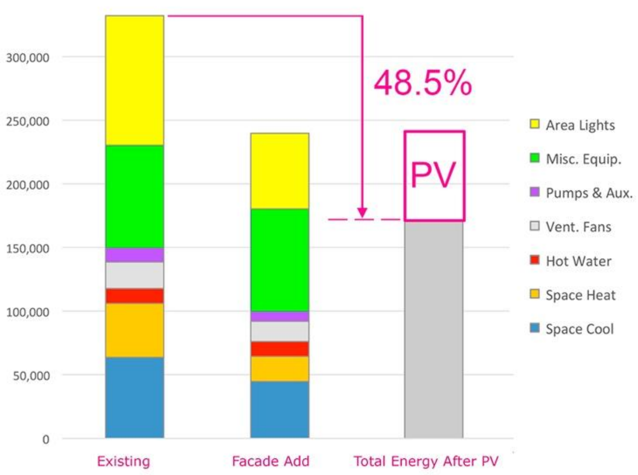


Figure 14: Sample Floor Facade Energy Impact (kWh)

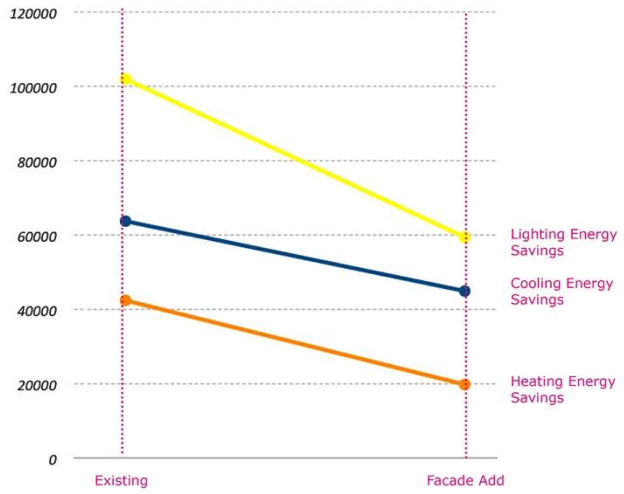


Figure 15: End Use Savings Comparison Chart (kWh)

In addition to energy benefits, the double-skin improves comfort around the perimeter of the building. The existing single-pane glazing is expected to reach surface temperatures well below 40°F (4.4 °C) during winter, radiating cold to nearby occupants. Increasing the façade U-value to 0.18 will maintain comfortable surface temperatures above 61°F (16.1 °C) and will eliminate the necessity for perimeter heating (Fig. 17). Because of this, occupants will be more likely to sit in well day-lit areas reducing electric lighting use (Fig. 16).

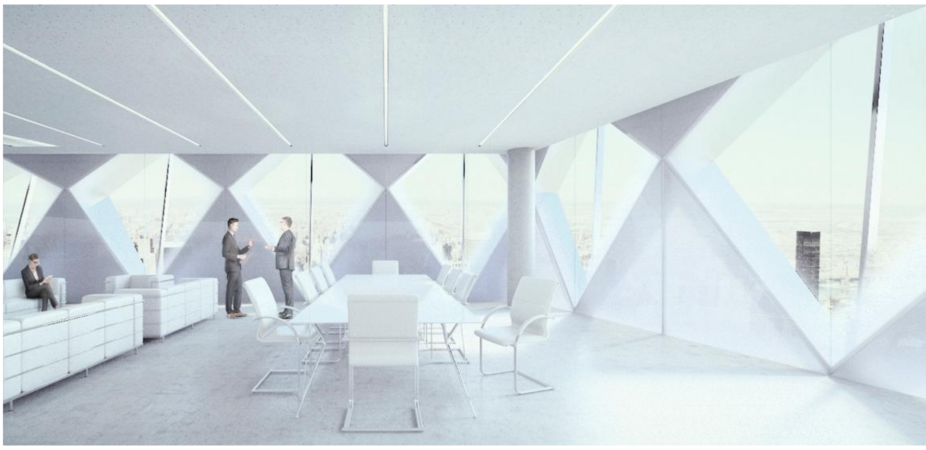


Figure 16: View of interior space adjacent to South-West corner of building

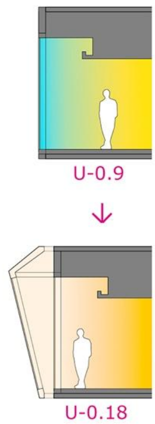


Figure 17: Comparative comfort diagrams

4. Conclusions

Designing the façade to allow the top third of the window to provide daylighting while insulating and shading the lower third of the façade with integrated solar collectors, reduces energy consumption and creates a more livable work environment. Implementing a parametric approach to the geometric optimization of the envelop can have a substantial impact on the solar potential and overall efficiency of the collectors, as well as in the quality of daylighting and reduction of excessive radiation, in both retrofits and new construction. Additionally, the proposed design strategy develops a new expression for the building as a whole, creating a faceted façade that reflects and refracts light and color over the course of the day (Fig. 18).

Figure 18: Aerial view of Met Life building with proposed system looking toward the East River at sunset

The multi-functional façade system recognizes that a majority of today's curtain wall systems already deploy a high level of geometric modularity and system standardization, making the integration of solar collectors and sun control the next logical step in the evolution of high-efficiency building envelopes. The system will be developed as a plug-and-play unit, manufactured in the factory using computerized processes for unitized curtain walls, and delivered on-site as part of a modular panel unit. Factory assembly will allow for greater precision, higher performance, and lower costs compared to current stick-built systems. The erection of modular panels on-site will result in a faster, simpler, cost-effective installation and reduce the risk of system failure.

Following a renewed interest by the design profession in prefabricated and modular construction, the parametric customization of folded-BISC systems is linked to a generalized acceptance of unitized curtain walls as the prevailing method of constructing building envelopes for new construction and retrofits. Key to bringing the system to market is close collaboration with curtain wall manufacturers as they expand their range of products and services to provide turn-key solutions, including engineering, manufacturing, and installation of complete building envelopes.

5. Acknowledgements

This paper is based in part on previous research on a cost-effective, low-maintenance BIST façade system, conducted by the authors and supported by the Architecture School at Pratt Institute in New York.

Colin Schless and Matthew Naugle of Thornton Tomasetti provided engineering advice for the energy analyses included in the Met Life evaluation study; Arturo Tedeschi provided computational advice for the same study.