ETFE Membrane Envelope Strategies

Adaptive Double Skin Façades For New Builds and Retrofits

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ABSTRACT

Airflow within the cavity of double-skin facades is a key component of adaptive building envelopes which change thermophysical properties to meet changing environmental conditions, occupant comfort demands, ventilation rates, etc. To consistently balance these requirements, adaptive building envelopes incorporate intelligent controls. Contemporary double-skin facades include configurations of two glazed panes with an in-between air gap, two opaque layers with an air gap, or a transparent layer and opaque layer with and air gap (i.e., Trombe wall). In high-rise buildings, the system can be separated by floor level with air intake and outlet installed per floor, or it can be built across multiple stories that share bottom air intakes and top outlets.

In this paper, the authors examine novel applications of ETFE (ethylene-tetrafluoroethylene) membranes in double-skin facades to discuss the opportunities and challenges for adaptive building envelopes. ETFE is a contemporary building material sought for its characteristics of 95% light transmission, lightweight, durability, and recyclability. The primary research questions are: 1. How does ETFE compare against other transparent materials that are typically used in double-skin facades? 2. What are the potential design strategies with ETFE for dynamic double-skin controls that can balance energy and human comfort? 3. What are the specific requirements for construction?

To address these questions, two case studies developed by the authors will be discussed in detail, (1) a proposed retrofit application for a high-rise building in New York that integrates a single skin ETFE membrane with a vent system integrating shape-memory alloy wire; and (2) a single-family home double-skin façade which encloses a solarium and green roof/wall that is to be constructed in Zhangjiakou, China. These case studies discuss the implications of innovative design concepts (i.e., embedding smart materials and environmental control systems) while elaborating on practical design considerations of inflated air cushion vs. single membrane systems.

KEYWORDS

adaptive-kinetic-dynamic, double-skin, dynamic facade, innovative facades, intelligent, kinetic facade, ventilation, ETFE, smart materials, academic/industry partnerships

INTRODUCTION

We as a species have been aware for some time now that our actions have a large and lasting impact on this planet. From the first photos of our ‘pale blue dot’ to the high-definition veins and clusters of light stretching across the earth's surface, humans have made a home for ourselves with our structures and transportation networks. Our building techniques have changed over millennia in accordance with our lifestyles; from early bone huts, to portable tent structures, stone castles, wood tract homes and aluminum, steel, and glass skyscrapers. The goal has been pretty much the same, seeking comfort from the elements.

As our construction methods have evolved, there continues to be somewhat of a transitory mentality to our buildings, which has only been exacerbated by the general culture of conspicuous consumption. Commodity construction has taken hold over the last 100+ years, unlike our predecessors in the nomadic tents who could easily deploy and dismantle their architecture reusing the same material, or the stone structures which, though more permanent, were carefully tended to and maintained over centuries and still stand to this day. Today we build, then 15-30 years later we demolish and build something new. The construction methodologies of the building industry in the last 100 years, coupled with exponential population, and the belief that buildings have a designated lifespan has created an interesting problem and one of the highest contributing factors to global carbon emissions.

Our built environment takes up a relatively small footprint of the earth's surface but our buildings (in material and operations) contribute to approximately 40% of all the global emissions (Hamilton et al., 2020) . Much of the focus on building energy and performance in the last 20 years has been on the high-rise towers in the urban centers of US cities, both commercial and residential, and though this is an extremely important building category, we estimate that the single family detached home takes 68% more land area and 12% more total building square footage on average than its high-rise counterpart. Here we have an opportunity to look at how we can find ways of retrofitting not only existing high rises but also single-family homes to become more energy efficient and carbon neutral.

We have an opportunity to blend old techniques and new materials to approach the single-family home and high-rise building typologies in different ways. The focus of this paper is to offer new insights from our design research of membrane based cladding strategies rather than presenting a complete and comprehensive study for performance upgrade strategies of the US building stock. With that, we ask the questions:

- What might it look like if a developer tract home was wrapped in a skin of ETFE (Ethylene Tetrafluoro-Ethylene) pillows to reduce winter heating and passively cool in the summer?
- Could a 1960’s high-rise office tower become a passive kinetic façade of stretched ETFE with increased ventilation, reducing air-conditioning and heating seasonally, while being one of the most carbon lean solutions and still honor the original architecture?

OVERCLADDING AS A BUILDING ENVELOPE RETROFIT STRATEGY

Climate-responsive energy-free architectural design practices which evolved with the 20th century studies of vernacular architecture have led to various building approaches which integrate adaptive systems that respond to the specific climate conditions. For example, in colder or temperate climate zones, highly insulated and air-tight walls and windows, or double-skin systems have been applied to reduce energy consumption. For warmer climates, solar shading and natural ventilation strategies are adopted. The US covers 9 climatic regions among which the top 2 most populous climate zones are 5A (Cool-Humid) and 4A (Mixed-Humid), which account for approximately 43% of the US population. Simultaneously, the majority of the most populous US cities exist within these regions. In order to understand which existing building typologies have the biggest impact on carbon and greenhouse gas emissions, we conducted a preliminary analysis of the building stock in major cities and concluded that single family detached houses occupy the largest building footprint and building envelope area, in comparison to low- and high-rise buildings. Which begs the question, which building type should we focus on to help us achieve the net zero emission goals in the next 8 and 28 years?

Looking at these two predominate building typologies; the single family detached home and high-rise, we can leverage the current rating systems that have been created, primarily, the Home Energy Rating System (HERS) for residential buildings, and the Zero Energy Performance Index (ZEPI) for commercial structures in addition to the code requirements of ASHRAE 90.1, the IECC, and other municipal stretch codes. The key is validating and quantifying the assumed impact of materials, construction techniques, and retrofit options.

It is interesting to consider that much of the focus for leveraging building envelope specialists and life cycle experts has been only traditionally employed on the larger buildings like the high-rise, with the understandable exceptions of the multimillion dollar homes. However, due to the sheer volume of single family detached homes, the enclosure square footage exceeds high rise tower. Even with the increased code requirements for the various enclosure assemblies for residential construction over the years, we are not even close to the existing building 'Net Zero' goals required by all buildings by 2050. The current rating systems like HERS, and Passive House are helpful, coupled with the free knowledge database provided by the Building Science Corporation for wall assemblies and best practices, the general home owner does benefit from the expertise of the envelope consultants working on the larger projects. However, there are helpful reports that outline strategies that home owners can do to help move the needle in the right direction.

In an excerpt from 'Energy Efficiency Potential in the US Single Family House Stock', by NREL (Wilson, 2017) key factors that could potentially save on electricity and by relation, the operational emissions for SFD homes, are recommended. Of these 12 upgrades, 4 of them are directly related to the envelope. From increasing attic insulation, sealing air leaks, and drill and fill wall cavity insulation; these are only a few retrofit techniques than the typical home owner can implement today, and see relatively immediate results in comfort and their electricity bill. It is highly important to validate these upgrades through modeling and testing, this is where there could be a huge opportunity for building envelope specialists to assist home owners with their SFD upgrades. An example could easily be thermal and freeze-thaw analysis of the existing wall assembly prior to a 'drill and fill' insulation retrofit to study the implications of modifying their wall assembly relative to vapor drive, mold potential, and other factors that could have harming consequences in the long run on the IAQ. Though helpful, these recommendations only scratch the surface as to what could be possible, especially if we start to consider alternative techniques of improvement.

When it comes to the building retrofit techniques, the high-rise typology has exploded in the last decade, with many buildings getting a 'face lift' in order for building owners to boast their lowering of operational cost and emissions. Of course, life cycle analysts and façade consultants have been working together for some time to validate the new designs, matrix costing the envelope improvements over the heating/cooling systems, etc. However, there is an argument to be made for the different types of retrofit techniques. Currently, the most common building envelope retrofit techniques are through replacement or over-cladding, the former be the more widely used (Martinez et al., 2015), but this is dependent upon a number of factors including but not limited to, the building, it's structure, window to wall ratio and the aesthetic intent of the architect hired by the building owner.

When we start to consider the life cycle, embodied carbon, and energy of the new enclosures of the replacement retrofits, coupled with the end-of-life cycle for the outmoded façade to be demolished, it prompts the question, why are over-cladding systems not as common? Could there be an alternative to over-cladding we have not fully explored?

THROUGH THE LOOKING GLASS

Generally, lowest performing elements in a building façade are the transparent areas of glass and glazing versus opaque systems. In the last 30 years, the glass industry has made exceptional strides in increasing the performance of glazing systems through coatings of all kinds, suspended films, insulated glass units, etc. Moreover, the application of thin films like ETFE have become more commonplace in larger structures like stadiums as alternatives for glass and glazing systems. Glass and ETFE used in a facade share some distinct similarities, generally the framing systems are aluminum and may require reinforcing steel. Gaskets, silicone, captured air, are all commonalities between these two. Glazing and ETFE systems can also be single ply where in lieu of an insulated glass unit or pillow, the glass is fully tempered or laminated and the ETFE is a stretched membrane spanning between framing elements, and of course they are both transparent with options for coatings like frits, low-E, solar, etc.

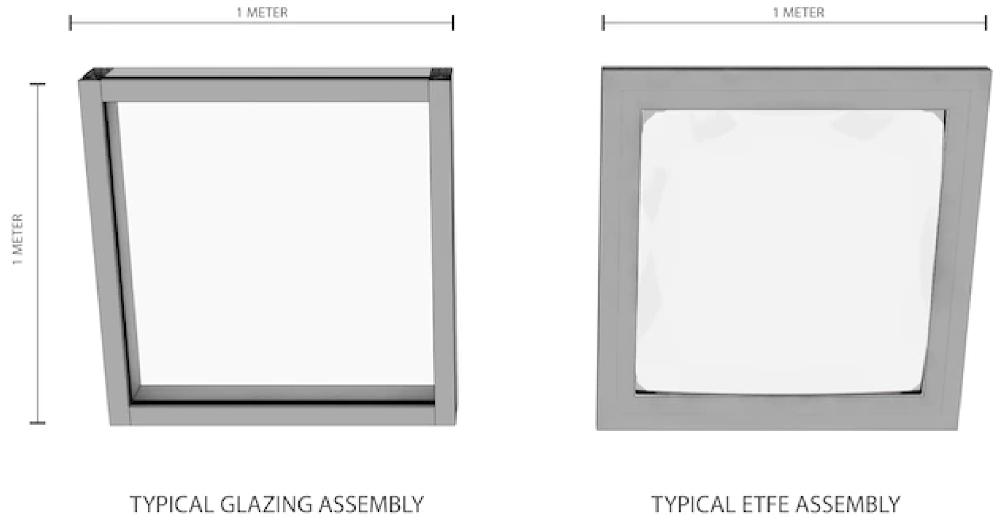
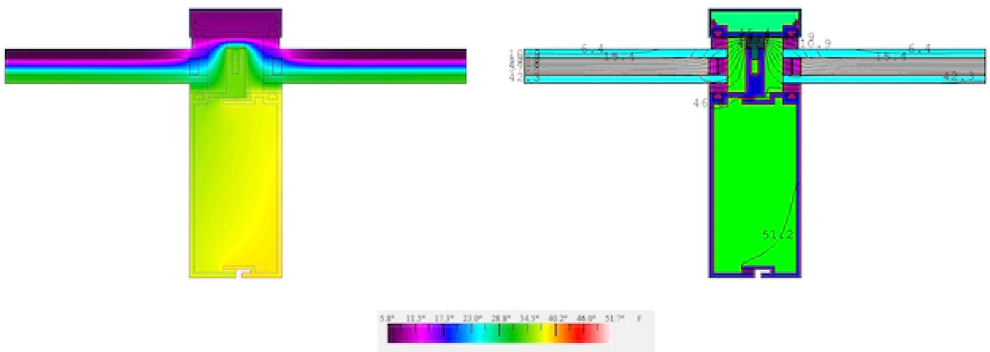


Figure 1 - Glass vs ETFE 1 meter squared assemblies

Though they share many similarities, they are very different. Weight is a huge difference. ETFE and Glass are close in density, while the operational thicknesses required are drastically different. In a 1 meter by 1 meter comparison, a double-glazed insulated glass unit will be ¼" thick with ½" air cavity and ¼", which weighs around 50lbs. The same area of an ETFE pillow with an air cavity of 3.5” is 0.8lbs. This is simply comparing the two traditional assemblies and has excluded the framing systems and any mechanical pumps or air supply systems. However, with this weight difference and the fact the ETFE pillows, or even stretched membranes can span greater distances than glass, there is a reciprocal reduction in framing required, even if the framing needs to be more robust to accommodate the internal stresses of the ETFE pillows and stretched skins.

Another area where they are different is the thermal performance. It is difficult to include all the permutations of available coatings between glass and ETFE, in eliminating all coatings and using the traditional framing styles for each material, the blended u-values for a 1-meter squared assembly of glass and ETFE show their performative differences.

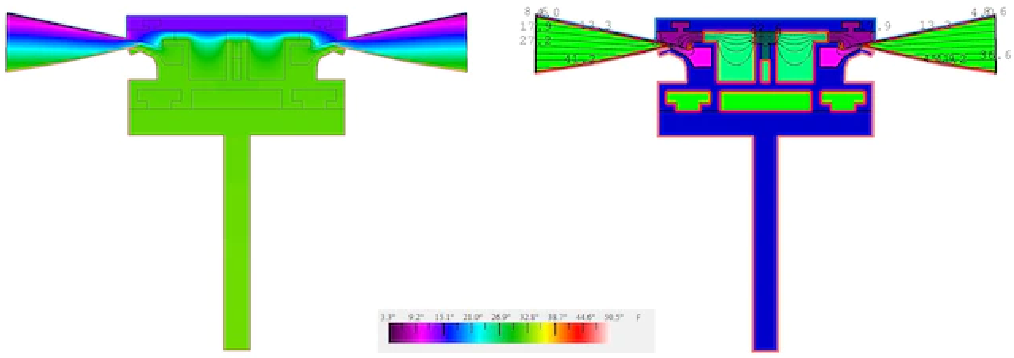


CURTAINWALL | FRAMES	U value [Btu/h·ft²·F]	Area of unit [ft²]	Heat loss [Btu/h·F]
CENTER OF GLASS (COG)	0.480	74.459	35.74
MULLION VERTICAL - FRAME	1.766	6.928	12.24
MULLION VERTICAL - EDGE	0.444	6.748	3.00
HEAD MULLION - FRAME	1.766	6.928	12.24
HEAD MULLION - EDGE	0.444	6.748	3.00
SILL MULLION - FRAME	1.766	6.928	12.24
SILL MULLION - EDGE	0.444	6.748	3.00
	TOTAL	115.49	81.45

	Area of unit [ft²]	Heat loss [Btu/h·F]	U value [Btu/h·ft²·F]
TOTAL HEAT LOSS TROUGH UNIT	115.49	81.45	**0.71**

NOTE: 1" IGU WITH 1/2" AIR. NO COATINGS AT ALL

Figure 1A – CW Thermal Analysis and blended U-value table



ETFE | FRAMES	U value [Btu/h·ft²·F]	Area of unit [ft²]	Heat loss [Btu/h·F]
CENTER OF PILLOW (COG)	0.362	74.459	26.97
MULLION VERTICAL - FRAME	1.199	6.928	8.30
MULLION VERTICAL - EDGE	0.392	6.748	2.64
HEAD MULLION - FRAME	1.199	6.928	8.30
HEAD MULLION - EDGE	0.391	6.748	2.64
SILL MULLION - FRAME	1.199	6.928	8.30
SILL MULLION - EDGE	0.391	6.748	2.64
	TOTAL	115.49	59.80

	Area of unit [ft²]	Heat loss [Btu/h·F]	U value [Btu/h·ft²·F]
TOTAL HEAT LOSS TROUGH UNIT	115.49	59.80	**0.52**

NOTE: 2 PLY PILLOW WITH 1 3.5" AIR. NO COATINGS AT ALL

Figure 1B – ETFE Thermal Analysis and blended U-value table

A traditional glazing system at 1 square meter, with ¼”-½"-¼" uncoated IGU with split mullion verticals and sheer block horizontals has a blended U-value of around 0.71 - now understanding that the Center of Glass (COG) is very high in comparison to what is available with Low E and solar coatings, this is to test the raw material of glass vs ETFE. The ETFE assembly, traditionally, a veneer extrusion with keders, mitered on four sides with a steel backup structure reveals a 0.52 U-value. Understanding that 1” of static air equates approximately to R-1, with the 3.5” pillow at its deepest point and the low conductivity of the ETFE ply itself, the pillow performs better than its glass counterpart. Additionally, with the ETFE, multiple plies can be added to the pillow assembly which only increases the thermal performance, much like adding another lite or suspended film for a triple glazed unit. The key take away is the weight and flexibility vs the thermal performance. Even with the ETFE framing weighing similarly, if not slightly heavier than the glazed assembly, the pillow vs IGU is exponentially lighter which puts less burden on the envelope framing and primary structure.

The Carbon Question

When it comes to comparing the embodied carbon and their Global Warming Potential (GWP) from cradle-to-gate (A1-A3), the results are intriguing. Using the same area and framing makeup as the thermal analysis, the 1x1 meter assembly for glass and the ETFE, it is the glass assembly that has a lower value than the ETFE system, if only just slightly.

Embodied Carbon: GLASS

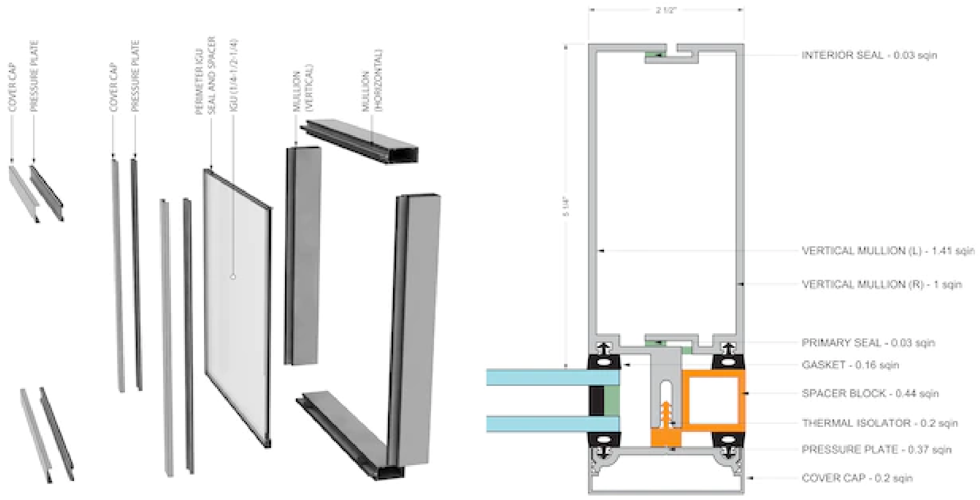


Figure 2 – Exploded Curtainwall assembly for 1x1 meter, Figure 2a – Curtainwall assembly detail

1 METER X 1 METER ASSEMBLY

CROSS SECTION	QUANTITY	MATERIAL	AREA (IN^2)	VOLUME (IN^3)	ASSEMBLY VOLUME (IN^3)	GWP (IN^3)	SUM GWP
INTERIOR SEAL	2	SILICONE	0.03	1.2729	2.5458	0.0114	0.03
VERTICAL SPLIT MULLION (L)	1	ALUMINUM (PAINTED)	1.41	59.8263	59.8263	0.0544	3.26
VERTICAL SPLIT MULLION (R)	1	ALUMINUM (PAINTED)	1	42.43	42.43	0.0544	2.31
HORIZONTAL MULLION	2	ALUMINUM (PAINTED)	2.56	94.4384	188.8768	0.0544	10.28
PRIMARY SEAL	2	SILICONE	0.03	1.2729	2.5458	0.0114	0.03
GASKET	4	SILICONE	0.16	25.3824	101.5296	0.0114	1.16
SPACER BLOCK	4	FRP	0.44	34.9008	139.6032	0.0918	12.82
THERMAL ISOLATOR	4	NYLON (PA6)	0.2	15.864	63.456	0.0994	6.31
PRESSURE PLATE	4	ALUMINUM (PAINTED)	0.37	29.3484	117.3936	0.0544	6.39
COVER CAP	4	ALUMINUM (PAINTED)	0.2	15.864	63.456	0.0544	3.45
GLASS (IGU 1/4-1/2-1/4 Clear)	1	GLASS (FLAT)	1217	608.5	608.5	0.0093	5.64

	LENGTH (IN)
VERTICAL FRAMING	42.43
HORIZONTAL FRAMING	36.89

TOTAL ASSEMBLY GWP	51.6586192
FRAME ONLY GWP	46.02

Figure 3 – Curtainwall GWP calculation for 1x1 meter

Embodied Carbon: ETFE

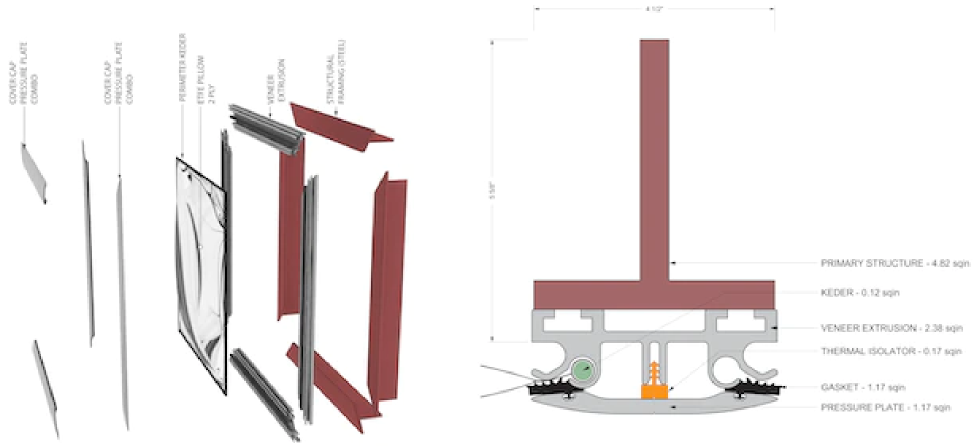


Figure 4 – Exploded ETFE assembly for 1x1 meter, Figure 4a – ETFE assembly detail

1 METER X 1 METER ASSEMBLY

CROSS SECTION	QUANTITY	MATERIAL	AREA (IN^2)	VOLUME (IN^3)	ASSEMBLY VOLUME (IN^3)	GWP (IN^3)	SUM GWP
PRIMARY STRUCTURE	4	STEEL	4.82	204.5126	818.0504	0.0044	3.61
VENEER EXTRUSION	4	ALUMINUM (PAINTED)	2.38	100.9834	403.9336	0.0544	21.98
KEDER	4	SILICONE	0.12	5.0916	20.3664	0.0114	0.23
GASKET	4	SILICONE	0.19	8.0617	32.2468	0.0114	0.37
THERMAL ISOLATOR	4	NYLON (PA6)	0.17	7.2131	28.8524	0.0994	2.87
PRESSURE PLATE	4	ALUMINUM (PAINTED)	1.17	49.6431	198.5724	0.0544	10.81
COVER CAP	4	ALUMINUM (PAINTED)	0.2	8.486	33.944	0.0544	1.85
ETFE (2 PLY PILLOW)	1	ETFE (Fluon Only)	1217	21.906	21.906	0.5985	13.11

	LENGTH (IN)
FRAMING LENGTH	42.43

TOTAL ASSEMBLY GWP	54.821337
FRAME ONLY GWP	41.71

Figure 5 – ETFE GWP calculation for 1x1 meter

The glass and all its constituent parts combined to equal a total assembly GWP of 51.65 whereas the ETFE is slightly higher at 54.82. However, the weight of the transparent material (glass vs ETFE) is still a huge factor for determining opportunity of a cladding assembly. Even if glass has a GWP per ton of 1430 and ETFE has 14 times that per ton at 20,869, the fact is that a 1x1 meter IGU weighs 50lb, compared to an ETFE pillow of the same size which weighs 0.8lbs - that is 62 times less than the IGU. Coupling this data with the thermal properties of the assembly – though conservative, the ETFE starts to really look like a potential contender for a cladding material over glazing systems, especially for those retrofit projects leveraging the overclad techniques. A lower overall cladding weight puts less load on the existing façade and structure and could maximize the insulative value of air – a free and common gas that is the one thing we need that we don’t have to pay for, yet.

Taking into consideration retrofitting opportunities and ETFE vs glass comparisons, leads us to the following two case studies which look at a new approach to the Single Family Detached house and recladding a New York City icon.

ETFE SYSTEMS

The Solar Decathlon China 2021 Y-House Project (Single Family Detached House)

Overview of the Project

Developed for the Solar Decathlon China 2021 Competition, this project was developed by an international team of faculty and students from three universities – Xi’an Jiaotong-Liverpool University, Suzhou, Zhejiang University-University of Illinois Urbana-Champaign Joint Institute, Haining, and Thomas Jefferson University, Philadelphia, and industry partners. The initial faculty proposal was selected as one of the 15 finalist teams which then was further developed with student teams under the supervision of faculty. Each team received seed funding from the organizing committee and is responsible to raise necessary funding through various sources including industry sponsorships to build the projects. The Y-project aims to demonstrate a feasible high-performance housing model that integrates architectural, environmental qualities with energy efficiency through a 1,600 sqft prototype. Envisioned as a node of an urban network, the prototype is designed to improve the quality of public spaces and local ecosystem, interface with the smart grid, facilitate human and technological system interaction, enhance human health and wellbeing, and promote a circular economy and sustainable development. The team adopted an integrated design research approach that promotes lifecycle design, innovation, and collaboration through teaching and research activities at three international partner universities.

While in this case study we focus on discussing the design development process of the ETFE based double skin envelope system, the project integrates the following strategies into an innovative prototype for housing:

- Bio-based structural system, including bamboo and straw for structure and insulation
- Integrated and adaptive building envelope, providing dynamic thermal control, light transmission, ventilation, and air purification through an affordable double-skin façade system
- Flexible interiors spatially organized around a central solarium space, foldable wall-integrated furniture and openings facilitate flexible use of spaces and connection to the exterior.
- Interactive spaces, featuring smart technologies incorporated into architectural surfaces support live, work, play activities of the residents
- Hybrid environmental control which integrates active and passive systems such as the double-skin envelope, ground-source heat pump, photovoltaic systems, smart daylight control, demand-controlled ventilation system, to satisfy heating, cooling, and ventilation needs.
- Therapeutic landscape and urban farming, including a horticultural garden, a living green wall, a pre-vegetated green roof paneling system, an external greenhouse for urban farming, and a kinetic wind sculpture turbine.

The ETFE façade envelope system development was led by eleven 5th year architecture undergraduate students at Thomas Jefferson University in the ARCH507/ARCH 508 Design 9/10 studio courses.

Developing an ETFE air pillow double-skin envelope

This case study describes how the ETFE membrane system is proposed as a passive façade system and integrated with other building systems and practical constraints.

Initial Concept

The ETFE double-skin envelope concept evolved over multiple iterations. The initial proposal developed by the international faculty team focused on a double-skin façade enclosing the central solarium space of the house. Sited in Zhangjiakou, China, the climate is characterized by cold winters and moderate summers, thus the team focused on high thermal mass and insulation, natural ventilation, internal heat recovery, and passive solar direct gain. The design intent for the double skin was to create an air buffer space that would be passively heated by solar heat gain. Preheated air would be taken in by the building's HVAC systems to reduce heating loads. The system also maximizes daylight through the smart deployment of the automated operable PV and textile membrane layers. The double-skin was composed of three layers, for the outer layer (1) photovoltaic (PV) panels that act both as shading and energy generators and (2) foldable textile double membranes behind the PV panels that function as summer shading and thermal insulation during cold periods; and for the inner layer (3) a polycarbonate wall that encloses the interior atrium space. Figure 25 below shows the solarium and a section through this space and its double-skin system.

Schematic Design

Based on the initial proposal the envelope was further developed by the students through which an ETFE air cushion system that incorporated an adjustable shading and ventilation mechanisms (i.e., actuated by inflating and deflating ETFE layers), photovoltaics (PVs) incorporated ETFE panels, and glass cladding with printed PVs enclosing the solarium space. Figure 25 below depicts the main façade strategies.

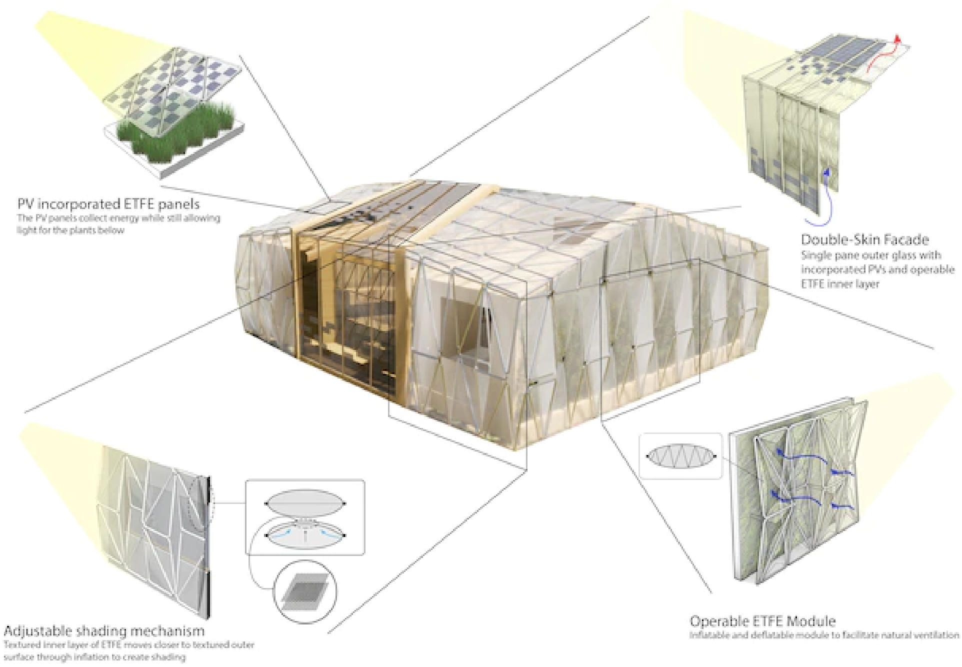


Figure 6 – Solar decathlon Y-House envelope assemblies

Design Development

During design development phase the team focused on refining the passive design strategies of the building envelope in relation to PV integration, and the green wall and roof system. First, a perovskite PV system became one of the sponsored systems by an industry partner for the project which can be printed on hard surfaces such as glass but not ETFE membranes. The southern building skin was revised to include glass surfaces on the two side-bays of the roof and walls to provide sufficient area to meet energy demands and the solarium outer skin was revised to ETFE to differentiate the solarium space appearance. Figure 26 highlights the design progression of the southern roof that addressed the PV roof cladding and roof configuration (i.e., flat vs. sawtooth PV roof configuration, PV area setback from roof ridge to allow daylight access to clerestory windows under the skin, and addition of PV cladding on southern walls).

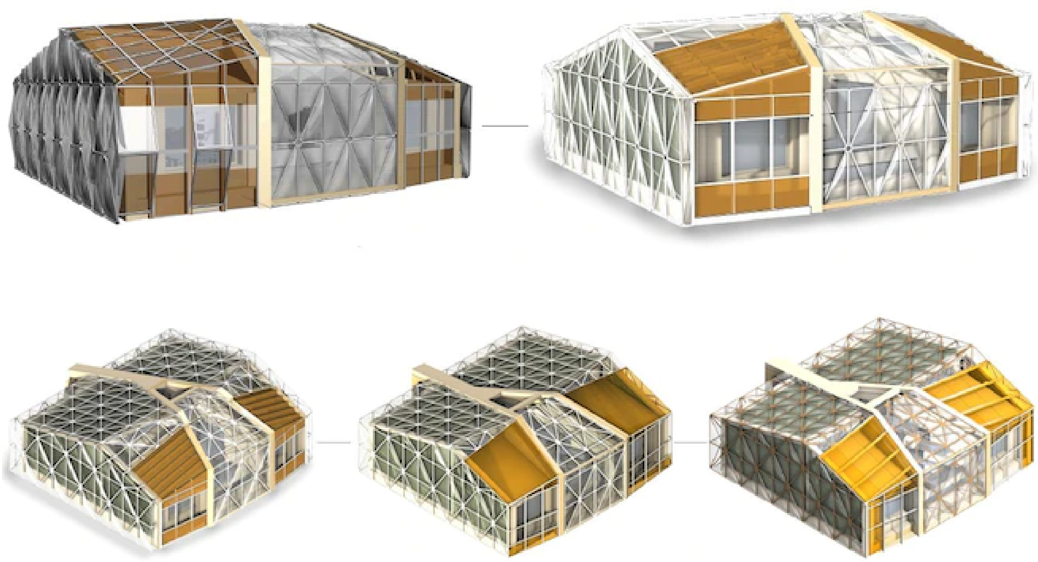


Figure 7 – Y-House exterior envelope evolution

Second, the envelope incorporated bifold doors into the outer double-skin façade of the solarium to allow natural ventilation that would prevent overheating, and to spatially extend the solarium to exterior space during moderate temperatures. Figure 27 indicates the location of operable doors and in section explains the passive heating and cooling strategy during summer and winter.

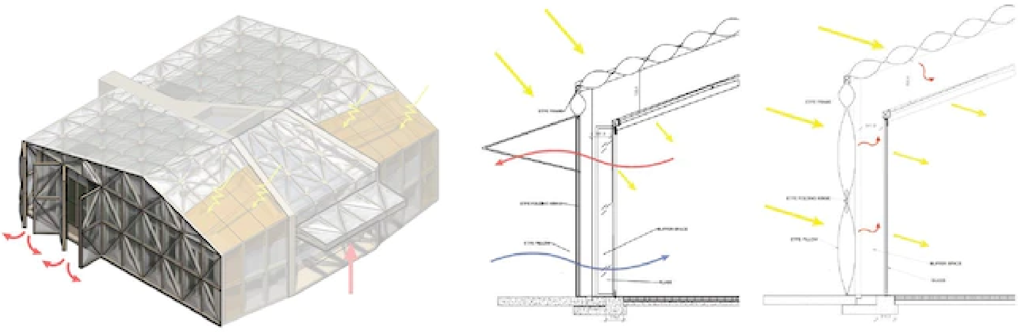


Figure 8 – Greenwall access through operable ETFE panels

Third, the green wall spaces require access to the plants for maintenance purposes, therefore, operable vertical doors on the east, north, and west walls, were designed for the ETFE skin.

Fourth, the structural frame of the ETFE was coordinated with the green wall panels and the struts within the straw bale walls, and the framing for the ETFE panels which also consists of laminated bamboo members (i.e., Glubam) which utilizes a consistent material throughout the building. In Figure 28, the exploded axon describes the wall composition.

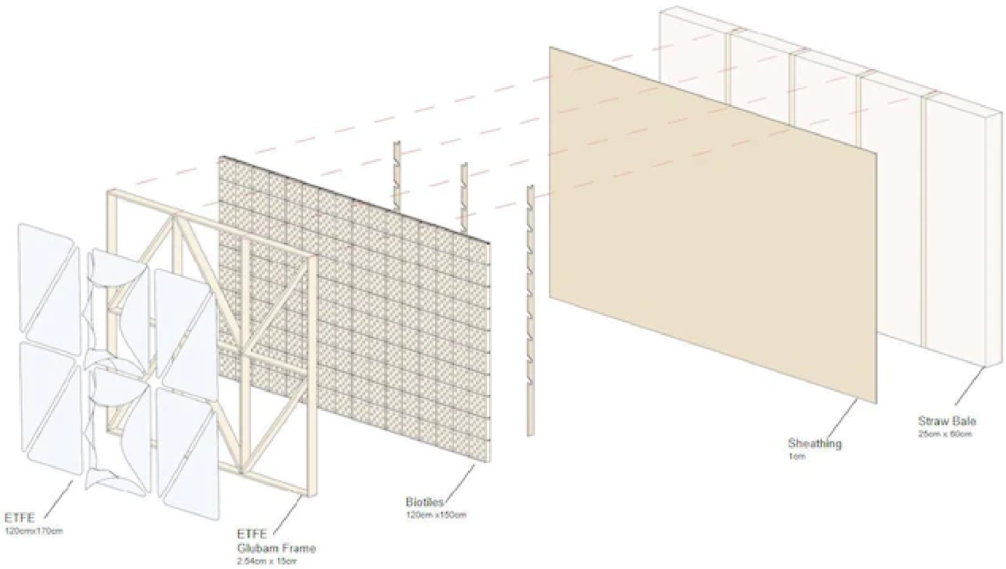


Figure 9 – Exploded wall assembly

Construction Documentation

Building on design development, the construction documentation phase started to address fabrication and installation considerations of the panel sizes of the proposed ETFE pattern. Because the triangulation pattern of the panels was denser than typical aluminum frame based ETFE panels, the team devised a novel patterning approach which incorporate tension wires on top of the external surface of the ETFE air cushions. This system benefits from fabricating larger rectangular ETFE panels which can then be formed into smaller triangulated patterns. Figure 29 illustrates the roof panel sizing, patterning layout, and drainage.

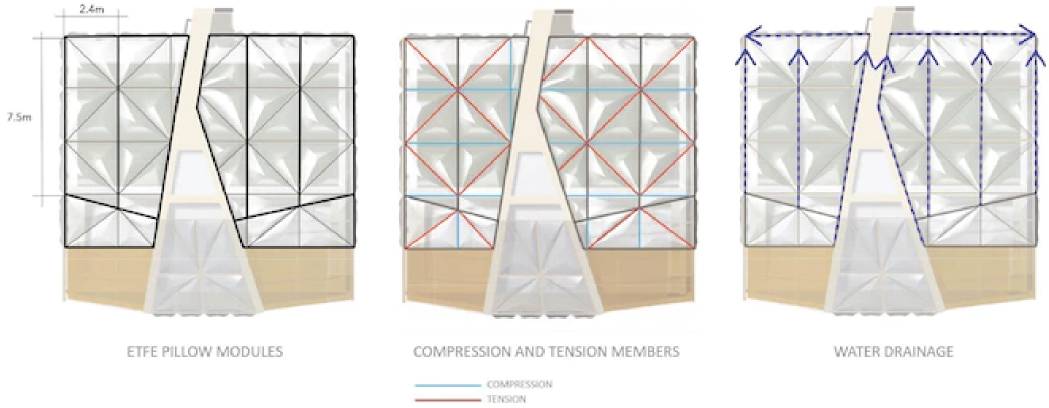


Figure 10 – Roof layout, drainage and panel sizing

Detailing studies followed the general panel layout of the roof and were iterated to accommodate cost constraints, including simplification of support aluminum extrusions, standoffs, and keder rails. Figure 30 and 30a illustrates two iterations, the first showing a lower cost approach.

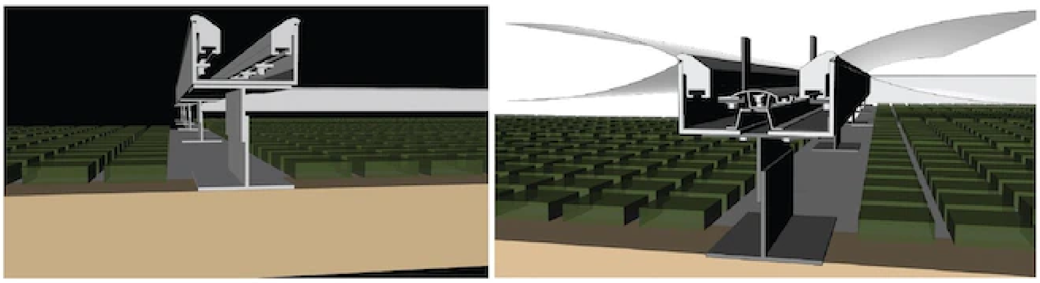


Figure 11 and 11a – Gutter development

Another key component is the ventilation of the ETFE double-skin roof system for temperature control that feeds into the HVAC system and maintains habitable temperatures for the plants on the roof and walls. A multiple vent system for the façade, including ridge vents at the peak of the building and alternatively on the northern tip of the roof were designed to guide airflow through negative and positive pressure from cold air intakes at the ground level to operable upper ridge releases.

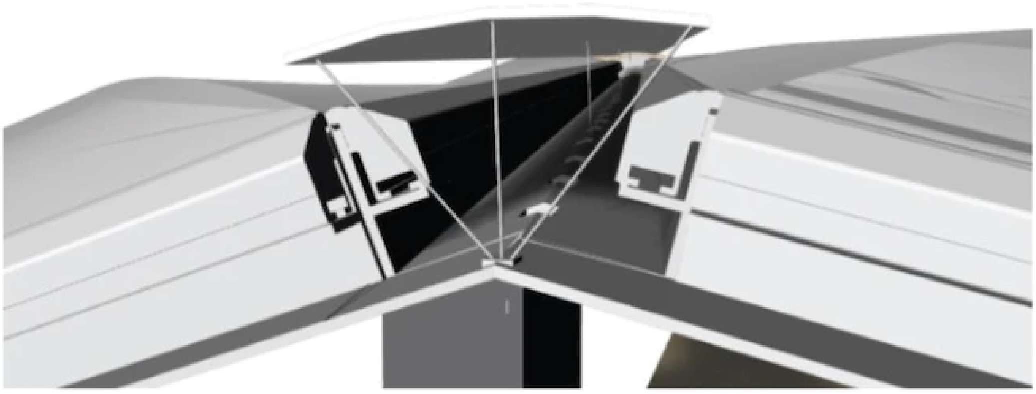


Figure 12 – Ridgeline vent strategy

Case Study Findings

This case study highlights the development process of an innovative ETFE air pillow system for a single detached family house which is currently under construction in Zhangjiakou, China. Understanding the practical constraints, including cost, and various technical constraints were critical for the team during the design process because many of the challenges emerged as many other building systems require higher integration with the envelope. The team went through many iterations for detailing which are beyond the scope of this paper.

Figure 13 – Final rendering of Y-House concept by Flying Architecture.

Figure 13b – Aerial photo of the completed SDC Y-House on site

MetLife Building Thermalswitch Façade (High Rise Overclad Double Skin)

Overview of the Project

Developed for the Metals in Construction 2016 Design Challenge, the Thermalswitch concept proposed utilizing a bespoke approach to recladding that would not dramatically alter the historic nature of the MetLife building in New York. Built in the 1960's, the building will need significant upgrades in order to meet the 2050 challenge and the façade will have a large impact on achieving that goal.

In this case study we focus on discussing the design considerations of the ETFE based double skin envelope system, mainly the integration of the following strategies into an innovative concept for recladding existing high rises.

- A passive and kinetic thermal control system utilizing nitinol wire springs that automatically senses internal cavity temperature and adjusts its length without the need for electrical or smart controls.
- Use of fiberglass pultrusions coupled with ETFE to increase thermal performance.

- Achieving a breathable façade that brings in fresh, pre-conditioned air throughout the year.
- Leveraging the Zone Green opportunities as required by the NYC building Code

Initial Concept

Paperweights, thermostats, and airflow are the primary inspirations for this reclad proposal. Over the four decades buildings have become more hermetically sealed and as a result, there has been a high burden placed on electrically powered mechanical equipment, equipment that has a much shorter lifespan than the building envelope or other building systems.

The paperweight inspiration is a reminder that air used to flow freely across the façade threshold. Before the digital age and air conditioning, offices would routinely leave the windows open to allow a breeze to flow and cool the space. Due to radiators in these buildings for heat, occupants in New York are known to open the windows even in the winter to temper the radiant heat.

In early analog thermostat technology, bimetal coils were used to set the temperature. Today, bimetals such as Nitinol are more common and have even been used in architectural installations, both interior and exterior. By utilizing these bimetals, architects have been able to achieve dynamic facades and skins through the use of solar gain and ambient temperature without the use of electrical currents.

Airflow, specifically fresh air flow, was the most critical element to this proposal. It draws on simple solutions like the Bedouin tent, trombe wall, and qanats of the desert structures as precedents to incorporate into a unitized façade and whole building mechanical systems. These techniques take advantage of the natural heating and cooling of the air to create airflow and convection currents without the utilization of mechanical equipment.

Schematic Design

To create the airflow required for this concept, the existing glazed frame is removed and replaced with a high performing fiberglass glazing punched window assembly with an integrated trickle vent at the head of the frame. Additionally, this glazing assembly is intended to be operable for maintenance and cleaning purposes. The overclad Thermalswitch unit creates a cavity of preconditioned air that can be pulled into the building during the winter. In the summer, the ETFE cavity vents through the head of the unit, pulling air through the façade and cool air from chases deep within the building.

Figure 14 – Overall image of the tower with Thermalswtich unit installed

The stretched layer of ETFE film delineates the boundary of exterior air to cavity air and the existing precast panels, while still allowing the precast panels to be visible. It is designed to be a singular box unit which connects to the adjacent panels by primary and secondary dry gaskets. The use of ETFE in this manner allowed for a double skin while keeping the character of the building intact. Because the primary wall assembly of the existing façade remains, the overcladding Thermalswitch unit is considered to be secondary – effectively becoming a transparent rainscreen cavity. As result of this, coupled with the box unit compartmentalization, the system can alleviate some of the concerns the NYC building department typically has with double skin facades – primarily the mitigation of smoke and fire propagation between floors.

Figure 15 – Exploded assembly of Thermalswitch unit, Figure 15a – Plan view of precast batten with overclad unit installed

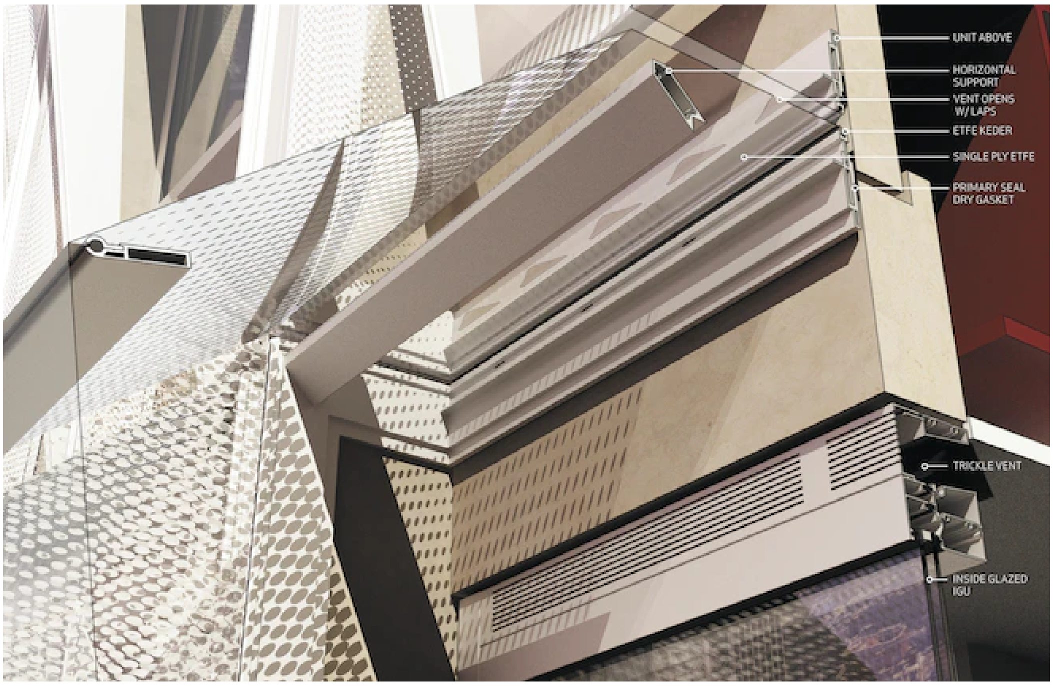


Figure 16 – Detailed rendering of Thermalswitch and punched window assembly with trickle vent

Design Development

The existing Metlife facade is constructed of a primary precast panel unit with integrated structural ‘battens’ on both sides of a single unit installed in an alternating A/B pattern. Bridging infill panels at the spandrel conditions connects the alternating A units creating a “zipper” effect and maximizing the structural nature of the precast unit. This patterning highly influenced the design and modularity of the Thermalswitch unit. The approach was to look at creating a hybrid between replacement, overcladding, and a double skin, which is hung off the existing precast unit battens. Knowing the existing glazing assemblies of the precast units were outmoded this was the ‘replacement’ portion of the hybrid strategy. The glass and framing are removed, the daylight opening (DLO) cleaned and prepped to receive the new fiberglass glazing assembly with trickle vent and operable componentry.

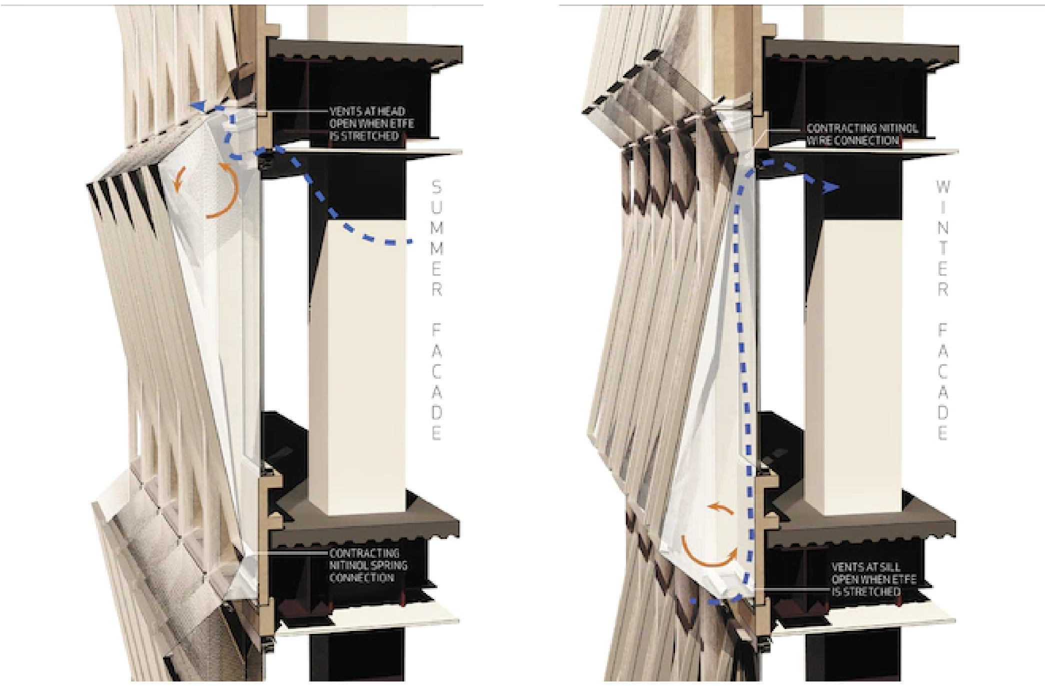


Figure 17 – Wall sections of the Thermalswtich operation during various seasons.

The overcladding unit anchors are first mounted to the top portions of each precast batten. This anchor is a custom strategy specific to the Metlife building's existing geometry. The Thermalswitch unit itself is comprised of a frame of fiberglass pultrusions and stretched ETFE film that mounts over the precast battens and is anchored to the existing facade. Because the battens are the primary vertical structure of the precast façade unit and exposed to the exterior, it was critical to overclad these fins to reduce the thermal bridging across the façade.

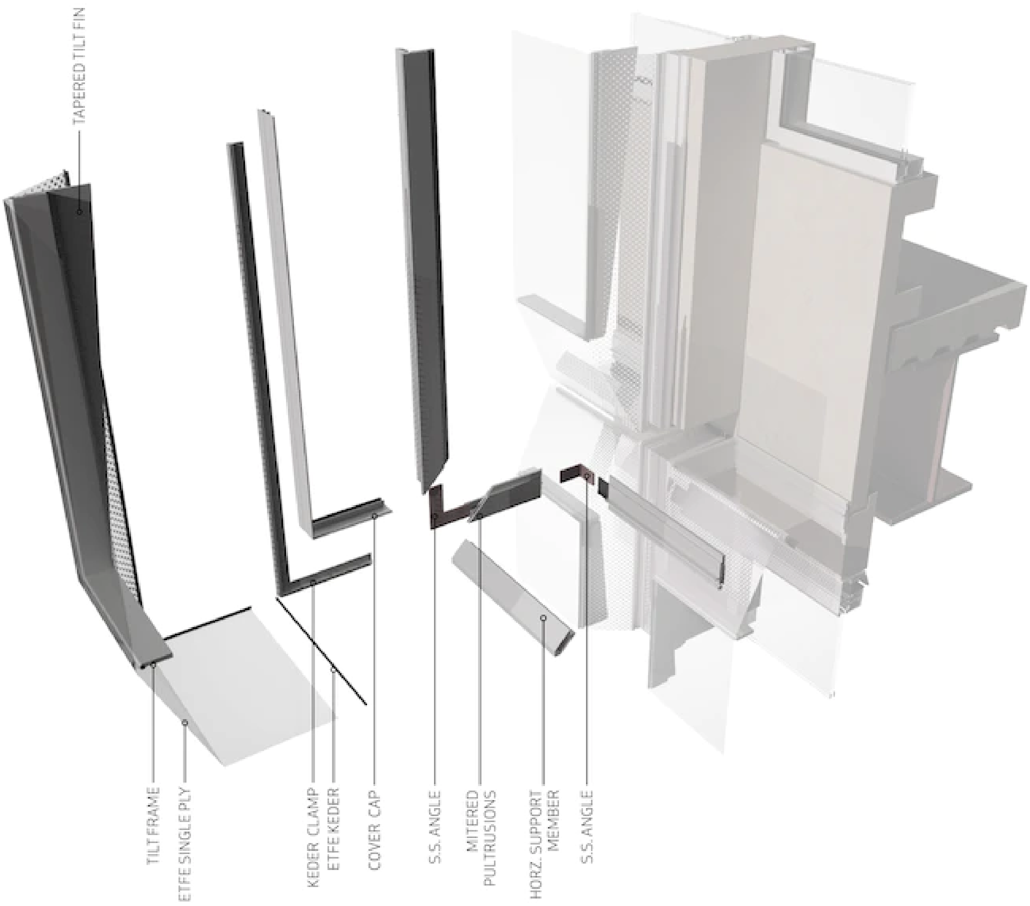


Figure 18 – Exploded assembly of Thermalswitch component parts

Additional insulative strategies like the aerogel mats or high-performance blankets could assist in further reducing the thermal bridging. However, due to the thermal mass of the precast batten, coupled with the preconditioned air on the left and right sides created by the Thermalswitch unit, the new, slightly ventilated cavity drastically improves the thermal performance of the whole building skin by approximately 200%.

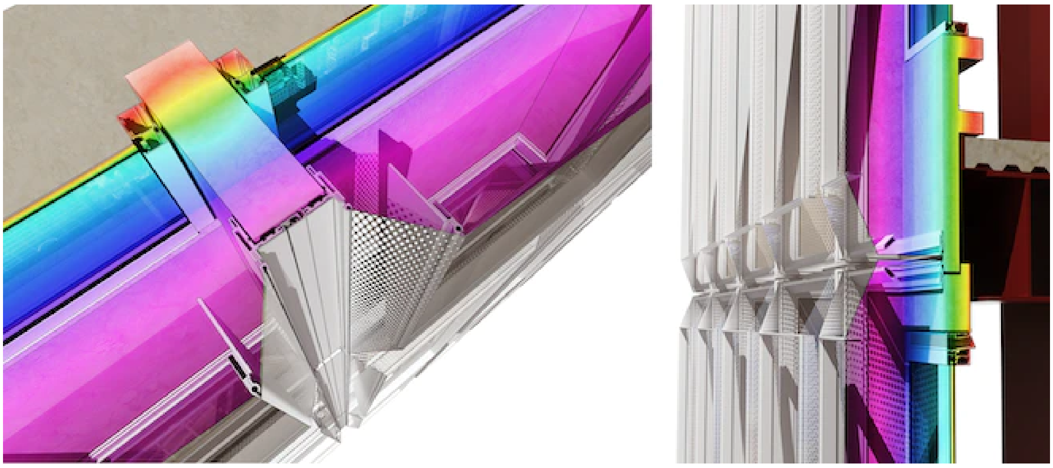


Figure 19 – Thermal overlay with overclad unit showing temperature gradient across the plan and section of the envelope

Due to the light weight nature of the ETFE, the Thermalswitch unit mounts directly onto the existing façade and does not require any additional structure to support it, nor does it drastically impede on the original daylight opening of the iconic facade. With ETFE having approximately 85% light transmission, the overall characteristic of the light entering the space is not significantly affected. Within the unit there is a tilting frame which the ETFE stretches over. In the summer, the unit tilts out at the top to increase the awning, the frit pattern aids in reflecting the summer sun. In the winter, the unit tilts out at the bottom to increase the angle to the sun and aids in the heating of the space inside the unit. This is controlled by two nitinol cables at the head and sill of the tilt frame. As the temperature changes through the seasons the nitinol cable contracts or expands tilting the unit.

The utilization of ETFE and fiberglass pultrusions, instead of aluminum and glass, drastically reduces the embodied energy of the systems while increasing the thermal performance as fiberglass pultrusions are less conductive than aluminum. This decision was made with the understanding that FRP does have a slightly higher GWP per metric ton than painted or anodized aluminum, the significant decrease in thermal conductivity between the two materials is worth the higher GWP. As for ETFE, it can cover complex frames and retain its elastic properties when stretched up to 3x its original length. Finally, because of ETFE's non-adhesive surface, dirt, dust and debris do not stick and are washed away by rain. This essentially removes the requirement for the washing of the exterior of the facade and any additional hardware required. Where cavity maintenance of the semi-ventilated cavity is concerned, the new punch window assemblies could be integrated with an operable vent, opening to the interior for required access.

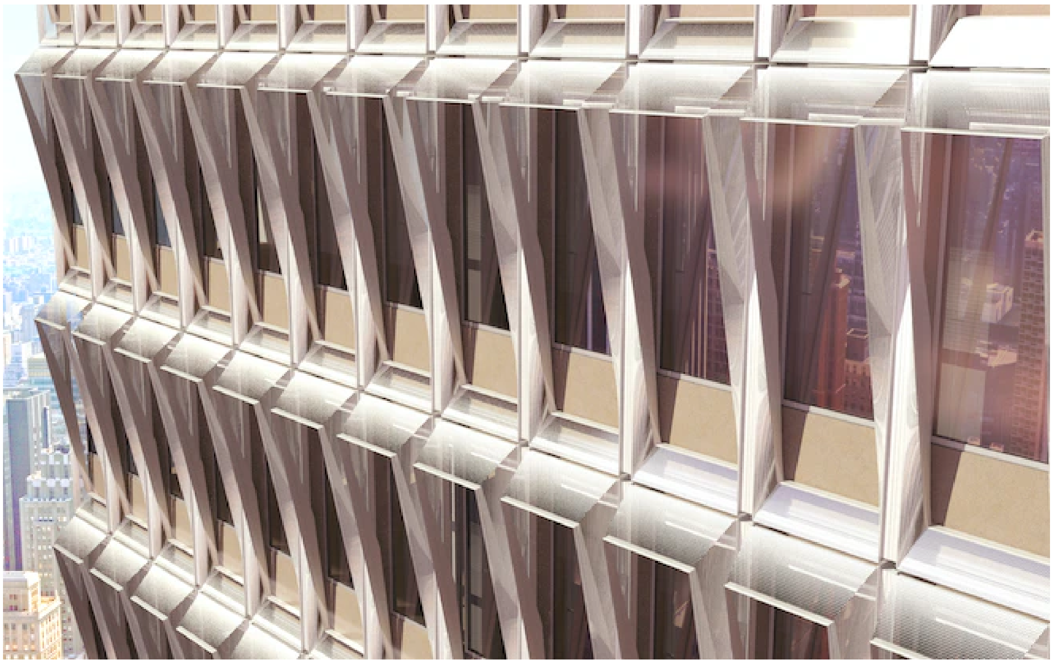


Figure 20 – Overall image of the Thermalswitch unit installed (summer orientation)

Case Study Findings

The 1960's-70's saw a building boom in skyscrapers that are now well past the 20-30 year expected lifespan of their facade systems. Deferring these renovations increase energy consumptions costs and can increase the amount that will have to be spent when the renovation will inevitably have to be done.

Double skin facades can be extremely energy efficient, however box window systems are not as common as the multistory systems but are becoming more of the norm due to their reduction in flame and smoke spread. However, the box overclad systems like the Thermalswitch unit could be an ideal way to renovate a facade as they minimize the impact to the buildings occupants by only affecting 1-2 floors at a time during the renovation, allowing the majority of the building to remain open and functioning. These overclad systems may also reduce the amount of shared air between occupants. This is beneficial in the sense that it minimizes the spread of pollutants, smoke, or contagions as opposed to a shaft-box, corridor, or multistory system. A key consideration for the success of most double skin units is ensuring that the double skin units do not overheat – this typically requires an in depth CFD model for various locations across the height of the façade in addition to the various elevations. Because ETFE can be coated with similar Low-E and solar coatings, as well as frits, this may help reducing any overheating potential.

There are key pieces of legislation, that if implemented, would affect all US existing buildings, such as the Green New Deal. As it stands now, the 2050 Challenge is a goal many municipalities and building owners are already striving towards. There are also major cities throughout North America already implementing their own unique versions of legislation that are similar to the Green New Deal:

- Los Angeles Sustainable City pLAn
- Seattle Buildings Tune Up Ordinance
- Milwaukee Milwaukee's Green New Deal
- Washington D.C. Clean Energy D.C. Omnibus Act of 2018
- Toronto Green Standard Version 3 Zero Emissions Building Framework
- New York Climate Change Mobilization Act

As we move into the future of existing building stock, we must consider new materials and passive strategies in order to meet energy needs. Novel uses for ETFE and bi-metals can open up possibilities for the re-clad needs that will be required to meet the 2050 challenge, the possibility of the Green New Deal, and the above listed cities' sustainability minded legislation.

FINAL REMARKS

In this paper we discussed ETFE based membrane strategies for residential and high-rise envelope applications for new and retrofit purposes. As mentioned in the earlier sections, the studies presented here are preliminary and are intended to highlight research needs for ETFE as a viable cladding strategy specifically for single detached family house and high-rise building typologies. As our work progresses, we continue to update the components which are part of a broader research framework. (1) The analysis of existing building stock is further refined with expanded sampling from additional sources and databases; (2) The double-skin typology and configuration of ETFE membranes for single detached family house and high-rise building are further developed involving studies at the scale of system assemblies and building scale, including physical prototyping, monitoring, and simulation studies. As mentioned, the Y-Project is nearing completion and operational performance data collection will commence; and (3) a holistic framework that integrates architectural, energy and environmental, technical, financial considerations in the respective context of new construction and retrofit applications will be refined.

From these two case studies, we can begin to see the beginnings of a potentially viable path towards achieving the 2050 goal of all existing buildings operating at Net Zero emissions for both site and source. If we are honest with ourselves, the heart of the climate crisis is the human desire for comfort. We created structures to protect us from hard nature and now it is our structures, through materials and operation, that are impacting the global climate at an alarming level. However, it is interesting to consider that some of the original tent and membrane structures used by our ancestors and modern-day outdoor enthusiasts, could – with the application of modern materials like ETFE – become a path to helping achieve a carbon neutral future for us on this pale blue dot we call home.

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RIGHTS AND PERMISSIONS

Hamilton, I., Kennard, H., Rapf, O., Kockat, J., and Zuhaib, S. (2020), 2020 Global Status Report for Buildings and Construction, https://globalabc.org/sites/default/files/inline-files/2020%20Buildings%20GSR_FULL%20REPORT.pdf

Martinez Arias, Andrea & Patterson, Mic & Carlson, Anders & Noble, Douglas. (2015). Fundamentals in Façade Retrofit Practice. Procedia Engineering.

Wilson, E, Christensen, C., Horowitz, S., Robertson, J., and Maguire, J. (2017) Energy Efficiency Potential in the U.S. Single-Family Housing Stock, National Renewable Energy Laboratory