8-25-2022

Exploring the Efficacy of Kinetic Facades in a Northern Climate [Rochester, NY]

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EXPLORING THE EFFICACY OF KINETIC FACADES IN A NORTHERN CLIMATE [ROCHESTER, NY]

BY

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A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE

THE DEGREE OF

MASTER OF ARCHITECTURE

DEPARTMENT OF ARCHITECTURE

GOLISANO INSTITUTE FOR SUSTAINABILITY

ROCHESTER INSTITUTE OF TECHNOLOGY

ROCHESTER, NEW YORK

AUGUST 25, 2022

COMMITTEE APPROVAL

EXPLORING THE EFFICACY OF KINETIC FACADES IN A NORTHERN CLIMATE

[ROCHESTER]

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Acknowledgments:

I am deeply grateful to have completed my studies and obtained my master's degree in architecture with the never-ending help of the faculty carefully guiding me to the right directions. I want to recognize and give a special thanks to my thesis advisor Julius J. Chiavaroli, (AIA,NCARB, LEED AP) for guiding me throughout the entire process. I would also like to thank my peers and fellow classmates as we were able to push each other to strive for excellence.

The most important shout out goes to my family for supporting me throughout my academic journey so far, I am deeply indebted to them.

And lastly, thank you to everyone who has positively impacted me along my architecture journey.

ABSTRACT

The quality of a building is greatly influenced by the design of its facades. Essentially, it serves as a barrier between an interior area and the outside environment. This implies that the façade serves as a conduit for communication between the activities going] on within and outside the building. Façade design has an impact on the appearance of a structure, and consequently on the perception of its users.

The adoption of Kinetic façades may dramatically reduce energy consumption in buildings, which accounts for around one-third of total energy consumption worldwide. This thesis will investigate a computational technique to improve building energy efficiency based on the design of kinetics on a building façade that can alter its thermal and visible transmittance for dynamically shifting climatic conditions. The kinetic façade design approach is powered by an automated optimization approach that combines building energy modeling software with an optimization strategy using a parametric design program.

This thesis will examine case studies of buildings with kinetic facades that are controlled by automated control systems and the impact that this has on the building's performance and attain the plausibility of this system working in Rochester. The conclusion of the thesis will attempt to illustrate whether these facade systems and techniques may be applied to the buildings in Rochester to improve daylighting and increase building performance by regulating solar gain.

Finally, the study aims at incorporating dynamic facades into buildings as an environmental management system in order to create a sustainable design and achieve excellent energy efficiency in buildings.

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4. Introduction

The steady increase in the building load demand and individuals calling for all glass facades has sparked new ways by which we think of building facades. Since insulation is detrimental to building performance and there is only so much research and development that can be applied to glazing in terms of insulation, other methods of integration have been developed such as daylight regulation, and sun shading in different aspects have been incorporated into building facades to achieve this goal.

Keeping in mind that glass panes keep getting bigger heat loss and retention are also inversely dropping Table 1 and 2 shows the large difference between a glass construction and a traditional opaque wall, the U-values of typical wall construction in comparison to glazed systems.

TABLE 3-4 Typical Glazing Characteristics (center of glass)

Type of Glazing	U-Value (R-Value)	Visible Light Transmittance	UV Light Transmittance*	Solar-Heat-Gain Coefficient	Recommended Applications
Single glazing, clear	1.0 (1.0)	90%	71% (85%)	.86	None
Double glazing, clear	.50 (2.0)	81%	56% (59%)	.76	None
Double glazing, low-E, high-solar gain	.35 (2.9)	75%	47% (51%)	.71	Cold climates; passive solar
Double glazing, high-solar gain, low-E, argon**	.29 (3.4)	75%	47% (51%)	.71	Cold climates; passive solar
Double glazing, moderate-solar gain, low-E, argon	.27 (3.7)	78%	23% (40%)	.58	Cold or mixed climates
Double glazing, spectrally selective low-E, argon***	.25 (4.0)	71%	16% (33%)	.39	Hot or mixed climates; west-facing glass
Double glazing (1 inch) with clear Heat film	.21 to .26 (3.8 to 4.8)	20 to 81% (varies with coating type)	<1% (28% to 53%)	.14–.57	Match coating to climate and design needs.

*Number in ( ) is "damage-weighted transmittance (T-dw)," which includes the portion of visible light that contributes to fading. Lower numbers indicate less fading.
**High-solar-gain glass uses "hard-coat" or pyrolitic coatings.

Table 1: Typical glazing construction

Assembly	Basic Construction	Other Thermal Components	Insulation R-value °F ft² h/Btu	Insulation R-value K m²/W	Assembly U-factor Btu/°F ft² h	Assembly U-factor W/K m²
Wall	Wood studs, nominal 2 in. × 4 in., 16 in. o.c. (50 mm × 100 mm, 400 mm o.c.)	Exterior air film, stucco, exterior gypsum board, interior gypsum board, interior air film	11	1.94	0.096	0.55
	As above	Above plus R-4 (SI: R-0.7) continuous insulation	15	2.64	0.068	0.39
	Wood studs, nominal 2 in. × 6 in., 24 in. o.c. (50 mm × 150 mm, 400 mm o.c.)		18	3.17	0.065	0.37

Table 2: Typical wall assembly

In table 2 a typical wall assembly is broken down to show the construction type and the U-values and if one compares an opaque wall to a glazed wall the difference can be seen clearly, to further paint a clearer picture large expanses of glass curtain wall exacerbate this inefficiency, as more glazing in the façade leads to lower insulation values in the building envelope.

Daylighting and solar gain are also key factors when it comes to building performance and facades. Every decision that affects daylighting sets the tone for future ones. Architectural decisions form the context for design decisions, and construction decisions become the context for installation and operation. The major daylighting design goals are to give a view of the outside and enough daylight to support all or part of the required illumination for the tasks conducted in the space

a) **Present home**	**Rotated factor loadings**				b) **Ideal home**	**Rotated factor loadings**	
	Luminosity	Accessibility	Architectural quality	Apartment configuration		Architectural quality / comfort	Accessibility
Orientation	0.895	0.225	-0.344	-0.006	Orientation	0.834	0.145
Amount of daylight	0.879	0.242	-0.267	-0.150	Ventilation	0.831	0.121
Ventilation	0.759	0.189	-0.377	-0.305	Daylight	0.801	0.063
Quality of view out	0.657	-0.001	-0.371	-0.017	Absence of noise	0.788	0.189
Proximity to work/school	0.101	0.859	-0.048	-0.069	Room layout	0.778	0.343
Proximity to city center	0.208	0.832	-0.363	-0.143	Climatic conditions	0.755	0.348
Apartment quality	0.416	0.212	-0.845	-0.215	Apartment quality	0.745	0.406
Building quality	0.286	0.193	-0.807	-0.203	View outside	0.715	0.166
Climatic conditions	0.534	0.401	-0.664	0.207	Room size	0.671	0.390
Absence of arch. barriers	0.237	0.142	-0.605	-0.008	Building quality	0.622	0.450
Room size	0.476	0.273	-0.482	-0.684	Absence of arch. barriers	0.482	0.034
Room layout	0.514	0.304	-0.529	-0.644	Proximity to work/school	0.221	0.807
Absence of noise	0.552	0.121	-0.563	0.387	Proximity to city center	0.226	0.793
Eigen values	4.978	1.475	1.244	1.033	Eigenvalues	6.152	1.361
% of variance	38.288	11.349	9.567	7.945	% of variance	47.326	10.468
α	0.812	0.635	0.720	0.768	α	0.901	0.587

Table 3: Daylighting Comparison

during the day and most importantly to minimize artificial lighting and reduce HVAC requirements. Table 3 shows the optimal daylight metrics for given spaces.

There is Likelihood that building loads (heating, cooling, lighting and plug loads) will decrease in the nearest future is slim to none, it will most likely increase and so the logical solution seems to be constructing more energy efficient building facades.

4.1.1. Problem

Because glass has poor insulation values, glass facades are generally viewed as incredibly inefficient. The development of a building skin completely composed of glazing on the curtain wall creates a scenario in which the sun can reach the building under certain conditions if it is not required, or where heat can leave and cannot be retained in vacuum. This inefficiency is made worse when the wide expanses of the glass curtain wall contribute to a decrease in insulation values in the concrete envelope from an increased use of the glazing of the facade. The emergence of independent glass units has led to growing performance, but the sun does not yet regulate it, and neither are the U values high. In the past kinetic facades were introduced but their key function for many of them is not to regulate the environment, but as interactive instruments used for aesthetic and social purposes.

4.1.2. Hypothesis

The building envelope or facade, from an aesthetic point of view, basically has a public face and thus has a major influence on the vision of the building. The envelope works in a powerful way as a barrier for the world within and outside. Kinetic façade systems can help alleviate different environmental issues, minimize the need for mechanical systems such as HVAC and artificial lighting systems, improve the convenience of the occupants. Thus, dynamic facade systems are not designed to replace mechanical systems but could greatly minimize the energy demands of the building.

4.1.3. Objective

The goal of this thesis is to design an office building in the heart of Rochester and integrate a kinetic façade onto it, the façade would positively impact building performance, regulate solar gain, and optimize daylighting. The synthesis will be to develop an automated shading system that track the sun to provide optimal shading at different times and conditions of the day. The design will take into consideration the real-life feasibility of the system while also considering simplicity and controls. This will all be performed by creating a Digital model of the system and conducting computer simulations. And measuring the results

The Kinetic façade will take into consideration optimal geometric panels to regulate solar radiation. Therefore, the method of discovering generative-parametric shapes to respond to different solar conditions will be a solution to have more adaptability to sunlight. This research aims to propose a method of kinetic façade that can concurrently boost visual and thermal comfort for occupants by managing on-site renewable energy supplies consisting of solar radiation. The research aims to analyze how kinetic facades can have a beneficial influence on the building by reducing the need for mechanical comfort systems. For this review, explorations will be performed on current solutions for kinetic facades to explain the various methods known and available.

The thesis will seek to demonstrate if these facade systems and methodologies can be applied to buildings in Rochester to improve daylighting and building performance through solar gain regulation and if so, the integration of this system onto the building will create sustainable design and achieve energy efficiency in the building. Rochester as a location was chosen because it is in the colder region where there is longer winter month and short summer months, cloud cover is at an average of 30 percent meaning it is mostly cloudy therefore harvesting as much usable daylight is one of the main goals. The idea is to generate the plausibility of such a facade being utilized in every climate if it succeeds in a cold region such as Rochester, NY.

4.1.4. Methodology

Computational programs will be used to ascertain data that will be the key to success or failure of this analysis of the building, it will be used to set a metric for calculating daylight and energy efficiency by means of reducing solar gain (radiation).

Figure 1:Lux scale

Research shows that an office building needs 250 to 2000 lux (which is the measure of light) for optimal working conditions. The goal in terms of daylight factors will be to fall between the stated percentile, preferably 500 lux as seen in figure 1 above, by means of the integrated kinetic façade. This will provide better naturally lit spaces through the admission of natural diffused light. LEED v4 states that "no more than 10% of a space should have direct sunlight more than 1000 lux for a maximum period of 250 hours per year (ASE1000/250)", hence the metric for calculation in this case would be the SDA (spatial daylight autonomy) which indicates that a certain percent of area must meet or exceed 300 lux for at least 50% of the working hours per year. This will be measured using the energy plus programs as will be seen further into this thesis.

Secondly solar gain will be mitigated to improve energy efficiency as radiation from the sun can heat up spaces which increases cooling loads of building in the summer period and vice versa in the winter. The desired energy saving set for this building regarding the individual office spaces (rooms) will be at least 50% and 25% for the overall building. This will comply to ASHRAE standards 90.1 as using air conditioners and electric fans to stay cool accounts for nearly 20% of the total electricity used in buildings around the world today. Energy plus will also be used in deriving the efficacy of the façade in terms of solar gain/ loss in the building for when it is required and vice versa.

Ladybug

As high-performance design becomes more popular in the realm of architecture, so does the need for environmental analytic tools to assist architects. One of the most extensively utilized platforms among designers nowadays is Rhino/Grasshopper. For Rhino/Grasshopper, a variety of environmental plugins have already been developed. Ladybug, on the other hand, has several advantages that existing Rhino/Grasshopper-related environmental design plugins do not.

Ladybug integrates standard EnergyPlus Weather files (.EPW) into Grasshopper and generates a variety of 2D and 3D designer-friendly interactive visualizations to aid decision-making during the design process. It also streamlines the analytical process, automates, and speeds up calculations, and gives simple graphical displays in Rhino/3D Grasshopper's modeling interface. It also allows users to work with energy and daylighting engines like Energy Plus, Radiance that have been verified. Integration with grasshopper's parametric tools enables near-instantaneous feedback on design changes, and the information and analysis is interactive because it runs within the design environment. Users can tweak the tool to meet their own needs and contribute to the source code because it is free and open source.

This program will be used analyze the designed building in relation to its environment, it will factor in elements such as climate, context, location and orientation. These elements will in-turn advise on how the office building will be oriented, what facades required the integration of the kinetic system, what for the building will take on and most importantly it will simulate how sunlight gets into the building in inform the percentage of perforation of the intended kinetic façade to optimize daylight and solar gain.

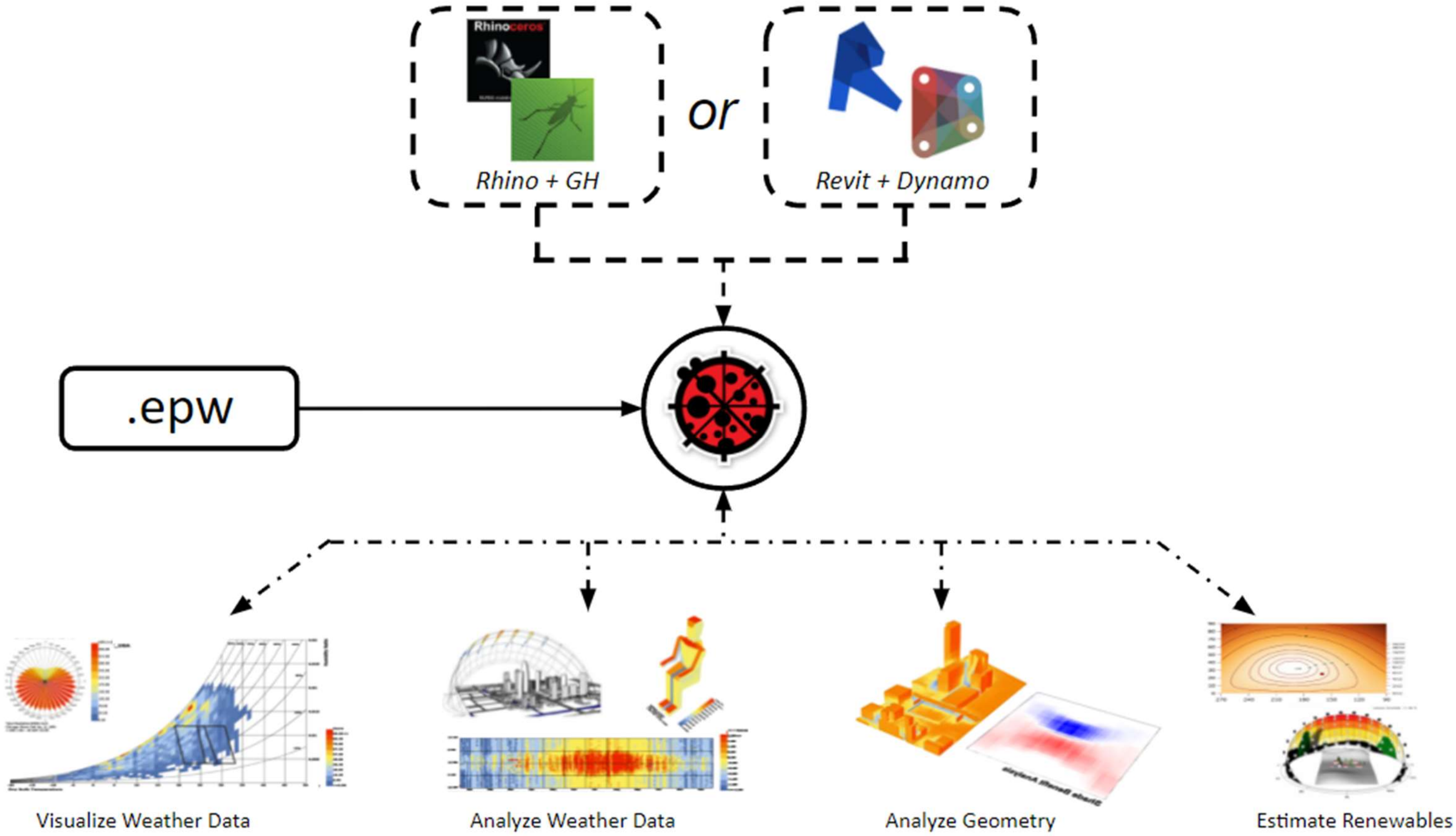


Figure 2 Ladybug flow diagram

The chart above (figure 2) shows information flow to building model computation. The model is carried out in Rhino and Revit, this model is then able to work hand in hand with ladybug to carry out weather data, and analyze it, it is also able to analyze the geometry of the 3D model as designed in the primary programs (Rhino and Revit)

EnergyPlus

EnergyPlus is an open-source BEM software that is widely used by researchers, engineers, and architects to model the energy performance of buildings [*EnergyPlus*]. The Building Technologies Office of the United States Department of Energy (DOE) is funding the development of EnergyPlus (BTO). This program can be used to model energy consumption in buildings from lighting, HVAC, and plug and process loads. Because EnergyPlus is a console-based tool, it processes text-based inputs and returns results in several text forms (e.g., .html, .txt, .cvs). As a result, many users regard EnergyPlus as a challenging program. Fortunately, EnergyPlus can be integrated with a variety of graphical user interfaces, including Autodesk Revit, DesignBuilder, OpenStudio, AECOsim Energy Simulator, Google SketchUp, gEnergy, and Simergy. These programs packages can be used to design the building's shape as well as extract the EnergyPlus Input Data File (.idf) needed for simulation. The geometry of a building is generated for the performance simulation in EnergyPlus using Rhino [39], which is more precise and efficient than the graphic-based technique. After constructing the building geometry in Autodesk Revit, the model is sent to Green Building Studio, an Autodesk tool that converts the geometry into an EnergyPlus Input Data File (.idf), which is ready to run the energy simulation. However, there are no built-in functions for sophisticated analyses such as automation, parametric analysis, or optimization in EnergyPlus. To put it another way, anything you do in EnergyPlus, including changes to material attributes, counts as manipulation.

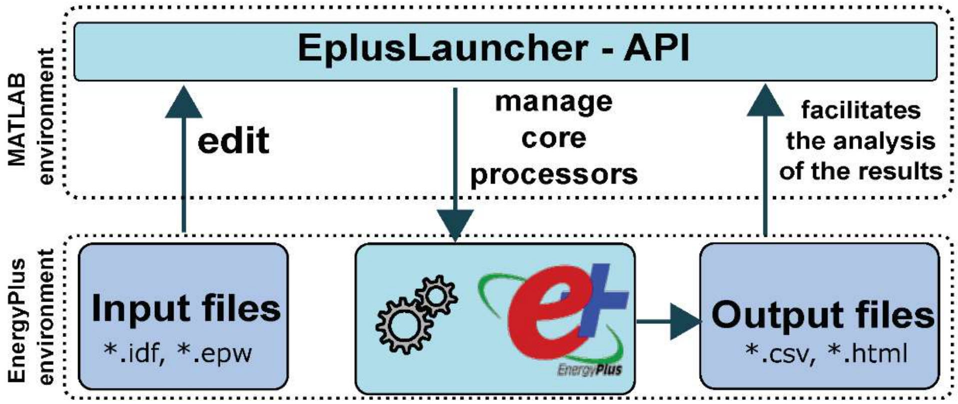


Figure 3:EnergyPlus Building Energy Simulation and Output

Energy plus is somewhat the backbone of this thesis as it is going to be used to analyze all the data and summarize it to then be turned into design moves. All the data from Rhino, Revit, Lady bug feed into this database to be turned into usable data. Data such as average BTU per floor, daylighting factor and insolation will be derived in order to determine the efficacy of the designed office building in tandem with the kinetic façade

5. Kinetics

Glass has become more common in recent times, but this has intensified the problem of excessive cooling in the winter and overheating in the summer. As early as 1929, the connection of building skins and building mechanics was crucial to the successful translation and realization of the goals of a revolutionary façade concept. Modern environmental concepts use the gap between the façade layers to moderate the room close to the façade, whereas Le Corbusier wanted to moderate the room adjacent to the façade with an artificial environment in the building envelope.

Because it is the most visible aspect of the building, the façade is a strategic component. As a result, a building's environmental and aesthetic efficiency increases. The façade also transfers energy with the outside world, improving energy efficiency.

Facades that adapt to the environment are regarded a as part of the building's envelope. Dynamic facades respond to changing environmental circumstances and performance needs by actively adapting their behavior over time.

5.1.1. Integration

With kinetic facades they are generally fixed onto a static building by way of connecting points with the intention being that the system can have a positive effect on the building. The system employed in this research is know as an embedded type of system where structures are usually used in a broader context and are closely linked to the architecture. These systems are developed particularly for the building, location, and purpose on which they are installed. They are typically defined by various kinetic facades since their use is dependent on their ability to regulate the building design.

By managing aspects like light, thermal comfort, and ventilation, embedded systems have the greatest immediate influence on building users and their comfort. The success of this system is generally measured in terms of performance, and its utilization is evaluated in terms of cost vs benefit value,

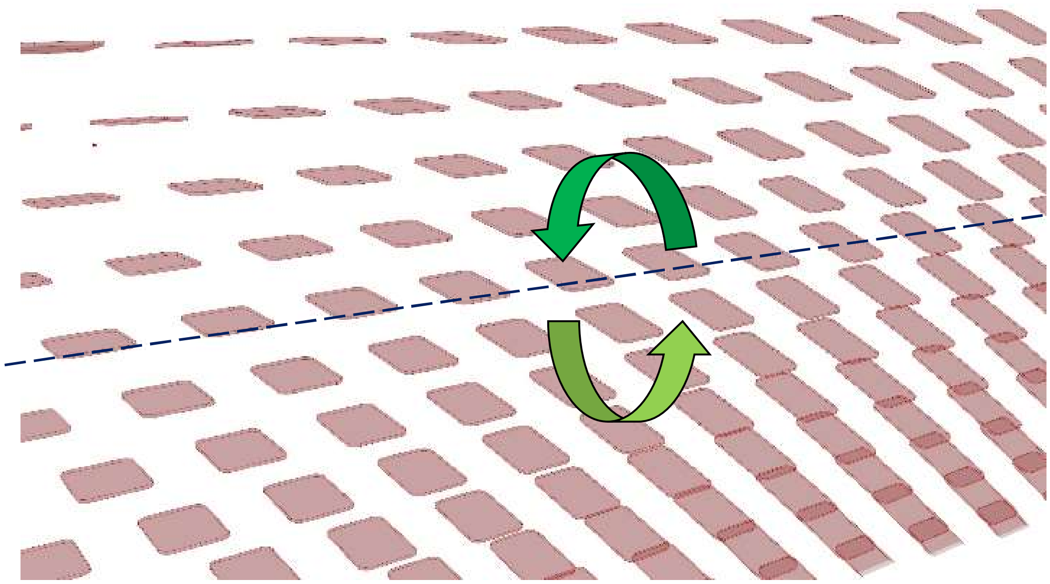


Figure 4: Kinetic movements including hinge points and rotation

such as energy savings.

The numerous mechanical motions required to make a component move are referred to as these methods of movement such as folding, sliding, expanding, and morphing are some examples of movement techniques. In addition to these broad categories, there are specific ways for achieving various motions, such as hinged, scissor hinged, ball and socket, and linear actuated however the primary methods of movement for the designed façade in this design thesis will be rotating with the use of actuators and hinge as seen in (figure 4).

5.1.2. Control system

Every kinetic system has a method of control. The control system employed in this thesis is a building management system commonly known as BMS. A façade as intelligent as this needs an automated system rather than a direct (manual) method of control. The system will be structured in such a way that each component sends data to a centralized processing system, which evaluates the information and sends commands to each component.

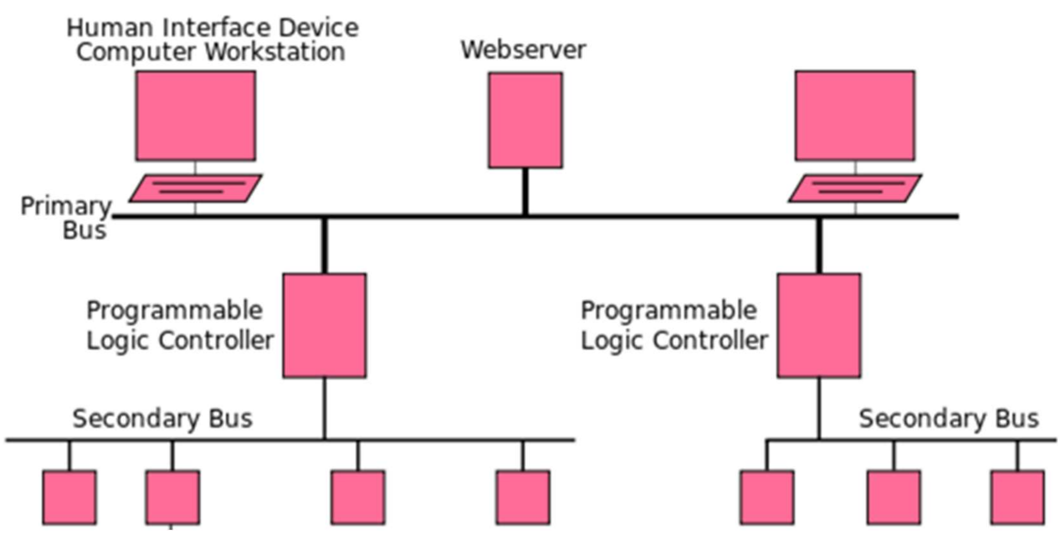


Figure 5: Typical building management system breakdown

As stated, before the method of control will be an automated approach capable of taking in several factors and processing each component to provide more refined outputs depending on complex criteria The primary downside of this system is the high cost and knowledge required to control it. Because each component must link back to the centralized processing unit, the system will require substantial wiring and system maintenance. For this project, these disadvantages are acceptable since the cost benefits from having whole building management balance the additional expenses of installing the system.

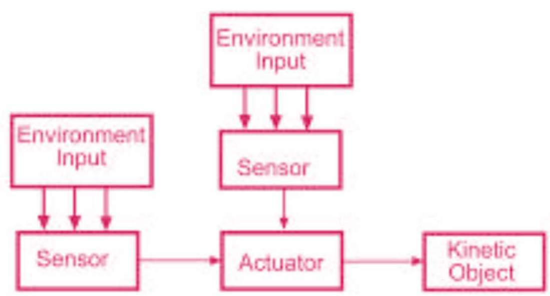


Figure 6: Automated control system

5.1.3. Environmental Impact

In recent years researchers and designers have witnessed the inclusion of kinetic envelopes into different types of buildings, it is the belief that kinetic facades will play a big role on improving the environmental performance of buildings. Since facades are the most important protection against harsh weather, this use of this advanced dynamic system can lead to a shift, in some cases. Adaptive systems incorporate the best of current strategies: low energy consumption and environmental control. For example, if the architecture can respond to cyclic changes in temperature, the energy needs of a building can be substantially decreased. An adaptive device that is modulated in response to external and internal conditions to monitor the amount and direction of thermal flow may increase comfort and energy efficiency. Kinetic façade systems will minimize environmental impacts and lead to reducing the dependency on mechanical building energy systems. kinetic façade solutions are around 30 per cent more capable of minimizing energy consumption for heating and cooling than the non-kinetic system [Schumache 2020].

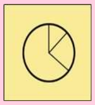
6. Case studies

It is necessary to understand how kinetic facades have been applied in the past in order to better comprehend how they might have a positive influence on building systems.

The international research journal of engineering and technology (IRJET) created a matrix to divide and identify kinetic facade precedents into various categories to acquire a clear and structured knowledge of the precedent.

GENERAL INFORMATION		Al-bahar towers	Kiefer technic Showroom	Thyssen Krupp Q1	Moving landscape Bidaser House
	Image				
	Completionyear	2012	2007	2010	2012
	Architect, Location	Aedas architects, Abu-Dhabi	JSWD Architekten + Chaix& Morel ET Associates, Bad Gleichenberg ,Austria	Ernst Giselbrecht + Partner ZT, Germany	Gurjit Singh Matharoo,India

	Type	Office	Office & showroom	Office	Residence
KINEISM IN BUILDING	Kinetic elements	Aluminium & Duplexsteel Sheet	Aluminum Panels	Steel Louvers	Bidaser Forest Stone
		Whole exterior	Elevation elements	Whole Exterior	Whole Exterior
	Reason For Motion	Environmental – light control	Environmental – light control	Environmental – light control	Environmental – light control

PRINCIPLES OF MOVEMENT		Mashrabiya screen can trace the path of the sun over the course of a day and a year.	Facade change sEACH DAY, EACH HOUR showing new faces	Facade change saccording to the movement of sun position	Spinning & pivoting wall take 30 sec. of time for one rotation /Sliding.
		It has two degree of movement an dvisually creates a balance.	It has single degreeof movement and visually creates a balance.	It has Two degree of movement and visually creates a balance.	**SLIDING** 2 DEGREE of Movement **PIVOTING** 3 DEGREE of Movement
		The screen surface moves with a predetermined-speedand harmoniou sacceleration.	The screen surface moves with a predetermined-speed and harmonious acceleration.	The screen surface moves with a predetermined-speed and harmoniou sacceleration.	**PIVOTING** The speed is fixed while setting Gear and it have constant speed. **SLIDING** Acceleration is also predetermined duringconstruction itself.
		These are rigid materials made of (PTFE), creates a serial repetition.	These are rigid materials made of aluminum panels,	These are rigid materials made of Steel Slats	These rigid materials have serial Repetition along faces of the building.
		----	----	----	Wall cladding is light weight visually as it is hollow inside.
		It is complex visually and durin g	----	----	----

		construction			
		----	It shows mysterious effects for passersby.	It creates a various movement which gives interactive movement	----
		Rigid elements, which expand and contract according to sun rays.	Rigid elements, which expand and contract according to sun rays.	Rigid elements, which Open and Close contract according to sun rays.	Rigid elements, which move according to the user need.
	Actuator	LINEAR screw-jack actuator & electric motor-triangular facets,	By GUARD RAILS AND CARRIAGES,	By VERTICAL Actuator	By GEARS and MOTORS
		Pre-programmed sequence	Pre-programmed sequence And By user also	Pre-programmed sequence	Remote Control
	Materials	Frame –combo of aluminum and duplex stainless steel, Unit is made up of PTFE and mash is with fiber glass coated with Teflon.	Combo of aluminum panels, stainless steel and glass	combo of Stainless steel and combo of chromium- nickel-molybdenum	WALLS-combo of Bidaser stone and steel frame(bracing) & Glass inner façade.
	Control Systems	Indirect Control	Indirect Control	Indirect Control	External Control

Table 4: comparison chart

Three distinct examples from various locations (Table 4) were used to analyze the most popular form of adaptive facades with integrated shading features in this section of the research. The working sample group was selected from adaptive façade designs that adapt to their surroundings and give interior comfort while using the least amount of energy. Having additional knowledge about the buildings in the literature was also helpful during the design process of the facades, as their idea, physical features, and performance impacts were effective.

6.1.1. Al Bahar Towers

Figure 7: General view of the two towers

The Al-Bahr Towers, the headquarters of the Abu Dhabi Investment Council, was designed by Aedas architects and Arup engineers. It comprises of a PTFE-clad Mashrabiya shading system. By integrating shading elements on the exterior, the Al Bahar Towers adapt to climatic condition and strive to give both thermal and visual comfort conditions in the inside. the "Mashrabiyas" is a solar shade that is modular, dynamic in nature, and holds 1049 modules per tower. Umbrellas made to imitate origami and maximize the solar exposure of the façade, the shutters open and close in reaction to the movement of the sun. The shading system is built with an adaptive outer shell to decrease the negative effects of the sun and is influenced by traditional Arabic architecture and the airtight glass curtain wall is made up of panels and covers the round towers. To keep direct solar gain to a maximum of 400 watts per linear meter, each unit is controlled by a linear module that opens and closes once a day (Wikiarquitectura).

Controlling the amount of light that comes in from the sun is a crucial component of the system. Automatic shade and daylight control systems integrate and operate in line with all climatic condition on this type of facade, as they did on

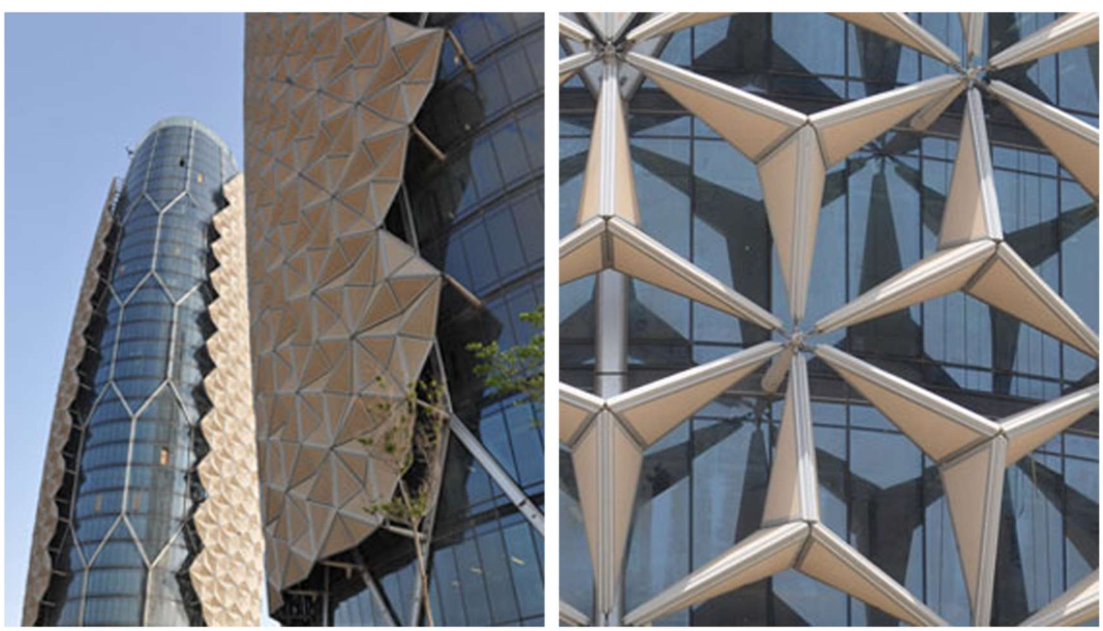


Figure 8: Shading system

the Institut du Monde Arabe building. The shading screen is computer controlled to adapt to optimal sun circumstances, and the elements are controlled by software that regulates the opening and closing of the devices based on the sun's movement. A multitude of sensors embedded into the building exterior give signals to the control unit to unlock all units under cloudy or high-wind conditions (Cilento, 2012). The climate in Abu Dhabi is hot and dry. The months of June through September are exceptionally hot and humid, with maximum temperatures exceeding 45 degrees Celsius so air conditioning is used to combat the sun's heat.

According to the Council on tall buildings and Urban Habitats this system is expected to reduce solar gain by 50%, reducing the requirement for air conditioning and reducing CO_2 emissions by 1,750 tons per year.

6.1.2. The Kiefer Technic Showroom

Figure 9: Facade movements

The Kiefer Technic Showroom by Ernst Gieselbrecht + Partner is a completed project in Steiermark, Austria. It is the first building type that include a "user-controlled dynamic facade" (Archdaily, 2010). The building's entire southern face is clad in white aluminum louver panels that open and close using a set of electrically controlled horizontal hinges. When no one is in the building, optimization systems can regulate the facade elements at the same time (Archdaily, 2010). The facade's 56 separate engines allow light and temperature levels to be adjusted in any room to produce optimal settings for various activities (Uys, 2016).

The architect used an adaptive facade to adjust the level of indoor ventilation and illumination throughout the southern facade of the showroom building, while also providing users with a variety of privacy and transparency options. The combination of such technology with intelligent elements on a building exterior allows for greater performance management while lowering environmental impact. Advanced window technologies, innovative frame systems, and automatic shade management are all part of dynamic building envelopes, which characterize the construction of all modern "smart" buildings. Even though it is a fantastic idea, designing and implementing such systems is a difficult undertaking (Sala, 2011).

The main goal this façade set out to achieve was creating comfortable indoor environment as it works as a sun protection as well as light and temperature regulator.

6.1.3. Institut du Monde Arabe

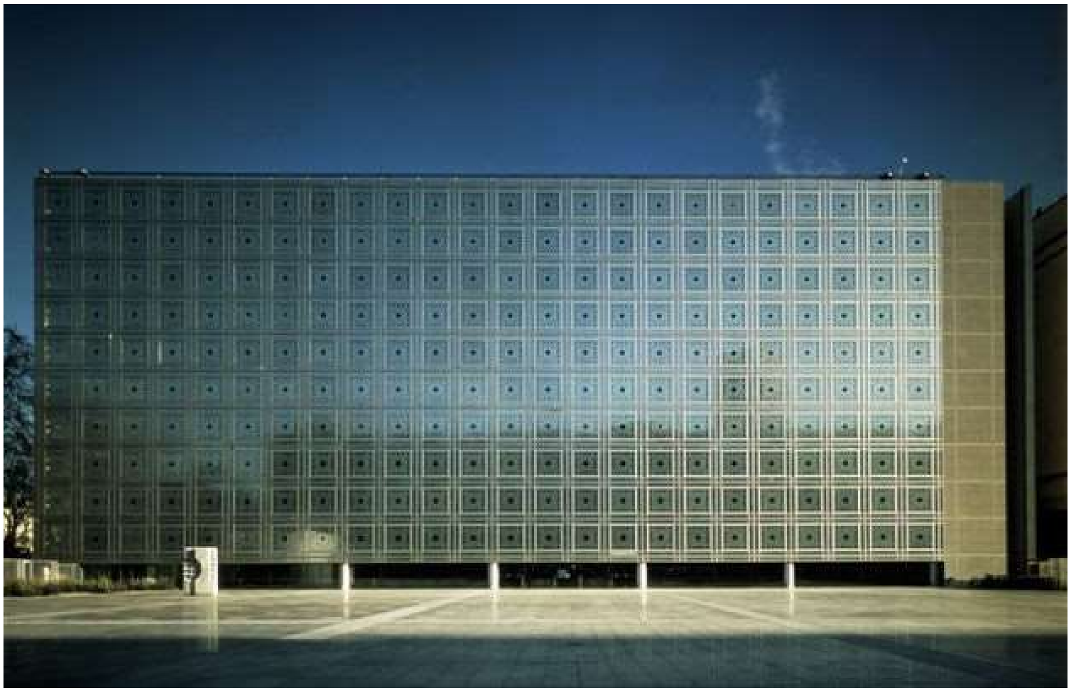


Figure 10: Institut du monde arabe (Paris Convention and Visitors Bureau,2015)

Jean Nouvel designed and built the Institut du Monde Arabe in Paris between 1981 and 1987. With daylight in mind the designers came up with a mechanical diaphragm made of 30,000 aluminum sheets that is regulated by an electropneumatic system according on the amount of light hitting the south façade. The sun is mediated by 270 spinning irises of varied sizes on the 60m high facade. The ability of these irises to manipulate the sun gives the interior of the building a dynamic feel that would be impossible to achieve with a static façade. As the focus of the system was to control daylight it is also important to note that it comprised of lots of mechanical moving parts and is no longer functional today. The big take away from this case study is to design a system that is functional yet simple and still operational past the first few years of its construction.

Figure 11: Detail of the shading unit (Archdaily, 2011)

In summary the case studies have their strength and weaknesses, in the case of the Al_Bahar towers there is a lot to take from there as the main purpose of the façade was to cut down cooling in the building which the designers successfully accomplished, this case study was aimed from an energy saving perspective which will be incorporated into this design thesis by means of the dynamic façade regulate sunlight and daylighting in the building.

The Kiefer showroom focused more on the aesthetics which they also accomplished perfectly in my opinion. It does talk a little bit on the type of control system that was used in the building which was said to be a user control interface where the occupants of the building can control the façade operation. The big takeaway from this case study was that for the kinetic façade to be as efficient as possible the human interface needed to be limited or taken away as it may seriously affect the efficacy of the designed façade.

Lastly the Institut du Monde Arabe showed the drawback of old technology in relation to modern day technology. function is a big factor as the façade must function for a long period of time but in this case, it fell short in that regard. This was a big case of form over function and the takeaway from this case study is to design the façade in such a manner that one faulty component does not compromise the entirety of the system.

7. Pre-Design Analysis

As indicated earlier in this thesis, Rochester as a location was chosen because it is in the colder region where there is longer winter month and short summer months, cloud cover is at an average of 30 percent meaning it is mostly cloudy therefore harvesting as much usable daylight is one of the main goals

Rochester is the third biggest city in Upstate New York. It sits on Lake Ontario's southern shore and the Genesee River bisects the city. Rochester is an industrial city in Monroe County, New York, which was founded in 1821. It is part of a metropolitan region that encompasses Greece, Irondequoit, Perinton, Henrietta, and Brighton these, as well as Gates, Chili, Pittsford, Penfield, and Webster, are primarily residential, but several include industrial parks. In 1789, a settlement was established at the Genesee Falls, which powered a grist mill erected by Ebenezer Allen on a 100-acre (40-hectare) parcel granted on the condition that he satisfy the Seneca Indians' needs. The city is home to a lot of great architectural buildings that are still in existence till today.

7.1.1. Climate Study

Rochester is known for its harsh winters, which are intensified by its proximity to Lake Ontario, where below-freezing winds blow across the warmer lake, resulting in lake effect, snowfall that exceeds that of most northern states. In the summer, the same winds that cause the lake effect also create cool breezes, which can be beneficial during the hotter months.

7.1.1.1.1. Sun

The degree days in Rochester vary across the year with the shorter sunlight hours in the winter and longer sunlight hours in the summer. The summer solstice falls on June 21st with the sun rising at 5:31 AM and setting at 8:54 PM, with an azimuth of 70 degrees. Keep that in mind the façade will adapt to conditions like this to mitigate solar gain while also allowing natural light into the building.

The winter solstice has the earliest sunrise at 7:39 AM and sunset at 4:38 Pm with an azimuth of 20 degrees this means the solar angle is closer to the ground therefore the light penetration and shadows are longer, this will also play a role in the kinetic façade design as it will have to allow optimal solar gain in the office spaces to heat up the room and reduce the AC demands in the building.

7.1.1.1.2. Temperature

The average temperature in the cooler months is around 50 degrees, with lows that range between 10 to 20 degrees. The warm months average around 75 degrees, with highs of about 90 degrees and lows of 60 degrees.

Relative Humidity ranges between 63 to 79% in the winter and in the summer, it is around 69 to 73%.

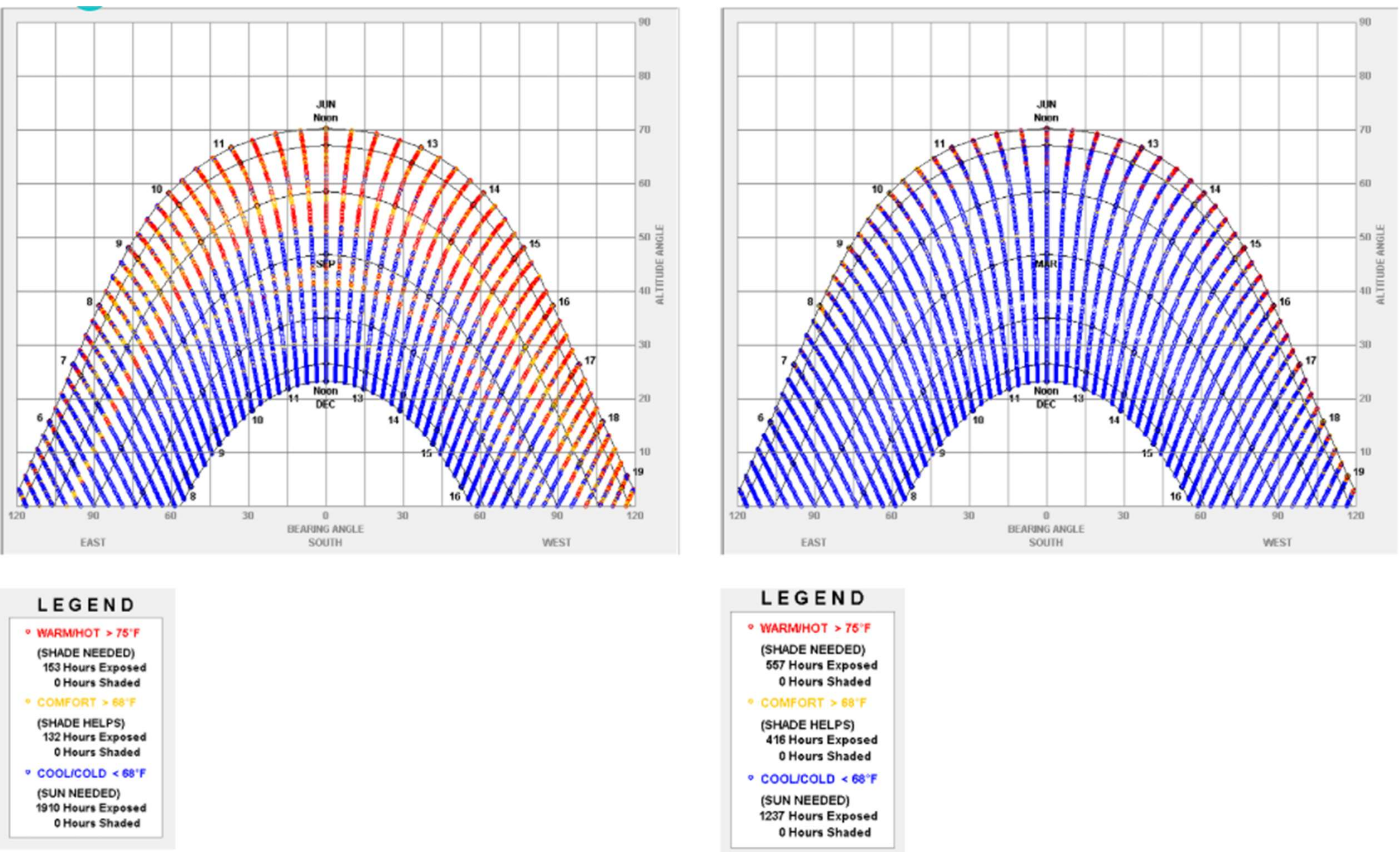


Figure 12: Average winter and summer temperatures (climate consultant)

7.1.1.1.3. Cloud cover

As one of the main focus of this thesis in daylighting, cloud cover has to be taken into consideration while developing the optimal kinetic façade for this region.

The clear month falls between May and November with August being the peak month at about 67 percent visibility. The cloudier months range from December to mid-March hence daylight is usually shorter in this period.

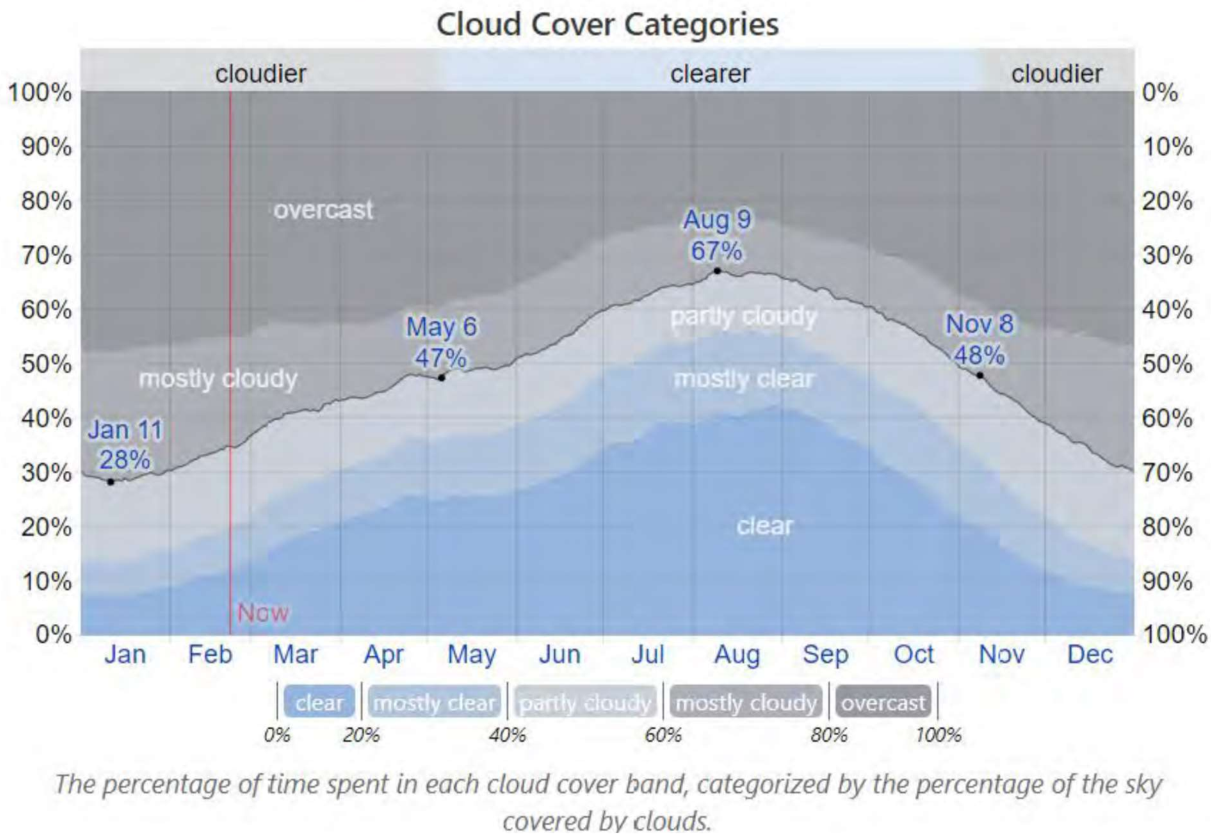


Figure 13: Annual cloud cover (climate consultant)

7.1.1.1.4. Wind

Due to the positioning on the border of a lake effect region, mild to severe westerly winds are prevalent year-round but are often more powerful and sustained in the winter months. The prevailing winter winds come from the west, with high winds up to 40 mph. Alternative winds during the

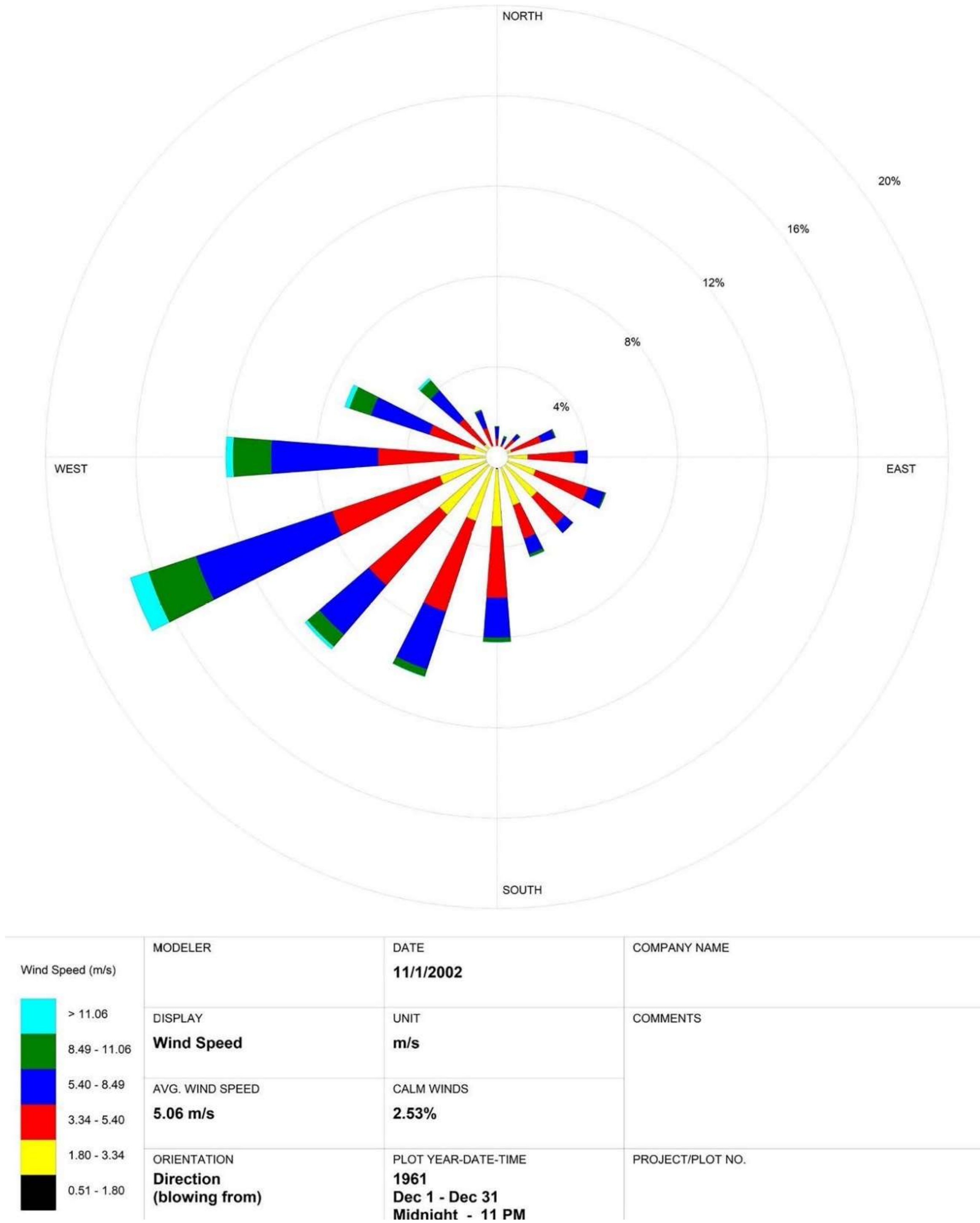


Figure 14 : Windrose (winter)

summer come from the southwest with speeds up to 25mph as can be seen in (figure 14-15).

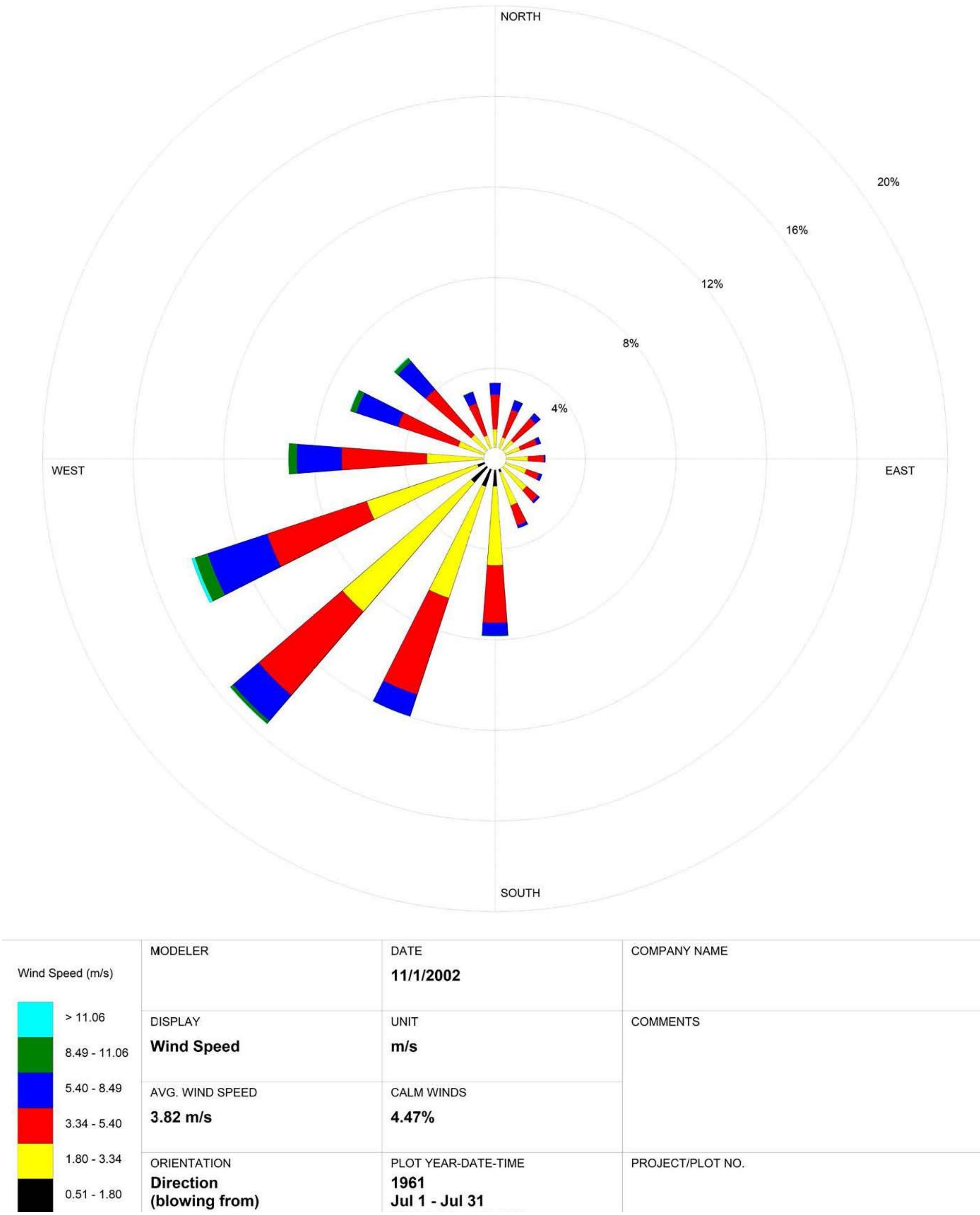


Figure 15: Wind rose (summer)

7.1.2. Site location

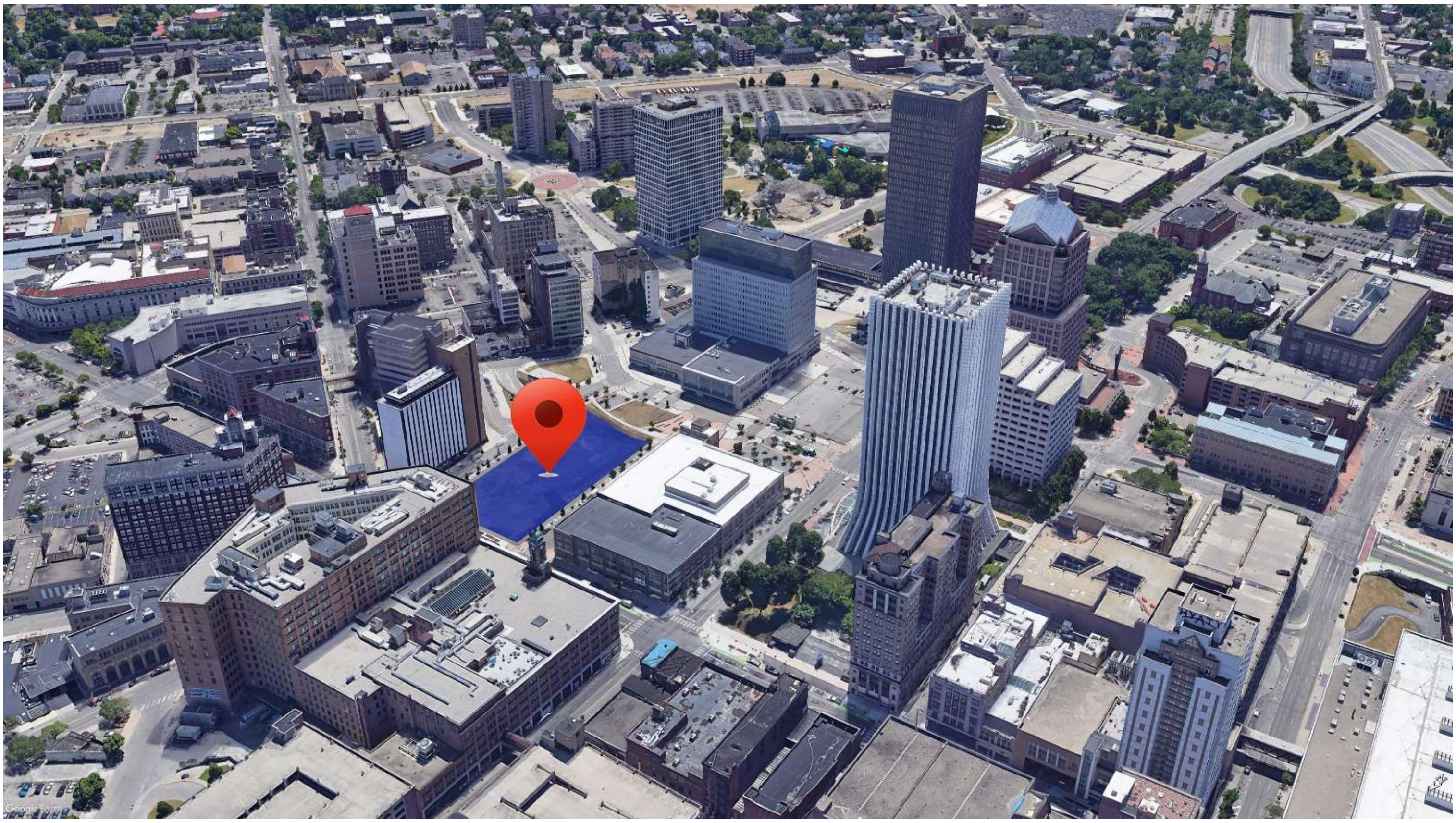


Figure 16: Ariel view of Rochester (University of Rochester)

The ariel view of Rochester show in Figure 16 gives a glimpse of the expected pros and cons of what the site has to offer. Located along east main street the site is centrally located in the downtown area on Parcel 5 which is a bare plot currently open for development. The side will offer unobstructed views and minimal shadows being cast from surrounding buildings.

7.1.3. Site analysis

As daylighting, solar gain and energy performance are the key factors in this thesis, a good understanding of the sites environmental factors aided the design of the building form, orientation, glazing and kinetic façade. Knowledge of solar angles and exposure in relation to southern and eastern facades determined the parameters the kinetic facades will have to input to generate movement that will in turn mitigate solar gain and optimize daylight. Given that the western and northern façades will not be receiving direct sunlight the kinetic façade will be at an open position throughout most of the day to allows as much daylight and

solar gain in those areas.

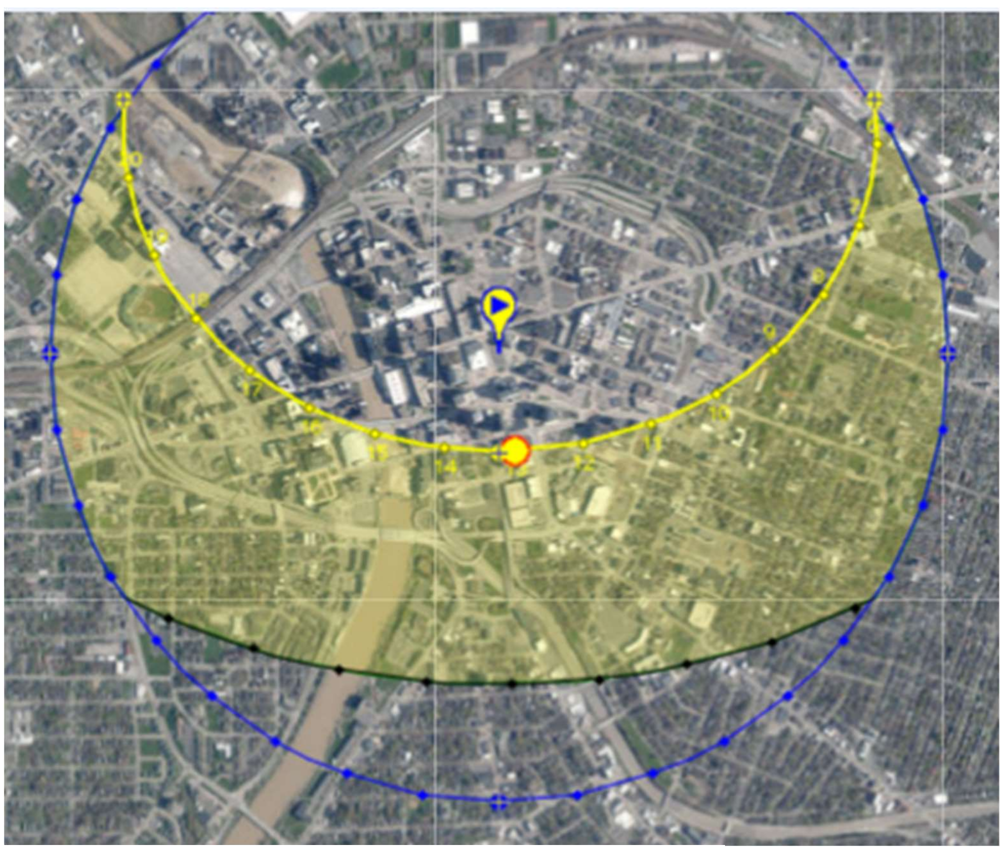


Figure 17: Summer sun path- June 21, 1:00PM (sunearthtools.com)

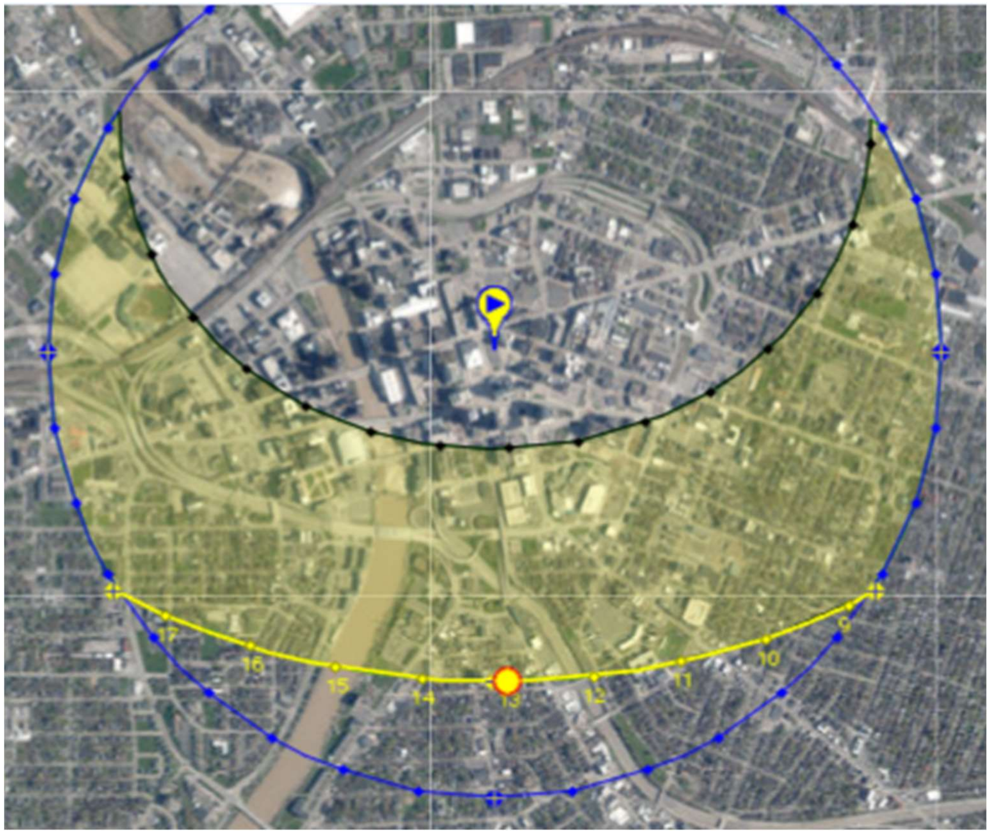


Figure 18: Winter sun path- December 21, 1:00PM (sunearthtools.com)

7.1.3.1.1. Solar gain

Given that the main object of this thesis is to design an automated system that acts according to the sun path, whereby orientation is a key factor. The building has four facades two of which will be a more closely packed and regulated while the other two that do not receive as much direct light will be opened to let as much light in. Given the building's location in the northern hemisphere, the edge between the two covered façades faces south.

In the summer solstice the at 1:00 PM., the sun is at its peak elevation of 70.12 degrees, and at 6:00 AM it is at its lowest elevation of 3.7 degrees. The summer solstice is an essential time to study sun angles since this is when the sun is at its hottest and emits the most radiation rays.

The winter solstice is also significant to read because, given the site is in Rochester, NY the position and the fact that the climate is usually snowy in the winter, having solar radiation flood the spaces and heat up rooms is useful. At 1:00 PM, the sun is at its peak elevation of 23.38 degrees, and at 9:00 AM, it is at its lowest elevation of 2.34 degrees. Having this angle of the sun will help with the automatic shading devices as well as having that winter sun to warm the area, since many people want the sun during the winter months.

Date:	21/03/2022 | GMT-5	
coordinates:	43.156921, -77.6046748	
location:	43.15692100,-77.60467480	
hour	Elevation	Azimuth
07:11:48	-0.833°	88.76°
8:00:00	7.95°	97.04°
9:00:00	18.63°	107.88°
10:00:00	28.63°	120.12°
11:00:00	37.34°	134.72°
12:00:00	43.86°	152.58°
13:00:00	47.09°	173.55°
14:00:00	46.24°	195.45°
15:00:00	41.54°	215.29°
16:00:00	34.01°	231.76°
17:00:00	24.69°	245.28°
18:00:00	14.36°	256.85°
19:00:00	3.54°	267.39°
19:24:02	-0.833°	271.51°

Table 5: Spring equinox, Rochester NY (sunearthtools.com)

Date:	21/09/2022 | GMT-5	
coordinates:	43.156921, -77.6046748	
location:	43.15692100,-77.60467480	
hour	Elevation	Azimuth
06:56:38	-0.833°	88.37°
7:00:00	-0.22°	88.95°
8:00:00	10.67°	99.33°
9:00:00	21.22°	110.44°
10:00:00	30.97°	123.16°
11:00:00	39.25°	138.51°
12:00:00	45.07°	157.23°
13:00:00	47.35°	178.73°
14:00:00	45.51°	200.4°
15:00:00	40.01°	219.48°
16:00:00	31.94°	235.16°
17:00:00	22.3°	248.11°
18:00:00	11.79°	259.33°
19:00:00	0.9°	269.73°

Table 6: Fall equinox, Rochester NY (sunearthtools.com)

Date:	21/06/2022 | GMT-5	
coordinates:	43.156921, -77.6046748	
location:	43.15692100,-77.60467480	
hour	Elevation	Azimuth
05:30:48	-0.833°	56.02°
6:00:00	3.7°	60.94°
7:00:00	13.67°	70.54°
8:00:00	24.24°	79.87°
9:00:00	35.12°	89.59°
10:00:00	46°	100.72°
11:00:00	56.4°	115.22°
12:00:00	65.28°	137.12°
13:00:00	70.12°	171.68°
14:00:00	67.96°	210.34°
15:00:00	60.32°	237.03°
16:00:00	50.36°	253.91°
17:00:00	39.6°	266.1°
18:00:00	28.67°	276.24°
19:00:00	17.94°	285.63°
20:00:00	7.7°	295.05°
20:53:47	-0.833°	303.98°

Table 7: Summer solstice, Rochester NY (sunearthtools.com)

Date:	21/12/2022 | GMT-5	
coordinates:	43.156921, -77.6046748	
location:	43.15692100,-77.60467480	
hour	Elevation	Azimuth
08:39:00	-0.833°	122.11°
9:00:00	2.34°	125.73°
10:00:00	10.56°	136.84°
11:00:00	17.14°	149.28°
12:00:00	21.56°	163.09°
13:00:00	23.38°	177.85°
14:00:00	22.36°	192.74°
15:00:00	18.65°	206.88°
16:00:00	12.64°	219.74°
17:00:00	4.84°	231.21°

Table 8: Winter solstice, Rochester NY (sunearthtools.com)

As the kinetic façade will be designed to take all these factors into consideration to optimize the best geometry, position and angle these parameters have been imported into the algorithm for the façade generation as will be demonstrated later in this thesis. The tables above will show the parameters the program will be working with (Table 5-8).

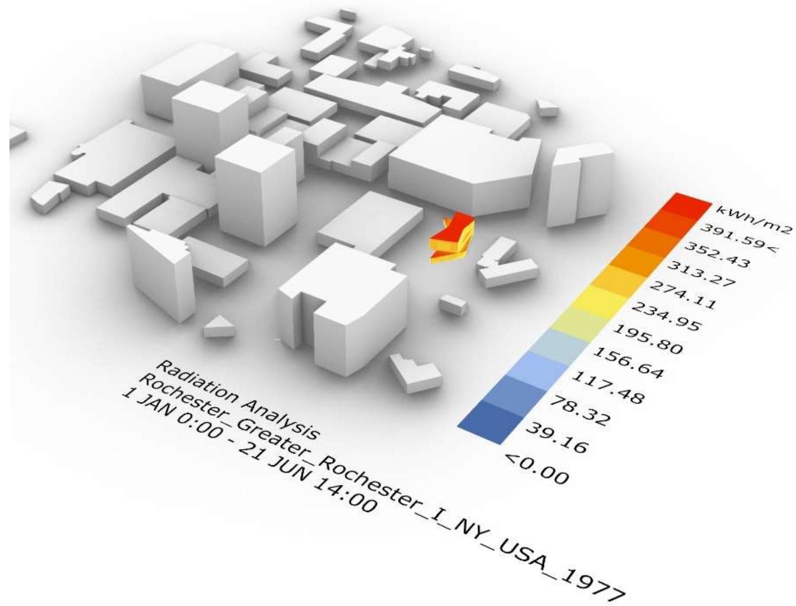


Figure 19: Average solar radiation from January to June

8. Proposed Project

10.1.1. Site Plan-Introduction

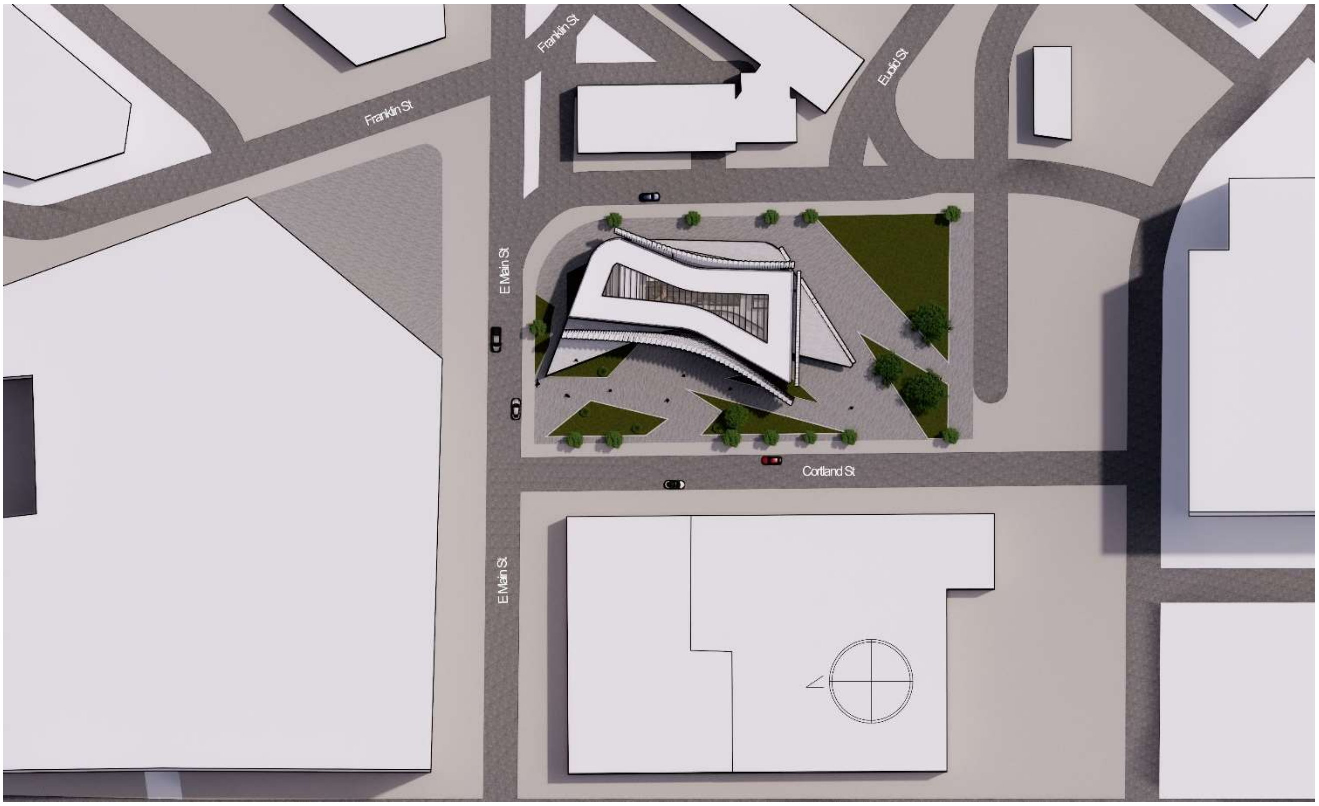


Figure 20: Site plan

The main entry point to the building is on the south façade on Courtland Street with ample plaza space. The secondary entry/exits are located on the east and southern façade to Andrew Langston way and Elm Street. It services multiple shops i.e. commercial retail space and a somewhat open plan on the first floor with shared courtyard space for both the surrounding community and the building occupants.

The building form takes on the double trapezoidal shape that shifts floor plates as it rises. The building shape is designed in such a way that its scoops as much light as it can on all sides. It features a skylight with a diffused screen to even out the light entering the building from the top and fill the central atrium space with light.

The building was formed by taking a typical rectangular shape and extruding it upwards to form a four-floor height. Then from the second level it is pushed inward to form terraces on the north and south side. This forms an overhang to shade the west fade first floor partially. Furthermore, the east and west facades were then pinched towards the center to for a bow like shape on each side and by doing so its shade some of the western façade from the southern sun. (Figure 25-29) show the progression of the form development.

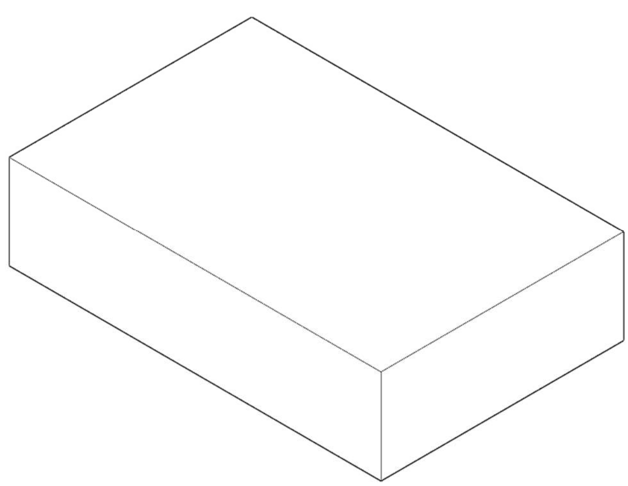


Figure 21: Form 1

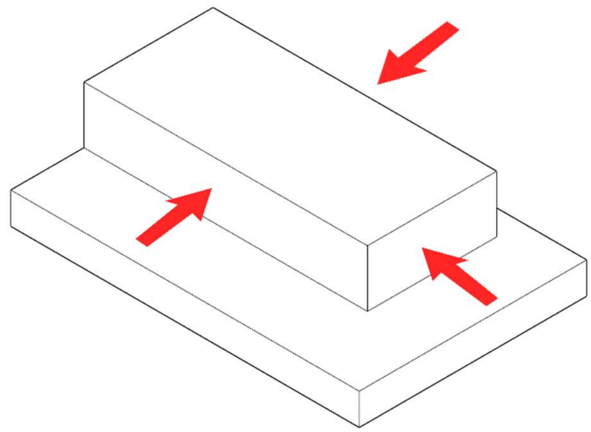


Figure 22: Form 2

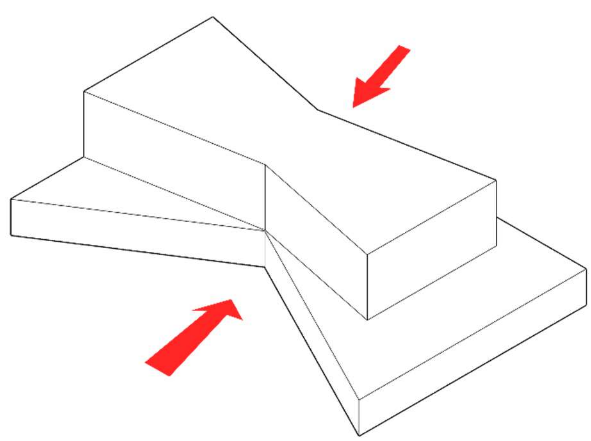


Figure 23: Form 3

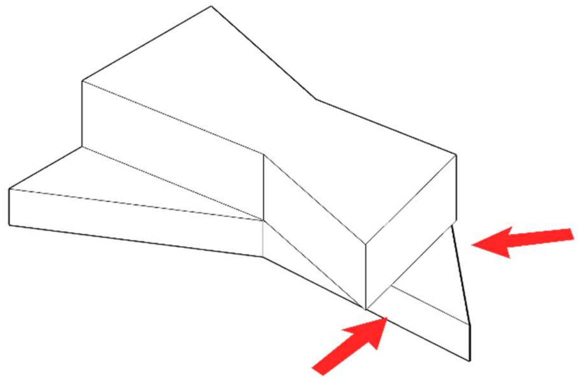


Figure 24: Form 4

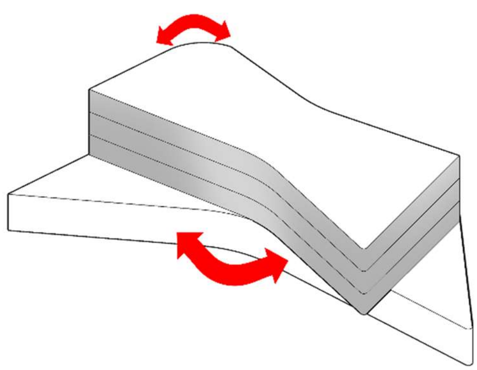


Figure 25: Form 5

The kinetic facades were designed to contour the shape of the building this were there are no negative spaces to create pockets for unaccounted sunlight to enter the building as seen in (figure 30). The design of the kinetic façade takes on the shape of square panels that draw inspiration from the repetitive windows of the surrounding context at a miniature scale.

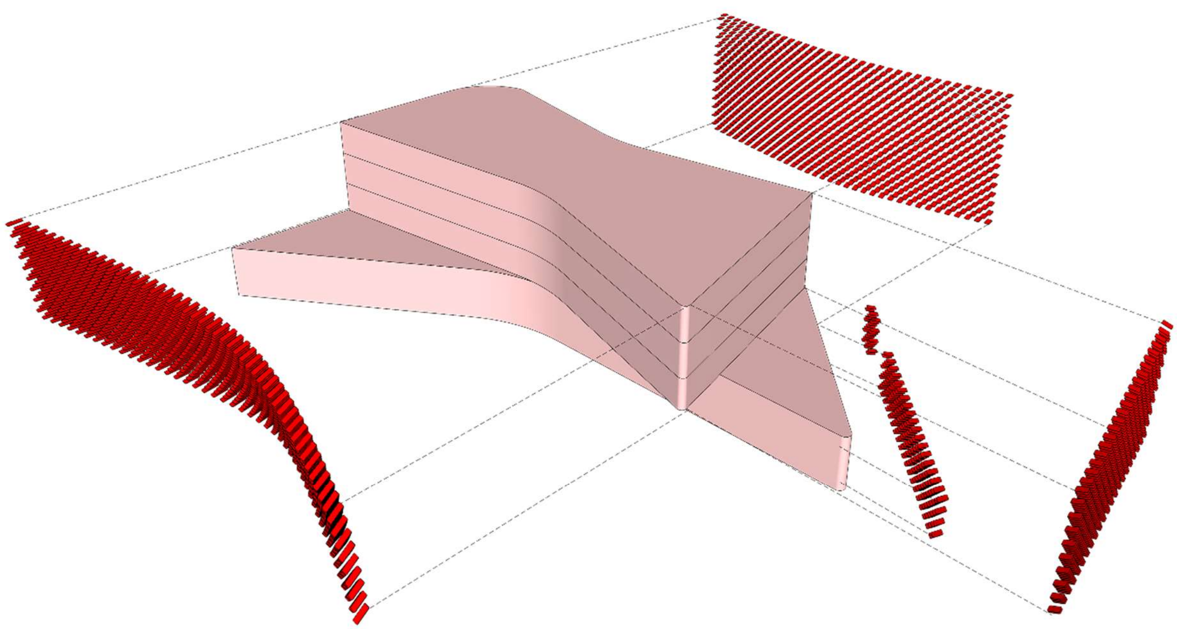
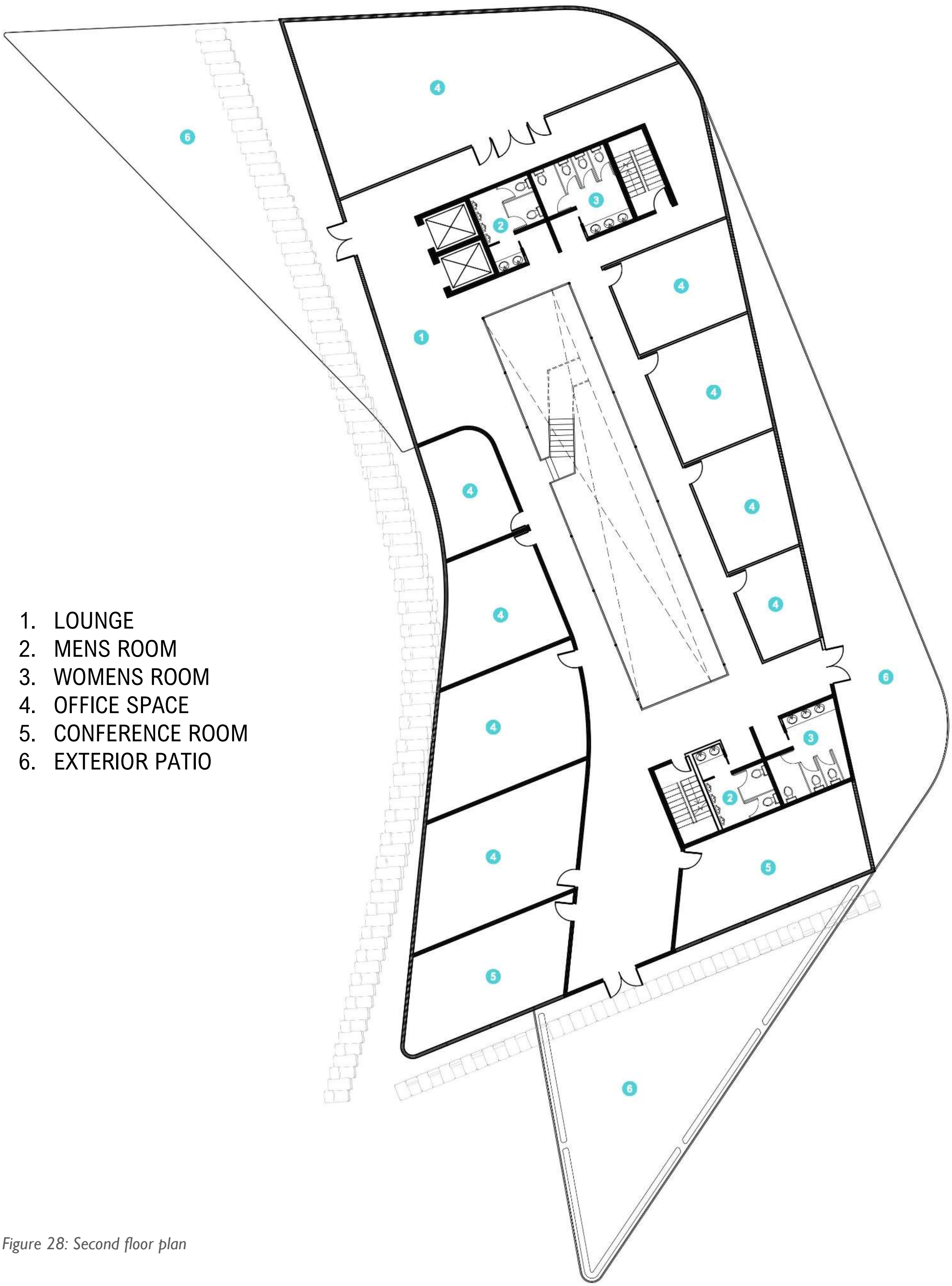


Figure 26: Exploded Axon

10.1.2. Floor Plans

1. ENTRY
2. WAITING AREA
3. RECEPTION
4. COURTYARD
5. CAFFE
6. RESTAURANT
7. MENS ROOM
8. WOMENS ROOM
9. OFFICE SPACE

Figure 27: first floor plan



1. LOUNGE
2. MENS ROOM
3. WOMENS ROOM
4. OFFICE SPACE
5. CONFERENCE ROOM
6. EXTERIOR PATIO

Figure 28: Second floor plan

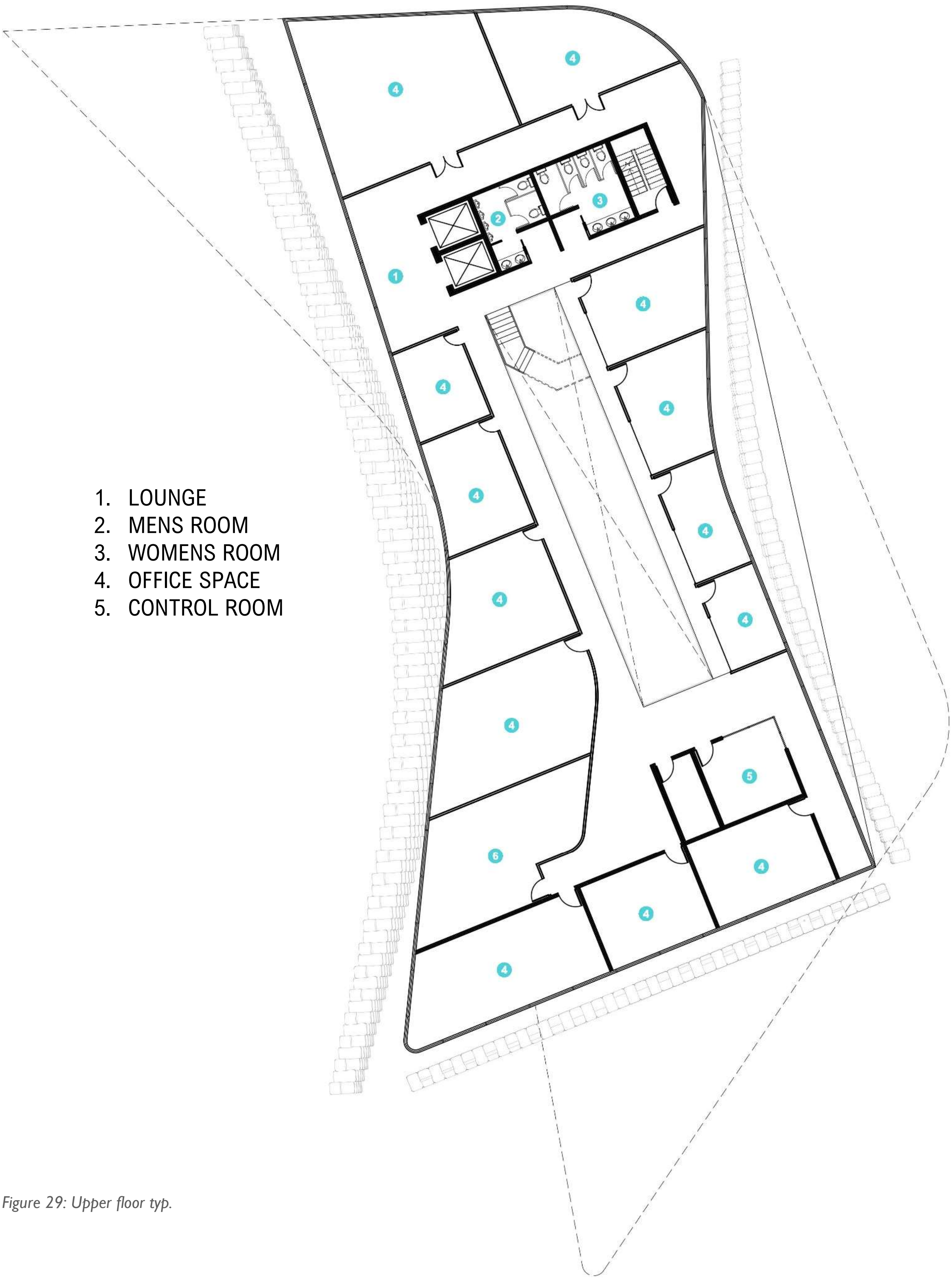


Figure 29: Upper floor typ.

The first floor is void of the kinetic façade as it is on the street level that features commercial spaces and public spaces such as restaurants, shops and café, such programs call for direct views to the street. Given the fact that the part of the second floor overhangs the ground floor, it provides shade along the west façade.

The second floor through the fourth floor feature an array of office spaces with a central open atrium space filled with diffused light from the large skylight at the roof level. It serves to promote natural light and reduce but not eliminate the need for artificial lighting throughout the building this in turn lighting loads

10.1.3. Sections

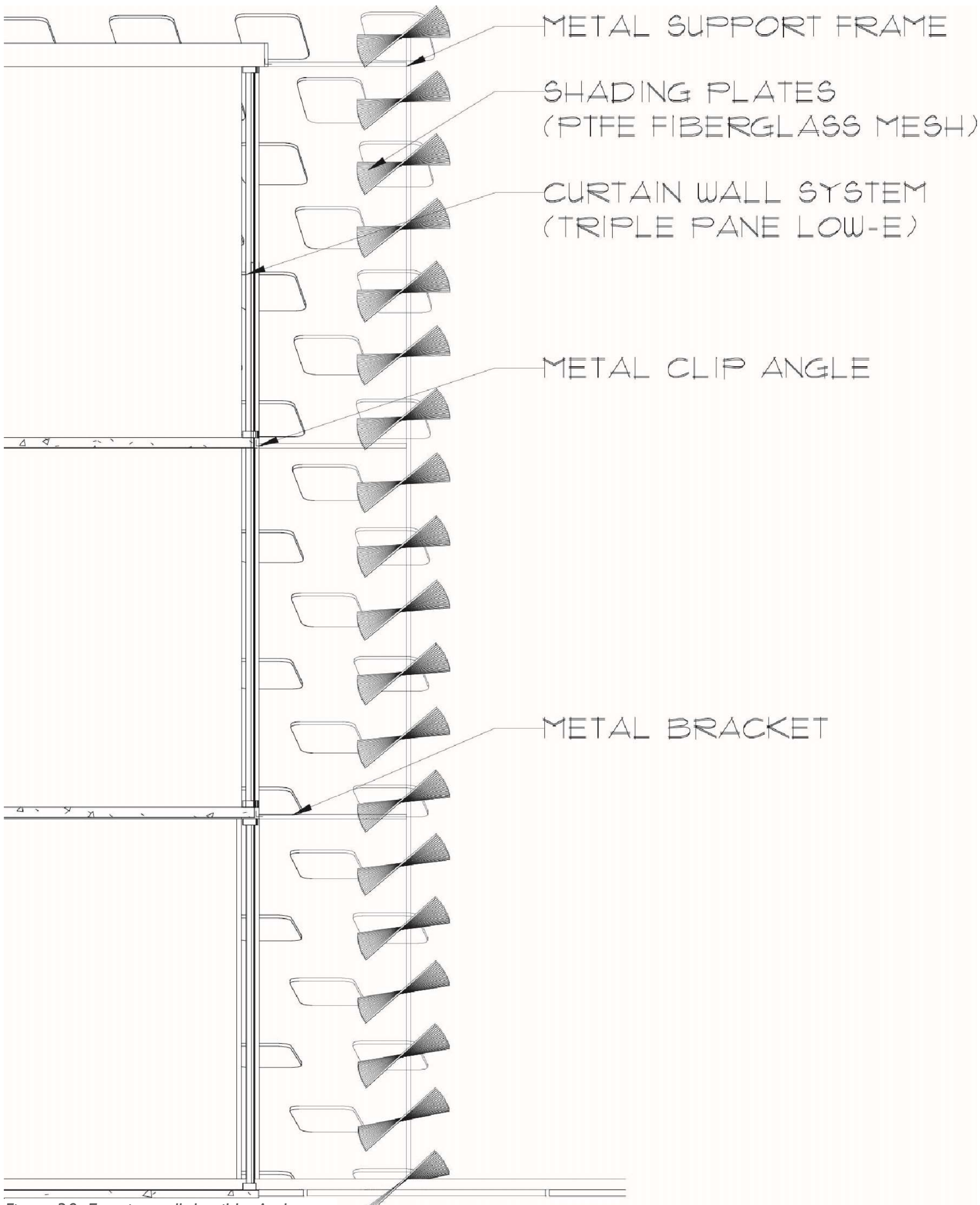


Figure 30: Exterior wall detail by Author

The façade is comprised of the mesh panel that is held up by a series of grid systems that is tied back to the main structure by metal brackets attached with metal clip angle as seen in figure 34 above.

Figure 31: Longitudinal section by Author

Figure 32: Longitudinal section by Author

Figure 33: Short section by Author

10.1.4. Elevations

Figure 34: South elevation

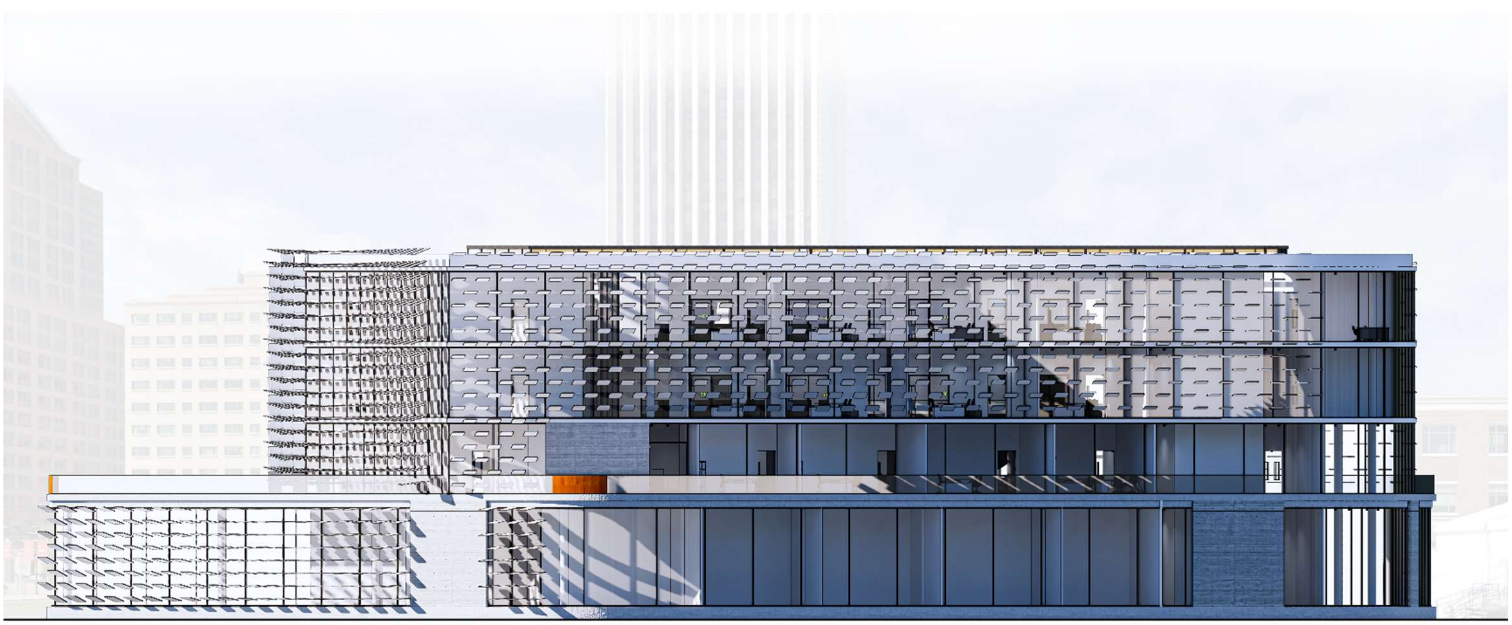


Figure 35: East elevation

Figure 36: West elevation

Figure 37: North elevation

1.1.5. Perspectives

Exterior Views-1

Figure 38: Aerial perspective

Figure 39: Exterior perspective

Interior Views-1

Figure 40: Interior perspective

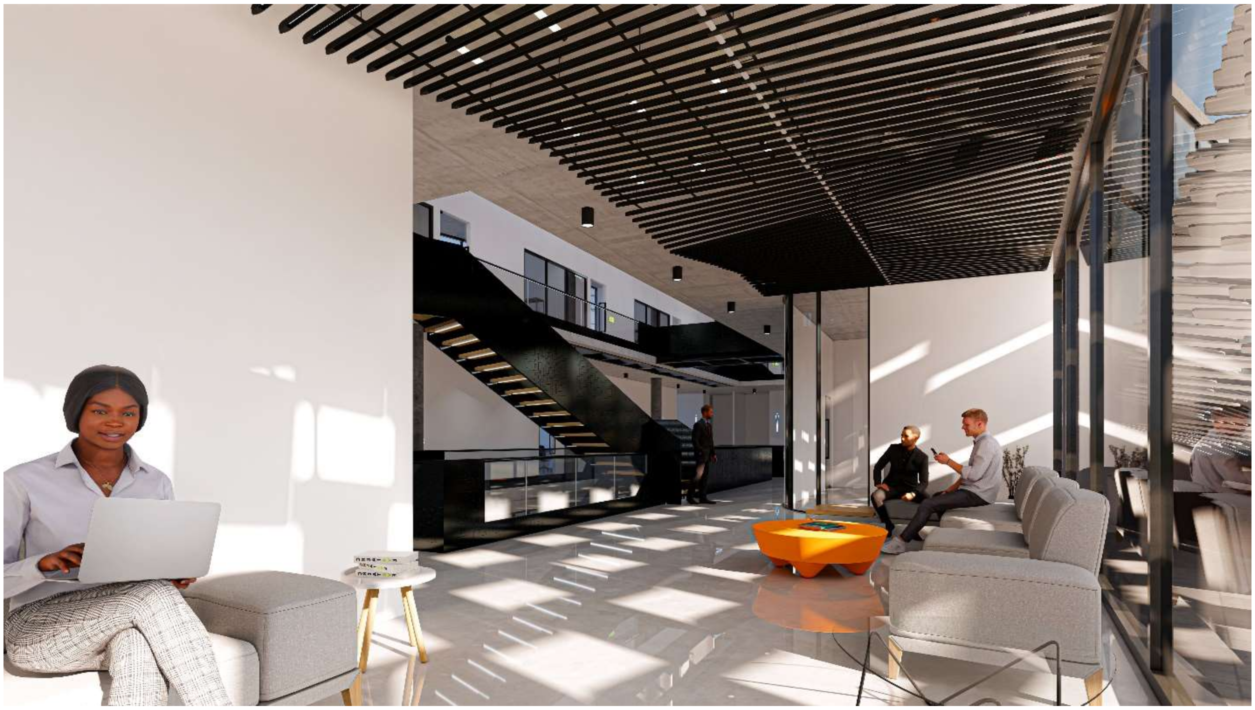


Figure 41: Second floor lounge

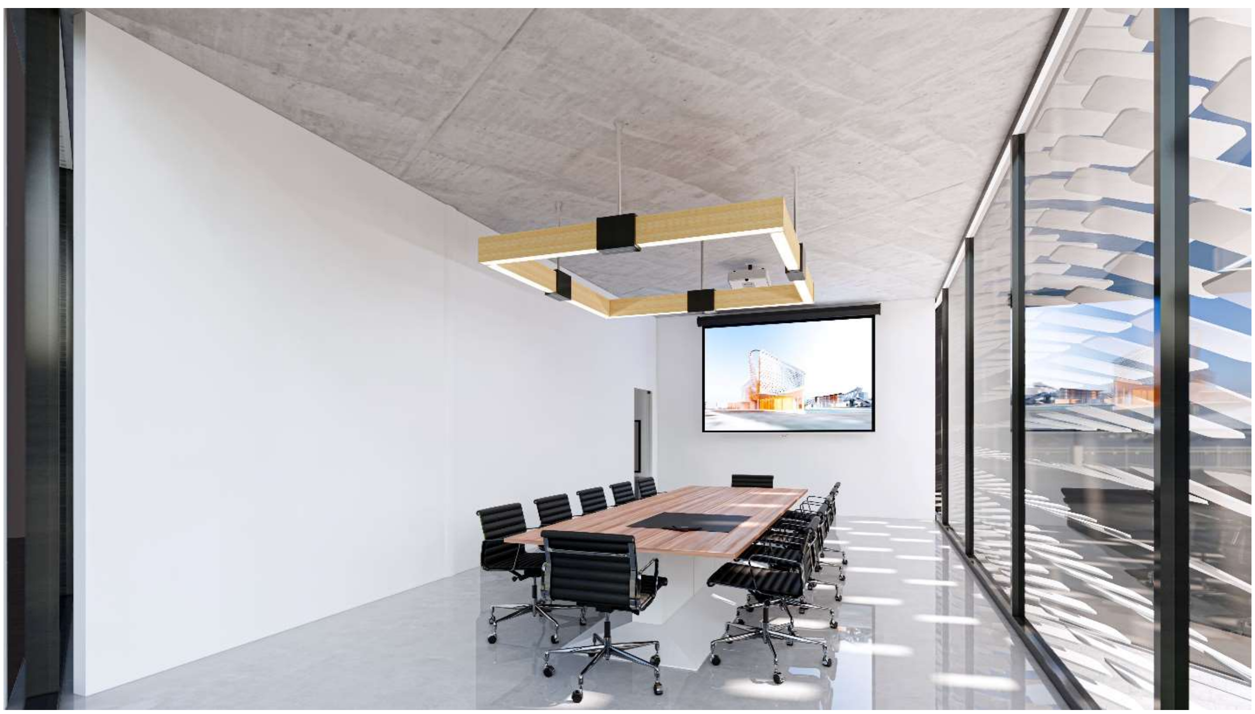


Figure 42: Conference room

Figure 43: Typical office space

Figure 44: Interior courtyard

9. Design/Data Analysis

A series of computer simulations were studied based on environmental aspects, solar thermal, daylighting, and energy efficiency in order to study the effectiveness of kinetic systems. These computer simulations will be carried out utilizing specific computer programs for each component. Solar thermal effects will be investigated with the use of the EnergyPlus tool, which will also give solar gain data. The same program will be used to investigate daylighting, which will deliver lux levels for a specific location in the interior space. Tests will be carried out on a typical office space in the building and then compared to the same apace with in integrated kinetic facade to see the changes in the results. The overall building will also be tested to determine the benefits of having a kinetic façade.

9.1.1. Solar analysis

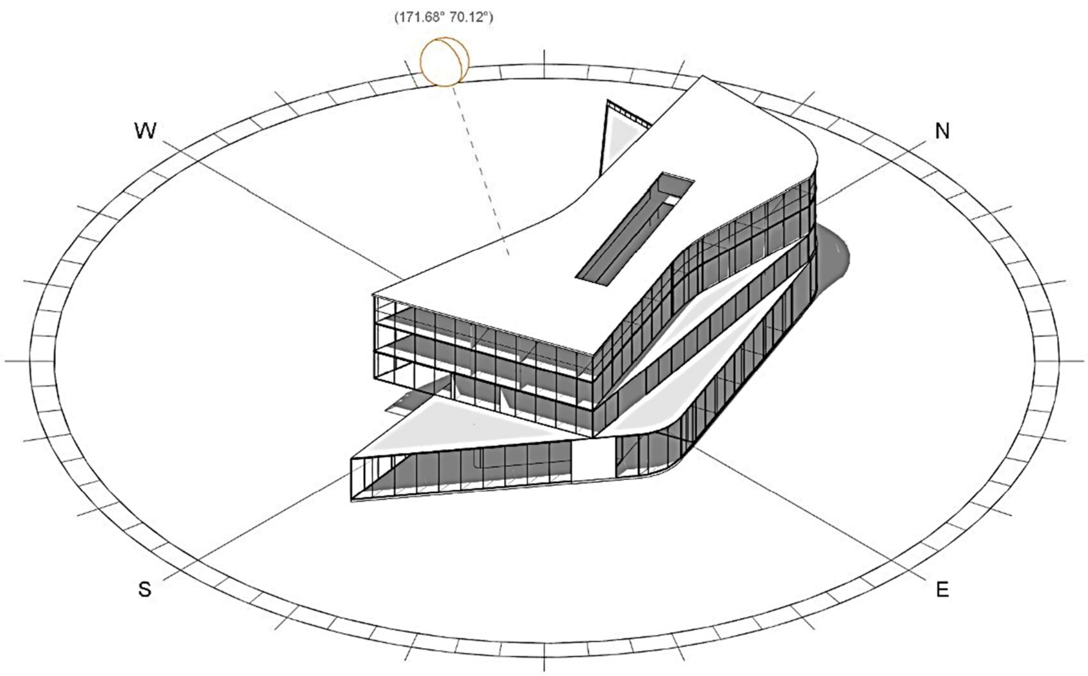


Figure 45: Summer solstice sun angle on southeast facade

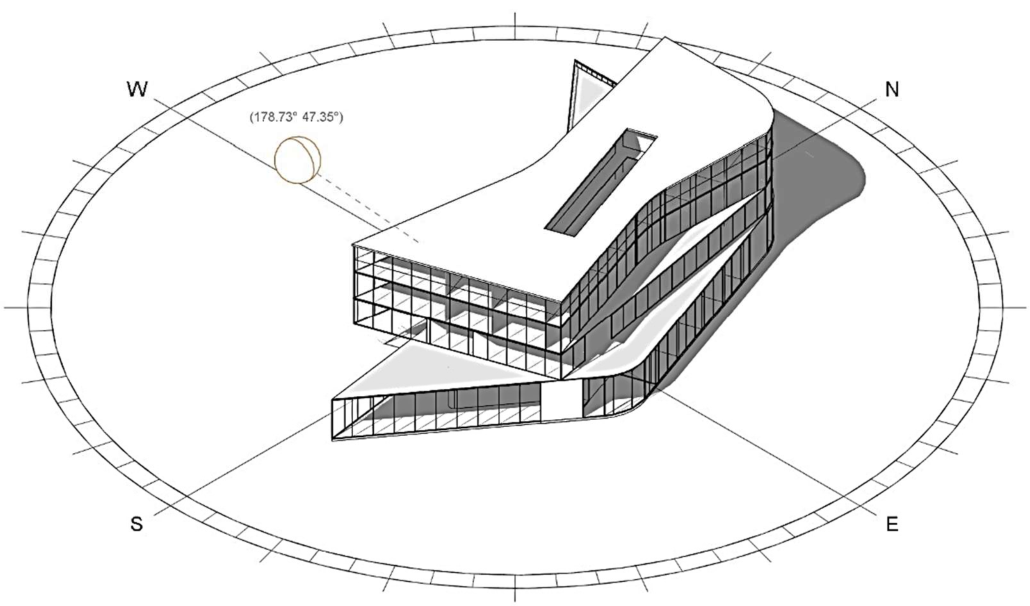


Figure 46: Spring equinox sun angle on southeast facade

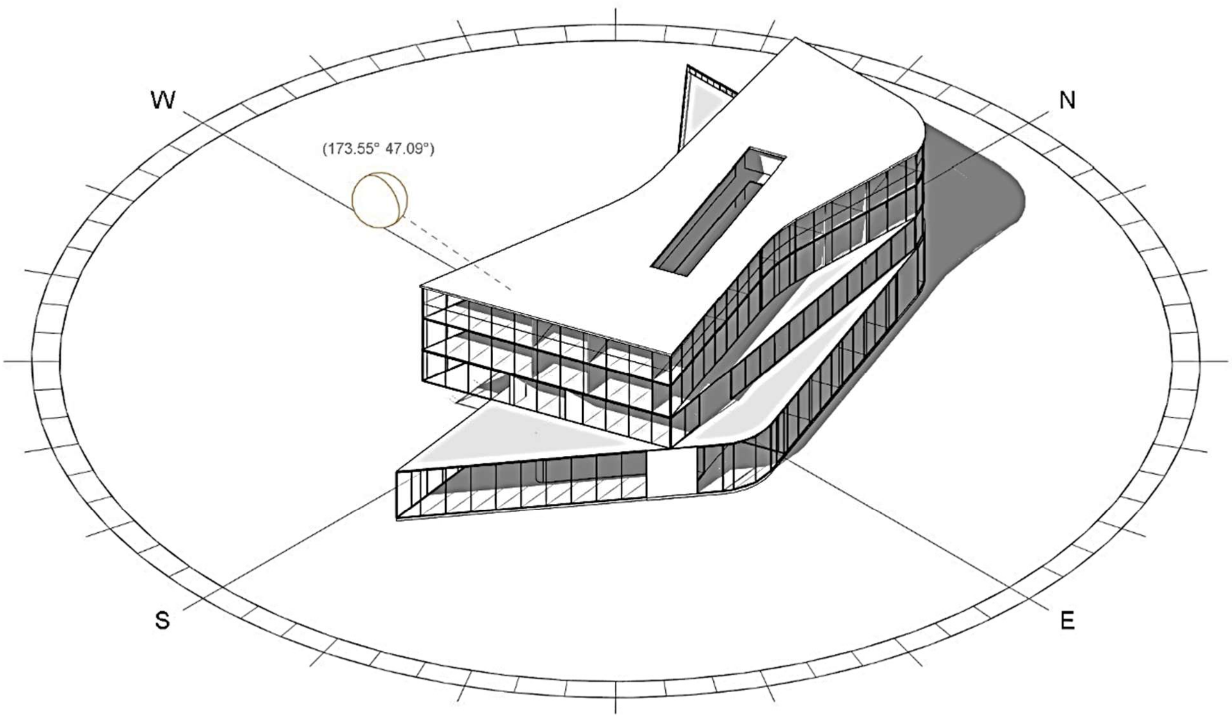


Figure 47: Fall equinox sun angle on southeast facade

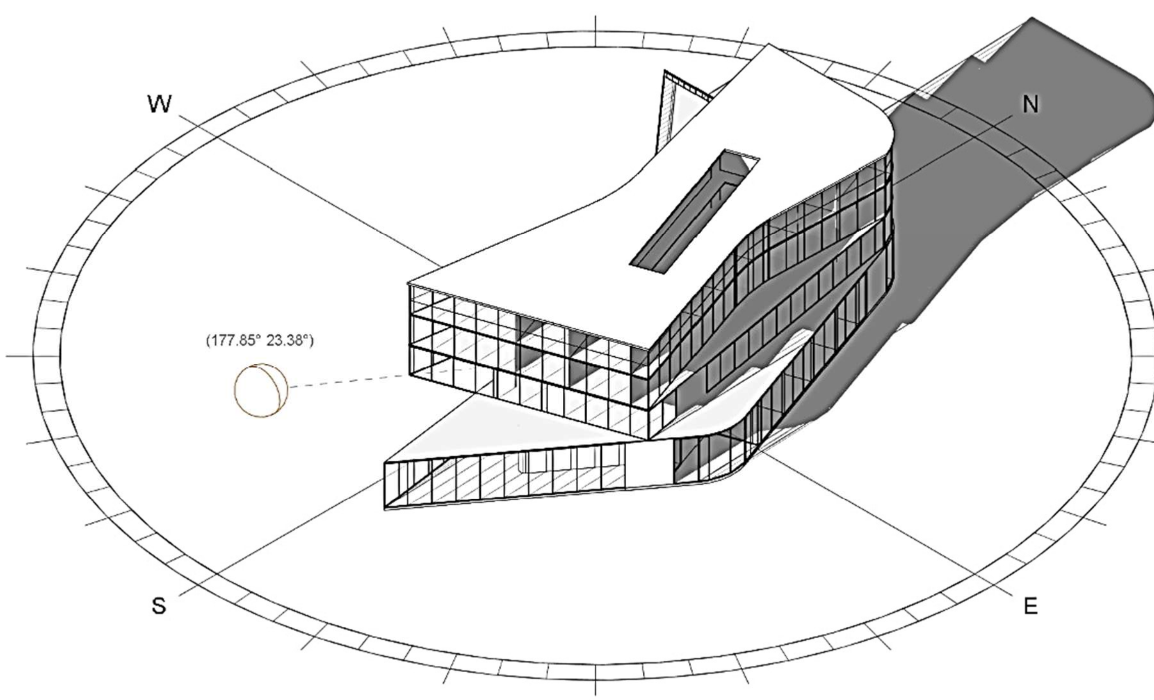


Figure 48: Winter solstice sun angle on southeast facade

The result of the analysis as seen in figures 20-23 shows the sun angles at different climate conditions ranging from summer, spring fall and winter. It shows in detail the azimuth and the elevations for the different seasons on how the sun affect the predominant South, East and partially the Western façade.

The sun is at its highest elevation of 47.09 degrees during the Spring Equinox, and it is at 70.12 degrees during the Summer Solstice. The sun angle during the fall equinox is trails that of the spring equinox, which is roughly 47.35 degrees, and the winter solstice is 23.38 degrees.

The design of the whole system is made to be a series of parametric generated geometry that will adjust to the optimal position, angle and spacing to keep as much radiation from entering the southern and eastern façade while also allowing the daylight in on parts of the western façade and the entirety of the northern façade. This is achieved by running simulations with the given location and parameters in BIM system the produces the best outputs based on the given inputs.

PURPOSE	Thermal comfort Energy conservation Visual comfort Aesthetic considerations
REACTIVE FUNCTION	Accept or reject solar heat gain Accept, reflect or direct visible light
TECHNOLOGY	Shading systems
SCALE	Facade (wall+window)

Table 9: Parameter table for the designed kinetic facade

9.1.2. Parametric façade

The complicated 3D geometry that needed to be simulated required to be generated to reflect the change from open to closed position. Another fundamental need was that any desirable component of the model may be simply adjusted once it was completed. The software used was Rhinoceros 3D, with Grasshopper for parametric modeling of both the origami piece and the building, and Enscape for project picture rendering, out of all the alternatives.

To create the façade the geometry had to be parameterized in other words represented in terms of parameters or given points. Grasshopper was used to achieve this as it is an IFC Shading device.

The first stage was to construct the plane in which the piece's base, which is the first square, was contained. As specified in the parametric element's definition, a base of 2 feet by 2 feet was built. Furthermore, a repetition function was created in both the X and Y axes (both of which coincided with the plane of the façade) so that once the entire piece was modeled, it was easy to repeat it.

Subsequently, three dynamic parameters were added, points were created for each individual panel along the XYZ plane to allow for maximum rotation about the axis, then a domain was created which takes into consideration the climate conditions and adjusts the façade to the required position.

The last stages involved crating a structured boundary to which the planes can rest on and make it dynamic. Following that the surface was created.

The resultant panels are made of Polytetrafluoroethylene (PTFE) coated fiberglass ventilated fabric mesh is the most durable fabric on the market. PTFE coated fiberglass provides uncompromised and unequaled beauty, longevity, and functionality.

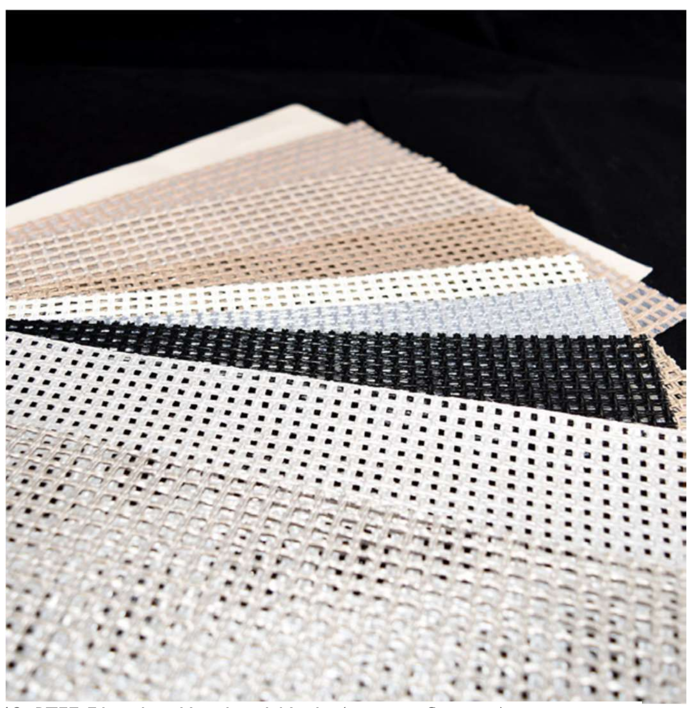


Figure 49: PTFE Fiberglass Ventilated Mesh -(structureflex.com)

Typically used in extreme weather conditions providing a more durable mesh type for ventilated facade screens (office buildings, parking garages, stadiums, roof screens) to provide shading/screening, lower heat gain, maintain views out, and maintain open airflow. It is best suited for this application as it is somewhat light permeable so the facades with no indirect light will not be deprived of natural daylight. As seen in Figure 50-53. The creation process from forming a 2D grid on which the individual panels will be formed to imputing a command to enable the sun tracking for the façade and then forming the shading panels which will be in a parametric form to contour the building unique shape and optimize shading.

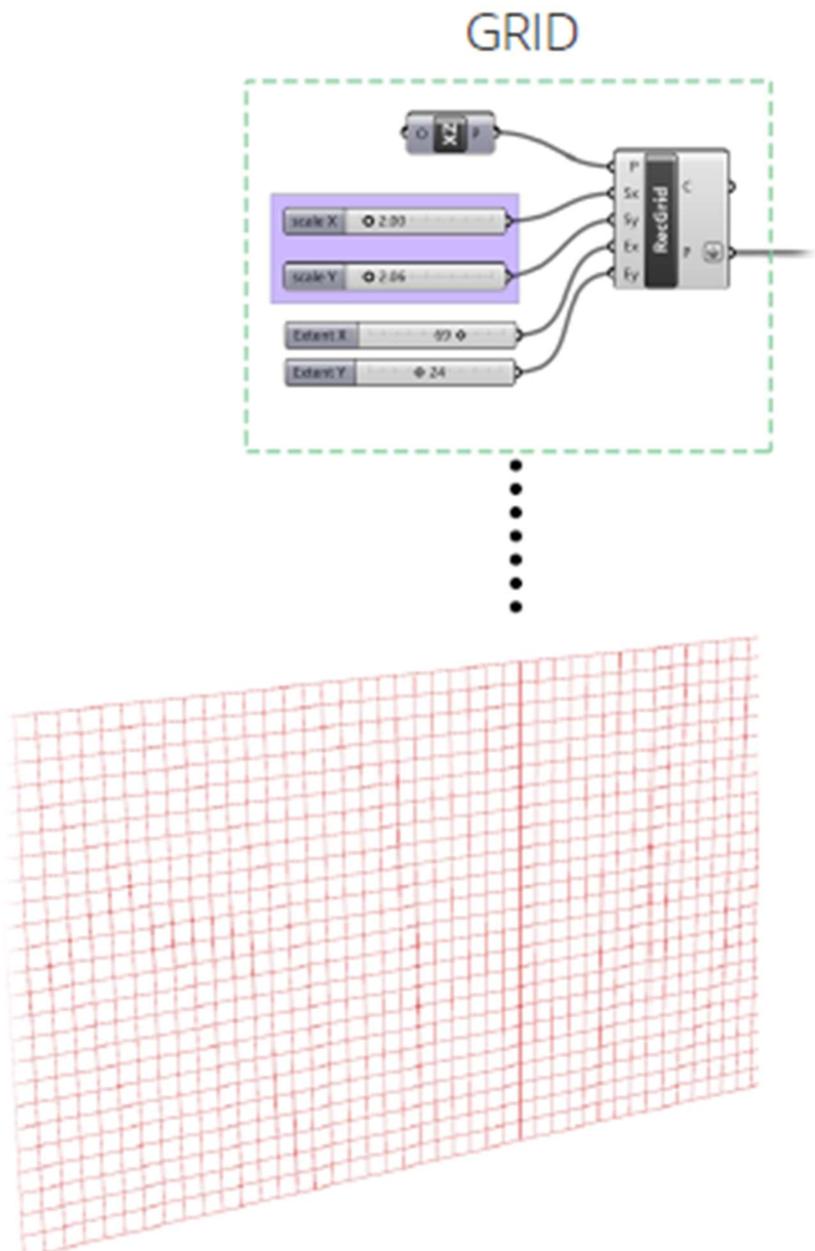


Figure 50: Creation of the grid

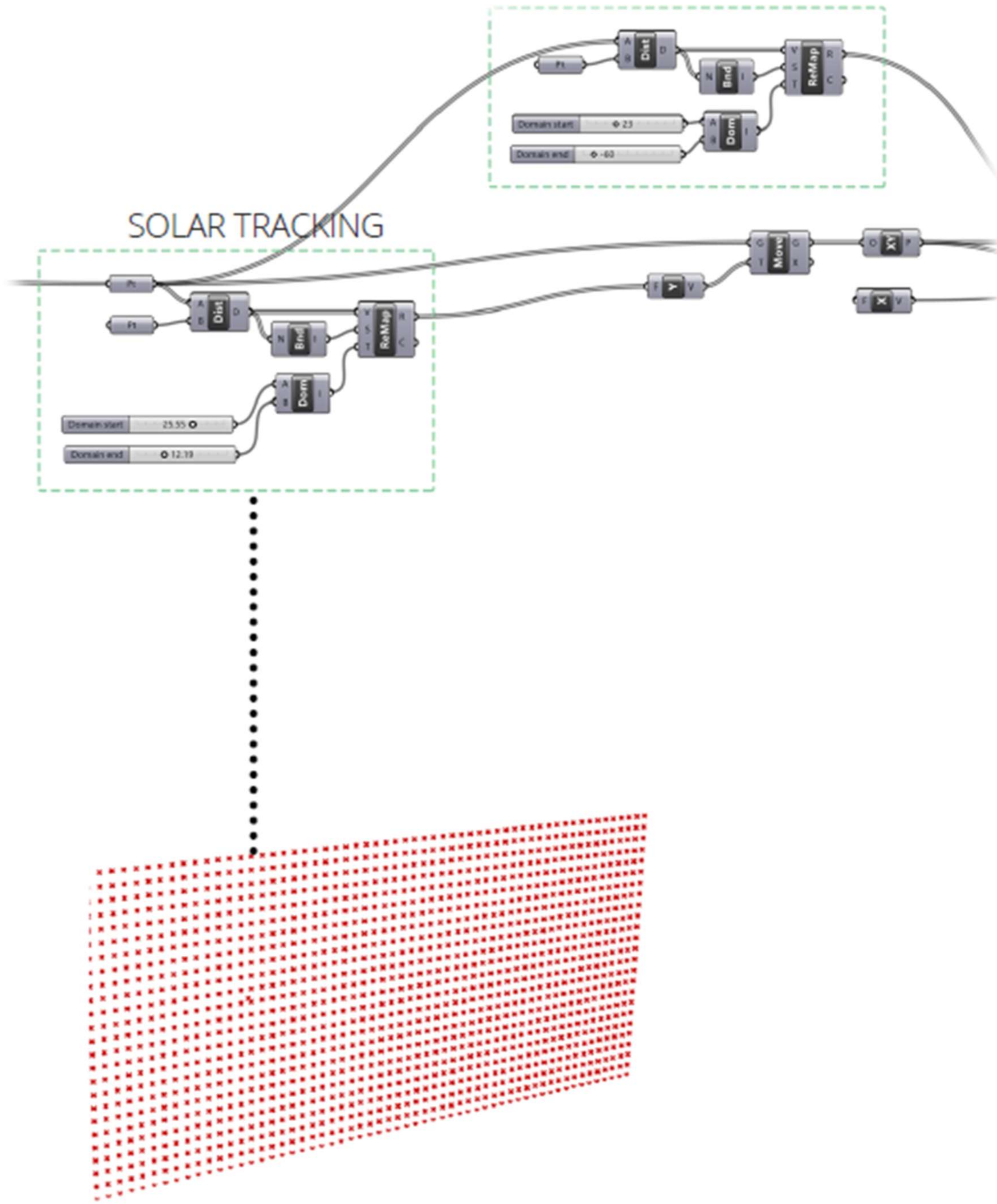


Figure 51: BMS system integration

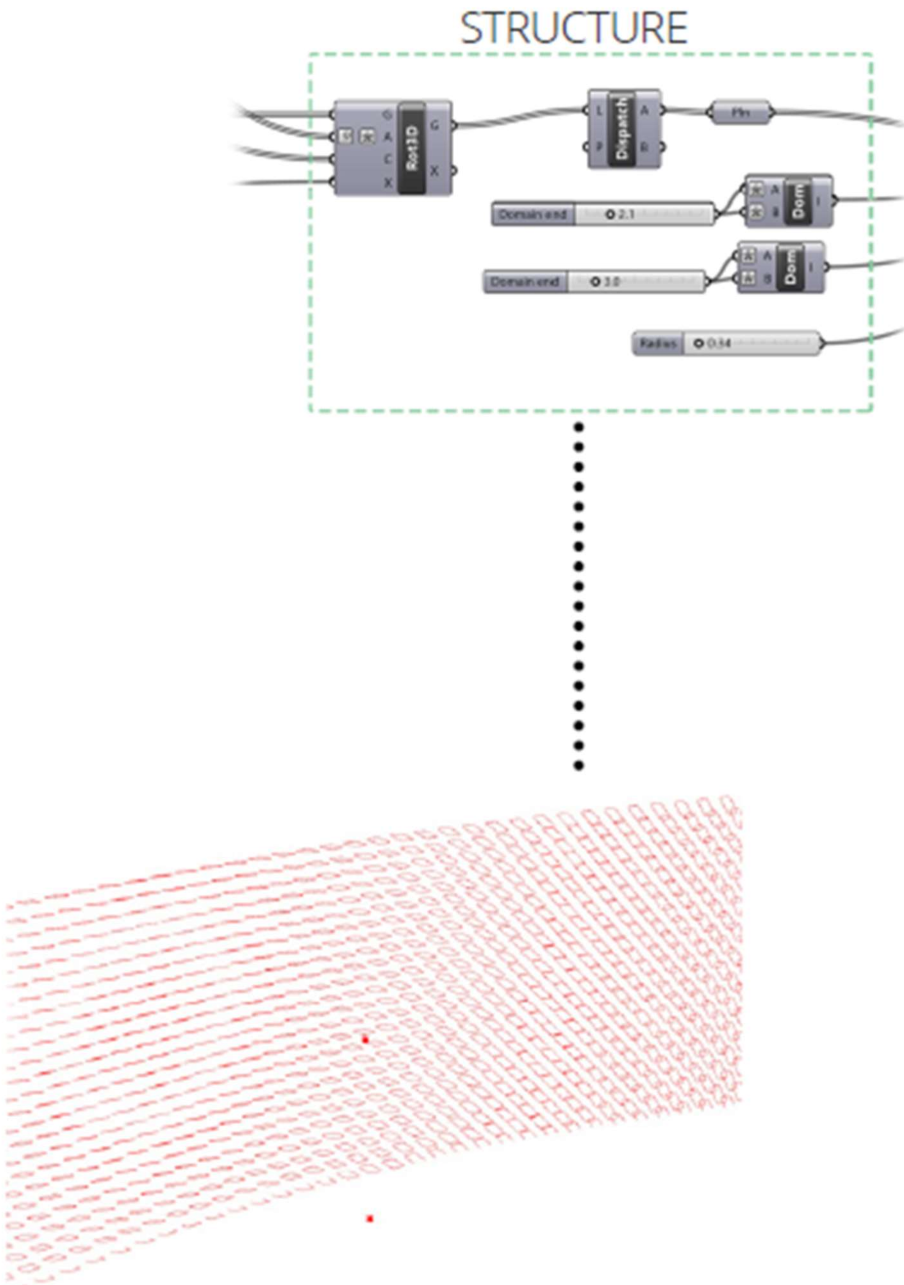


Figure 52: Complete structure

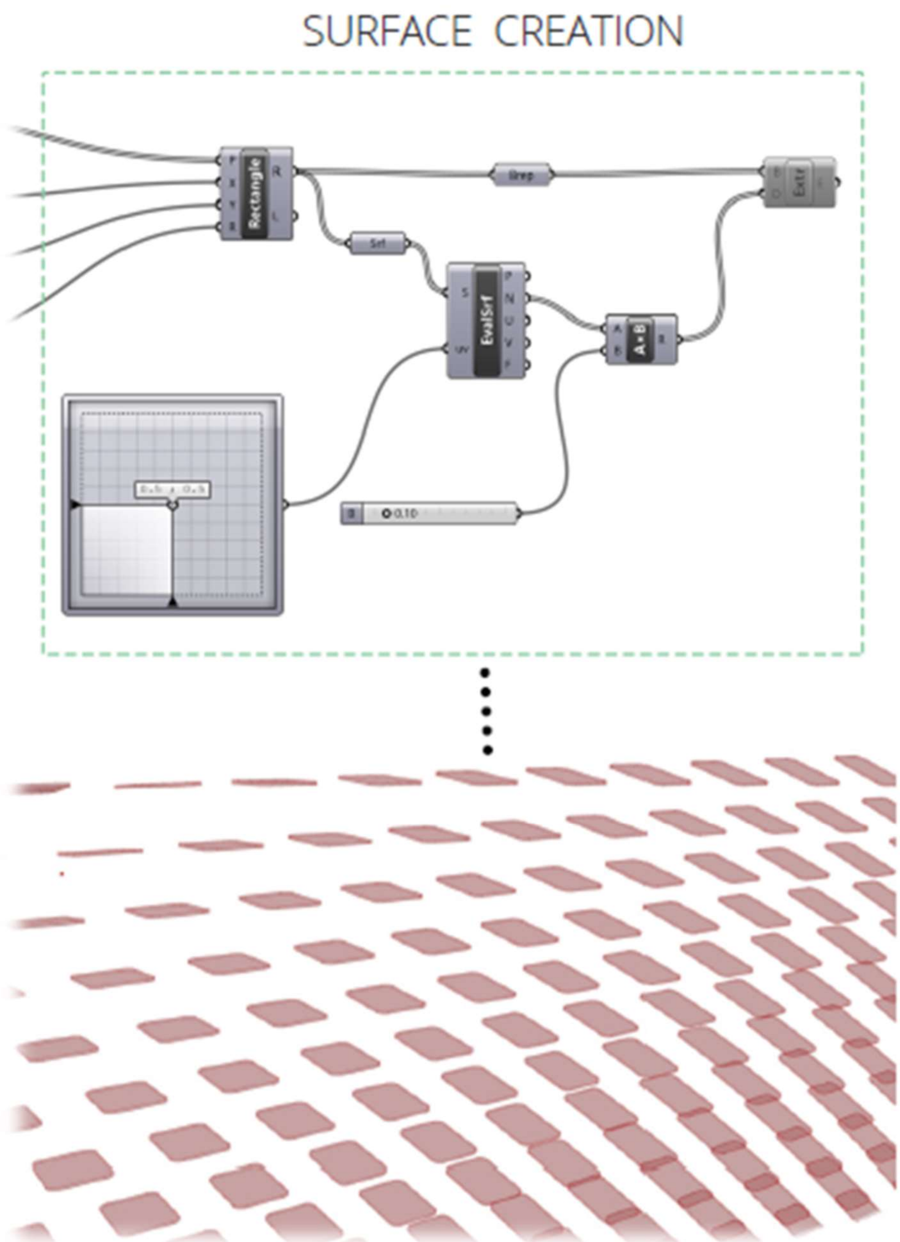


Figure 53: Panels with extruded surfaces complete

Because the geometry was organized in a grid system modifying the façade based on climatic requirements was made quick and easy. The result was a success as it was able to contour along the buildings for with a set offset of 16 inches for both visual and thermal comfort as seen in (figure 54).

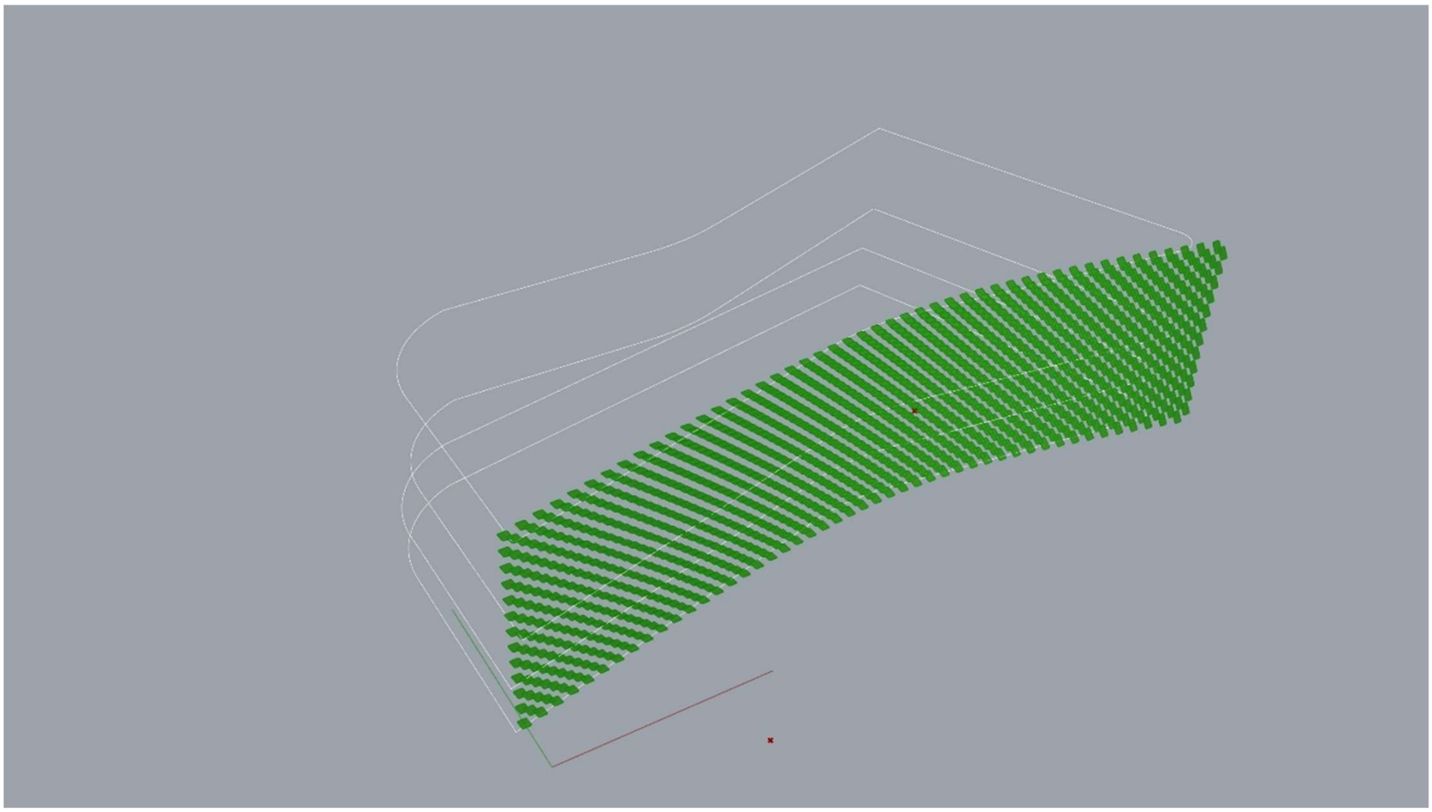


Figure 54: West Façade

Figure 55 represent the façade at fully opened, half opened and closed positions at different times of the day to accommodate the building interior needs.

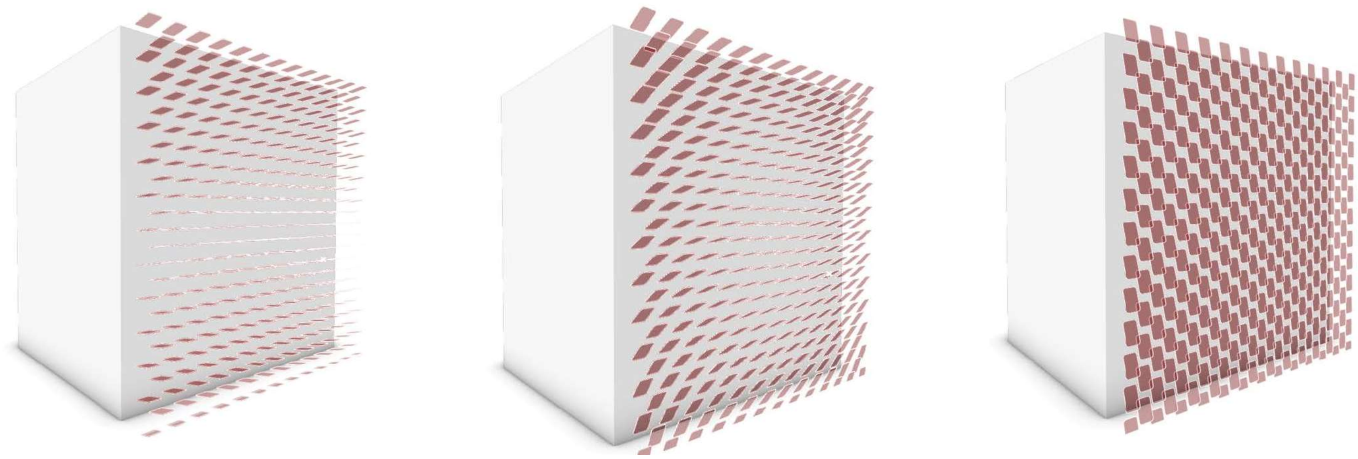


Figure 55: fully open facade at 7am, half open facade at 4pm and closed facade at 1pm

9.1.3. Daylight simulation

This section will investigate the daylight performance of the building with and without a kinetic façade to determine a benchmark for success. As stated in the objective section, the goal is to fall between the give optimal LUX rating for an office building which is between 250 to 2000 lux. The energy plus software will give a pass or fail while also giving the range the overall building fall in. The simulation will be carried out with clear sky conditions in June 21 and December 21 at 7:00 AM, 1:00 PM and 3:00PM. These time frames will be optimal enough to cover the time the building will be in operation. The data output of the program will be measure in illuminance on the surface in Lux. This data will be input in a table to compare the two instances.

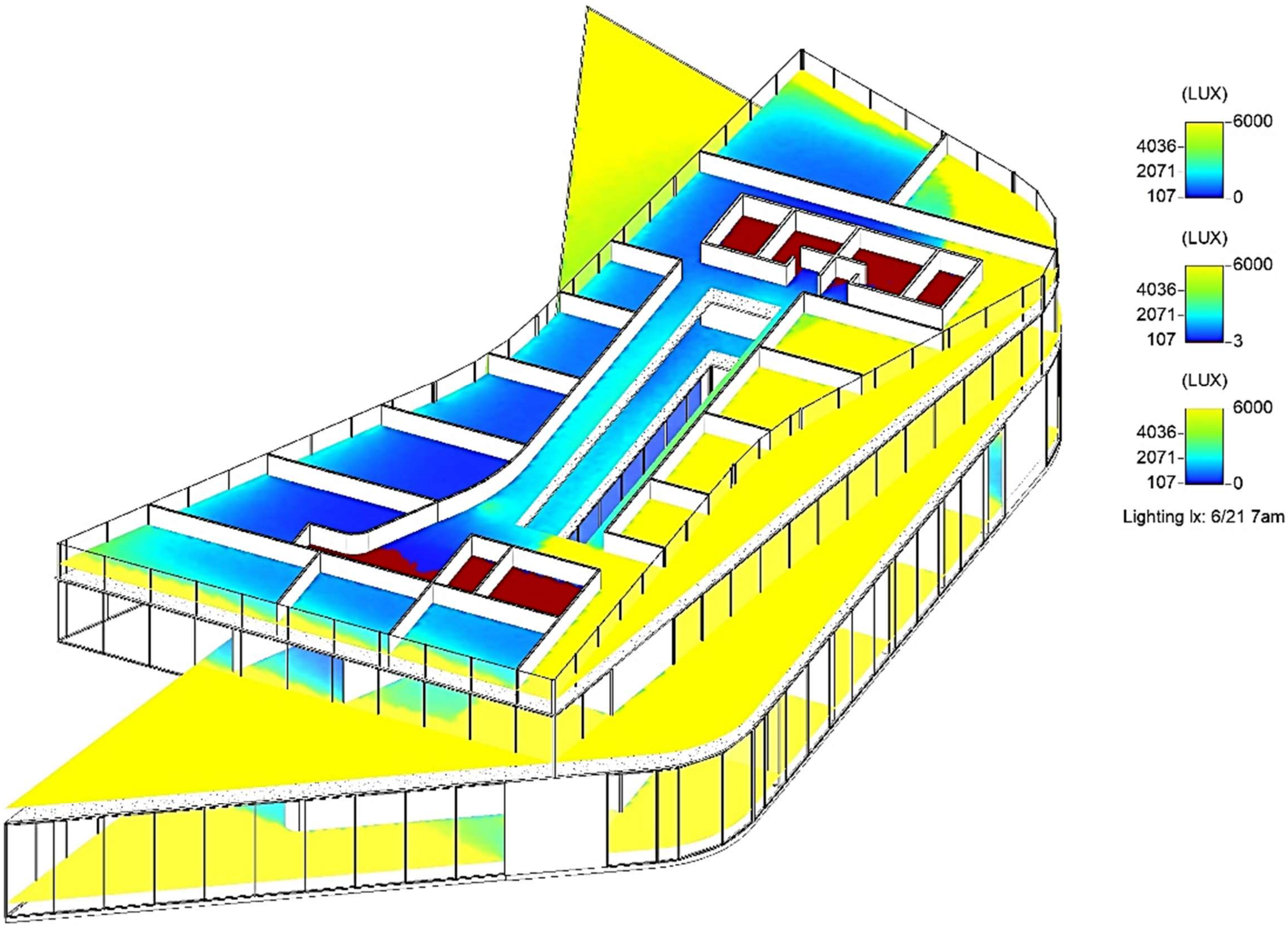


Figure 56: Daylight analysis of summer solstice at 7:00AM

The figure 56 above shows the daylighting analysis, they show the information based of the average two-month fame period at 7 AM. The lux level on the interior average around 1000 lux which is about 85 percent passing as can be seen in figure 57.

Custom Analysis

For all Rooms Included in Daylighting

Total Both - 0% Passing

100% either time below threshold

15% either time above threshold

7:00 am - 85% Passing

June 21

GHI: 258, DNI: 448, DHI: 74

0% below threshold

15% above threshold w/o shades

7:00 am - 0% Passing

December 21

GHI: 1, DNI: 1, DHI: 1

100% below threshold

0% above threshold w/o shades

Figure 57: 7AM daylight result

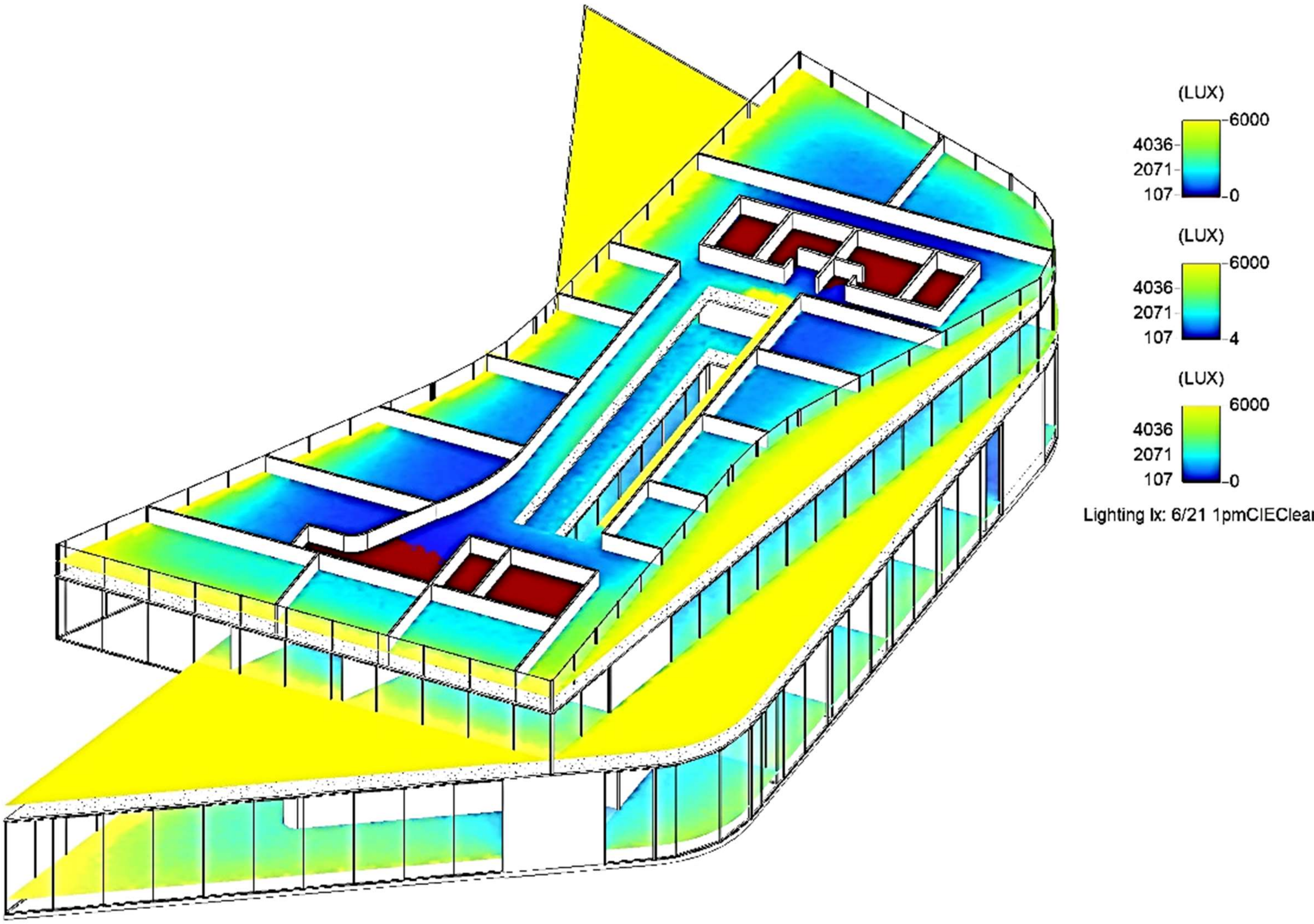


Figure 58: Daylight analysis of summer solstice at 1:00PM

Figure 58 shows the daylighting analysis, they show the information based of the average two-month fame period at 1 PM. The lux level on the interior average around 2000 lux which is about 32 percent passing as can be seen in figure 59.

Custom Analysis
For all Floor areas in the Analysis

Total Both - 30% Passing
8% either time below threshold
62% either time above threshold

2:00 pm - 32% Passing
July 21
GHI: 743, DNI: 765, DHI: 91
8% below threshold
60% above threshold w/o shades

2:00 pm - 38% Passing
December 21
GHI: 188, DNI: 369, DHI: 70
8% below threshold
54% above threshold w/o shades

Figure 59: 1PM daylight result

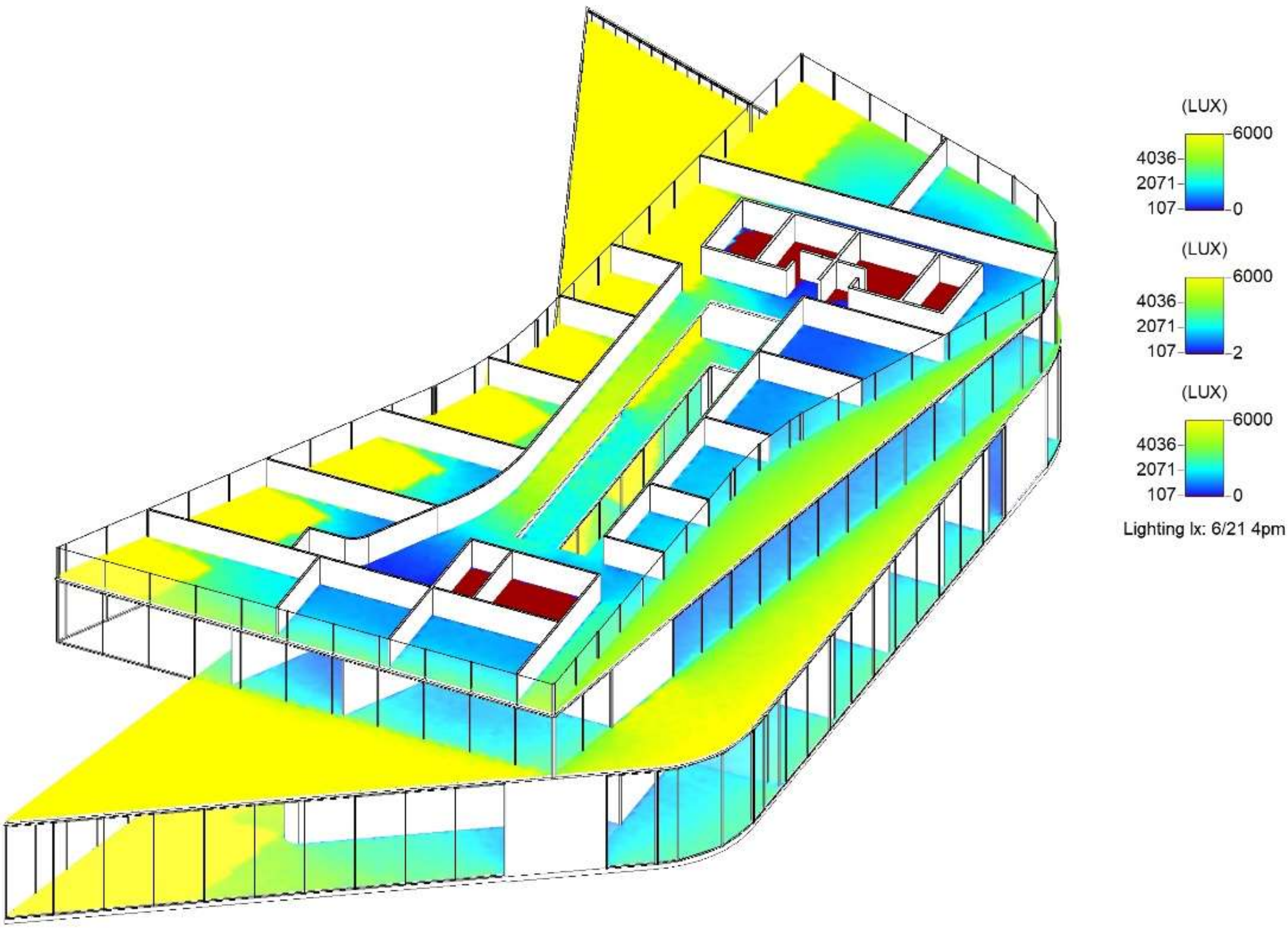


Figure 60: Daylight analysis of summer solstice at 3:00PM

Figure 60 above shows the daylighting analysis, they show the information based of the average two-month fame period at 3 PM. The lux level on the interior average around 1000 lux which is about 11 percent passing as can be seen in figure 61.

Custom Analysis
For all Rooms Included in Daylighting

Total Both - 11% Passing

0% either time below threshold
89% either time above threshold

4:00 pm - 11% Passing

June 21
GHI: 494, DNI: 639, DHI: 86
0% below threshold
89% above threshold w/o shades

4:00 pm - 100% Passing

December 21
GHI: 8, DNI: 2, DHI: 6
0% below threshold
0% above threshold w/o shades

Figure 61: 4PM daylight result

Interior studies

Solar studies have been captured in infusion stations during all four seasonal solstices. These models are produced in light view to show the illuminance (lux) and a clay rendering died by side to show a contrast between light and shadow, this will illustrate clearer as to how the light enters the space. The studies will be carried out over the peak solstices at 7AM, 1PM and 3PM respectively. The studies will focus on the southern and eastern façade as they induce the most rays from the sun.

Summer Solstice South Facade

As indicated from earlier tables and figures the summer sun does not reach deep into the space. This will help with unwanted summer heat gain. As mentioned earlier, the integrated kinetic façade will help mitigate direct sun rays. As can be seen in figure 62- 67.

The lux scale across the southern façade average around 1000 lux which falls in the range of 250 to 2000 lux as stated by LEED v4 EQc7 to be the acceptable threshold for office buildings.

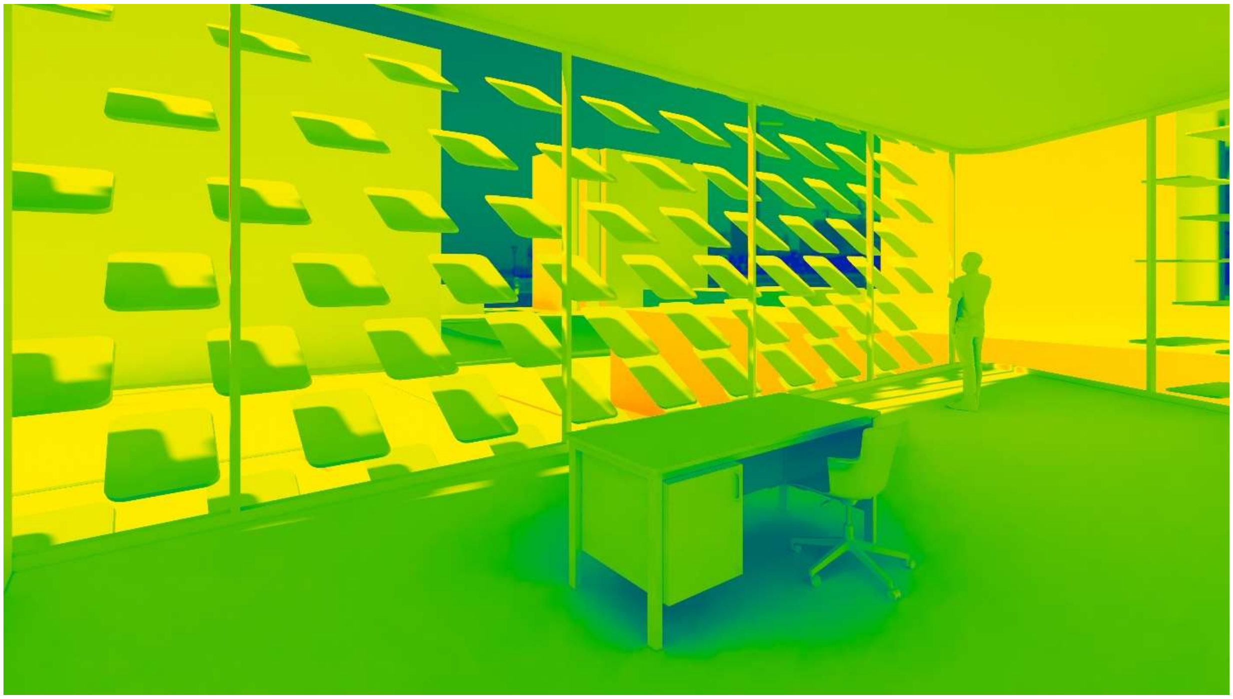


Figure 62: South at 7AM

Figure 63: South at 7am shade

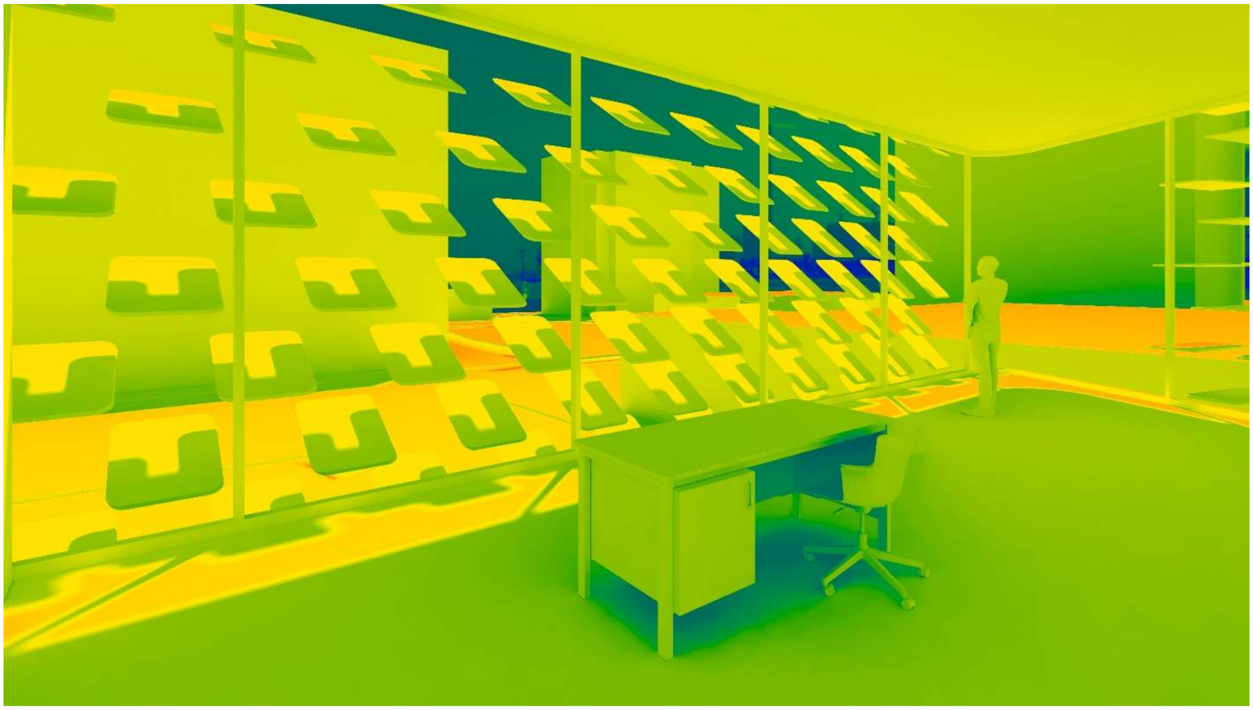


Figure 64: South 1pm

Figure 65: South 1pm shade

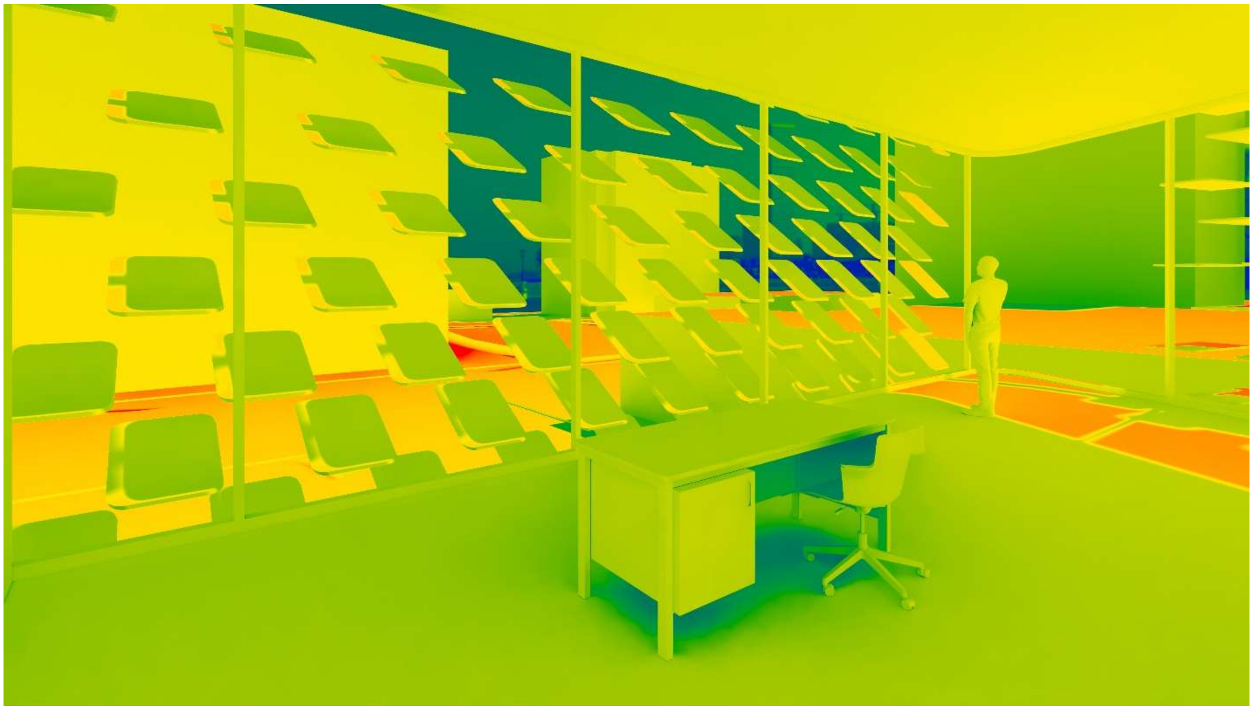


Figure 66: South 3pm light view

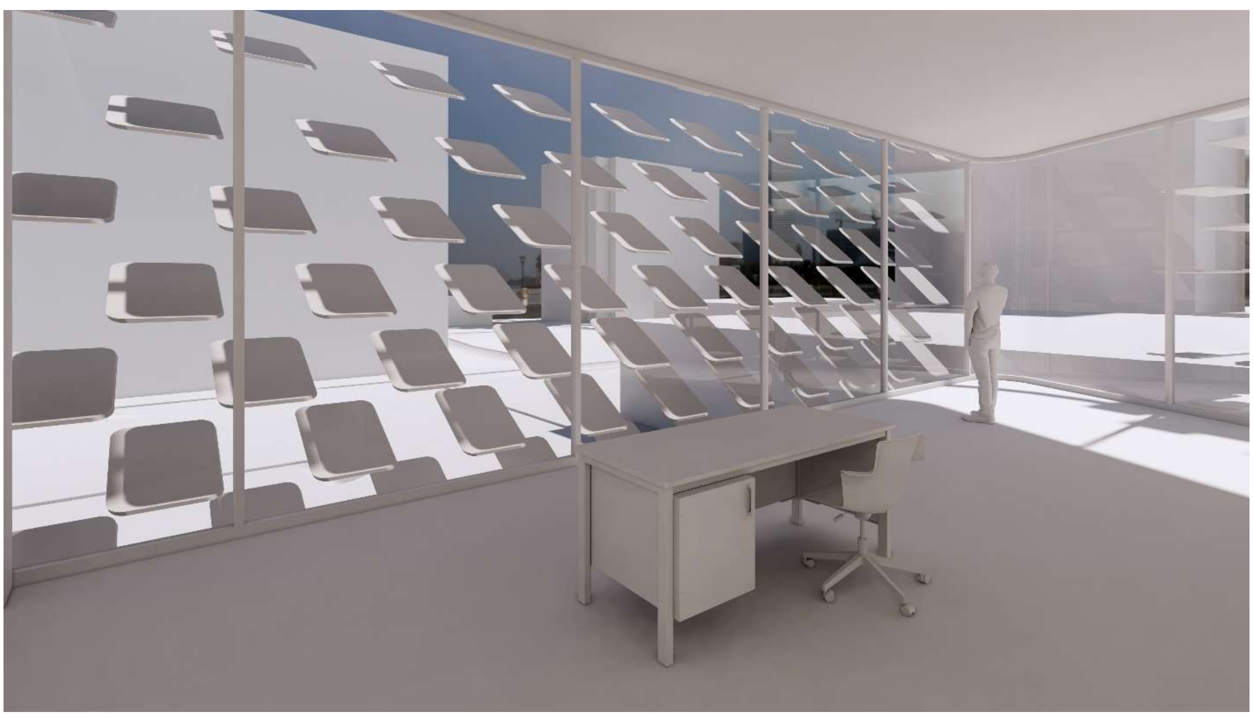


Figure 67: South 3pm shade

Summer Solstice East Façade

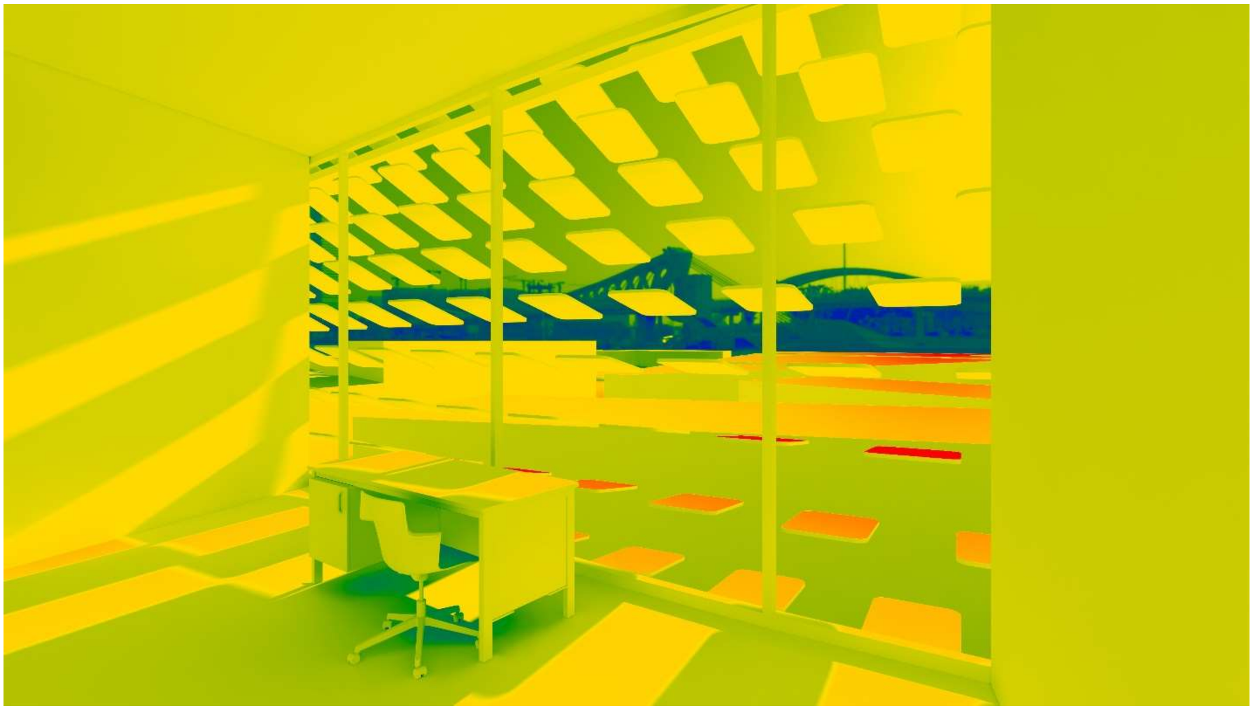


Figure 68: East 7am light view

Figure 69: East 7pm shade

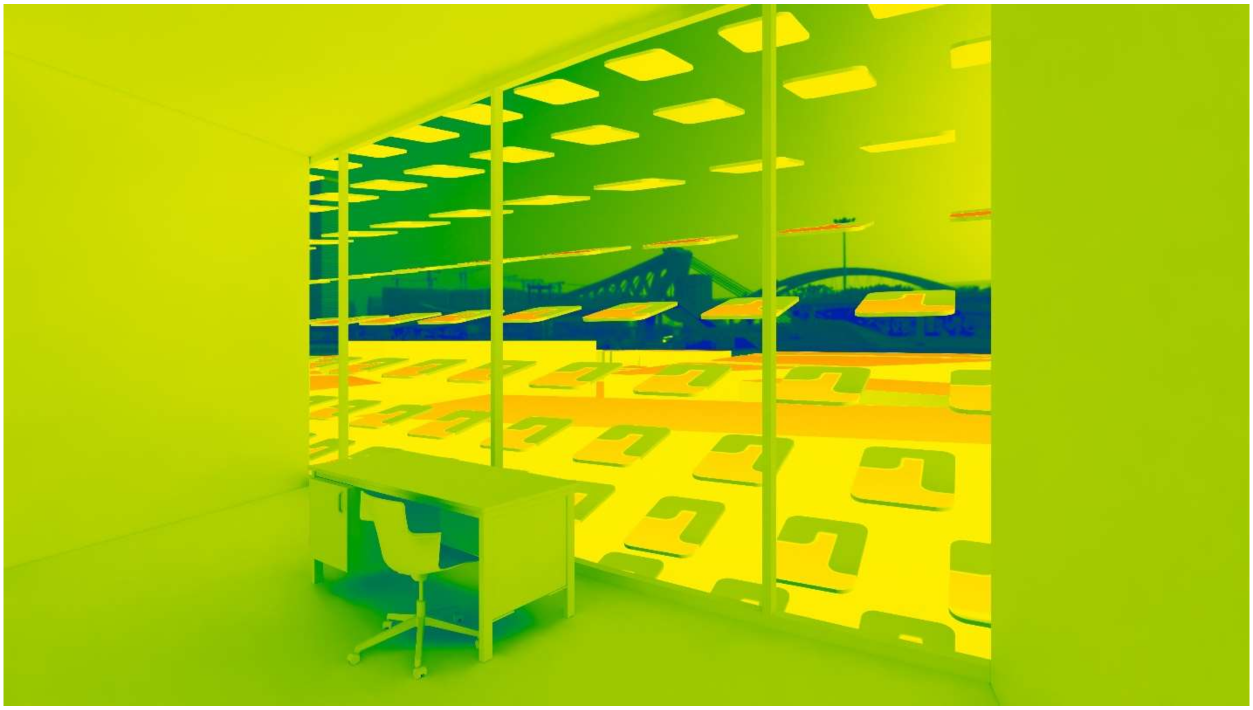


Figure 70: east 1pm light view

Figure 71: east 1pm shade

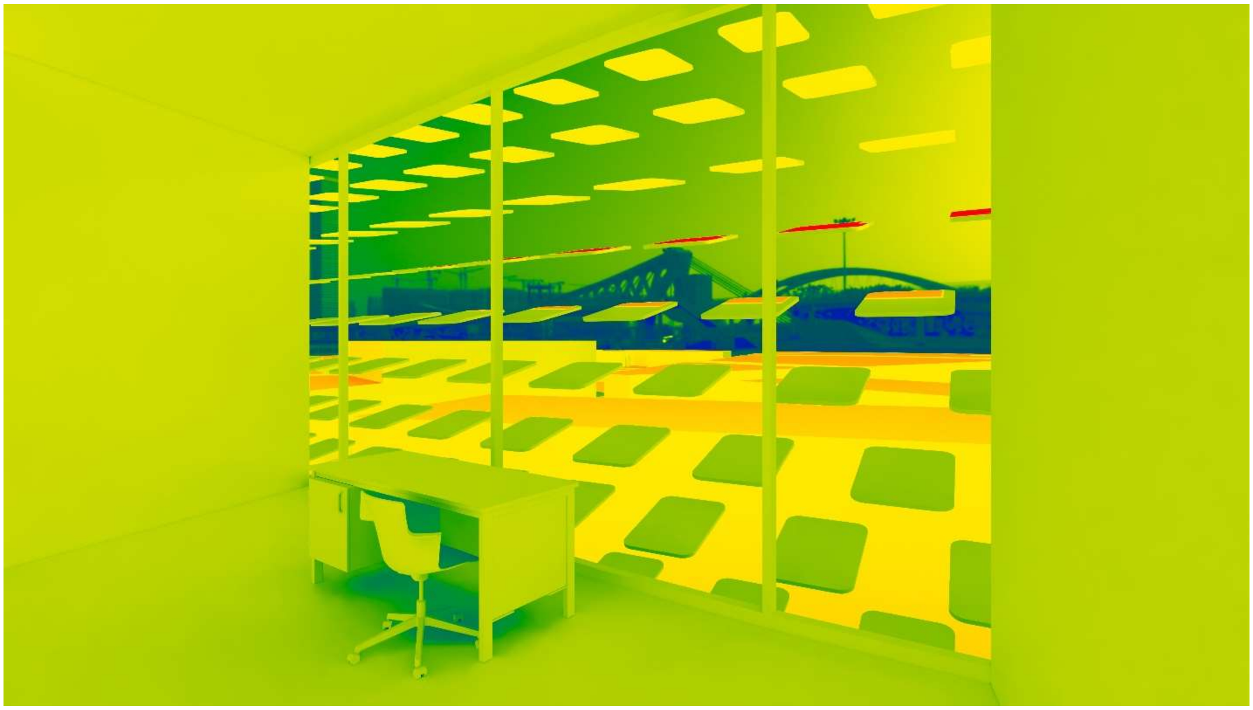


Figure 72: east 3pm light view


Figure 73: east 3pm shade

As the sun rises in the east and sets in the west, the eastern façade has more penetrating lights as the shadows are longer, but the façade does a good job of not letting let flood the room thereby keeping it optimal. As can be seen in figure 68-73 above.

The lux scale across the eastern façade average around 2000 lux which falls in the range of 250 to 2000 lux as stated by LEED v4 EQc7 to be the acceptable threshold for office buildings.

Winter Solstice South Facade

The winter solstice is a time when people yearn for the sun and warmth. The sun has better access to fill the entire space and reach further to the center of the structure because the peak altitudes of the sun are no more than 23 degrees. (Figure 74-79) will illustrate the lighting in the spaces and show the façade compensating for the condition.

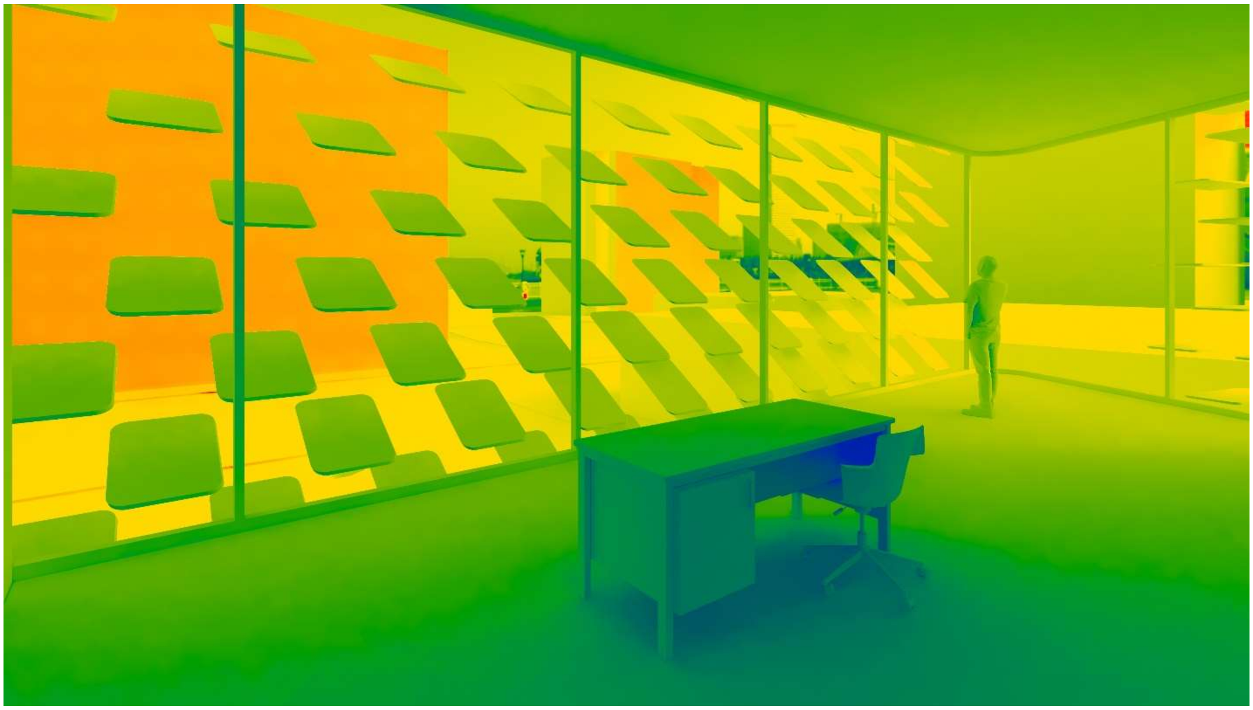


Figure 74: South at 7am

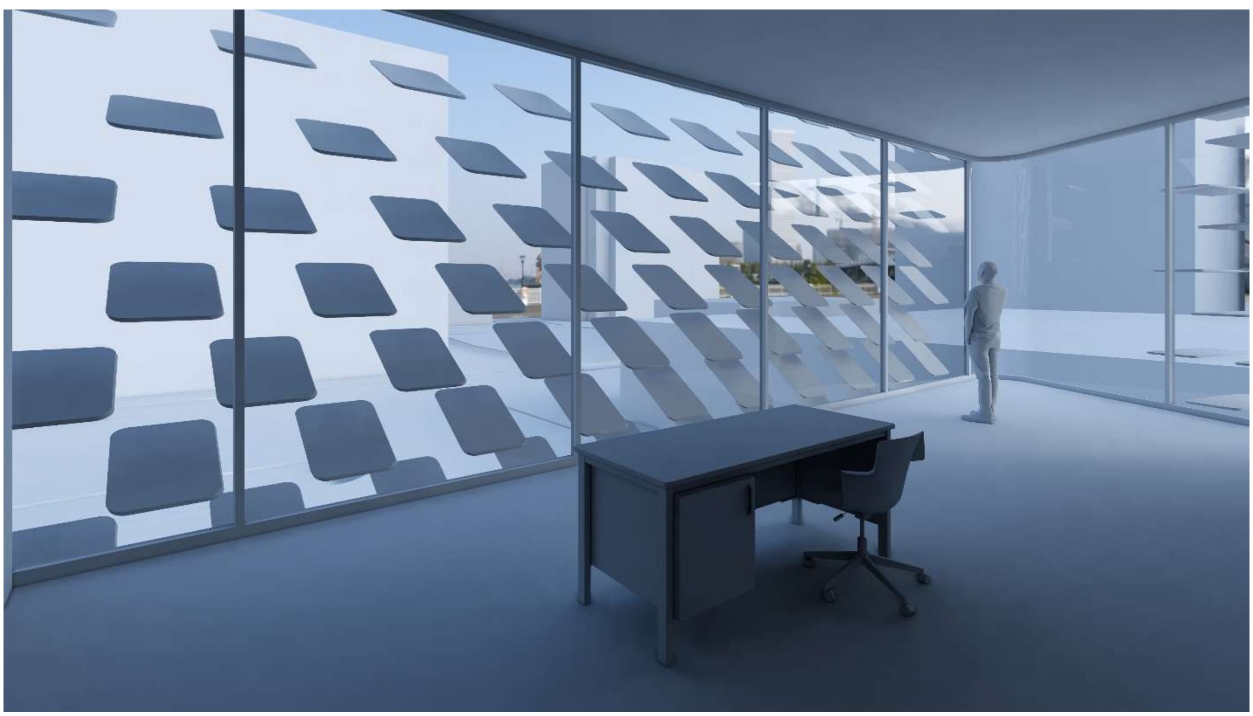


Figure 75: south at 7am shade

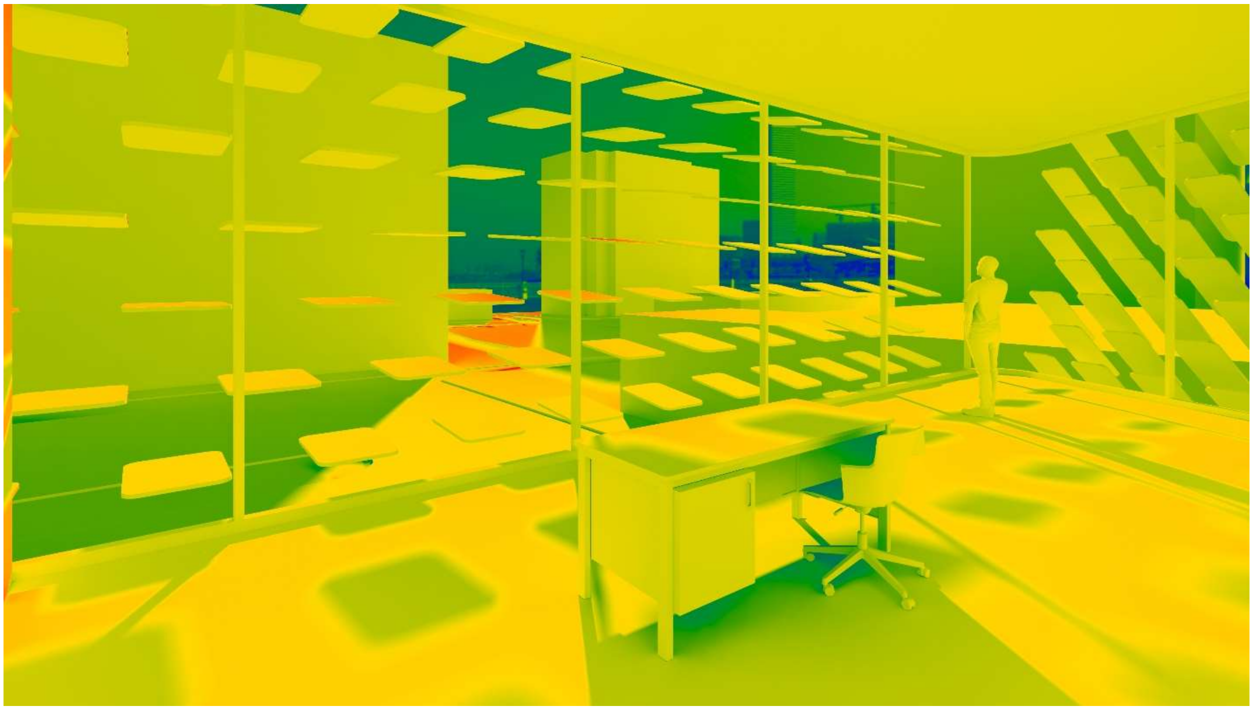


Figure 76: south 1pm light view

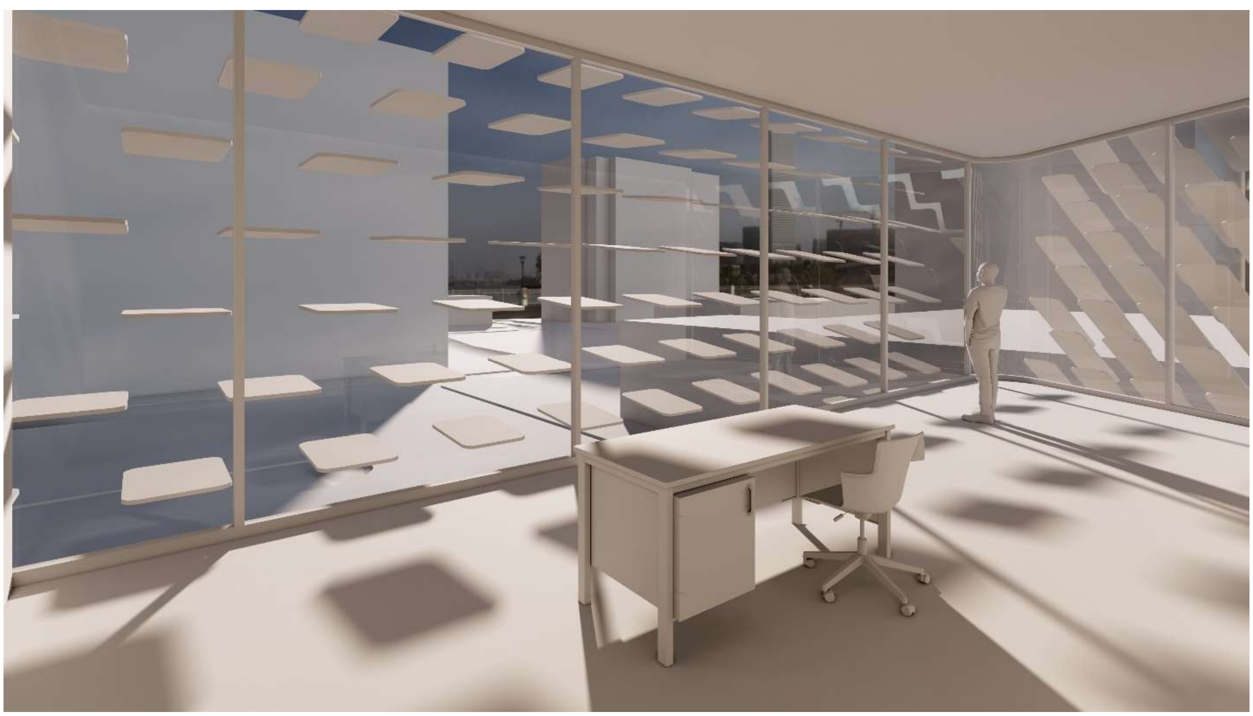


Figure 77: south 1pm shade

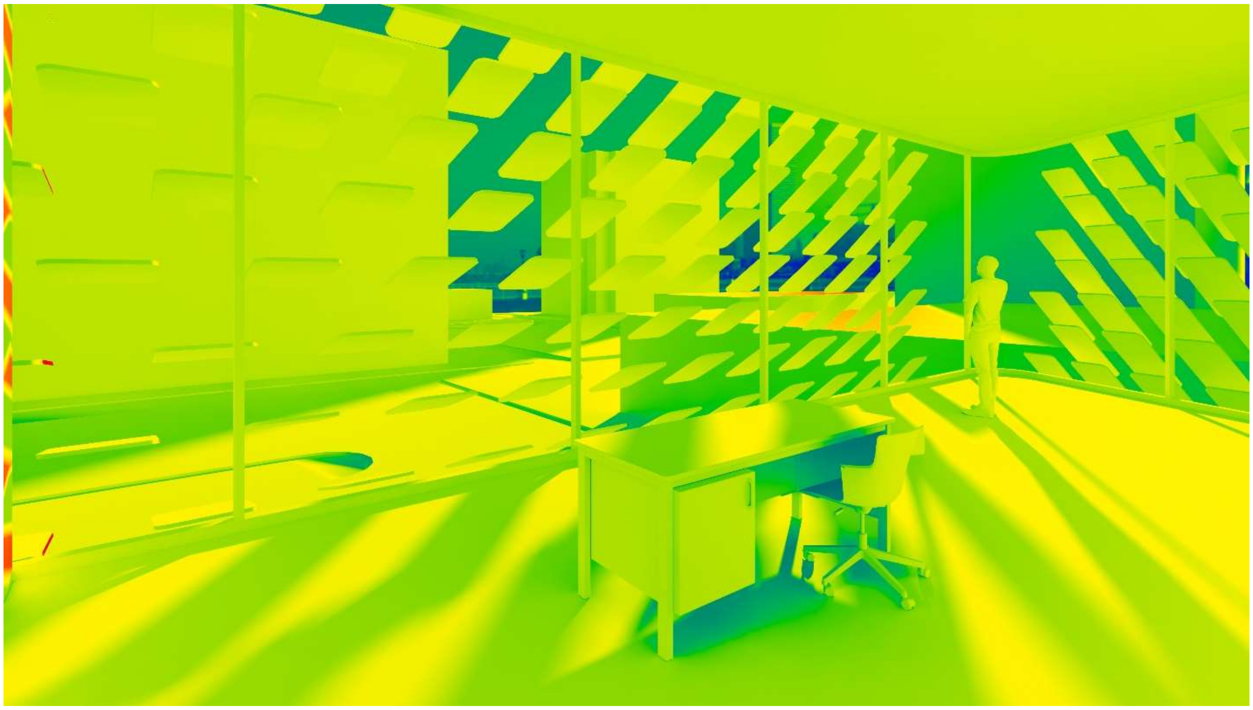


Figure 78: south 3pm light view

Figure 79: south 3pm shade

As the sun rise in the east and sets in the west the rooms along the east façade usually get sun as early as 7 AM to 3PM the sun starts to shift westward. the kinetic facade shades are designed to adjust and block some of that direct sunlight while also flooding the space with optimal amount of daylight.

Winter Solstice East Facade

There is a more diffused light across the spaces in this time as indirect sunlight bounces of the different surfaces before getting the occupants eyes.

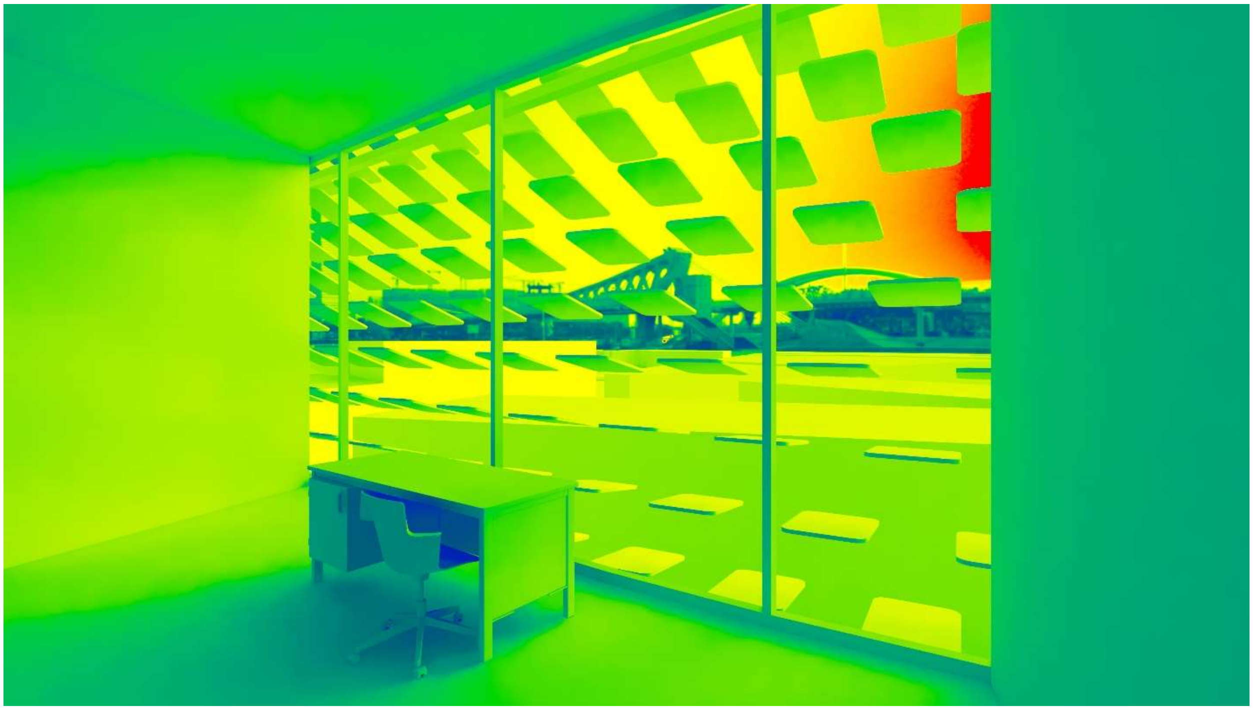


Figure 80: east 7am light view

Figure 81: east 7am shade

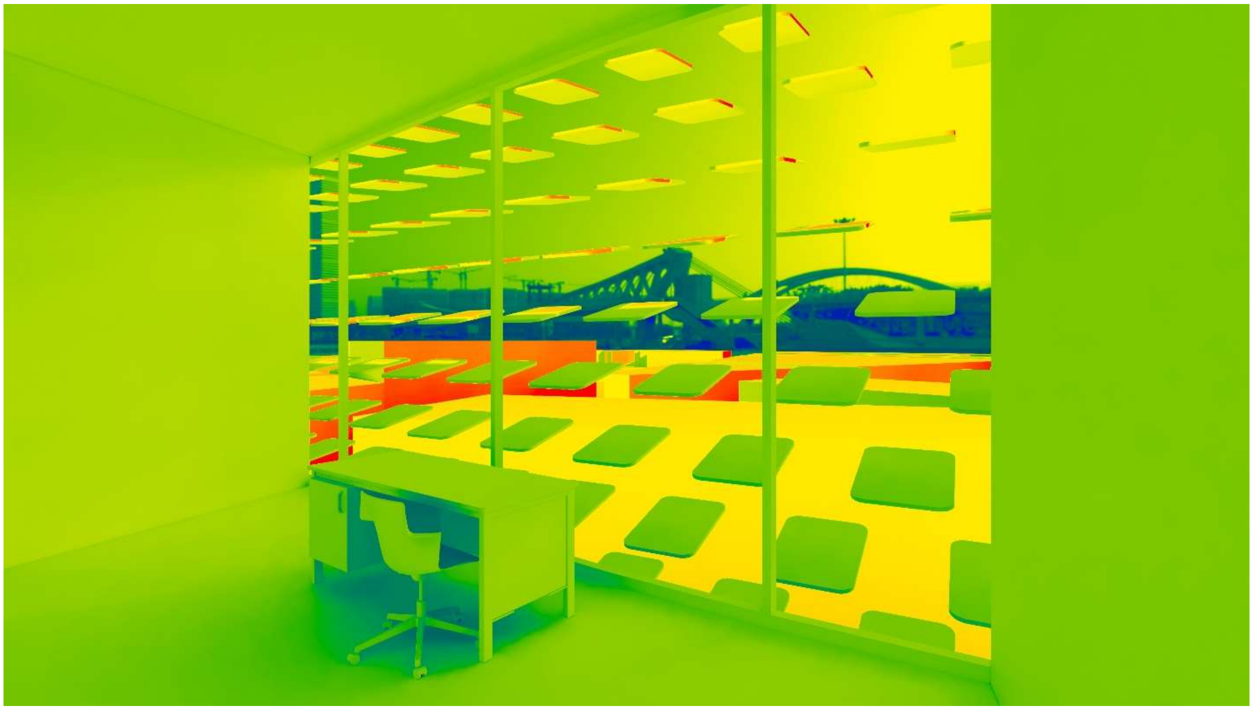


Figure 82: east 1pm light view

Figure 83: east 1pm shade

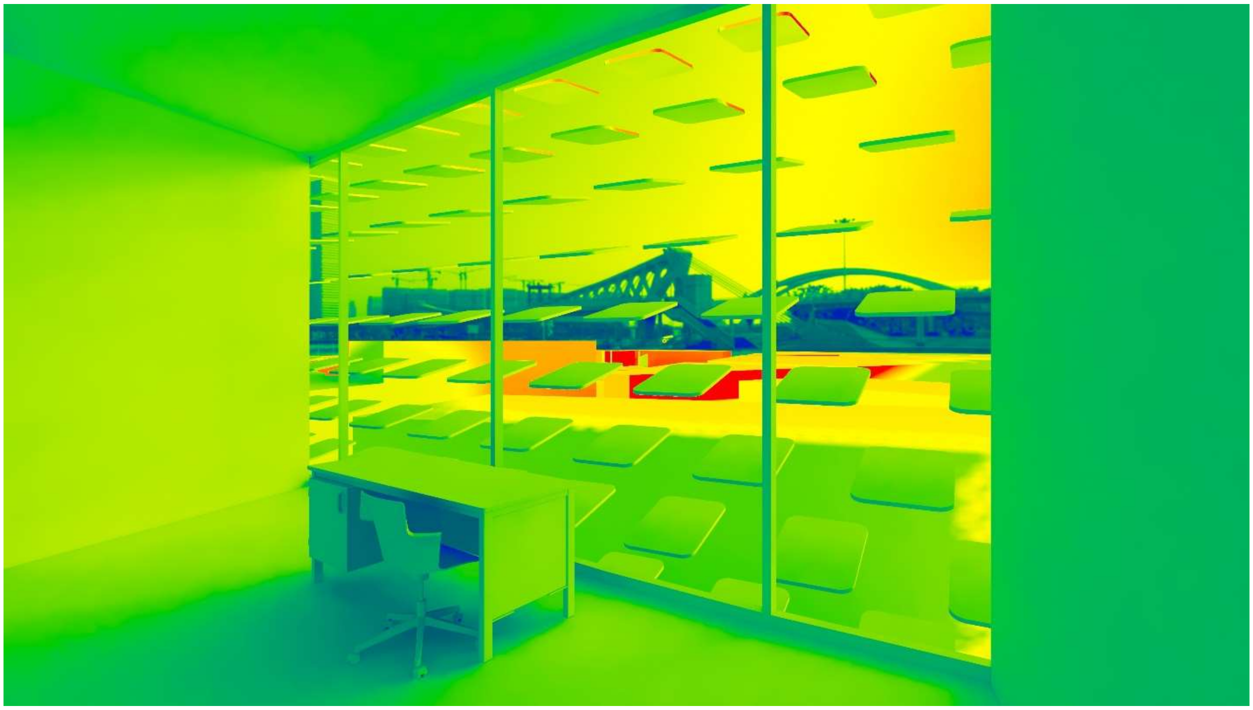


Figure 84: east 3pm light view

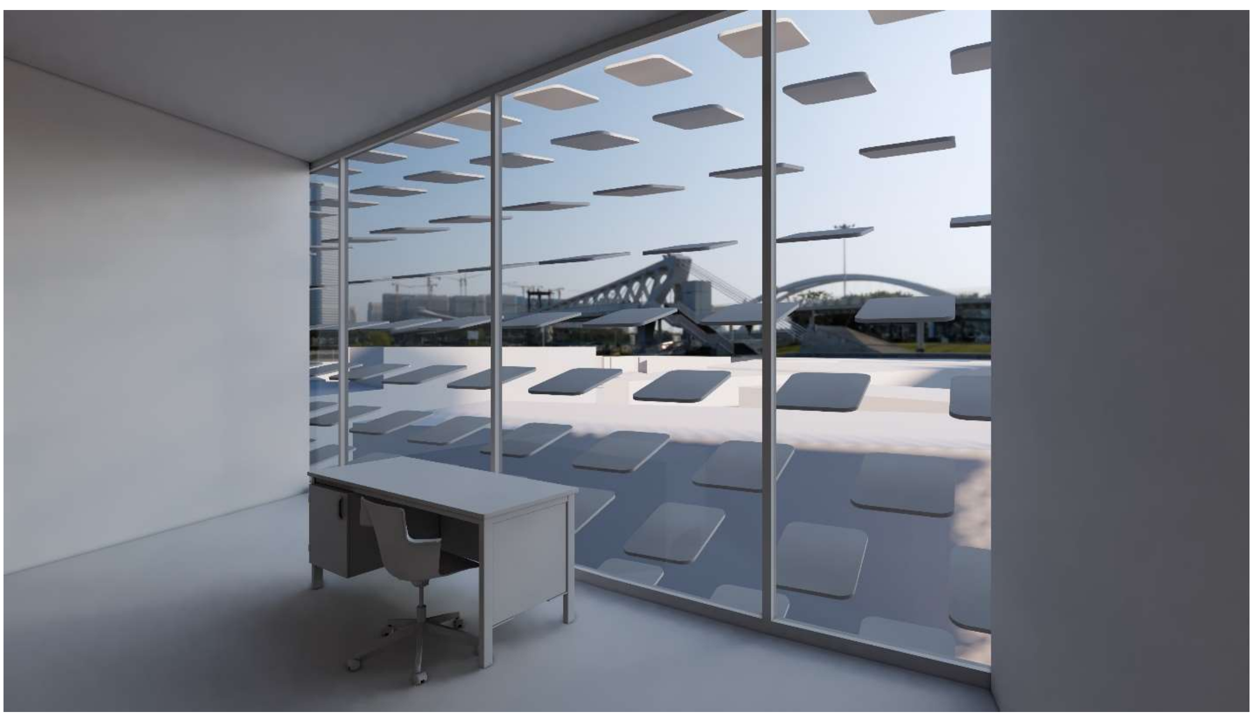


Figure 85: east 1pm shade

As seen in (figures 80-85) the eastern facades get more diffused indirect light through the study period of 7AM to 3PM and because of that the façade remains open to let as much daylight in as possible as there is no direct sunlight solar gain is not an issue during the study period.

The purpose of the interior studies was to give a more graphical view of the data represented in the beginning of the daylight simulation chapter. Given that LEED v4 states that “no more than 10% of a space should have direct sunlight more than 1000 lux for a maximum period of 250 hours per year (ASE1000/250)”, hence the metric for calculation in this case would be the SDA (spatial daylight autonomy) which indicates that a certain percent of area must meet or exceed 300 lux for at least 50% of the working hours per year.

The data in this section shows that at 7AM the luminance factor falls at 1000 LUX, 1PM at 2000 LUX and 3PM at 1000 LUX, these number all fall under the range of 250 to 2000 LUX as we stated earlier on in the thesis as the desired range for the building to attain.

9.1.4. Solar Gain simulation

This section of the thesis will be analyzing solar gain in the building and optimizing the radiation on the interior spaces by way of the kinetic façade. The analysis will be carried out using Ladybug in conjunction with EnergyPlus to determine and mediate solar again throughout the building. To improve energy efficiency as radiation from the sun can heat up spaces which increases cooling loads of building in the summer period and vice versa in the winter. The desired energy saving set for this building regarding office spaces will be at least 50% and 25% for the overall building. The simulation will primarily focus on the southeast façade as that is the orientation that receives the most amount of solar radiation. In response to this, a measure of how well the kinetic façade mitigates solar gain will determine the feasibility of such systems to combat high building loads. These results will be input into energy plus data base to generate the energy consumption the design building is using and then compare it to a non-kinetic façade office building.

The simulation was carried out in the summer solstice (June 21) and winter solstice (December 21). Over certain times of the day when the office building is being used to the maximum. The 7am analysis will represent the starting of the day as that is when most offices open for business and at this time the sun is low in the sky so the kinetic façade will determine what sections of the building will require solar gain and what sections of the building that would not require solar gain and adjust accordingly. A 1PM, the building will be back in full function as occupant would have returned from lunch and so the building operational needs would change such as HVAC needs and shading from the high intensity sun around this time. And lastly at 3PM, the building need will slowly start to decrease as occupant will be slowly leaving the building as the end of day approaches.

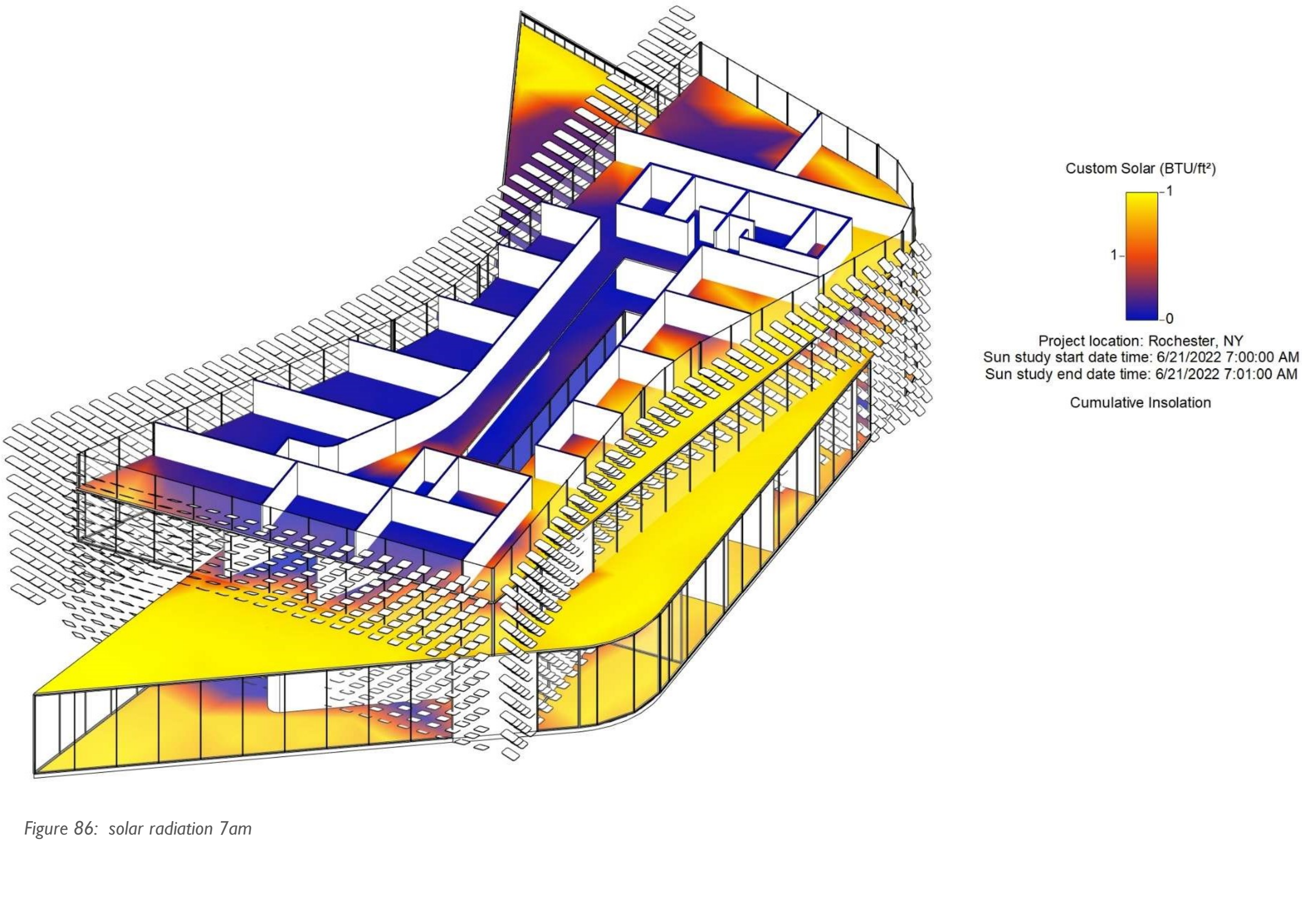


Figure 86: solar radiation 7am

The analysis in (table 10) shows the solar insolation per floor for the designed office building. The unit of measurement is set to BTU per square feet (BTU/sq.ft)

Source	Model	Type	Study Aver	Total surface	Insolation	Study Date	Study Time	Longitude	Latitude	Unit
Revit 2016	Office	Cumulative	**0.616475**	56691.9	34949.13	6/21/2022	7:00 AM	-77.6125	43.15571	BTU/ftÂ²
						6/21/2022	7:01 AM			
Analysis Surface	Parent Object	Category	Parent obj	Average Surf.	Surface Area	Total Surface Insolation Value				
271719095	Floor 1	Floors	375548	**0.356489**	1369.779	5256.1366				
271715063	Floor 2	Floors	375854	**0.62238**	1266.579	8485.1212				
-1810067081	Floor 3	Floors	385806	**0.467781**	924.4141	4654.5642				
567452055	Floor 4	Floors	401991	**0.488744**	847.4922	4458.4899				
-1924986569	Footprint	Roofs	404330	**1.287875**	858.5834	11902.176				

Table 10: Insolation output

The results of the analysis for the 7AM time frame with a total insolation of 34949.13 BTU/sq.ft with an average value of 0.616475 BTU/sq.ft as can be seen in table 10 and figure 86 above**.** The values are lower in this case the morning sun does not carry as much heat intensity as the afternoon hence the southern facade gets most of the direct light from the sun which is required for the building at said time. The façade is optimized to the in the fully open position to let as much sunlight in while also acting as a shade barrier to optimize solar gain and maximize daylighting.

Analysis point insolation	Insolation value	Parent surface	point x	point y	point z	normal x	normal y	normal z
1	1.1776791	271719095	11418.72	-698.201	-3.43E-11	0	0	1
2	1.1741167	271719095	11418.72	-708.178	-3.43E-11	0	0	1
3	1.1851506	271719095	11418.72	-718.155	-3.43E-11	0	0	1
4	1.1491173	271719095	11408.32	-668.269	-3.43E-11	0	0	1
5	1.1194393	271719095	11408.32	-678.246	-3.43E-11	0	0	1
6	1.1219389	271719095	11408.32	-688.223	-3.43E-11	0	0	1
7	1.111578	271719095	11408.32	-698.201	-3.43E-11	0	0	1
8	1.1057062	271719095	11408.32	-708.178	-3.43E-11	0	0	1
9	1.0974045	271719095	11408.32	-718.155	-3.43E-11	0	0	1
10	0.0729982	271719095	11408.32	-728.132	-3.43E-11	0	0	1
11	1.1428226	271719095	11397.92	-638.337	-3.43E-11	0	0	1
12	1.122392	271719095	11397.92	-648.314	-3.43E-11	0	0	1
13	1.0602083	271719095	11397.92	-658.292	-3.43E-11	0	0	1
14	1.0594386	271719095	11397.92	-668.269	-3.43E-11	0	0	1
15	1.0183752	271719095	11397.92	-678.246	-3.43E-11	0	0	1
16	0.007416	271719095	11397.92	-688.223	-3.43E-11	0	0	1
17	0.0069629	271719095	11397.92	-698.201	-3.43E-11	0	0	1
18	-5.66E-09	271719095	11397.92	-708.178	-3.43E-11	0	0	1
19	-5.66E-09	271719095	11397.92	-718.155	-3.43E-11	0	0	1
20	0.9952029	271719095	11397.92	-728.132	-3.43E-11	0	0	1
21	0.119211	271719095	11397.92	-738.109	-3.43E-11	0	0	1
22	1.1691784	271719095	11397.92	-748.087	-3.43E-11	0	0	1
23	0.0084306	271719095	11387.52	-608.405	-3.43E-11	0	0	1
24	1.0431113	271719095	11387.52	-618.383	-3.43E-11	0	0	1
25	1.0859244	271719095	11387.52	-628.36	-3.43E-11	0	0	1
26	0.0698012	271719095	11387.52	-638.337	-3.43E-11	0	0	1
27	1.0413903	271719095	11387.52	-648.314	-3.43E-11	0	0	1
28	0.0087211	271719095	11387.52	-658.292	-3.43E-11	0	0	1
29	0.0108651	271719095	11387.52	-668.269	-3.43E-11	0	0	1
30	0.0141901	271719095	11387.52	-678.246	-3.43E-11	0	0	1
31	0.0176074	271719095	11387.52	-688.223	-3.43E-11	0	0	1
32	0.0174381	271719095	11387.52	-698.201	-3.43E-11	0	0	1
33	0.0134967	271719095	11387.52	-708.178	-3.43E-11	0	0	1
34	-5.66E-09	271719095	11387.52	-718.155	-3.43E-11	0	0	1
35	-5.66E-09	271719095	11387.52	-728.132	-3.43E-11	0	0	1
36	0.0011523	271719095	11387.52	-738.109	-3.43E-11	0	0	1
37	1.0905534	271719095	11387.52	-748.087	-3.43E-11	0	0	1
38	1.1596821	271719095	11387.52	-758.064	-3.43E-11	0	0	1
39	1.1874543	271719095	11377.11	-588.451	-3.43E-11	0	0	1
40	1.0283348	271719095	11377.11	-598.428	-3.43E-11	0	0	1
41	-5.66E-09	271719095	11377.11	-608.405	-3.43E-11	0	0	1
42	-5.66E-09	271719095	11377.11	-618.383	-3.43E-11	0	0	1
43	0.0059406	271719095	11377.11	-628.36	-3.43E-11	0	0	1

44	0.0102554	271719095	11377.11	-638.337	-3.43E-11	0	0	1
45	0.0145791	271719095	11377.11	-648.314	-3.43E-11	0	0	1

Table 11: Analysis of insolation output

In order for the analysis to be accurate the energy plus program creates a number of points throughout the entire building as can be seen in table 11, these points serve to collect the data in terms of thermal gain and compile them to give an accurate summary output of the values that are required to determine the efficacy of the façade and in this case the building is on par with the median energy use intensity standards(EUI) research and data carried out by EnergyStar to which they state their calculated median at 116.6 kBTU/sq.ft.

The 1PM study carried out when the building is predicted to be fully occupied showed higher values which is to be expected as the heat intensity from the sun is high at this time. Figure 87 shows the graphic representation of thermal insolation and at this time it can be seen that the south west façade the most amount of sunlight with an average cumulative insolation of 2.18 BTU/sq.ft which given the fact that it a full curtail wall glass façade, the kinetic system is actively working to mediate solar gain.

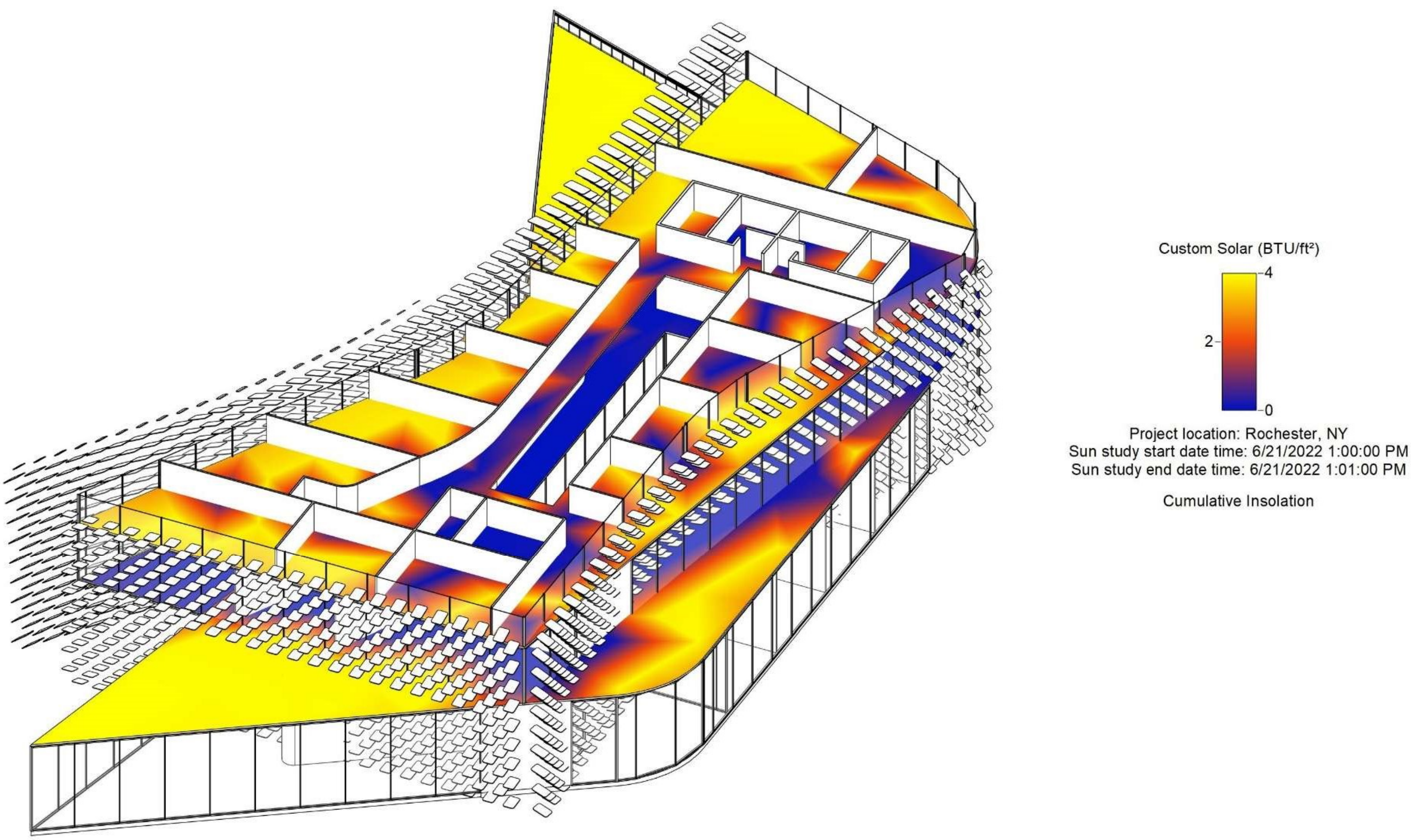


Figure 87: solar radiation 1pm

Source	Date	Model	Type	Study Average	Total Study	Total Study Insolation	Study Date	Study Time	Unit
Revit 2016	4/13/2022	Office	Cumulative	**2.184258808**	52248.831	**114124.9693**	6/21/2022	**1:00 PM**	BTU/ftÂ²

Analysis Surface	Parent object	Category	Parent object	Average Surface	Surface Area	Total Surface Insolation Value
-1234481195	Floor	Floors	375854	1.570892562	1266.57886	21416.5238
-1186784395	Floor	Floors	385806	-1.91E-08	924.4141155	-0.00018969
-1186784299	Floor	Floors	385806	2.441009706	924.4141155	24288.81552
480301174	Floor	Floors	401991	3.060262716	847.4921678	27916.73771
-1110881483	Footprint Roof	Roofs	404330	4.350375881	858.5834352	40204.95214
-1259404267	Floor	Floors	420878	0.188828168	32.5904522	66.24108366

Table 12: Insolation output

Energy plus program creates several points throughout the entire building as can be seen in table 12, these points serve to collect the data in terms of thermal gain and compile them to give an accurate summary output of the values. As stated above the total insolation is 114124.96 BTU/sqft which when converted to kBTU equals around 114.12 kBTU/sqft and in this case is below the set median of 116.16 kBTU/sq.ft as research by EnergyStar.

The 3PM study carried out when the building needs will slowly start to decrease as occupant will be slowly leaving the building as the end of day approaches. Figure 88 shows the graphic representation of thermal insolation and at this time it can be seen that the south west façade the most amount of sunlight with an average cumulative insolation of 1.67 BTU/sq.ft which given the fact that it a full curtail wall glass façade, the kinetic system is actively working to mediate solar gain.

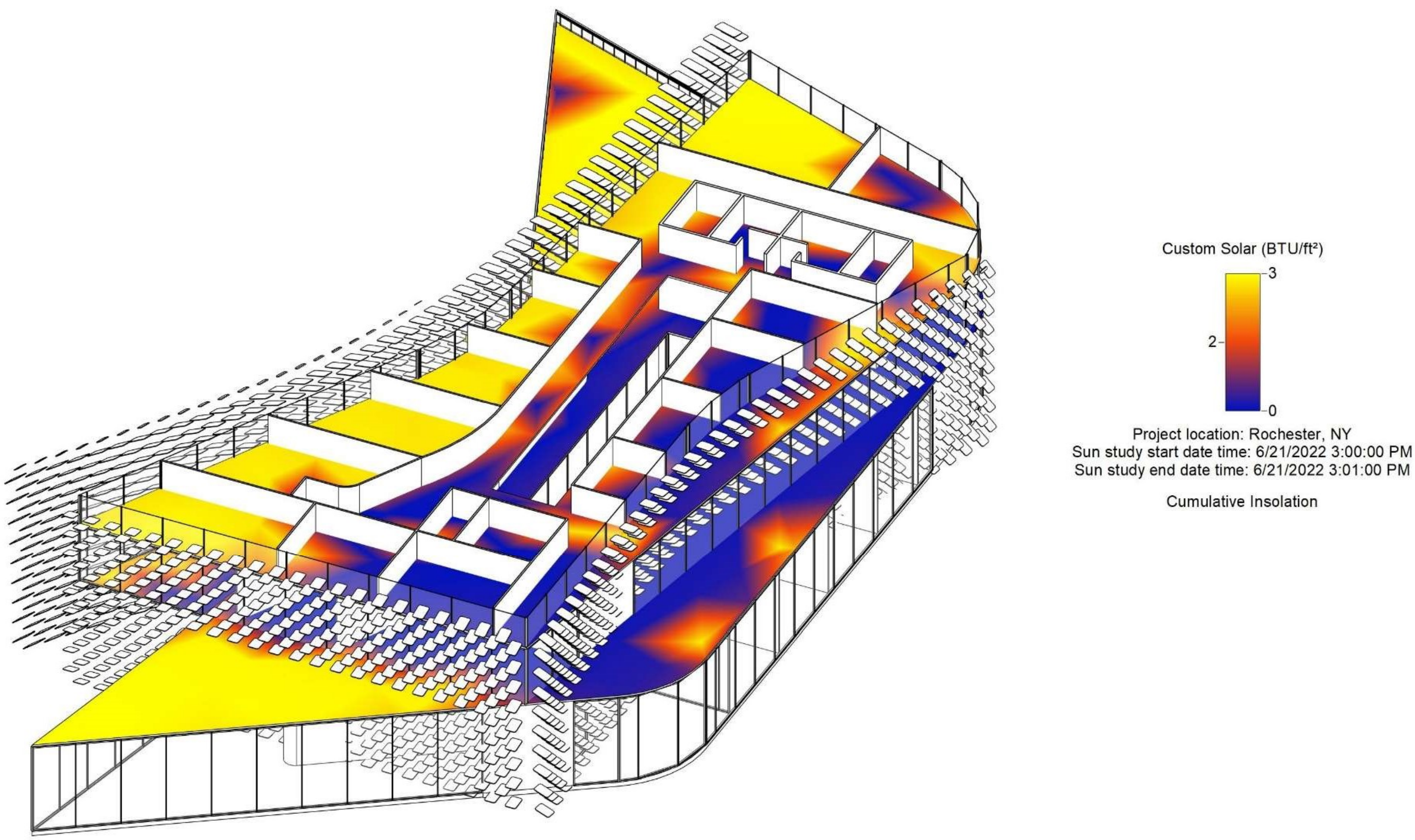


Figure 88: solar radiation 3pm

The Energy plus program creates several points throughout the entire building as can be seen in table 13, these points serve to collect the data in terms of thermal gain and compile them to give an accurate summary output of the values. As stated above the total insolation is 87389.07 BTU/sqft which when converted to kBTU equals around 87.38 kBTU/sq.ft. and in this case is below the set median of 116.16 kBTU/sq.ft as research by EnergyStar.

Source	Date		Model	Type	Study Average	Total Study Surface Area	Total Insolation	Study Date	Study Time
Revit 2016	4/13/2022		Office	Cumulative	1.672555647	52248.83	87389.07734	6/21/2022	3:00 PM
Analysis Surface	Parent object type	Category	Parent object ID	Average Surface Insolation Value	Surface Area	Total Surface Insolation Value			
- 1.2E+09	Floor	Floors	375854	1.214491	1266.57886	16557.58			
- 1.2E+09	Floor	Floors	385806	-1.53E-08	924.4141155	- 0.000152			
- 1.2E+09	Floor	Floors	385806	1.794737	924.4141155	17858.2			
4.8E+08	Floor	Floors	401991	2.162596	847.4921678	19727.92			
- 1.1E+09	Footprint Roof	Roofs	404330	3.486501	858.5834352	32221.26			

Table 13: Insolation output

The winter studies were also carried out under the same parameters keeping in mind that at 7am analysis will represent the starting of the day as that is when most offices open for business and at this time the sun is low in the sky so the kinetic façade will determine what sections of the building will require solar gain and what sections of the building that would not require solar gain and adjust accordingly. A 1PM, the building will be back in full function as occupant would have returned from lunch and so the building operational needs would change such as HVAC needs and shading from the high intensity sun around this time. And lastly at 3PM, the building need will slowly start to decrease as occupant will be slowly leaving the building as the end of day approaches. The big difference in this case is that solar gain is needed in the winter so the kinetic façade will work to keep the balance and not overheat the building.

The results of the analysis for the 7AM time frame with a total insolation of 28473.53 BTU/sq.ft with an average value of 0.50225 BTU/sq.ft as can be seen in table 13 above and figure 89 below**.** The values are lower in this case the morning sun does not carry as much heat intensity as the afternoon hence the southwest facade gets most of the direct light from the sun which is required for the building at said time. The façade is optimized to the in the fully open position to let as much sunlight in while also acting as a shade barrier to optimize solar gain and maximize daylighting.

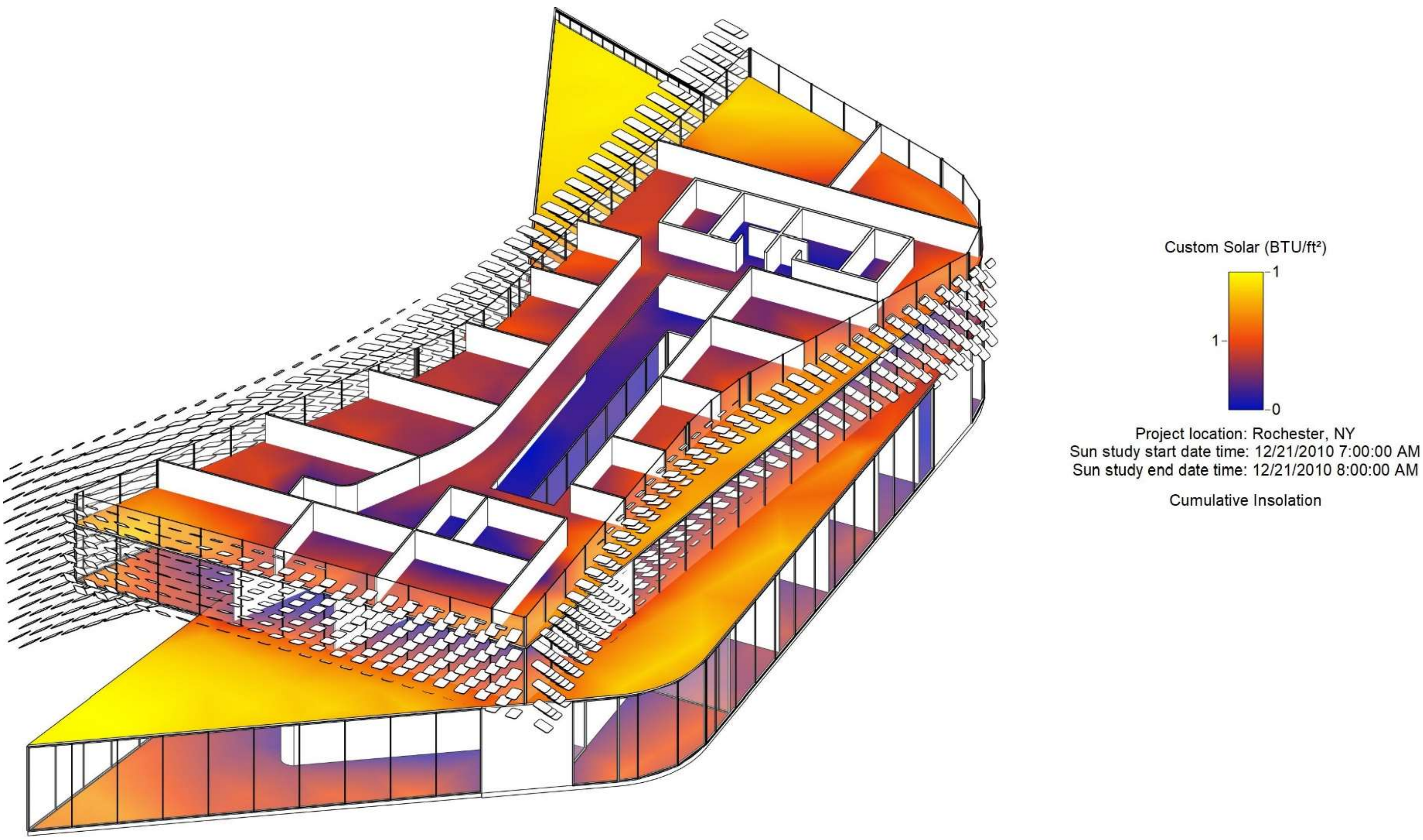


Figure 89: solar radiation 7AM winter

Source		Type	Study Average	Total Study Surface Area	Total Study	Study Date	Study Time	Unit	Unit
Revit 2016		Office	Cumulative	0.502250622	56691.9	28473.54	12/21/2010	7:00 AM	BTU/ftÂ²
Analysis Surface	Parent object type	Category	Parent object ID	Average Surface Insolation Value	Surface Area	Total Surface Insolation Value			
2.72E+08	Floor	Floors	375548	0.209368498	1369.77861	3086.967			
2.72E+08	Floor	Floors	375854	0.421766863	1266.57886	5750.094			
-1.8E+09	Floor	Floors	385806	0.447292558	924.4141155	4450.702			
5.67E+08	Floor	Floors	401991	0.546141326	847.4921678	4982.083			
-1.9E+09	Footprint Roof	Roofs	404330	1.097204481	858.5834352	10140.06			

Table 14: Insolation output

As stated above in table 14 the total insolation is 28473.53 BTU/sqft which when converted to kBTU equals around 28.47 kBTU/sq.ft. and in this case is below the set median of 116.16 kBTU/sq.ft as research by EnergyStar. In this case the heating system will only need to work at less than 50 percent capacity since the energy from the sun is already helping to slash needs of the building.

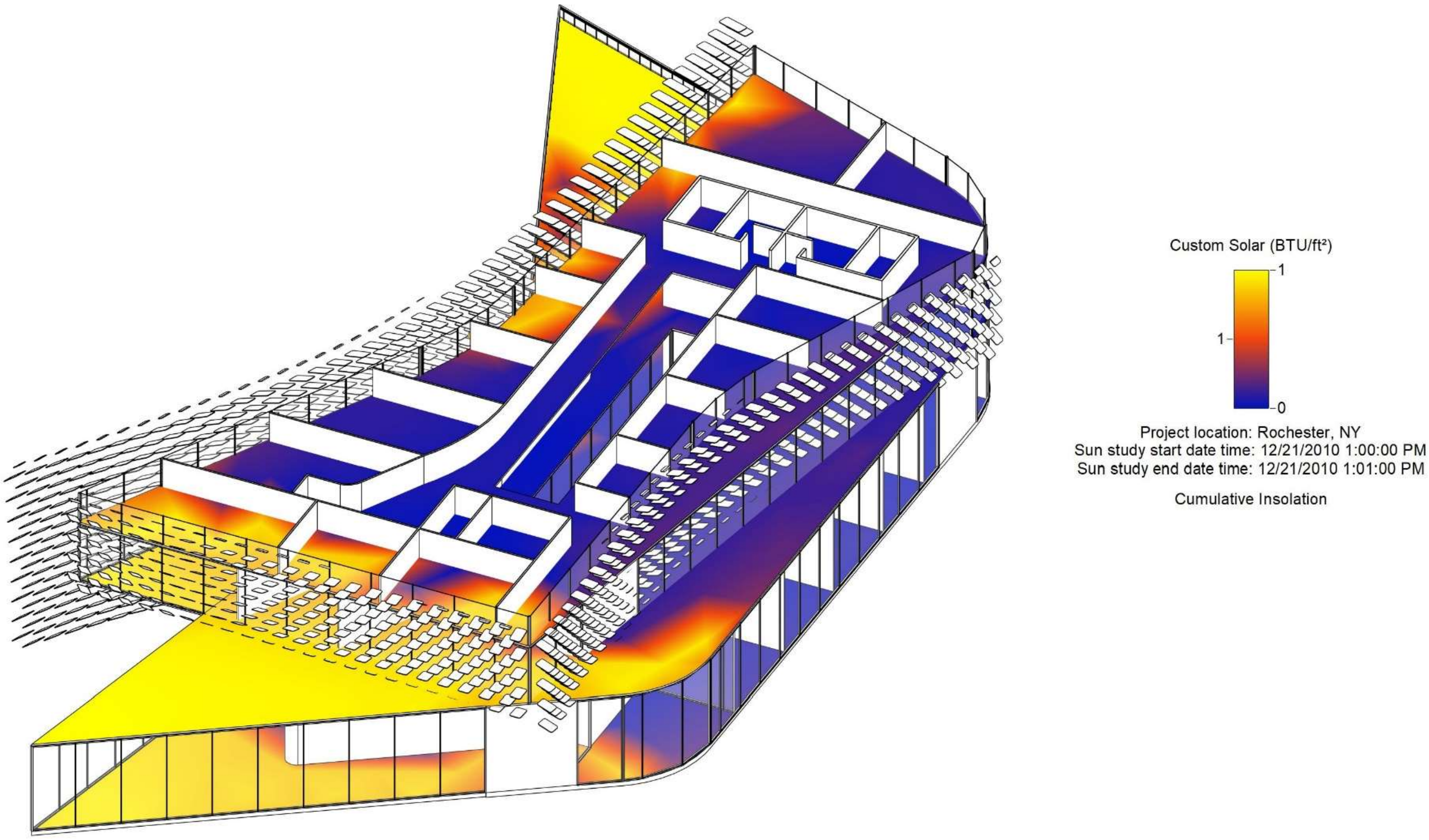


Figure 90: solar radiation 1pm winter

The 1PM study carried out when the building is predicted to be fully occupied showed higher values which is to be expected as the heat intensity from the sun is high at this time given that the sun is lower in the sky in the winter period. Figure 90 shows the graphic representation of thermal insolation and at this time it can be seen that the south west façade the most amount of sunlight with an average cumulative insolation of 0.46 BTU/sq.ft which given the fact that it a full curtail wall glass façade, the kinetic system is actively working to mediate solar gain.

Source	Model	Type	Study Average Insolation Value	Total Study Surface Area	Total Study Insolation Value	Study Date	Study Time	Unit
Revit 2016	Office	Cumulative	0.46667	66993.0116	31263.63678	12/12/2010	1:00 PM	BTU/ftÂ²
Analysis Surface	Parent object type	Category	Parent object ID	Average Surface Insolation Value	Surface Area	Total Surface Insolation Value		
- 1.2E+09	Floor	Floors	375548	0.32817275	1369.77861	4838.638		
- 1.2E+09	Floor	Floors	375854	0.53414436	1266.57886	7282.176		
- 1.2E+09	Floor	Floors	385806	-5.68E-09	924.4141155	-5.66E-05		
- 1.2E+09	Floor	Floors	385806	0.27749856	924.4141155	2761.198		
4.8E+08	Floor	Floors	401991	0.38692963	847.4921678	3529.701		
- 1.1E+09	FootPrintRoof	Roofs	404330	1.29360047	858.5834352	11955.09		

Table 15: Insolation output

Energy plus program creates several points throughout the entire building including all floors as can be seen in table 15, these points serve to collect the data in terms of thermal gain and compile them to give an accurate summary output of the values. As stated above the total insolation is 31263.63 BTU/sqft which when converted to kBTU equals around 31.26 kBTU/sqft and in this case is below the set median of 116.16 kBTU/sq.ft as research by EnergyStar.

The 3PM study carried out when the building needs will slowly start to decrease as occupant will be slowly leaving the building as the end of day approaches. Figure 91 shows the graphic representation of thermal insolation and at this time it can be seen that the south west façade the most amount of sunlight with an average cumulative insolation of 1.67 BTU/sq.ft which given the fact that it a full curtail wall glass façade, the kinetic system is actively working to mediate solar gain.

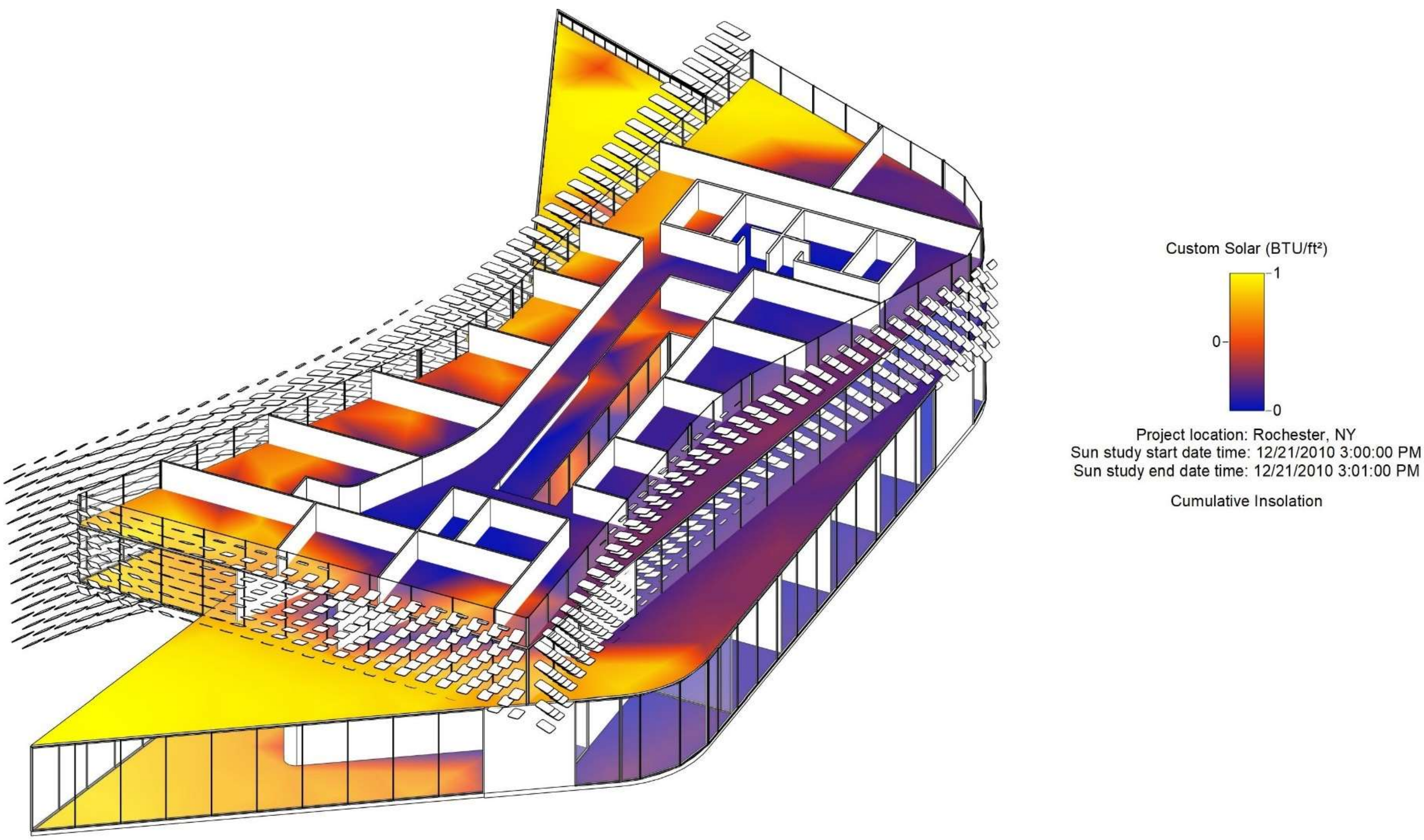


Figure 91: solar radiation 3pm winter

Source	Model	Type	Study Average Insolation Value	Total Study Surface Area	Total Study Insolation Value	Study Date	Study Time	Unit
Revit 2016	Office	Cumulative	0.22631742	66993.0116	15161.6856	12/21/2010	3:00 PM	BTU/ftÂ^2
Analysis Surface	Parent object type	Category	Parent object ID	Average Insolation	Surface Area	Total Surface Insolation Value		
-1.189E+09	Floor	Floors	375548	0.208406401	1369.77861	3072.78161		
-1.234E+09	Floor	Floors	375854	0.233467936	1266.57886	3182.94944		
-1.187E+09	Floor	Floors	385806	-2.41E-09	924.414116	-2.40E-05		
-1.187E+09	Floor	Floors	385806	0.169636706	924.414116	1687.93866		
480301174	Floor	Floors	401991	0.195798223	847.492168	1786.13673		
-1.111E+09	Footprint Roof	Roofs	404330	0.550447683	858.583435	5087.0829		

Table 16: Insolation output

The analysis of all the floor surfaces and several points throughout the entire building can be seen in table 16, these points serve to collect the data in terms of thermal gain and compile them to give an accurate summary output of the values. As stated above the total insolation is 15161.68 BTU/sqft which when converted to kBTU equals around 15.16 kBTU/sqft and in this case is below the set median of 116.16 kBTU/sq.ft as research by EnergyStar.

In summary all analysis prove that the kinetic system is actively optimizing solar gain throughout the building, in some instances energy use intensity is drastically cut down to less than 50 percent of the total median for office building in the United States.

10. Summary and Conclusion

With all the data analyzed and explained it is safe to say that the efficacy of kinetic facades in the northern region which the building is located is a plausible means to reducing energy use in an office building by means of technologically and systematically optimized daylighting and mitigating solar gain to when it is needed.

The building boasts of being below the ASHRAE standard 90.1 of max $5.22 per square feet per year and 41.2 kBTU/sq.ft. this benchmark was derived directly from the energy model calculator that puts the designed office building at $0.88 per square foot per year below the $1.17 benchmark average and 34.9 kBTU/sq.ft. (figure 92-93) at an operating schedule of 12 hours a day at 7 days in

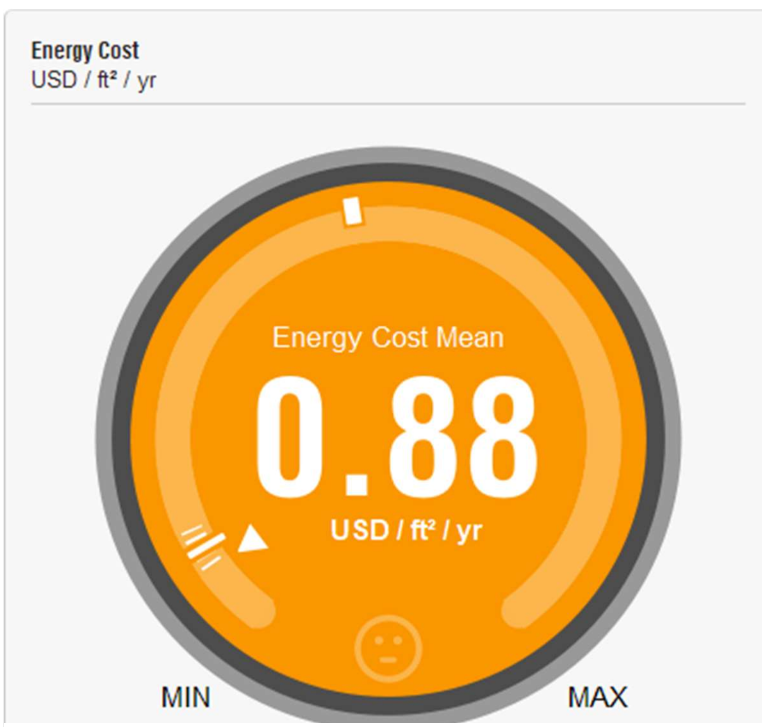


Figure 92: Energy cost

a week as indicated in figure 94 below. As the goal was to achieve at least 50% saving the use of kinetic façade has cut down energy use to more than half as indicated above and give that the cost save translates to more than 50 percent saving a simplified in this section.

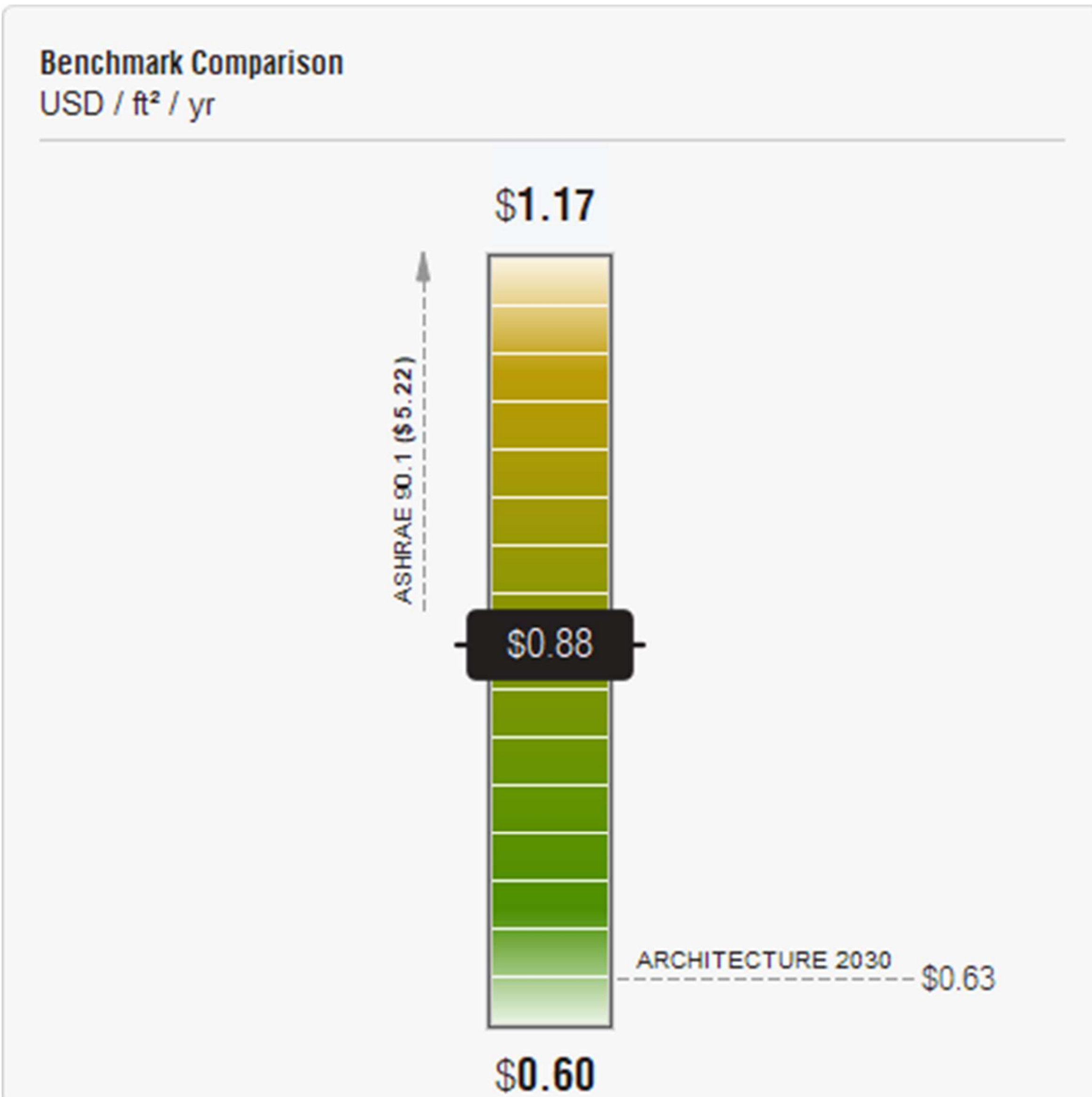


Figure 93: Benchmark Comparison

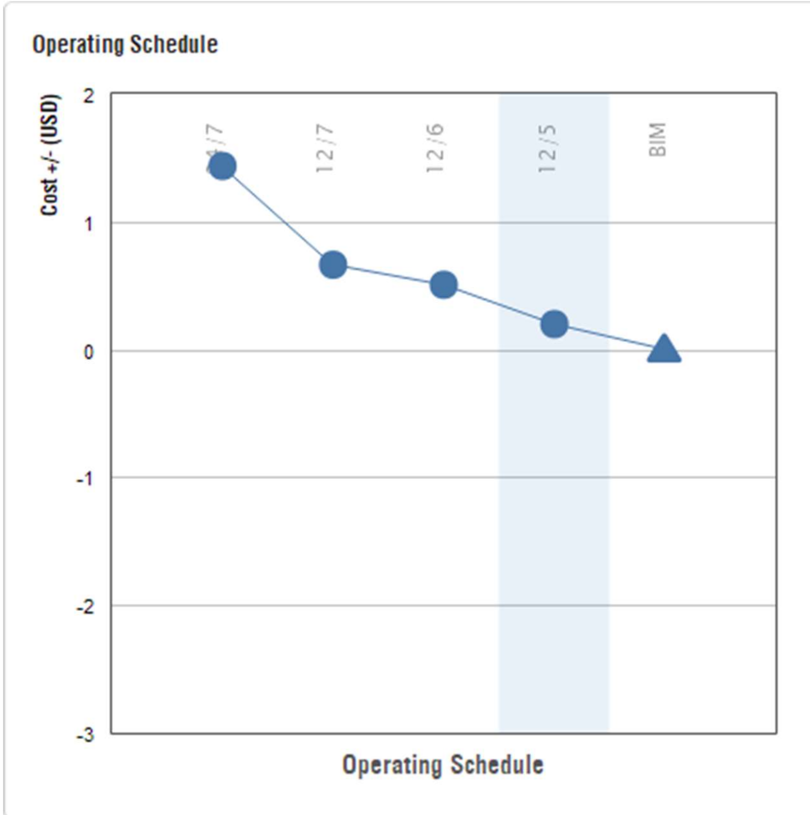


Figure 94: Operating Schedule

As stated in the objective section, the goal of this thesis was to design a building that incorporated a kinetic facade onto a new office building and positively impact building performance, regulate solar gain and optimize daylighting with the metric of success in terms of daylight factors to fall between the stated percentile (250-2000lux). From the several analyses the newly designed office building with a kinetic façade 1333 LUX given that at 7AM it equals 100lux, 1pm it equals 200lux and at 3pm it falls at 1000lux.

The desired energy saving was set for this building regarding office spaces was at least 50% and 25% for the overall building.

Given that both the energy use intensity and cost of running the building per year falls below the median set by ASHRAE 90.1, it would be safe to say the goal was achieved in every sense.

METRICS	GOAL	DESIGN ACHEIVMENT
Energy	50% (office spaces), 25% (overall building)	$0.88 per square foot per year (below the $1.17 average)
Daylighting	(250-2000 lux) percentile	1333 Lux
Solar gain	41.2kBTU/sqft	34.9 kBTU/sq.ft

Table 17: Metrics Summary

In Recognition

Okezie Ray-Offor

Chituru Ray-Offor

Reynold Ray-Offor

Stephanie Ray-Offor

Cidi Olujie

11. List Of Figures:

12. List Of Tables:

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