X/O SKELETON

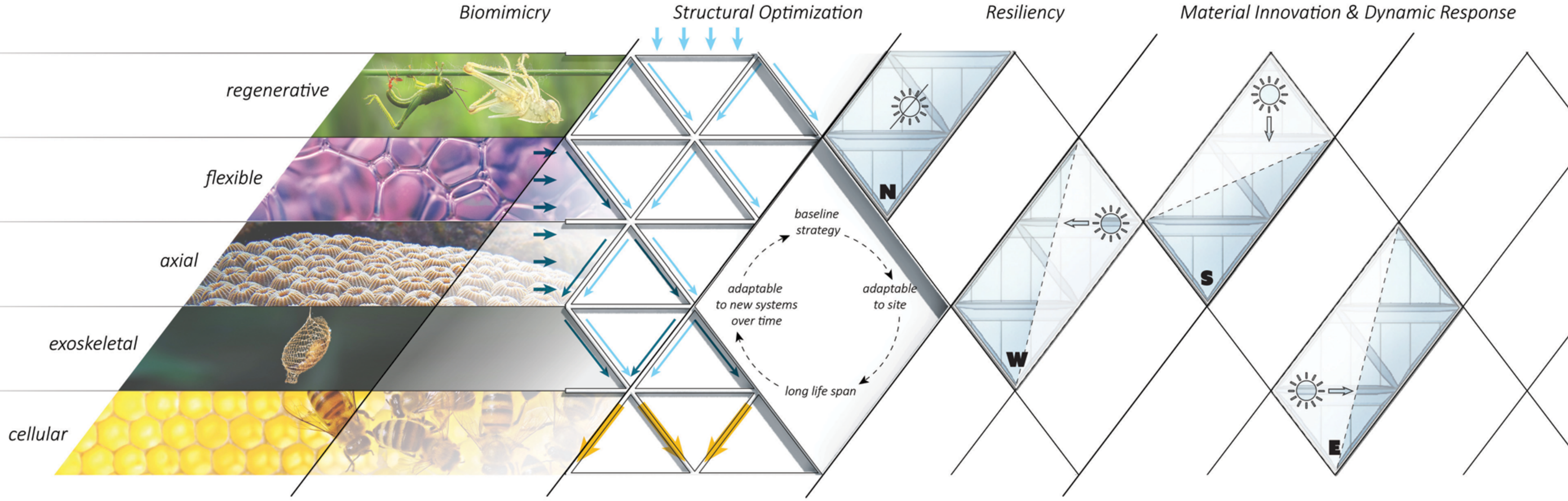
Mr. McGuire: *I want to say one word to you. Just one word.*
Benjamin: *Yes, sir.*
Mr. McGuire: *Are you listening?*
Benjamin: *Yes, I am.*
Mr. McGuire: *Plastics.*
Benjamin: *Exactly how do you mean?*
Mr. McGuire: *There's a great future in plastics.*
Think about it. Will you think about it?

Nichols M. (Director). 1985. The Graduate

X/O Skeleton

It could be said, in the light of new understanding about material choices and life-cycle impact that we are suffering under the weight of our buildings. The knowledge that the embodied energy of a building can far exceed its lifetime energy usage demands an innovative response of materials and systems. ***Our proposal asks: how light can buildings be?***

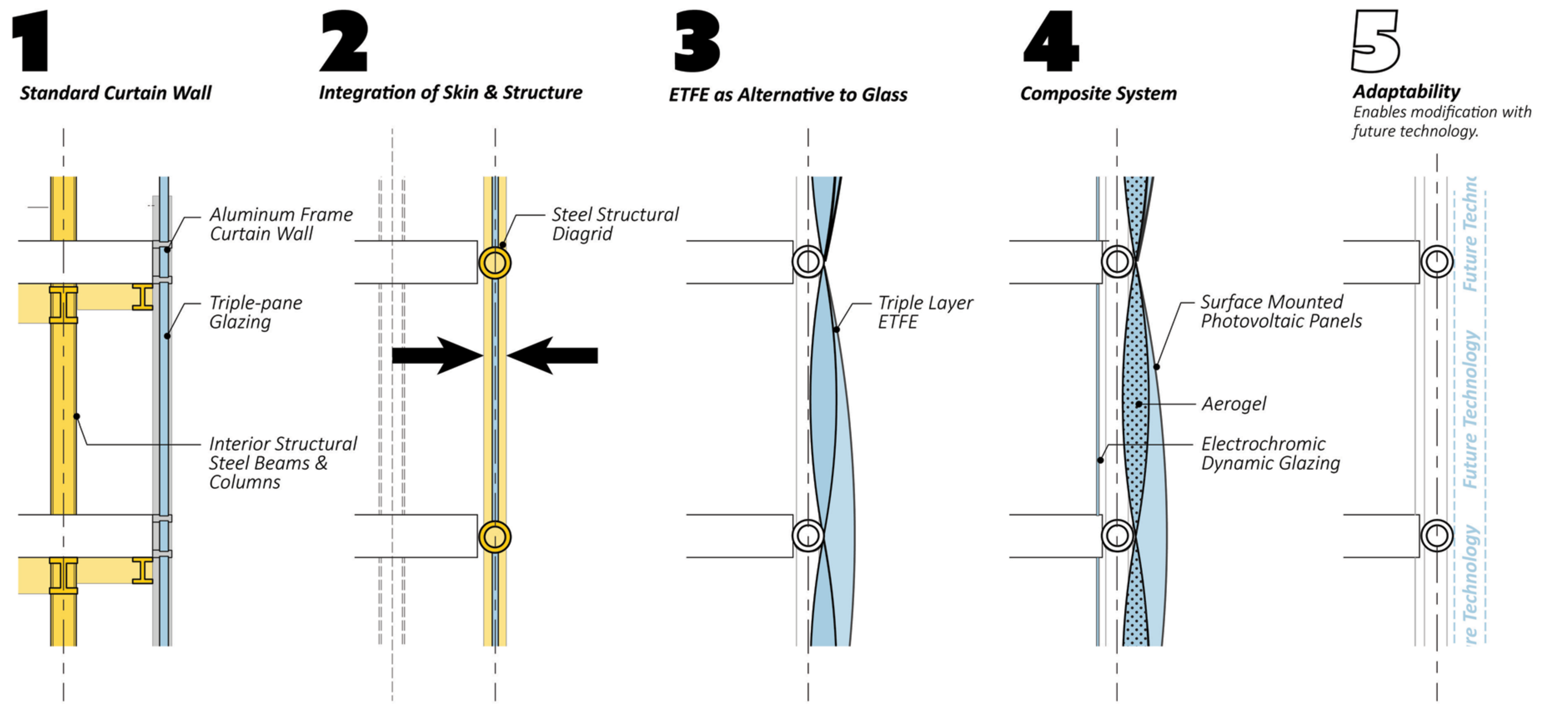
X/O Skeleton proposes a new way of thinking about high rise façade construction. Drawing from natural formations like coral reefs, we propose to combine structure and skin in a single ***X/O Skeleton***.

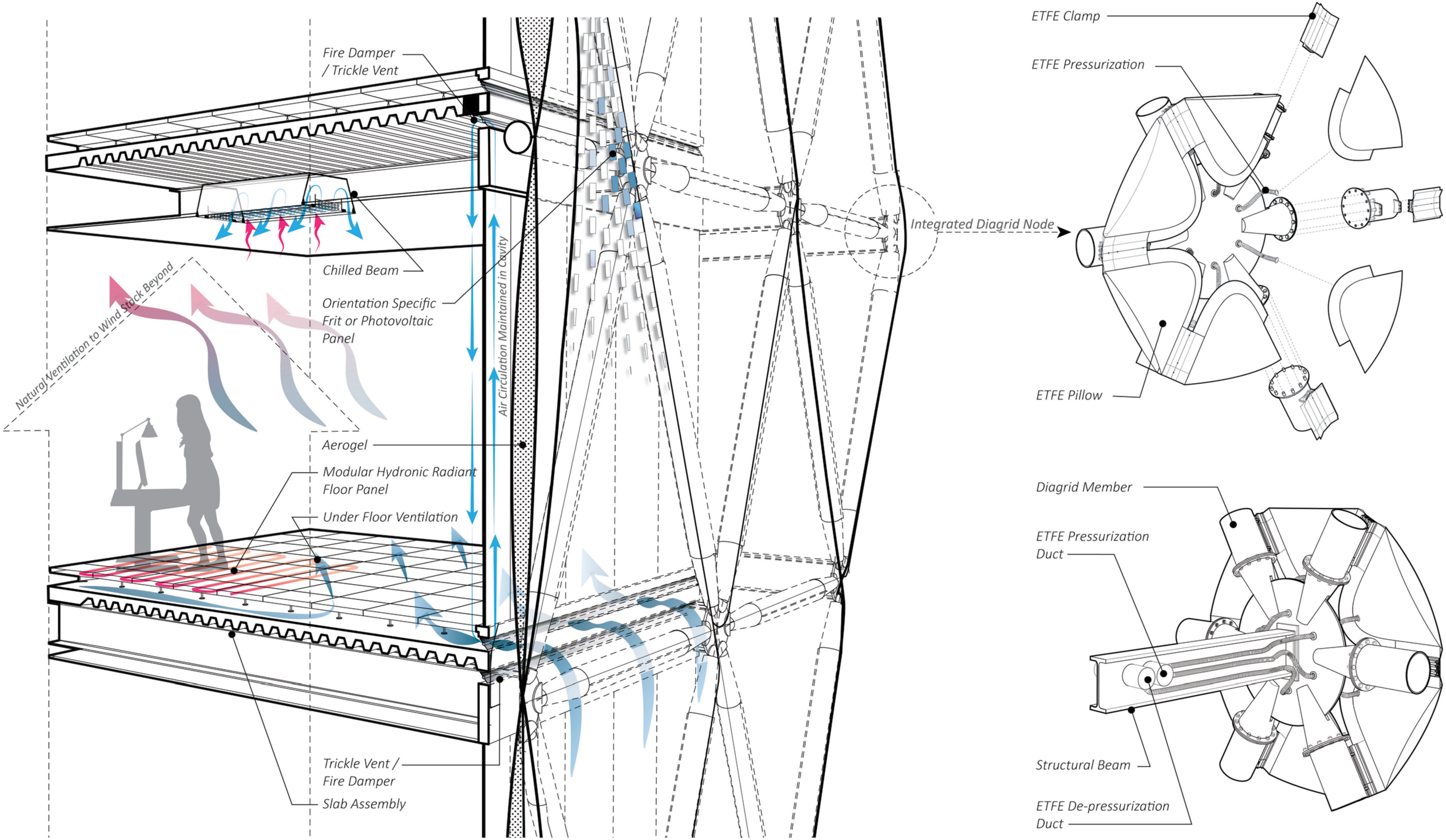


The "***X***" is our nomenclature for a diagrid system, an optimized structural form, which efficiently combines lateral and gravity loads at the perimeter of a building. In our system, the diagrid is sized to balance the needs of: a column free environment, maximized view, and at a frequency to serve a dual function as the primary backup for building cladding.

The "*O*" represents our proposal to replace glass curtain wall with pillow-like infill panels of ETFE, (*Ethylene tetrafluoroethylene*) a fluorine-based plastic. While plastics are high in embodied energy, the relative weightlessness compared to glass makes it an order of magnitude better on a square foot basis and has added benefits of reduced weight and cost of shipping, construction, and the eventuality (as explored in last year's Metlife competition) of recladding.

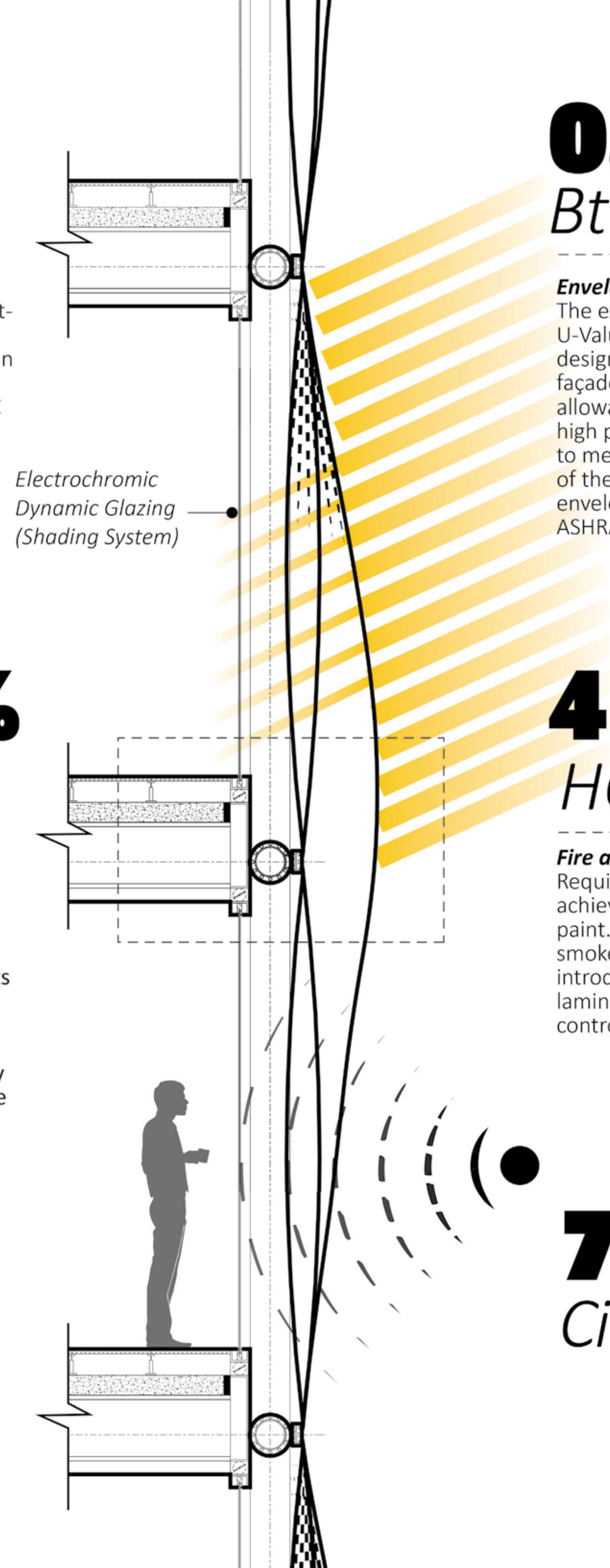
We recognize that ETFE by itself does present technical challenges and have therefore proposed a composite wall system in which ETFE serves as the primary weather, thermal, and solar control layer.




Fire Damper
/ Trickle Vent
Chilled Beam
Orientation Specific
Frit or Photovoltaic
Panel
Natural Ventilation to Wind Stack Beyond
Air Circulation Maintained in Cavity
Aerogel
Modular Hydronic Radiant
Floor Panel
Under Floor Ventilation
Trickle Vent /
Fire Damper
Slab Assembly
Integrated Diagrid Node
ETFE Clamp
ETFE Pressurization
ETFE Pillow
Diagrid Member
ETFE Pressurization
Duct
Structural Beam
ETFE De-pressurization
Duct

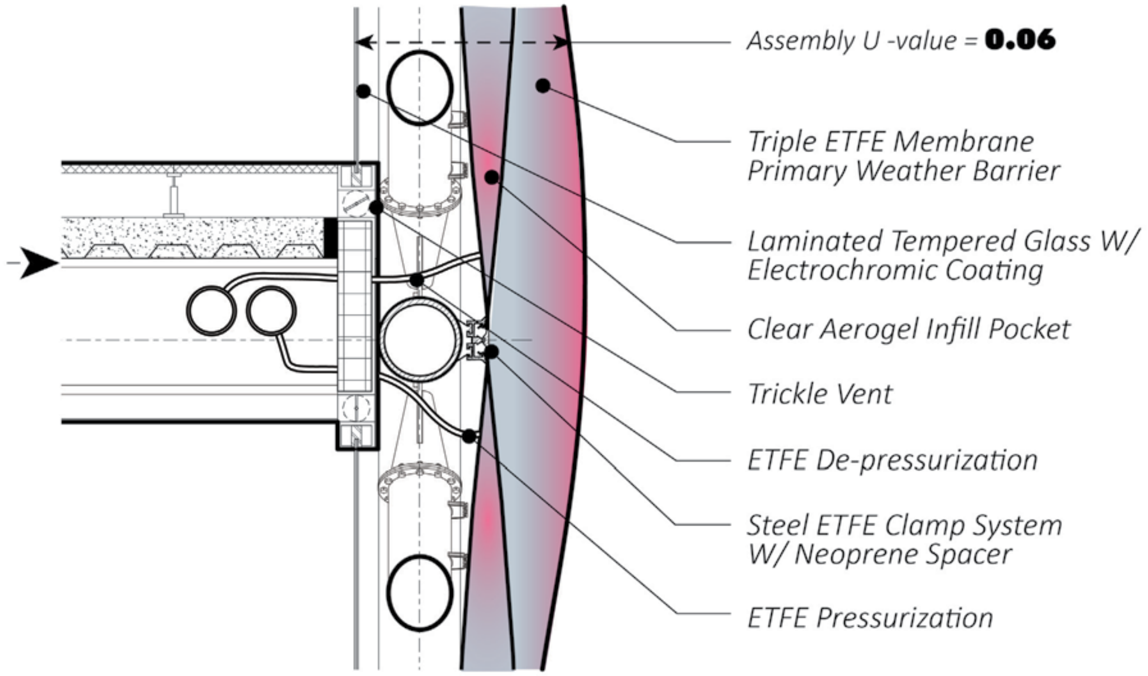
0.1 - 0.3
SHGC

Solar Heat Gain:
The electrochromic coating on the laminated tempered glass has the dynamic capability of achieving a range of solar heat gain coefficients from 0.10-0.30. The exterior wall assembly meets and exceeds the NYC ECC 2016 energy code required performance values for solar heat gain allowance.



0.06
Btu/hr-ft²°F

Envelope Thermal Performance:
The exterior wall assembly has a design U-Value of 0.06 Btu/hr-ft2 °F. Despite the design having an almost entirely glazed façade which exceeds the max code allowable 40% window to wall ratio, the high performance glazing assembly is able to meet the perspective code compliance of the NYC ECC 2016 through the building envelope trade-off option allowed by ASHRAE 90.1-2013.

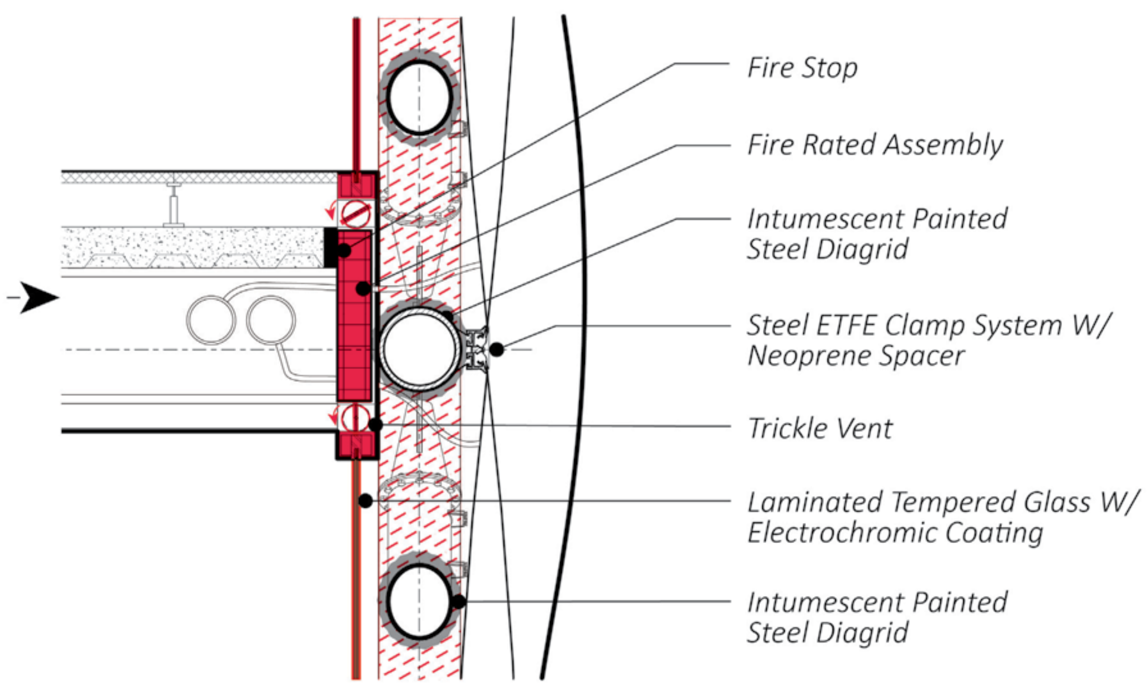


85% - <1%
VT

Daylighting:
The designed ETFE foil assembly in addition to dynamic glazing has the flexibility of achieving a range of visible light transmittance from 85% - <1%. The dynamic control allows building occupants to optimize daylight entering the space and minimizes all potential for glare discomfort. Custom frit patters and photovoltaic film are applied to clearstory height ETFE foil assembly based on façade orientation for solar shading.

4
HOUR

Fire and Smoke Protection:
Required rating for the steel diagrid is achieved through the use of intumescent paint. Compartmentalization of heat and smoke is achieved through the introduction of an inner layer of laminated/tempered glass and smoke control dampers at trickle vents.



31db
Whisper

Sound Attenuation:
The facade system has an STC of 39 decibels reducing the noise level of city traffic to the sound level of a whisper

70db
City Traffic

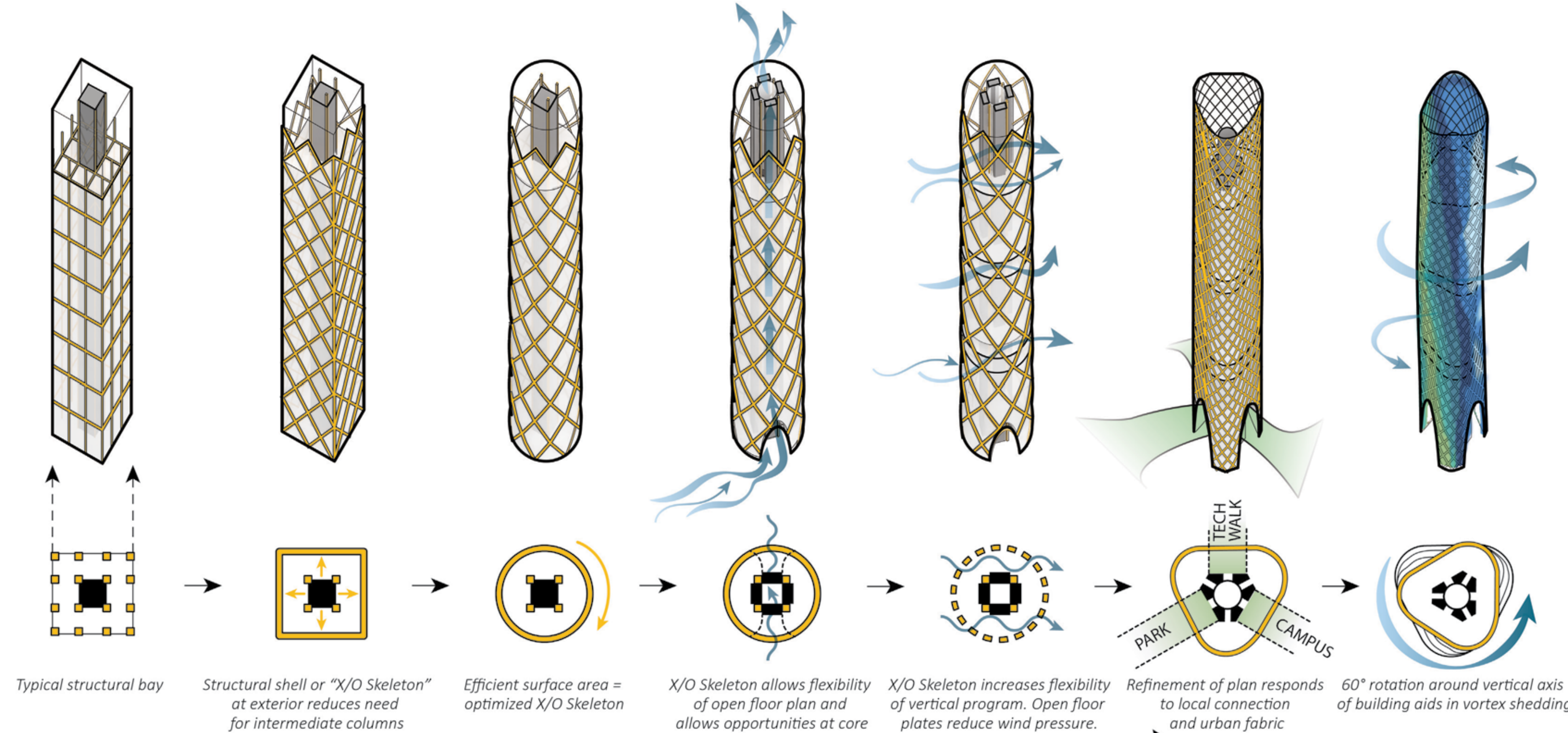
Site and Adaptation

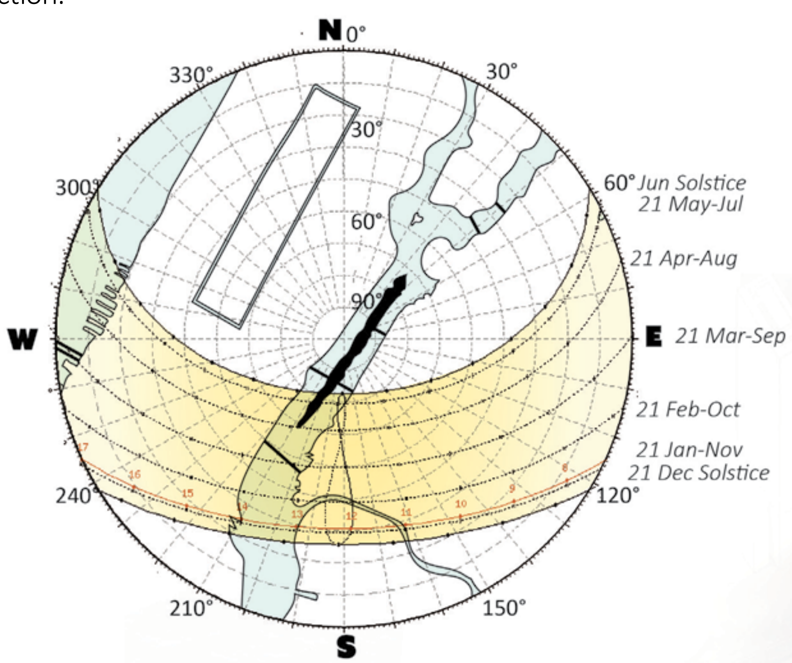
The Roosevelt Island Net Zero New York Tech Campus is an optimal location to display a progressive approach to high rise design. The site is well situated for views and is within close proximity to public transportation and recreational amenities.

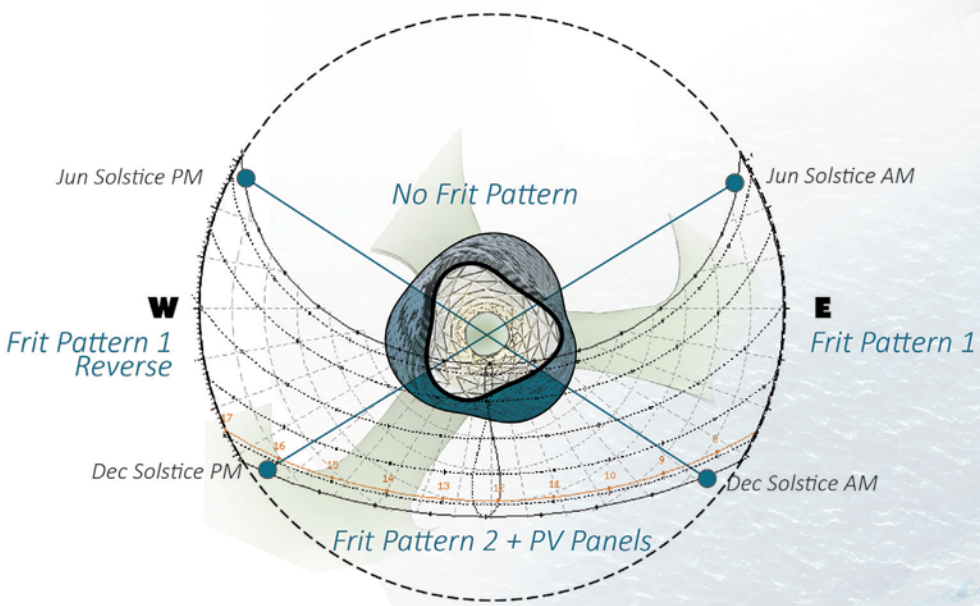
The ***X/O Skeleton*** engages the Tech Campus' raised pedestrian friendly site, by pulling the primary routs through the base of the building, encouraging interaction and activation.

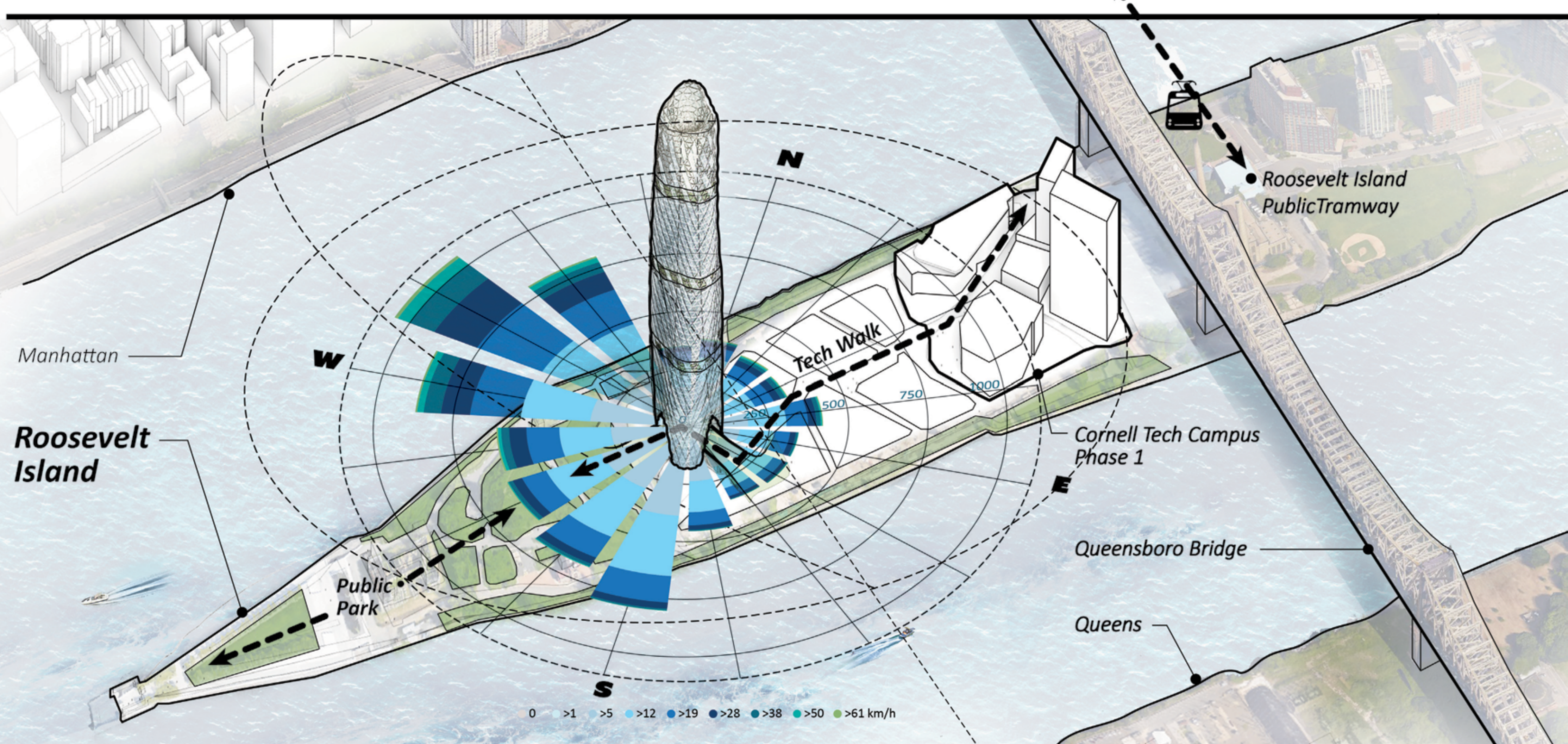
It further engages the site by elevating the greenspace above the campus, allowing tech education to be experienced from multiple levels.

The adjacent diagrams explain the evolution of our tower from conventional construction to ***X/O Skeleton***, while illustrating the morphological response to site, solar orientation and wind direction.









Structural Analysis

Structural System:

Structural analyses of both a conventional system and the proposed diagrid system were performed. In order to simplify the analyses a circular floor plate was modeled in both cases.

Design Criteria:

Building Code: New York City Building Code, 2014
Dead Load: Slab Construction: 3" composite steel metal deck plus 2-1/2" normal weight concrete
Superimposed Dead Load: 20 psf including partitions.
Live Load: 50 psf
Basic Wind Speed: 98 mph
Exposure Category: C
Importance Factor: 1.0
Risk Category: II
Drift Limit for Wind Loads: Building Height/450 under the 100-year mean recurrence interval (MRI) wind
Seismic Loads: Not considered

Conventional System			Diagrid System	
Floor	**Column Size**	**Brace Size**	**Floor**	**Diagonal Size**
49-50	W14x53	HSS 6x6x5/16	49-50	W8x24
46-48	W14x99	HSS 6x6x5/8	46-48	W8x31
43-52	W14X120	HSS 7x7x1/2	43-45	W10x45
40-42	W14x176	HSS 8x8x1/2	40-42	W10x49
37-39	W14X211	HSS 8x8x5/8	37-39	W12x58
34-36	W14X283	HSS 9x9x1/2	34-36	W12x65
31-33	W14X342	HSS 9x9x5/8	31-33	W12x72
28-30	W14X398	HSS 10x10x1/2	28-30	W12x87
25-27	W14X455	HSS 10x10x5/8	25-27	W14x90
22-24	W14X605	HSS 10x10x3/4	22-24	W14x99
19-21	W14X665	HSS 10x10x3/4	19-21	W14x109
16-18	W14X730	HSS 12x12x5/8	16-18	W14x109
13-15	W14X808	HSS 12x12x5/8	13-15	W14x120
10-12	W14X808	HSS 12x12x5/8	10-12	W14x132
7-9	W14X873	HSS 12x12x3/4	7-9	W14x145
4-6	W14X873	HSS 12x12x3/4	4-6	W14x145
1-3	W14X873	HSS 12x12x3/4	1-3	W14x176

Conventional System:

The conventional scheme consists of a steel frame with an exterior ring and an interior ring of columns. The distance between the interior and exterior rings is *40 feet* which allows for ample column free space. There are *14* columns at each ring. The exterior columns are *37.5 feet* apart while the interior columns are spaced at *20 feet*. Steel beams span the *40 feet* between the interior and exterior rings. The lateral system consists of braced frames located at the perimeter of the building. While the braced frames would most typically be placed at the core of the building, we modeled the braced frames in the perimeter of the building in order to simplify the analysis and allow for an easier comparison of the conventional and diagrid systems. By making all the interior steel framing equal in both systems and changing only the perimeter steel the difference in tonnage between the two systems can easily be calculated by just looking at the difference in the perimeter framing. In order to help control the drift belt trusses were placed at mid-height and at the top of the building.

X/O Skeleton System (Diagrid):

The diagrid scheme consists of diagonal members at an angle of *67.5 degrees* with respect to the horizontal. With this slope and a floor to floor height of *15 feet* the nodes of the diagrid are spaced at *12'-6"* approximately. The elements of the diagrid resist the gravity and wind lateral loads as well as the wind loads on the façade. The interior framing is the same as in the conventional scheme with an interior ring of columns and beams that span *40 feet* between the column line and the perimeter diagrid. The interior beams frame into the nodes of the diagrid and therefore do not introduce bending stresses into the perimeter spandrel elements.

Analysis Results:

The design of both schemes meet all strength and stiffness requirements including the story drift limit of *Building Height / 450*. The conventional system has a maximum of *19" lateral drift* or *Building Height / 473.* The diagrid system has a maximum of *10.5" lateral drift* or *Building Height / 857*.

The final member sizes of the conventional and diagrid systems are shown in the table to the left.

The quantity of structural steel was calculated for the perimeter structure only as the interior framing is identical in both schemes. The conventional system has a tonnage of exterior steel of *3206 Tons* while ***the diagrid system has a tonnage of 3341 Tons which is an increase of 135 Tons with respect to the conventional system. This increase in tonnage of steel was expected as in the diagrid system the structural steel works as the lateral and gravity systems of the building but also the diagrid elements resist the wind loads applied on the façade and transfer those loads to the floor diaphragms.*** In the conventional system, the façade elements transfer the wind loads to the floor diaphragms.

> ***"The diagrid system has a tonnage of 3,341 Tons which is an increase of 135 Tons with respect to the conventional system. This increase in tonnage of steel was expected as in the diagrid system the structural steel works as the lateral and gravity systems of the building but also the diagrid elements resist the wind loads applied on the façade and transfer those loads to the floor diaphragms."***

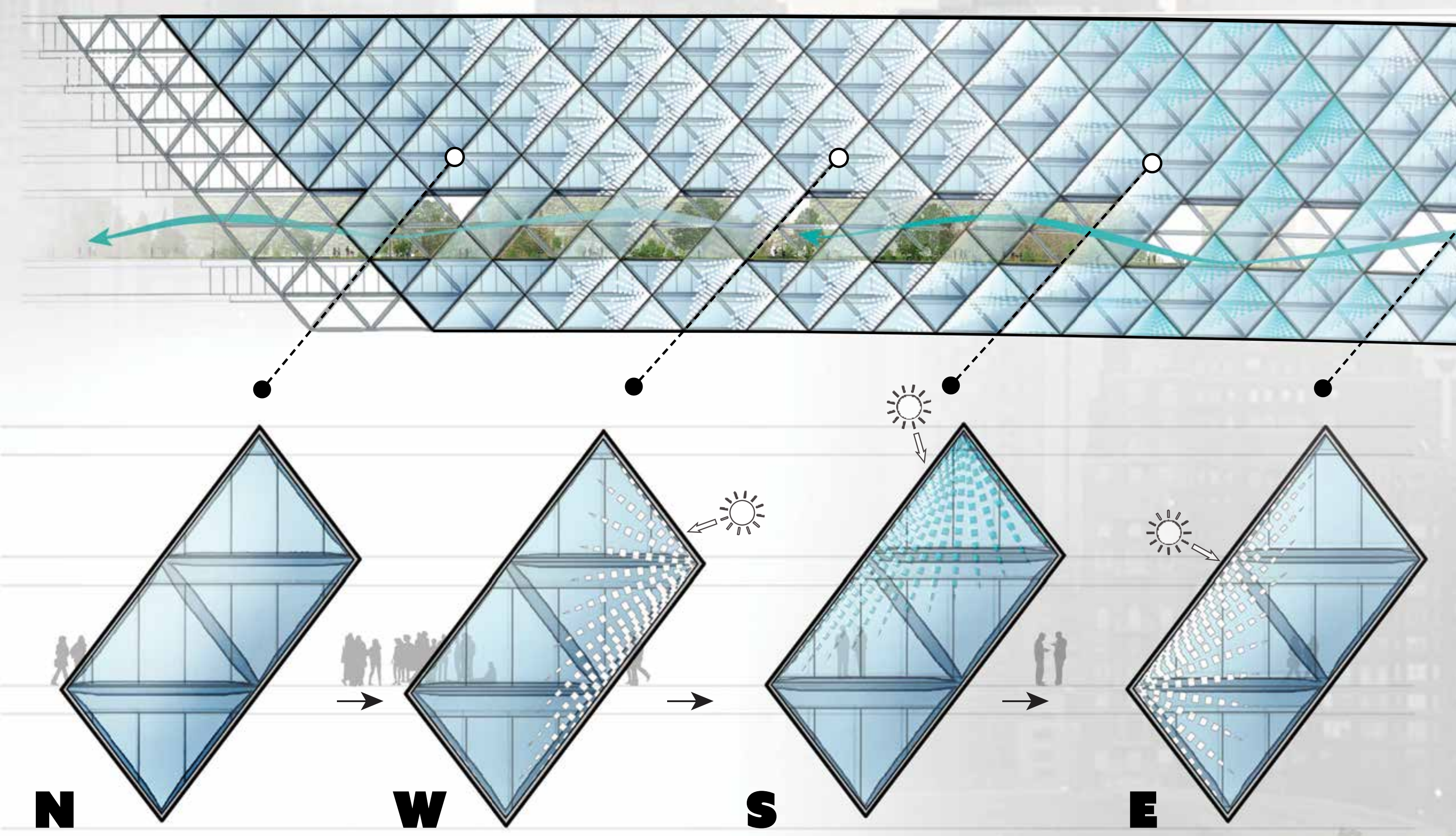
Conventional System
Structure concentrated at core and interior columns

X/O Skeleton
Structure at perimeter

Energy and Efficiency

The structural envelope of the building is integrated with PV fritted ETFE panels that are optimized based on orientation and sun exposure. This will allow the building to harvest solar energy while simultaneously providing visual comfort within.

As the building is extruded upwards, the floor plates rotate for improved air flow around its uppermost levels. Intermittent sky gardens serve the dual purpose of relieving wind load and providing recreational space.

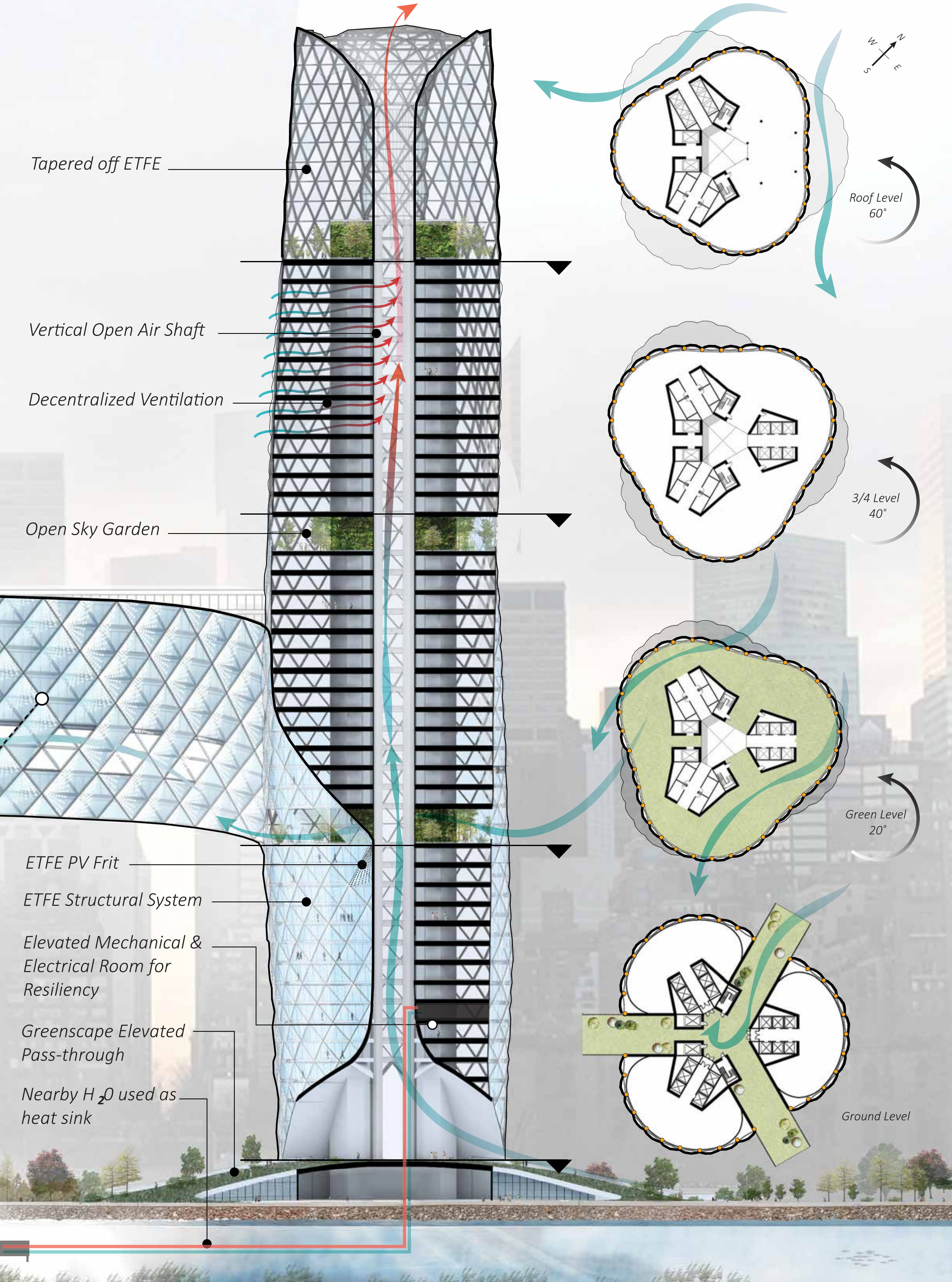


North oriented ETFE shown without PV frit, as sun exposure is limited.

Similar to the east, the western exposed ETFE PV frit accumulates on the western edge.

Due to intense sunlight exposure, the southern exposed ETFE PV frit gradients from the top of the panel.

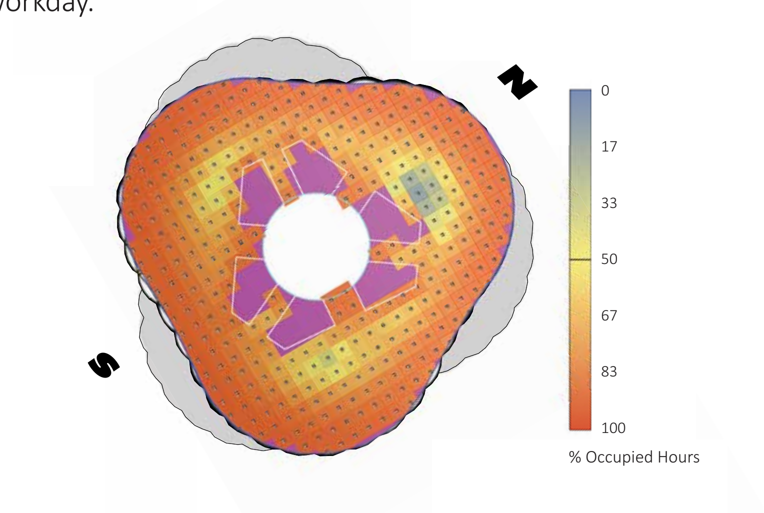
Eastern exposed ETFE panels accumulate PV frit pattern in upper right corner to capture sunlight.

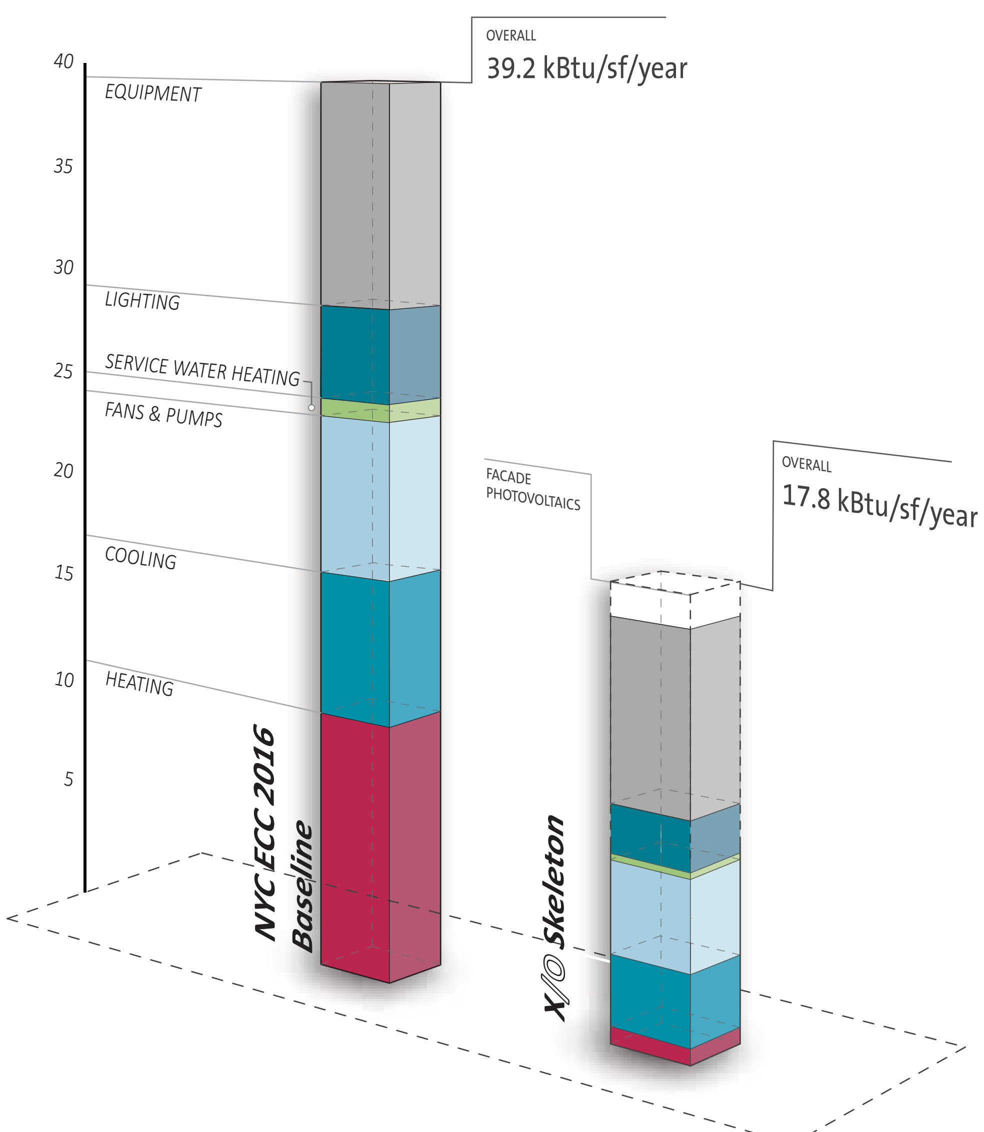


Energy and Occupant Comfort

Daylight Autonomy Analysis (sDA, 300lx)

Natural views and daylight are available to 95+ percent of the floor plate which allows the building occupants to connect to the outdoors while also allowing for the natural function of their circadian rhythms due to access to natural daylight throughout the workday.





Occupant Health and Wellness

This building has been designed with the building occupant in mind in order to achieve an environment that promotes health and wellness as well as provides optimal conditions for productivity and function.

Air
Ventilation Effectiveness
VOC Reduction
Air Filtration
Humidity Control

Water
Water Treatment
Drinking Water Promotion

Nourishment
Food Production
Mindful Eating

Light
Visual Lighting Design
Circadian Lighting Design
Glare Control
Shading/Dimming Control
Daylight Harvesting

Fitness
Interior Fitness Circulation
Exterior Active Design
Active Furnishings

Comfort
Ergonomic Design
Thermal Comfort
Sound Barriers
Radiant Thermal Comfort

Mind
Beauty and Design
Biophilia
Adaptable Spaces

Summary of Savings

Annual Energy Cost Savings

Photovoltaic film attached to exterior ETFE foil creating 267 kW photovoltaic fixed array.

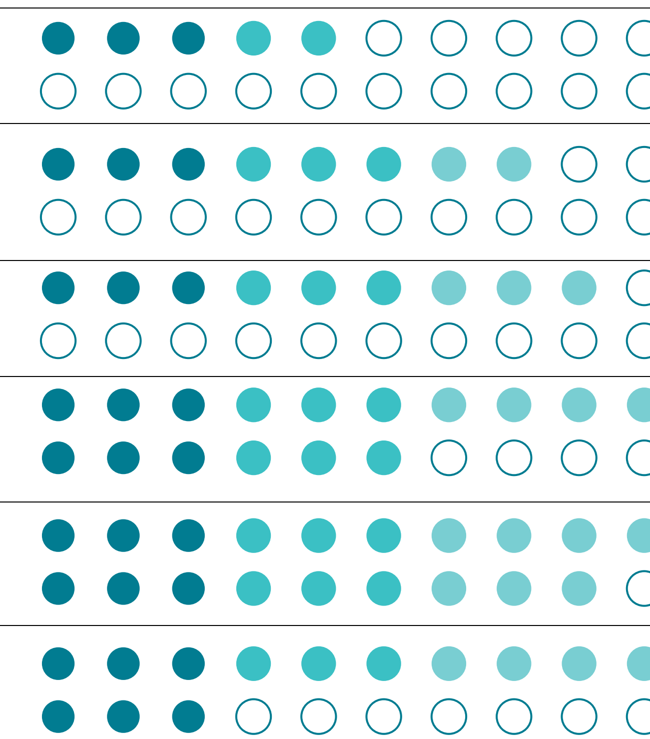
High efficiency water source heat pump units use nearby river as heat sink for low energy production of building hot/chilled water. Space thermal conditioning is delivered through effective radiant devices such as chilled beams and radiant heating floor system.

Low level LED overhead lighting systems supplemented with occupant operated LED task lights achieve decreased lighting power density levels for the building.

High performance envelope design including aerogel ETFE foil for high thermal performance and dynamic glazing for solar penetration control.

Decreased fan energy due to decentralized ventilation units located at every floor and use of waterside system versus airside for heat transfer throughout the building.

Dedicated outdoor air system used in conjunction with underfloor air displacement delivery system allows for demand controlled ventilation, heat recovery and decreased energy with conditioning outdoor air.



Additional Strategies for Sustainability

Rainwater harvesting system allows for reduction in potable water usage as well as resiliency of having a dependable building water source.

Increase renewable energy available to the building through purchasing RECs. In urban locations, buying RECs can achieve support of efficient renewable energy generation sites located in optimal areas.

Resilient design and layout elevates mechanical and electrical rooms to upper floors to for allow vital building systems to be less prone to potential flood damage.

Standard Curtain Wall System

Exterior Envelope

Material	ALUMINUM CURTAIN WALL	GLAZING (TRIPLE PANE)	RIGID INSULATION (2 in)	TOTAL EXT. ENVELOPE EMBODIED ENERGY (MJ)
Material Weight (lbs/sf)	4.0	14.0	3.0	
Surface Area for Exterior Envelope (sf)	44,055.0	365,445.0	133,500.0	
Weight (lbs)	176,220.0	4,990,230.0	400,500.0	
Weight (kg)	79,932.0	2,263528.4	181,663.6	
Material Embodied Energy (MJ / kg)	155.0	23.5	16.6	
Total Exterior Envelope Embodied Energy (MJ)	12,389,457.2	53,192,917.5	3,015,615.7	**68,597,990.5**
Embodied Energy /sf (MJ/sf)				171.3
Embodied Energy /m (GJ/m^2)				1.8
Material Embodied Carbon (kg CO_2/kg)	8.2	1.3	1.2	
Total Ext. Envelope Embodied Carbon (kg CO^2)	658,639.5	2,874,681.1	217,996.3	**3,751,316**
Embodied Carbon /sf (kg CO_2/sf)				9.4

Structural Systems

Material	STRUCTURAL STEEL	METAL DECKING	CONCRETE SLABS	TOTAL EXT. ENVELOPE EMBODIED ENERGY (MJ)
Material Weight (lbs/sf)		3.0	50.0	
Material Square Footage		816,750.0	816,750.0	
Material Weight (lbs)	26,930,000.0	2,450,250.0	40,837,500.0	5,566,950.0
Material Weight (kg)	12,215,232.6	1,111,413.8	18,523,563.3	31,850,209.7
Material Embodied Energy (MJ / kg)	25.4	25.4	2.1	
Total Exterior Envelope Embodied Energy (MJ)	**310,266,907.0**	**28,229,910.5**	**39,269,954.2**	**377,766,771.7**
Embodied Energy /sf (MJ/sf)				943.2
Embodied Energy /m (GJ/m^2)				10.2
Material Embodied Carbon (kg CO_2/kg)	1.8	1.8	0.2	
Total Ext. Envelope Embodied Carbon (kg CO^2)	21,743,114.0	1,978,316.6	4,464,178.8	**28,185,609.3**
Embodied Carbon /sf (kg CO_2/sf)				70.4

Office Fit-Out

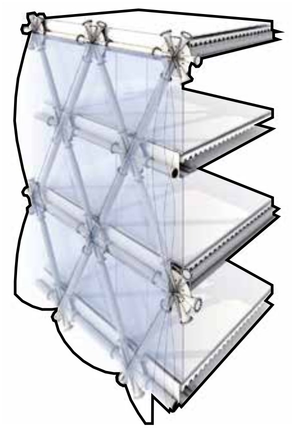
Material	10 YEAR MED GRADE OFFICE FIT-OUT
Total Usable Floor Area (ft^2)	694,238.0
Material Embodied Energy (MJ /ft^2)	158.0
Total Office Fit-Out Embodied Energy (MJ)	**109,689,604.0**
Embodied Energy per square meter (GJ/m^2)	1.7

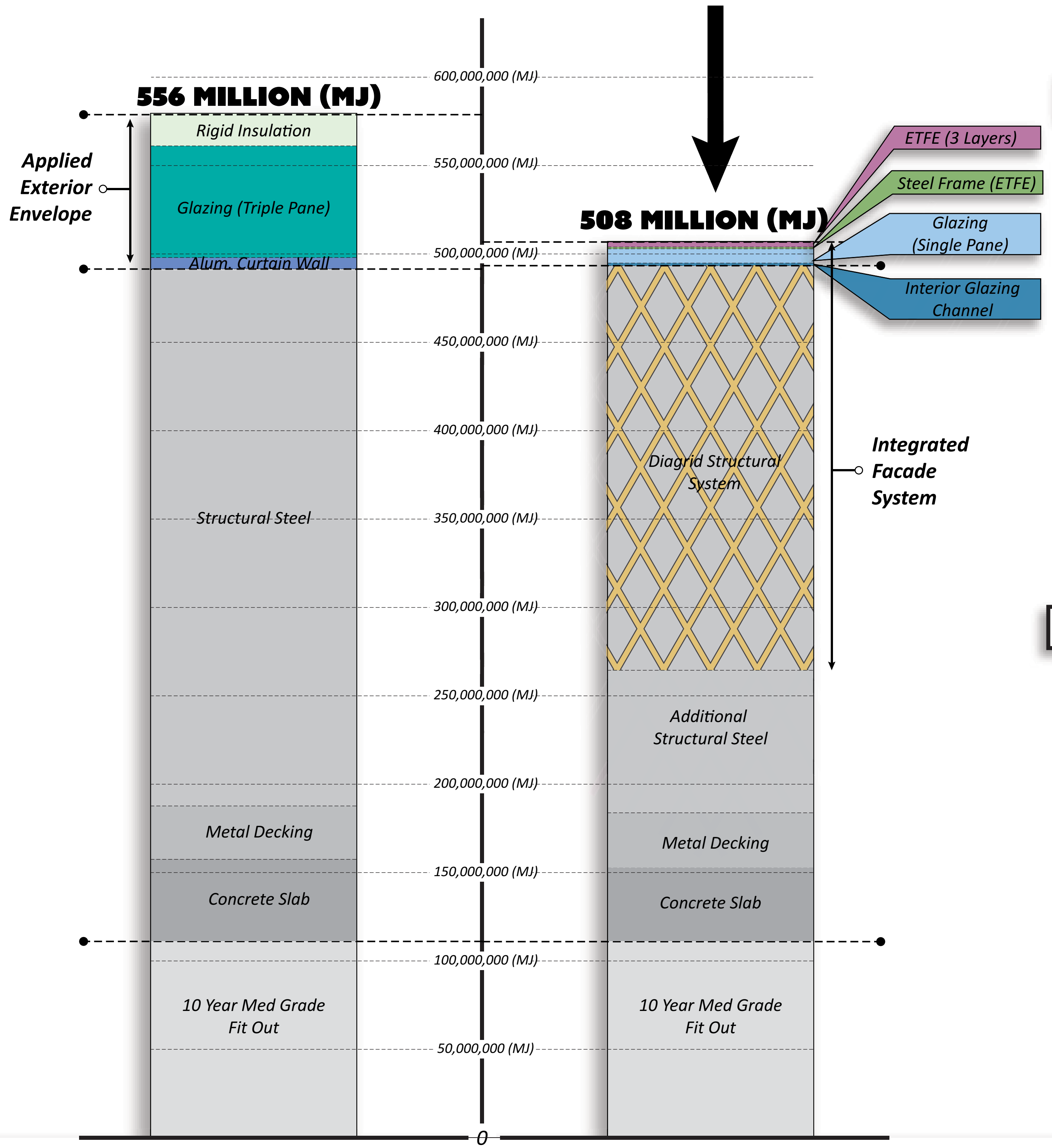
75%

Reduction in embodied energy and embodied carbon (psf) of facade

9%

Reduction in overall building embodied energy





X/O Skeleton

Exterior Envelope

TOTAL EXT. ENVELOPE EMBODIED ENERGY (MJ)	INTERIOR GLAZING CHANNEL	GLAZING (SINGLE PANE)	STEEL (ETFE)	ETFE (3 LAYERS)	Material
	3.0	6.6	2.5	0.108	Material Weight (lbs/sf)
	8,811.0	215,469.0	11,748.0	388,752.0	Surface Area for Exterior Envelope (sf)
1,519,883.6	26,433.0	1,422,095.4	29,370.0	41,985.2	Weight (lbs)
689,407.0	11,989.8	645,051.1	13,322.0	19,044.2	Weight (kg)
	25.4	23.5	25.4	80.5	Material Embodied Energy (MJ / kg)
17,334,675.1	304,540.9	15,158,700.8	338,378.7	1,533,054.7	**Total Exterior Envelope Embodied Energy (MJ)**
43.3					Embodied Energy /sf (MJ/sf)
0.5					Embodied Energy /m (GJ/m^2)
	1.8	1.3	1.8	2.5	Material Embodied Carbon (kg CO_2 /kg)
912,451.6	21,341.8	819,214.9	23,713.2	48,181.7	Total Ext. Envelope Embodied Carbon (kg CO_2)
2.3					Embodied Carbon /sf (kg CO_2 /sf)

Structural Systems

TOTAL EXT. ENVELOPE EMBODIED ENERGY (MJ)	CONCRETE SLABS	METAL DECKING	ADDITIONAL STRUCTURAL STEEL	FACADE DIAGRID STRUCTURAL SYSTEM	Material
	50.0	3.0			Material Weight (lbs/sf)
	816,750.0	816,750.0			Material Square Footage
1,493,450.6	40,837,500.0	1,111,413.8	20,318,000.0	6,682,000.0	Material Weight (lbs)
31,972,679.5	18,523,563.3	1,111,413.8	9,216,082.3	3,030,901.7	Material Weight (kg)
	2.1	25.4	25.4	25.4	Material Embodied Energy (MJ / kg)
380,877,505.6	39,269,954.2	28,229,910.5	234,088,489.3	76,984,904.3	**Total Exterior Envelope Embodied Energy (MJ)**
951.0					Embodied Energy /sf (MJ/sf)
10.2					Embodied Energy /m (GJ/m^2)
	0.2	1.8	1.8	1.8	Material Embodied Carbon (kg CO_2 /kg)
28,403,605.6	4,464,178.8	1,978,316.6	16,404,626.4	5,395,005.1	Total Ext. Envelope Embodied Carbon (kg CO_2)
70.9					Embodied Carbon /sf (kg CO_2 /sf)

Office Fit-Out

10 YEAR MED GRADE OFFICE FIT-OUT	Material
694,238.0	Total Usable Floor Area (ft^2)
158.0	Material Embodied Energy (MJ /ft^2)
109,689,604.0	**Total Office Fit-Out Embodied Energy (MJ)**
1.7	Embodied Energy per square meter (GJ/m^2)