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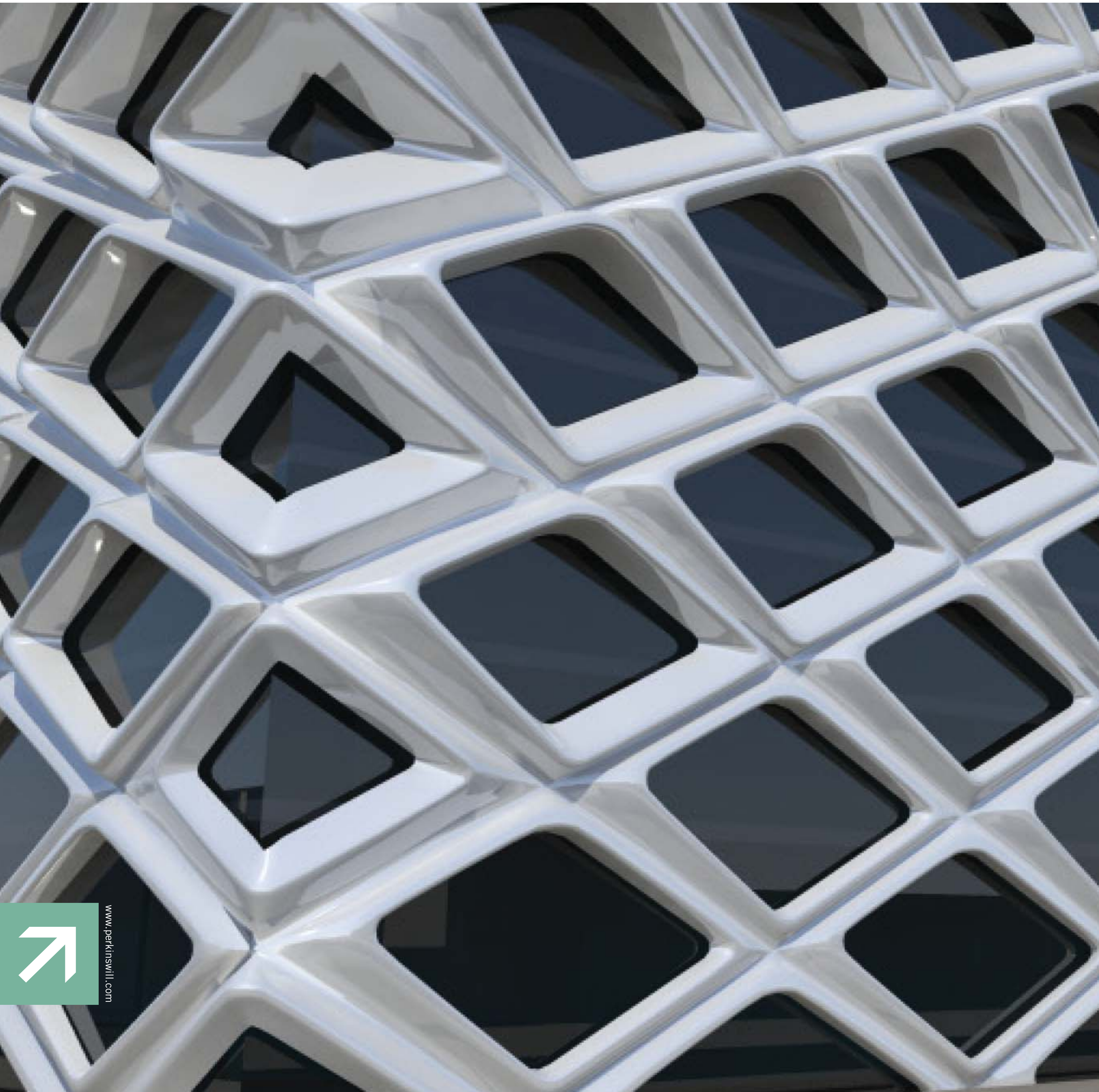

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05.
SUSTAINABLE DESIGN STRATEGIES AND TECHNICAL DESIGN DEVELOPMENT:
Rush University Medical Center Entry Pavilion

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ABSTRACT
This paper discusses unique design of the Rush University Medical Center Edward A. Brennan Entry Pavilion, specifically focusing on the sustainable strategies considered and investigated during the design as well as the technical aspects. The first part of the article reviews background information about the Rush University Medical Center and its Entry Pavilion, while the second part of the article reviews sustainable design strategies that were considered as an approach for meeting the Living Building Challenge. Building performance analyses that were performed during the different stages of the design process are discussed in detail. The article also reviews obstacles that were encountered with the Living Building Challenge requirements and lessons learned from this process. The last part of the article discusses the design development, technical solutions and construction of a glass terrarium as one of the distinctive aspects of the Edward A. Brennan Entry Pavilion.

KEYWORDS: building performance, sustainability, simulations, building technology

1.0 INTRODUCTION

1.1 Project Description
Rush University Medical Center (RUMC) is located in Chicago, Illinois. In 2004, RUMC revealed plans to initiate the most comprehensive construction and facilities improvement project in its history, known as the Campus Transformation Project. This plan called for investments in new technologies and facility design that would modernize operations for the 21st century and reorient the campus around the comfort of patients and their families. The guiding principles of the transformation plan were:

- Optimize the patient and family experience
- Conscientiously consider safety of patients and staff
- Organize services around delivery of care
- Use technology on behalf of patients and staff
- Ensure integration of research and education
- Design a comfortable environment to support Rush core values
- Anticipate change through adaptable/flexible best practices
- Embrace the community through design
- Incorporate sustainable design where applicable
- Standardize when possible.

RUMC enlisted Perkins+Will to plan and design parts of the medical campus, which included a new 840,000 square foot state-of-the-art hospital building (Tower), a new medical office building and orthopedics care facility and a centralized power plant/parking garage (Figure 1). The design of this major healthcare facility started in 2006 and the building was completed in early 2012. The existing hospital building is connected to the new Tower with the 10,000 square foot Edward A. Brennan Entry Pavilion.

Figure 1: Rush University Medical Center Transformation Plan and its components (Tower, Entry Pavilion, Orthopedics Ambulatory Care Building, Garage and Centralized Energy Plant).

1.2 RUMC Tower

The program for the RUMC Tower included an emergency department, a center for advanced emergency response, non-invasive diagnostics department, interventional platform, women's services and neo-natal critical care units, critical care unit and patient rooms. Figure 2 shows the Tower, Entry Pavilion and the existing Atrium Building on the west side. The Entry Pavilion connects the existing Atrium Building and the Tower and provides an inviting lobby and entry space for the patients, families and the medical staff. A series of bridge connections were also designed and constructed that link the existing Atrium Building to the Tower.

Figure 2: The Tower, view from Harrison Street. Photo credit James Steinkamp © Steinkamp Photography.

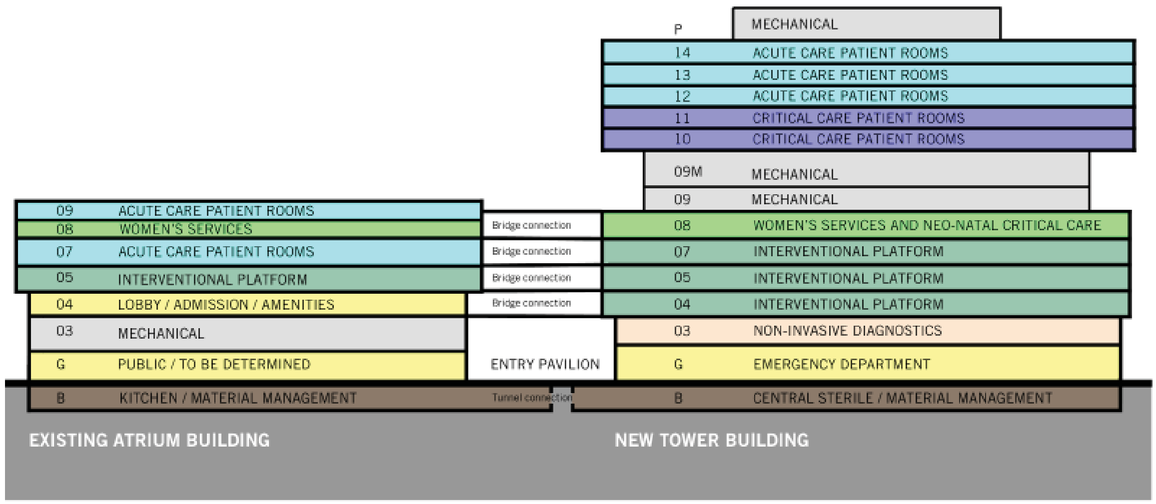

Figure 3: Stacking diagram.

The major formal components of the Tower include the rectilinear base (Levels 1 to 8), mechanical floor (Level 9) and bed tower (Levels 10 to 15), as seen in Figures 3 and 4. The distinctive butterfly shape of the bed tower was directed by the operational and pragmatic requirements with the intention to minimize travel distances between medical staff and patients. The findings of recent research indicates that design layouts and locations of nurses' stations that minimize staff walking increase patient care time and support staff activities, such as communication and collaboration among medical staff[1]. This concept directly correlates to the guiding principles of the project and was a driving factor for the design and layout of the Tower.

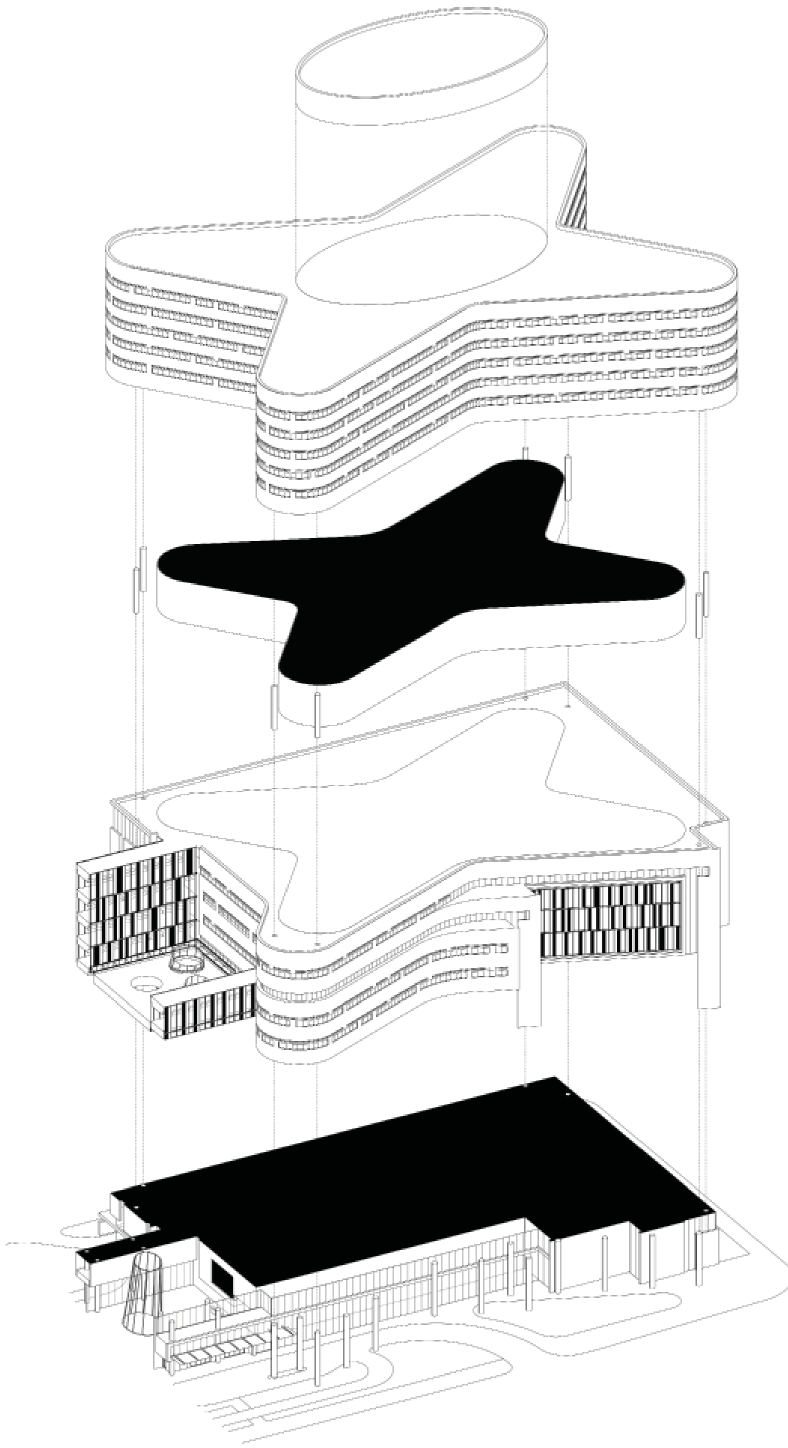

Figure 4: Exploded axonometric view of the Tower.

1.3 Entry Pavilion Design

The Entry Pavilion is a grand public entry space connecting the Tower with the Atrium Building. It was designed to address the arrival experience for those coming to the Rush's large, urban campus.

On Level 1, an open-to-above "terrarium" greets incoming guests with trees and a forest floor garden, as seen in Figure 5. A publicly accessible roof garden on Level 4 provides an outdoor space, specifically designed to allow building occupants access to nature, as seen in Figure 6. Also, two large circular skylights provide daylight to the interior space.

Previous research studies have produced strong evidence that hospital gardens can lower stress levels for medical staff and improve their productivity, improve patients' outcomes and can also improve patient and family satisfaction with the overall quality of care[1]. For example, based on post-occupancy evaluations of four hospital gardens, it was concluded that many nurses and other healthcare workers used the gardens for achieving escape and recuperation from stress[2]. Other post-occupancy studies indicated that patients and family members who use hospital gardens report positive mood changes and reduced stress[3]. Therefore, access to nature, roof gardens and terrarium were important design elements. A "staff only" roof garden was specifically designed at Level 9 as respite area for caregivers. Figure 7 shows these major programmatic components in an exploded axonometric view.

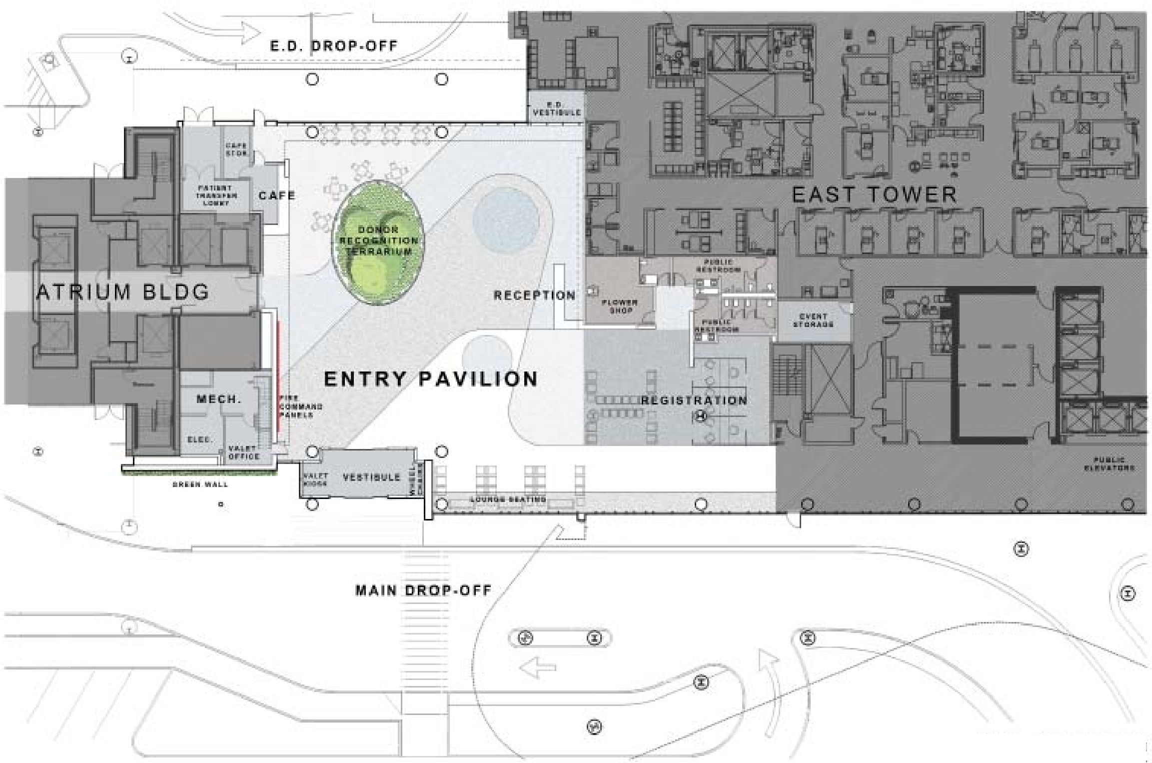

Figure 5: First floor plan of Entry Pavilion.

In the early design stages, the Atrium Building and the Tower were completely connected and aligned since a continuous large floor plate was preferred. The main challenge with this design concept was the existing kitchen, which is located in in the basement directly below the space between the Atrium Building and Tower. This would require that the structural columns would have to be constructed amongst an operational kitchen, which would shut down the hospital. For this reason, the idea of doing the two buildings was too intrusive and costly. The idea of separating the two buildings was then explored and the connections were maintained via bridges. This separation allowed room for an entry pavilion. Therefore, unlike standard design process where an entry is designed at the beginning, the RUMC Entry Pavilion was designed towards the end.

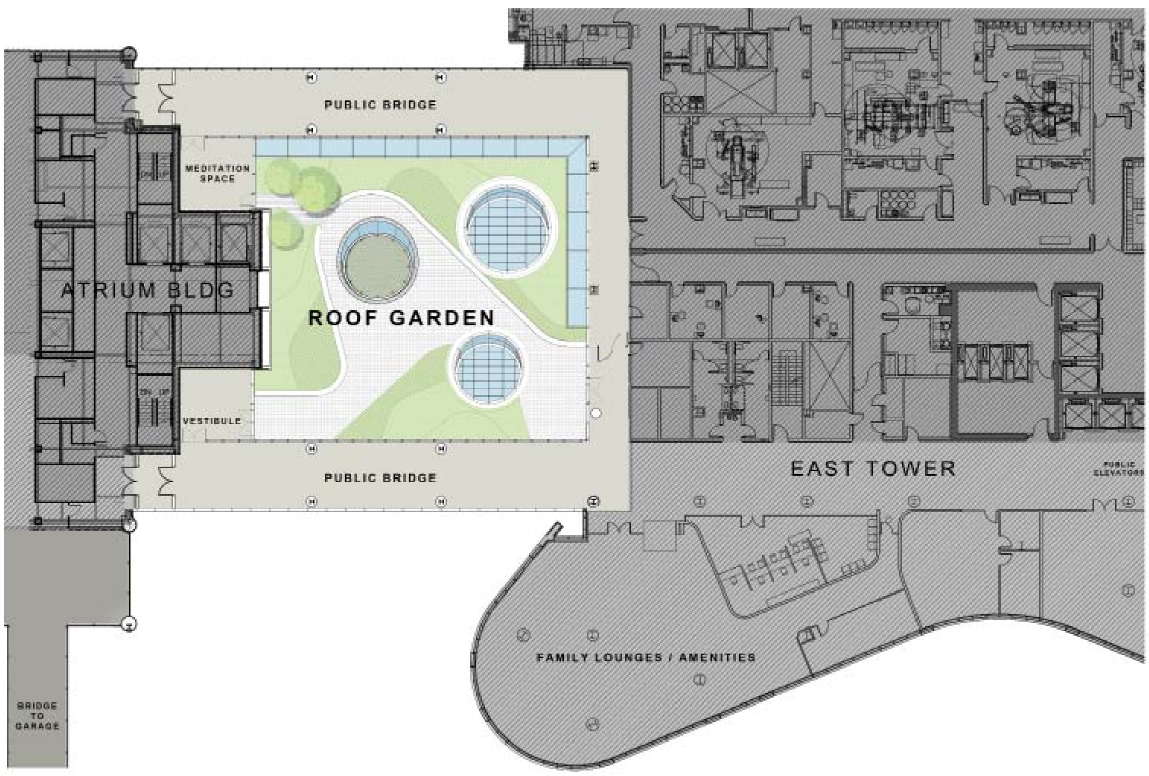

Figure 6: Fourth floor plan indicating roof garden and skylights.

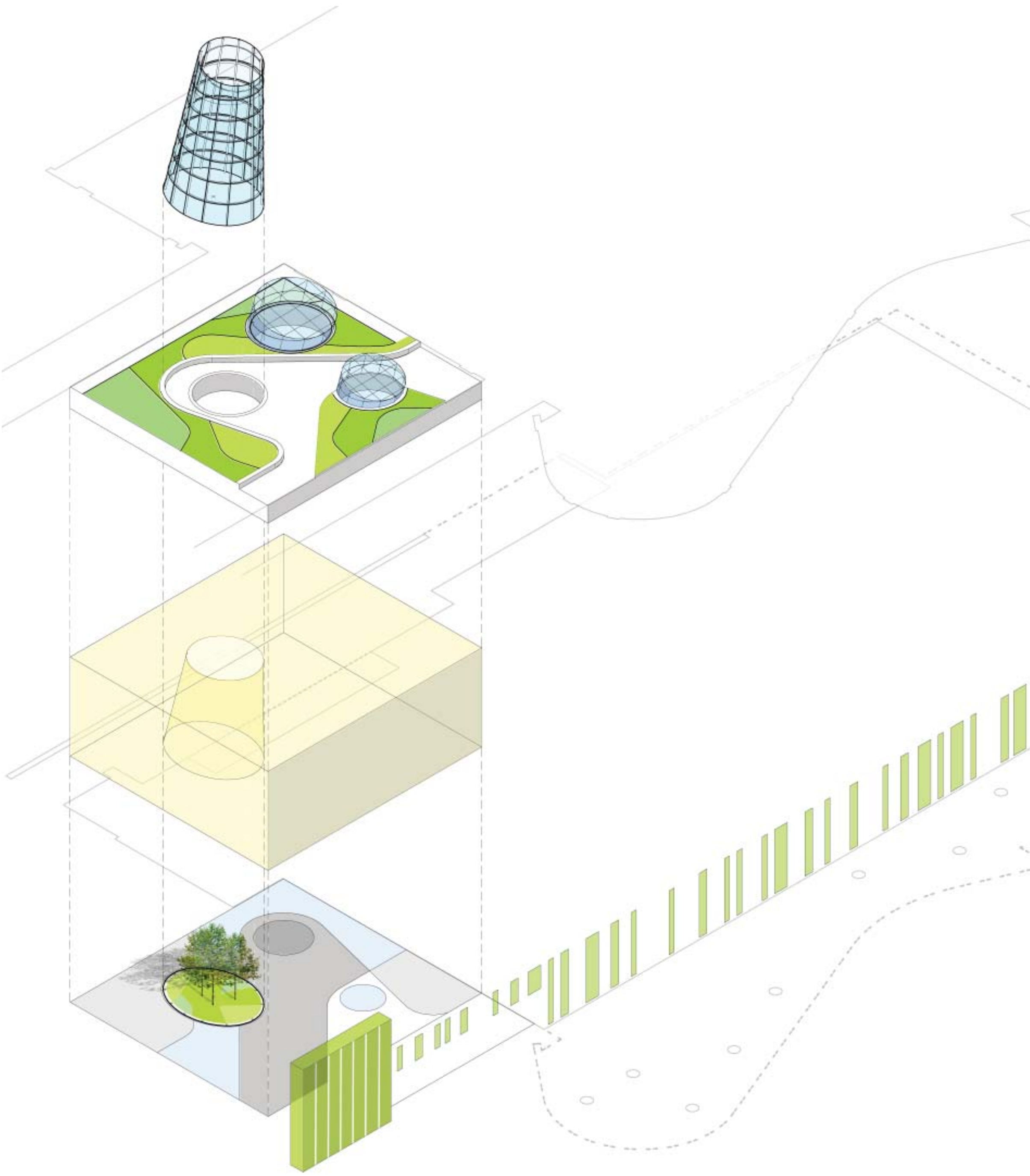

Figure 7: Exploded axonometric view of the Entry Pavilion.

Figure 8: Entry Pavilion interior and terrarium, view from north-east.
Photo credit Steve Hall © Hedrich Blessing Photographers.

Figure 9: Entry Pavilion roof garden after construction, view from south-west.
Photo credit Steve Hall © Hedrich Blessing Photographers.

2.0 SUSTAINABLE DESIGN STRATEGIES AND BUILDING PERFORMANCE

2.1 Sustainable Design Strategies and the Living Building Challenge

The design of the RUMC Entry Pavilion was started with a goal of achieving the Living Building Challenge[4]. The Living Building Challenge is a certification program that promotes one of the most advanced measurements of sustainability in the built environment today. Living Building Challenge comprises seven performance areas: site, water, energy, health, materials, equity and beauty. These are subdivided into imperatives and can be applied to buildings (new construction and renovation of existing structures), landscape, urban design, community development and infrastructure. This certification program is based on actual performance, which must be measured and verified after the building or development project is completed and occupied. It requires that the building or development is designed and operated as net-zero energy, among the other requirements, where all of the project's energy needs are supplied by on-site renewable energy. It also requires that all of water usage needs come from captured precipitation or closed loop water systems that are appropriately purified without the use of chemicals; and that all occupied spaces have direct access to operable windows and daylight.

The design process the Entry Pavilion considered multiple sustainability strategies for meeting the Living Building Challenge, as seen in Table 1 and Figure 10.

Table 1: Considered design strategies in response to the Living Building Challenge.

Performance area	Imperatives	Design strategies
Site design	Responsible site selection Limits to growth Habitat exchange	Habitat preservation on the campus
Energy	Net-zero energy	Building-integrated PVs on skylights, south facades of bridges PV panels on Atrium roof Daylighting Stored solar energy for nightime Displacement ventilation Heat recovery systems Double skin facade along the south facade of the bridge Radiant system in the floor Solar hot water system
Materials	Materials red list Carbon footprint Responsible industry Appropriate materials radius Construction waste	Alternatives to thin-set epoxy-based terrazo Calculations for carbon footprint Recycled wood Local stone and wood
Water	Net zero water Sustainable water discharge	Rainwater use for green roof irrigation Rainwater use for toilettes Rainwater divertion from roofs into cisterns
Health	Civilized work Ventilation	Operable windows Daylighting Double skin facade along the south facade of the bridge Exhaust hot air from the atrium via double skin wall cavity
Beauty	Design for spirit Inspiration and education	Plant Terrarium Art mural Energy performance LED screen Exposed rainwater retention system Permanent displays explaing building's features

Figure 10: Entry Pavilion section and the considered sustainable design strategies.

Building performance analysis was used to investigate several key aspects during the design, such as solar exposure and shadows for the roof garden, performance of a double skin facade along the bridge corridor, solar access analysis for several facades and daylight analysis. Use of simulations and building performance analysis during the design process improves design decision-making[5,6]. The following sections review the results of various studies and performance analyses conducted for the RUMC Entry Pavilion.

2.2 Solar Exposure Studies for Roof Garden

The objective of solar exposure study was to investigate the amount of solar radiation available for the Entry Pavilion roof area. The primary driver was to investigate whether this area will have access to sufficient solar radiation since this portion of the building is used as a roof garden. Figure 11 indicates solar exposure and shading hours for the Entry Pavilion roof area on June 21 and December 20. There are approximately thirteen hours of sunlight available on June 21 and only seven on December 20. Maximum direct solar radiation on June 21 reaches 230 Btu/hr-ft^2, while on December 20 reaches 76 Btu/hr-ft^2. Diffuse solar radiation was found to be comparable for both dates.

The next step considered hourly shadow ranges for two specific dates during the summer and winter seasons.

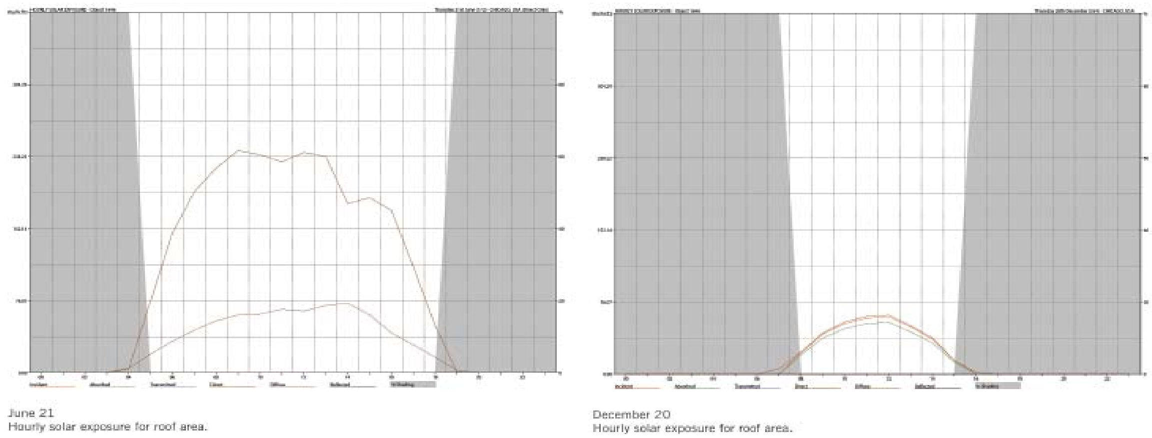

Figure 11: Solar exposure and shading hours study for the Entry Pavilion roof area.

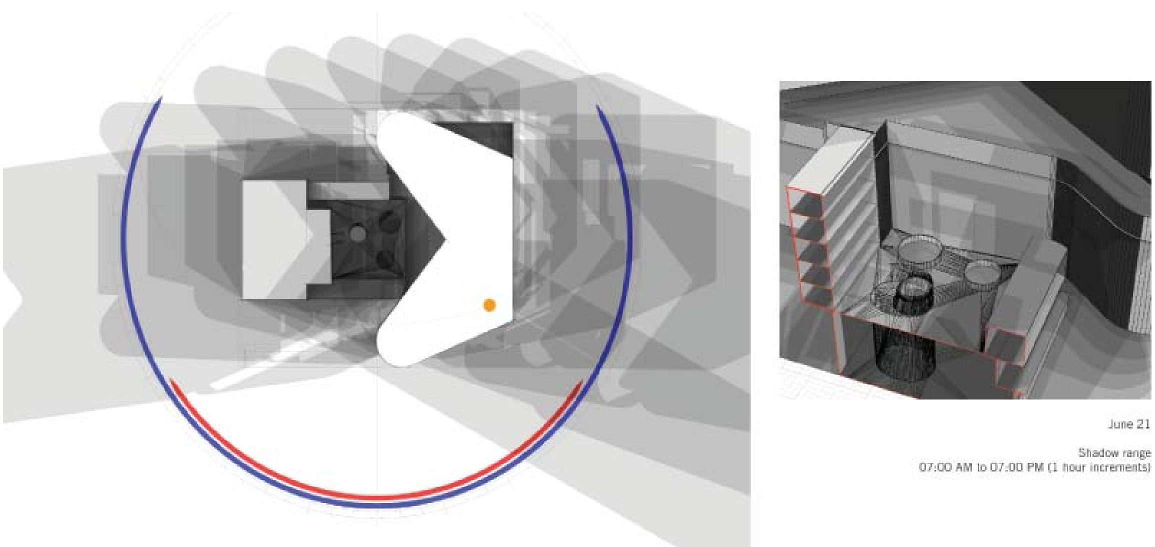

Figure 12: Shadow ranges for June 21 from 7AM to 7PM.

Figure 12 shows shadow ranges for June 21 from 7AM to 7PM. Shadows are displayed in relation to the duration (one hour increments) and darker areas indicate regions of the roof garden that are less exposed to direct solar radiation on this particular day. Figure 13 shows shadow ranges for December 21 from 7AM to 7PM.

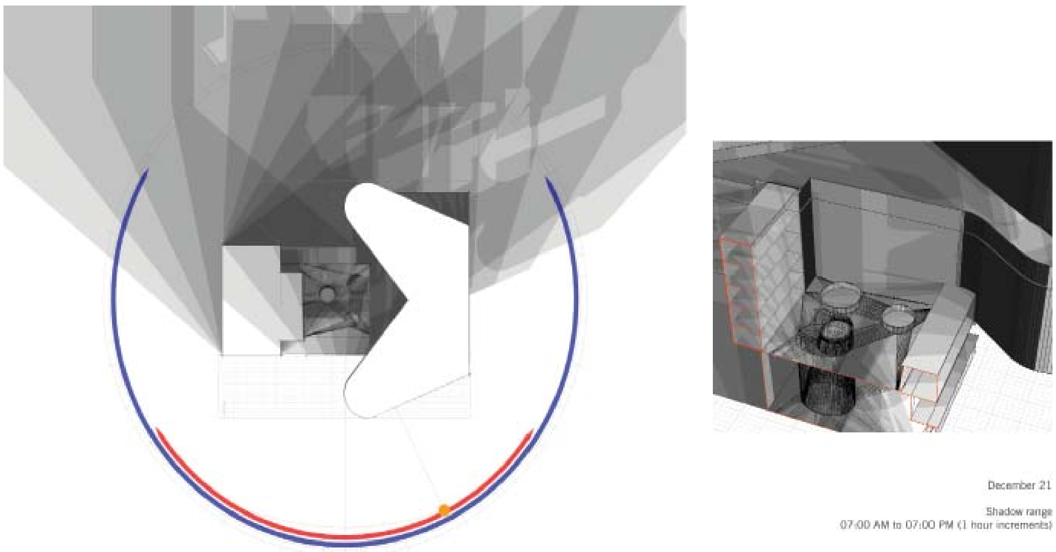

Figure 13: Shadow ranges for December 21 from 7AM to 7PM.

Since this study showed that the Tower and the existing Atrium Building partially shade the roof garden, hourly solar position and shadows were studied to determine how much time the roof garden spends in shade on two specific dates (June 21 and December 21). The diagrams in Figure 14 show hourly sun position and projected shadows on June 21 from 7AM to 6PM. The roof garden is in total shadow from 7 to 9AM as well as from 5PM to sunset. Partial shadows are present from 10 to 11AM and from 2 to 5PM. From noon to 1PM the roof garden is fully exposed to the sun.

The diagrams shown in Figure 15 show hourly sun position and projected shadows on December 21 from 7AM to 6PM. The roof garden is in total shadow from 8 to 10AM. Partial shadows are present during the majority of the day from 10AM to 4PM. Therefore, it was concluded that there is enough solar exposure for plant life and landscaping as well as occupants' comfort.

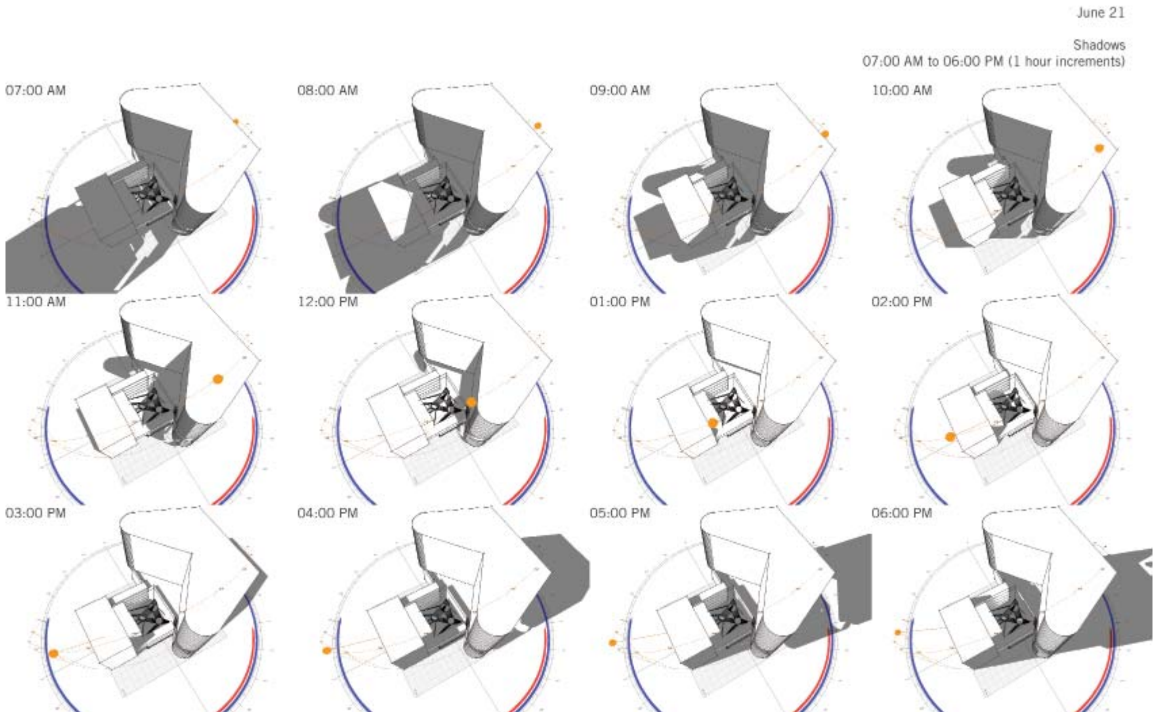

Figure 14: Hourly sun position in relation to the roof garden and projected shadows on June 21 from 7AM to 6PM.

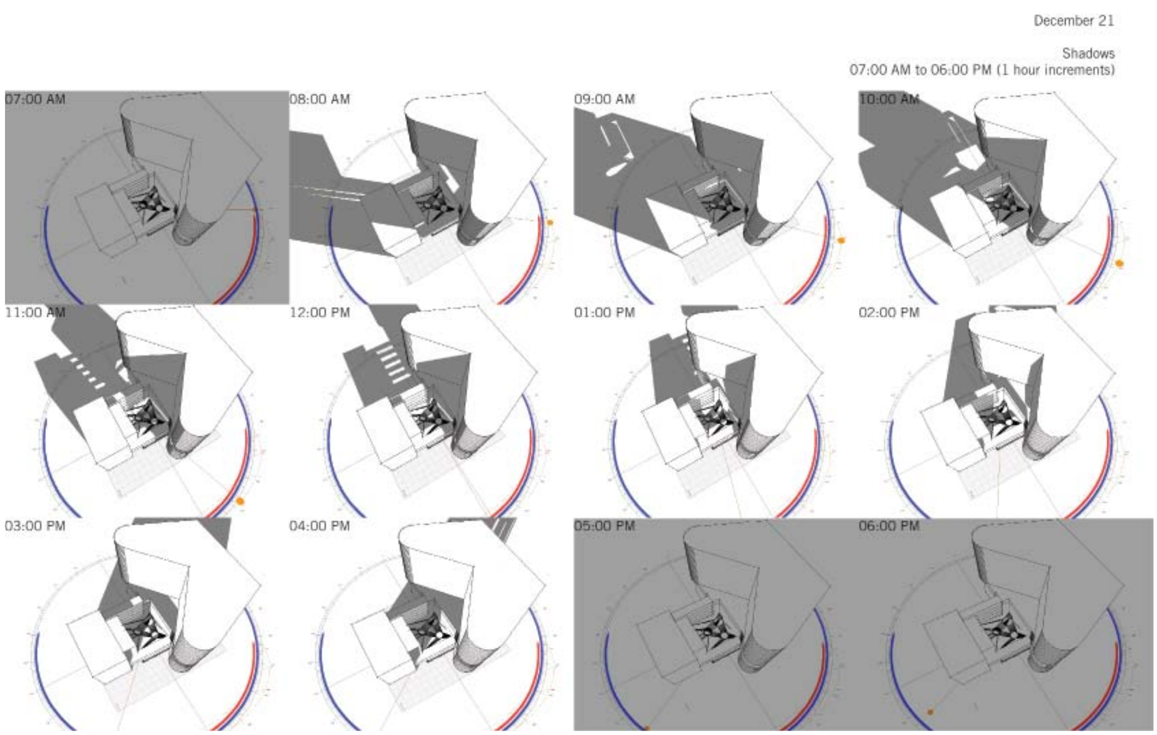

Figure 15: Hourly sun position in relation to the roof garden and projected shadows on December 21 from 7AM to 6PM.

2.3 Double Skin Facade Studies

Double skin facade along the south side of the bridge was considered during the schematic design as one of the energy-efficient design methods, shown in Figure 16. Several design parameters and their effects on energy consumption were studied, such as air cavity dimensions between the two skins, location of double air-insulated glazing and the differences in operation during winter and summer months[7].

Constant design parameters for all facade types that were used in the study are shown in Table 2. In order to study the effects of changing air cavity geometry, location of double skin as well as different air flow types, different design scenarios were investigated, shown in Table 3. Base model included single skin facade with low-e glazing, consisting on a curtain wall with double air-insulated low-e glazing unit. For double skin facade options, location of double glazing was varied from the internal to external side as well as cavity depth from 1.5 to 4 feet. Two different types of air flow were investigated, exhaust air during all year as well as combination of exhaust air during summer months and air curtain during winter months. This combined air flow type would allow use of warm air during winter to preheat the air cavity. All double skin scenarios included blinds within the air cavity.

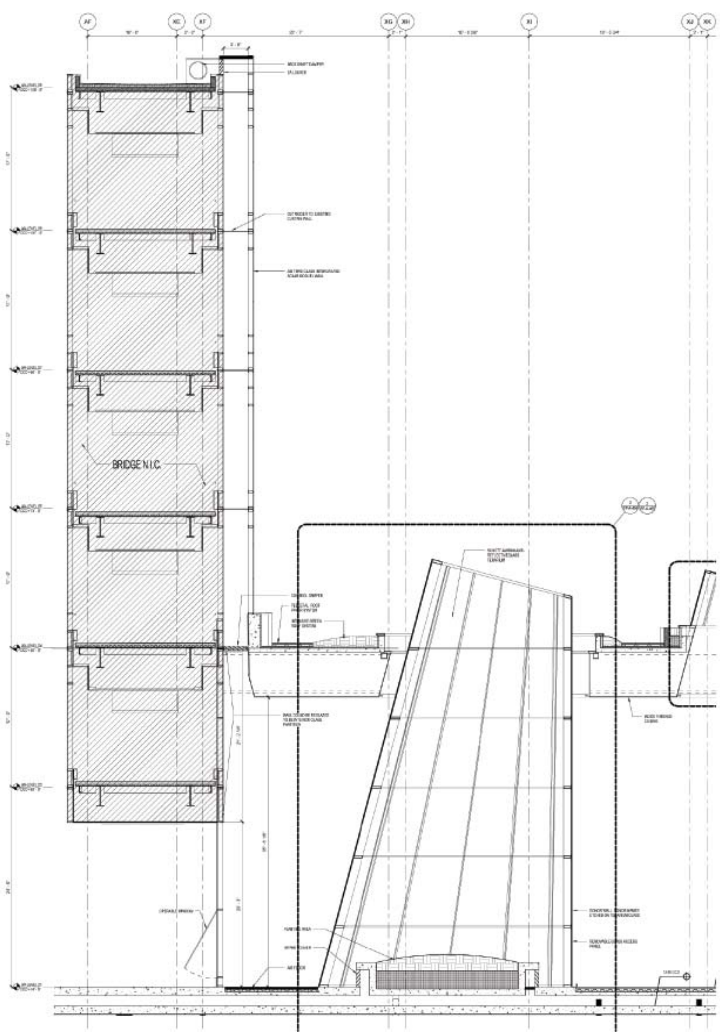

Figure 16: Double skin wall section.

Table 2: Static variables for all facade types.

All Facade Options	
Location	Chicago, IL
Orientation	South
Temperature Min (deg F)	68
Temperature Max (deg F)	79
Humidity Max (%)	60
Occupancy load (people/SF)	1.1
Lighting requirements (fc)	20
Air change rate (AC/hr)	1.8
Dimensions (ft)	
Depth	18
Width	70
Height	60
Glazing type	low-e
Window area	80
Double Skin Facade	
Type	Multi-story
Ventilation mode	Hybrid (natural, assisted by mechanical fans)
Shading	Blinds in air cavity that respond to temperature

Table 3: Dynamic variables for facade types.

Scenarios	Location of double glazing	Air flow type	Air cavity
Base model	-	-	-
Scenario 1	in	Exhaust air (interior vent supply, exterior vent exhaust)	1.5 ft
Scenario 2	in	Exhaust air (interior vent supply, exterior vent exhaust)	2ft
Scenario 3	in	Exhaust air (interior vent supply, exterior vent exhaust)	3 ft
Scenario 4	in	Exhaust air (interior vent supply, exterior vent exhaust)	4 ft
Scenario 2.1	out	Combination (exhaust air summer, air curtain winter)	2ft
Scenario 3.1	out	Combination (exhaust air summer, air curtain winter)	3 ft
Scenario 2.1.1	out	Combination (exhaust air summer, air curtain winter)	2 ft
Scenario 3.1.1	out	Combination (exhaust air summer, air curtain winter)	3ft

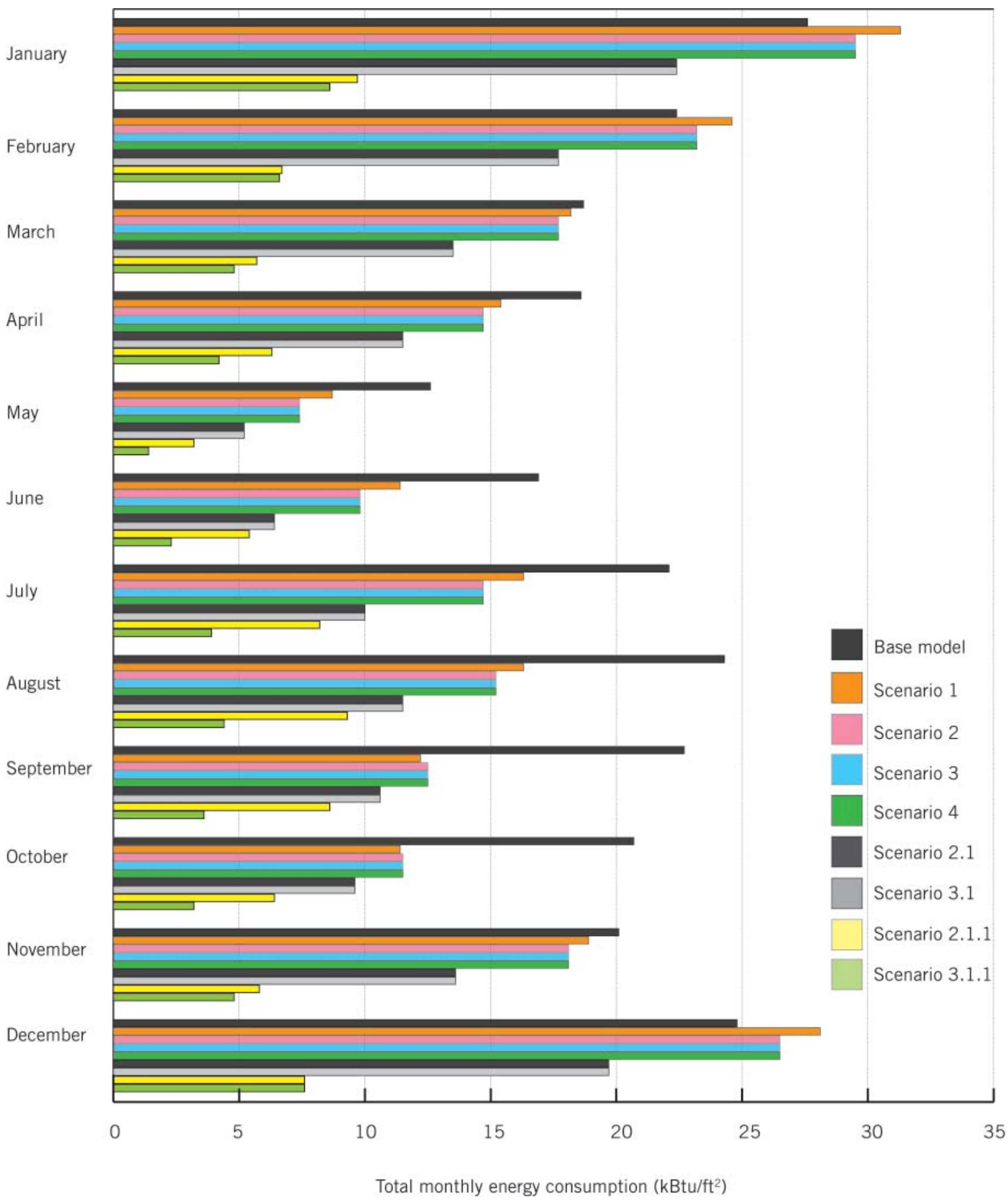

Figure 17: Annual energy demand for single skin and double skin facades.

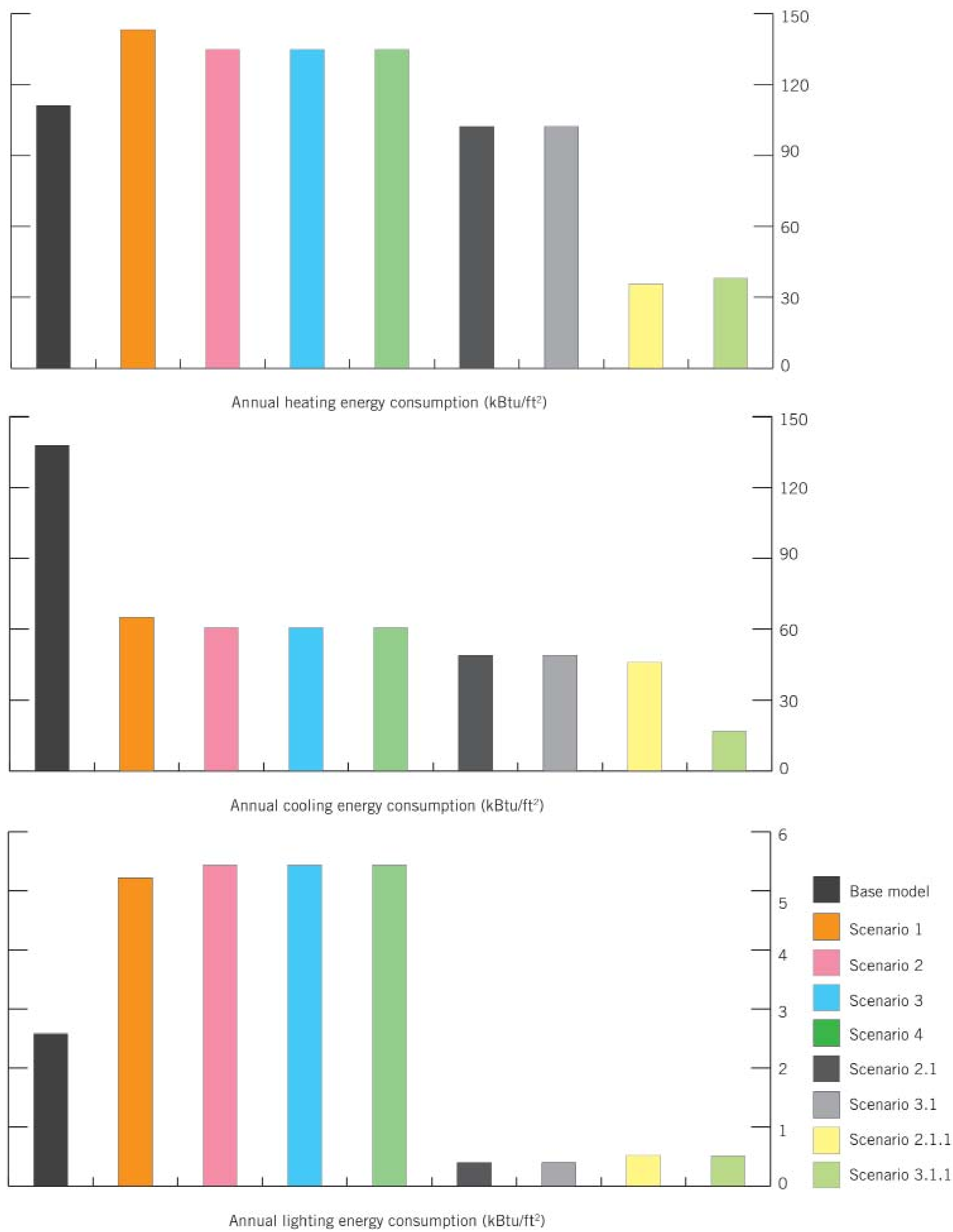

Figure 18: Results for heating, cooling and lighting energy use.

Results are shown in Figure 17. Base model (double glazed single skin facade) has highest overall energy demand. However, looking at the annual energy demand reveals that some cases of double skin wall have higher heating loads during the winter months (Figure 18). In particular, air flow type has a major effect since exhaust air type increases heating demand. Results indicate that trapping air within the air cavity during winter months insulates the double wall, thus significantly lowering the heating loads.

Air cavity size has an effect on energy consumption. However, results indicated that the location of the double glazing is more important and has a greater effect on energy consumption. Results show that exterior placement of double glazing would significantly reduce energy consumption compared to placement on the interior side. Size of air cavity also has an effect, where cavity with a small opening can negatively influence natural buoyancy and stack effect. Also, air cavities that are too large increase the cost. Results showed that the design scenario that performs well for all seasons has air cavity size of 3 feet.

Based on the performed energy analysis for several possible design scenarios, it was concluded that the best possible candidate would contain double glazing on the exterior and single glazing on the interior side, with an air cavity of 3 feet, and hybrid airflow mode (exhausted air during summer months assisted with mechanical fans and air curtain during winter months to decrease heating loads). However, the double skin wall was eliminated in the design development stage due to the high initial costs. The final design incorporated a curtain wall facade with fritted glass to limit the solar heat gain and reduce cooling demand.

2.4 Solar Access Analysis

Solar access analysis was performed for several parts of the Entry Pavilion including the south facade of the north bridge as well as the south facade of the entry vestibule. Figure 19 shows average incident solar radiation for the south facade of the north bridge. It ranges from 1,400 to 6,800 BTU and it is highest in the afternoon hours, especially during the winter months. Table 4 shows comparison between available solar radiation on the site and incident solar radiation for this facade. It is evident that this facade spends most of the time in shade.

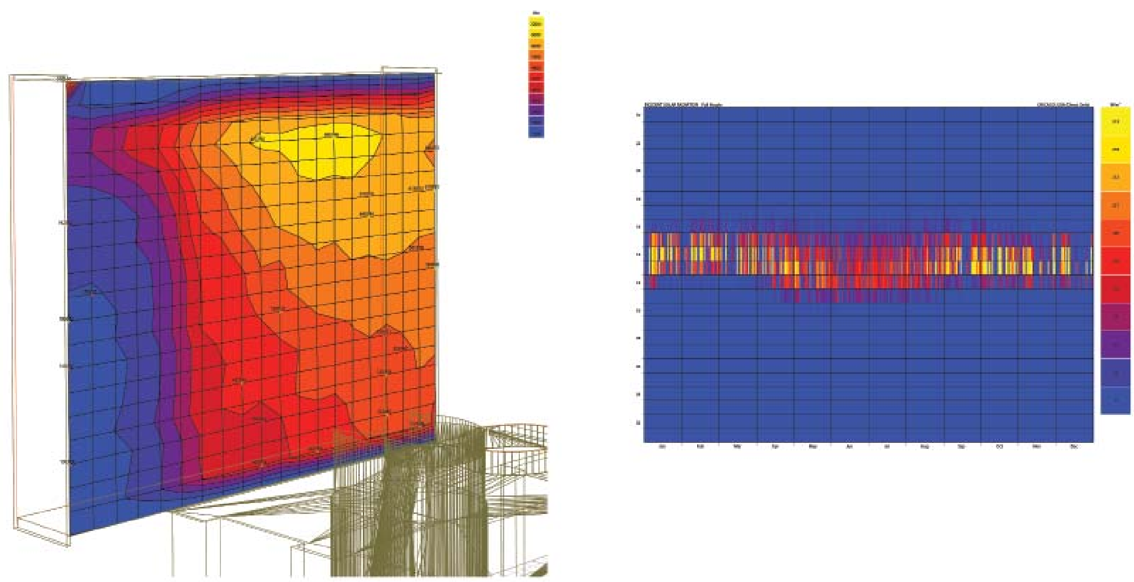

Figure 19: Solar radiation on the south facing facade of the north bridge.

Table 4: Comparison of available and incident solar radiation for the south facade of the north bridge.

Month	Available solar radiation (Btu/ft^2)	Average shade	Incident solar radiation (Btu/ft^2)
Jan	22,045	81%	4,173
Feb	24,526	84%	3,648
Mar	29,137	83%	3,458
Apr	37,267	79%	4,237
May	51,043	75%	4,930
Jun	48,763	76%	3,593
Jul	52,775	76%	4,571
Aug	40,975	77%	4,157
Sep	36,775	82%	4,225
Oct	31,658	82%	4,513
Nov	19,110	80%	3,372
Dec	14,378	78%	2,639
Total	**408,452**		**47,516**

Solar radiation analysis for the south facade of the Entry Pavilion considered three different surfaces, as seen in Figure 20. The first surface receives most of the solar radiation during winter months and incident solar radiation is high during the enitre day due to direct south orientation. The second surface is shaded by the cantilevered part of the facade and has very low incident solar radiation during the summer months. The third surface is shaded during the entire year and has very low incident solar radiation. Table 5 compares average monthly available solar radiation and the incident solar radiation for these three facade surfaces as well as the percentage of time that they spend in shade.

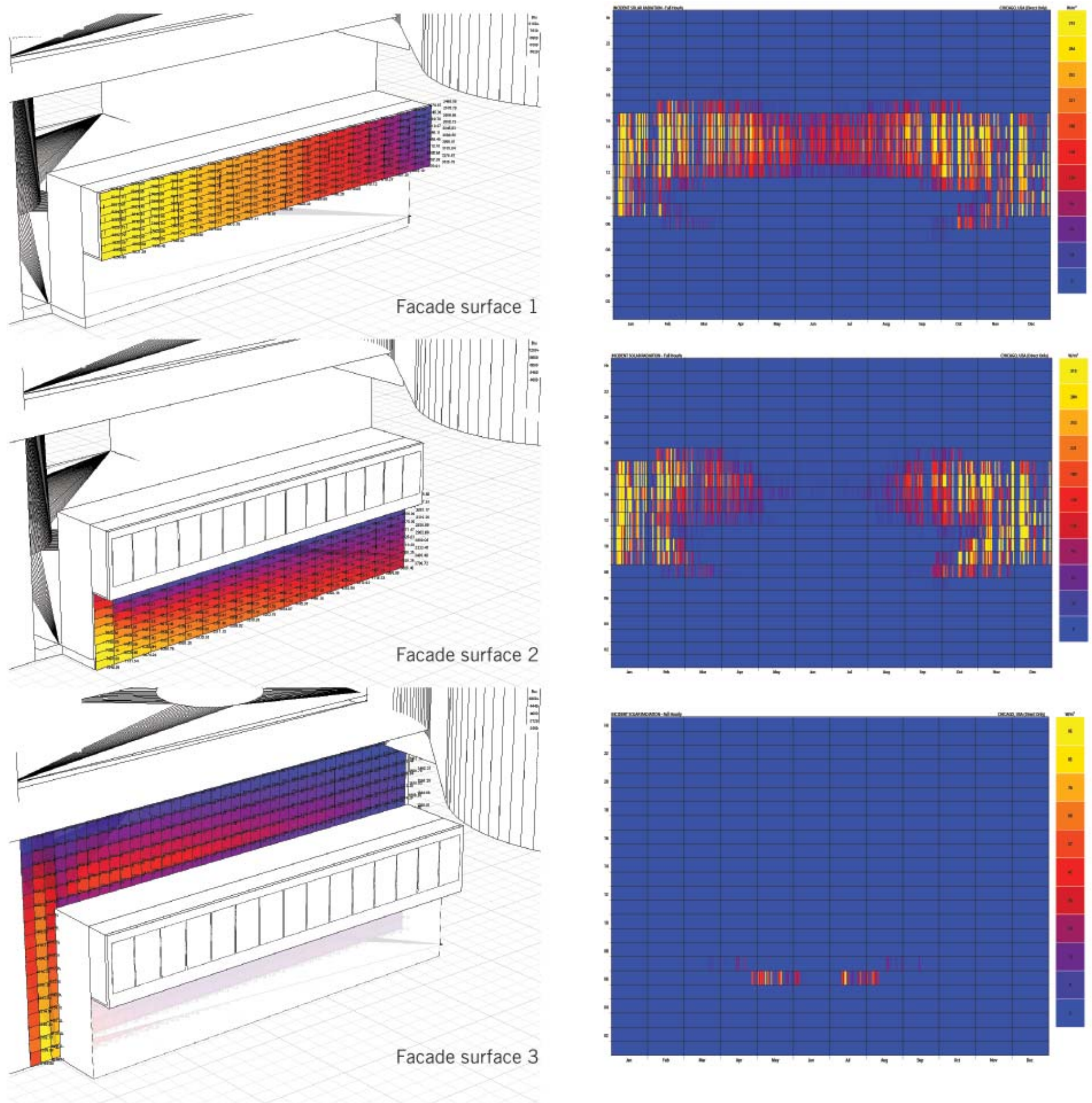

Figure 20: Solar radiation at the south facade.

Table 5: Comparison of available and incident solar radiation for the south facade of entry pavilion.

Month	Available solar radiation (Btu/ft²)	Facade surface 1		Facade surface 2		Facade surface 3	
		Average shade	Incident (Btu/ft²)	Average shade	Incident (Btu/ft²)	Average shade	Incident (Btu/ft²)
Jan	22,045	34%	11,187	11%	15,627	100%	0
Feb	24,526	42%	8,827	34%	9,335	100%	0
Mar	29,13	51%	6,787	65%	4,234	98%	13
Apr	37,267	61%	5,557	87%	2,254	97%	66
May	51,043	65%	4,808	97%	679	97%	238
Jun	48,763	76%	3,035	97%	208	100%	44
Jul	52,775	70%	3,970	98%	310	97%	162
Aug	40,975	63%	4,841	92%	1,411	97%	127
Sep	36,775	53%	6,937	70%	4,167	100%	5
Oct	31,658	45%	9,477	43%	8,722	100%	0
Nov	19,110	36%	8,343	14%	11,576	100%	0
Dec	14,378	24%	8,094	11%	11,444	100%	0
Total	**408,452**		**81,863**		**69,965**		**655**

Photovoltiac system was also considered during the design process and an analysis was performed to understand solar access for the roof area of the atrium building[8]. Two different photovoltaic arrays were studied, one being placed on the roof top of the atrium building (covering 2238 SF and with a 35 kW rating) and the second on the roof of the tower (covering 9,873 square feet and with a 143 kW rating). The results showed that the surrounding buildings would not overshadow PV array on the atrium building, however, the payback time for both PV arrays was found to be too high to justify investements into this renewable energy source.

2.5 Daylight Analysis

Daylight analysis was performed for two areas of the entry pavilion. The first study analyzed available daylight levels in the terrarium, as seen in Figure 21. Results of the daylight analysis indicated that natural lighting levels in the terrarium would be approximately 120 foot candles (fc) for the horizontal plane (ground level). Analysis of the vertical distribution indicated that the terrarium would receive between 110 and 330 fc of natural light. The middle section receives between 120 and 150 fc. Therefore, the results of the analysis indicated that sufficient lighting levels would be present for the plants and landscaping in the terrarium. The results also indicated that areas of the entry pavilion directly below the skylights would have high daylight levels, therefore, subsequent analysis focused on two design options for distributing daylight evenly in the interior space.

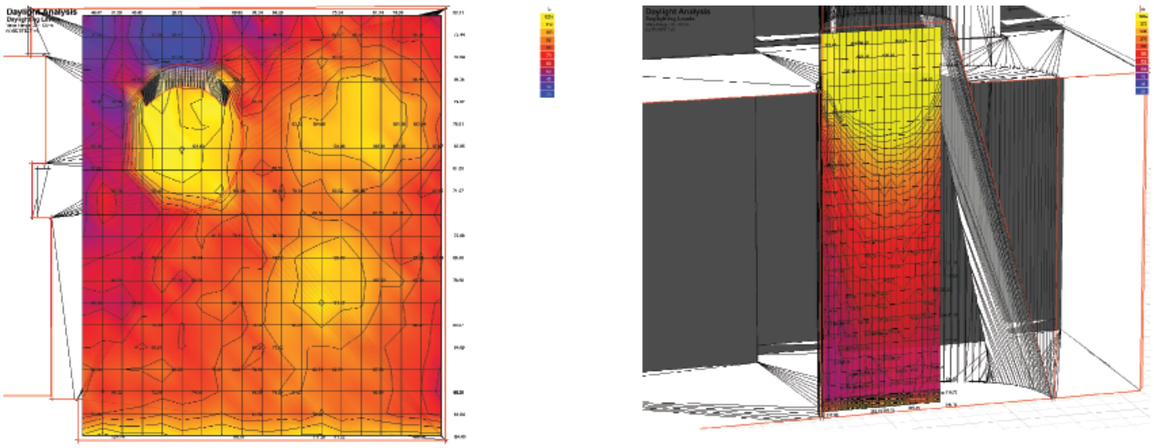

Figure 21: Daylight analysis in the horizontal plane of first floor (left); Daylight analysis along the vertical plane of the terrarium (right).

Results are shown in Figure 22 for two design scenarios. The model on the left side shows daylight levels where ceramic frit is incorporated in both facades (40%). The daylight levels range from 60 to 90 fc. The model on the right side shows daylight levels for a scenario that incorporates ceramic frit coverage in skylight glass as well as building facades. This would reduce daylight levels directly underneath the skylights and would create a more uniform distribution of natural light. The daylight levels would be in the range from 60 to 80 fc.

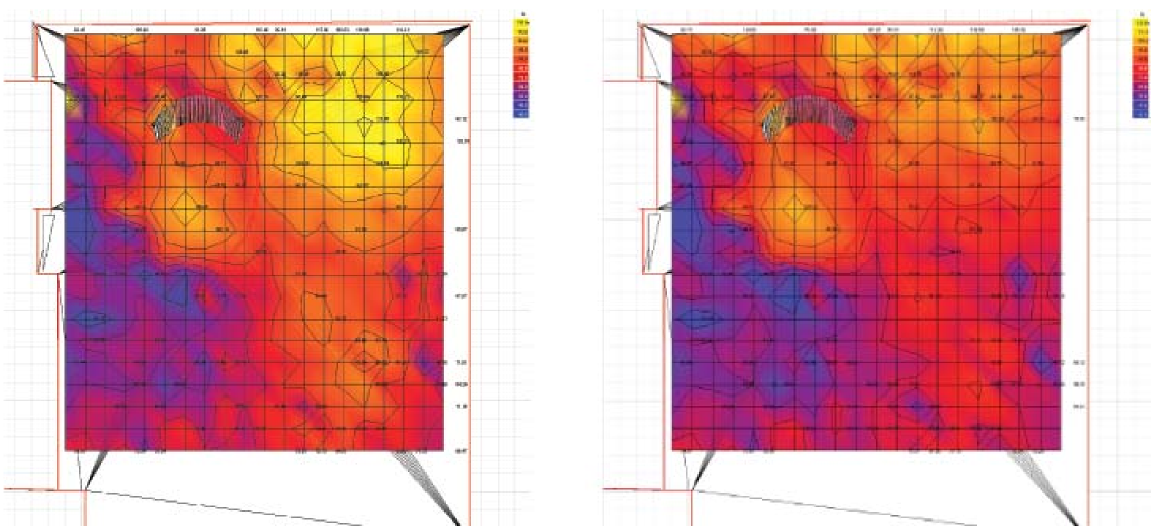

Figure 22: : Daylighting levels - 40% frit coverage for south and north building facades (left); Daylighting levels - 50% frit cover age for skylight and 40% frit coverage for building facades (right).

2.6 Living Building Challenge and the Lessons Learned

Although building performance analyses performed during the design process were useful for the assessment of some of the sustainable design strategies and to investigate different design options, the RUMC Entry Pavilion was not able to meet the Living Building Challenge. Primary obstacles that were encountered during the design were:

- Multiple energy-efficiency design strategies were employed to minimize energy consumption. However, it was not possible to design a net-zero energy facility without using renewable energy sources. The initial high costs of renewable energy systems, such as photovoltaics, were prohibitive for including them in the design. Therefore, one of the major requirements of the Living Building Challenge was not met.
- Use of natural ventilation for healthcare facilities (even the lobby areas, such as the Entry Pavilion) is not acceptable for most of North-American hospitals due to infection control strategies. Therefore, inclusion of operable windows, which is one of the requirements of the Living Building Challenge, could not be met.

Still, the employed design strategies resulted in significant energy savings. The modeled Energy Usage Intensity (EUI) for the Entry Pavilion was 62 kBtu/SF compared to the 155 kBtu/SF for a baseline building resulting in 40% energy reduction. Table 6 compares the modeled annual energy consumption for the Entry Pavilion with a baseline building.

Table 6: Modeled annual energy consumption for the Entry Pavilion and a baseline building.

Building system	Energy consumption (kBtu/yr)	
	Baseline building	Entry Pavilion
Lighting	310,400	201,300
Space heating	373,200	41,800
Space cooling	147,300	77,900
Pumps	0	53,500
Heat rejection	22,200	0
Fans	386,100	53,200
Receptacles	81,000	81,000
Stand-alone base utilities	39,600	36,300
Total	**1,359,800**	**545,000**

3.0 TERRARIUM TECHNICAL DESIGN DEVELOPMENT

3.1 Terrarium Design Approach and Geometry

Skylights provide natural light for the interior space of the Entry Pavilion and also act as sculptural elements in the roof garden. One of these elements project down to the floor of the Entry Pavilion to introduce an exterior landscaped space without compromising internal contamination issues associated, thus creating a terrarium as one of the feature elements. As per definition, a terrarium is a sealed transparent globe or similar container in which plants are grown. An open-to-above truncated elliptical cone shape, which is an interior courtyard with curtain wall enclosure, greets incoming guests with a grove of trees and a forest floor garden, as seen in Figure 23. The terrarium was introduced as an interesting design feature in the lobby space bringing nature to the interior and breaking down the large volume, as seen in Figure 24.

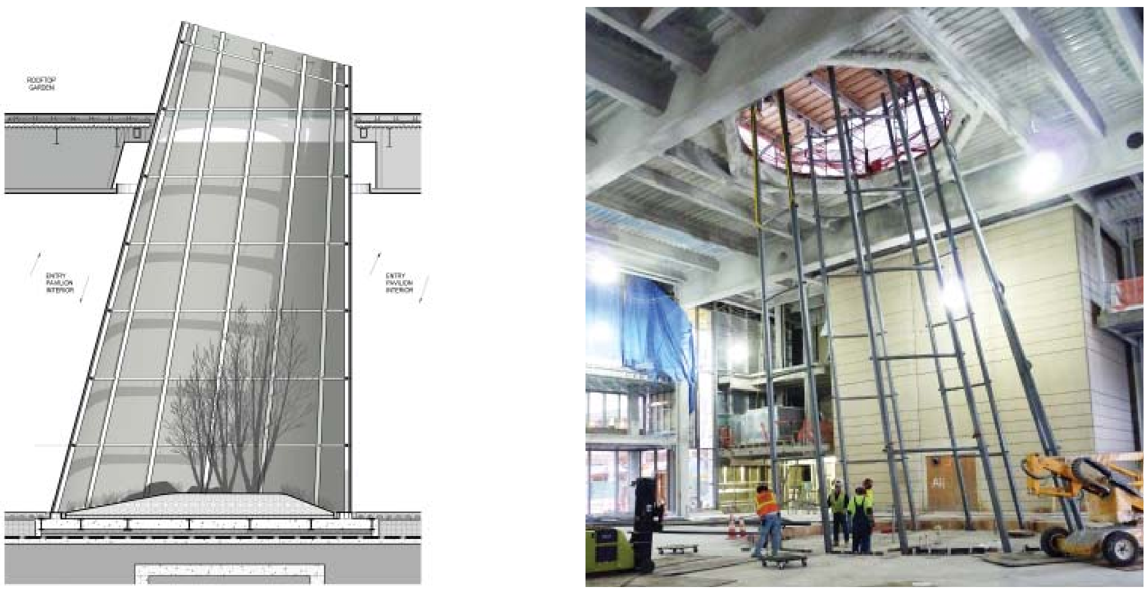

Figure 23: Terrarium cross section (left); Terrarium under construction (right).

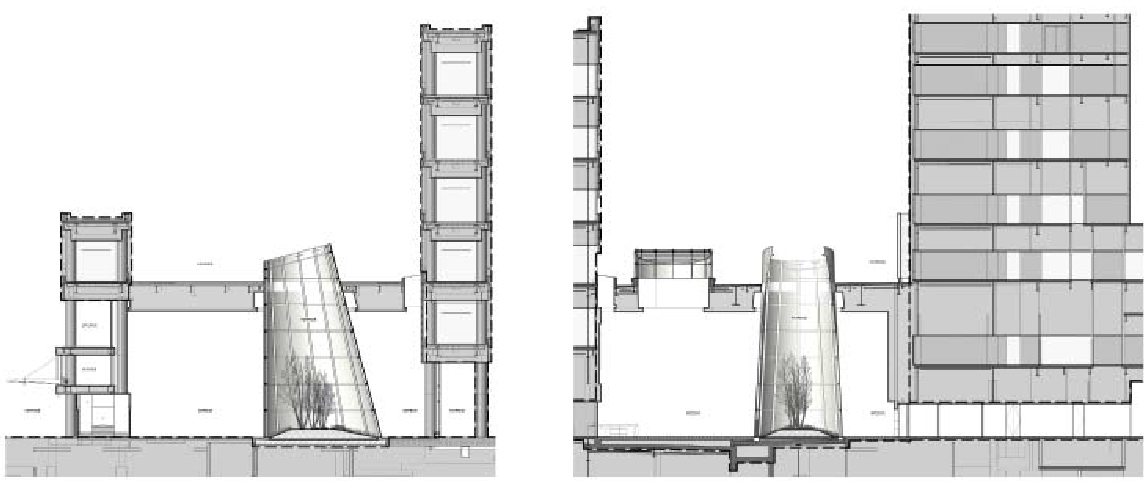

Figure 24: Entry Pavilion north-south cross section (left); Entry Pavilion east-west cross section (right).

Geometrically and three-dimensionally, the terrarium is not a simple shape. In the early design stages, the form was conceived as an ellipse at the base and an angled circle at the top, connected at the quadrant points. The challenge with this concept was that it was very difficult to define the intermediate shapes as they are not ellipses. Therefore, moving from design concept to construction required the adoption of "stacked ellipse" to define the form. The series of plan rings are definable ellipses and transform into a circle at the top ring, which is essentially an ellipse with equal X and Y axes. The enclosure generated from these shapes was projected beyond the roof and then cut in an angle. These two ideas are shown in Figure 25. The ellipses and circle are stacked at one side, while they are offset in the other directions, as seen in Figure 26. When approached through the primary entrance from the south, the vertical edge is perpendicular to the approach direction. Gradually, the form angles on the opposite side. The other two skylights were designed as regular cylinders with an inclination related to the roof plane and then cut off.

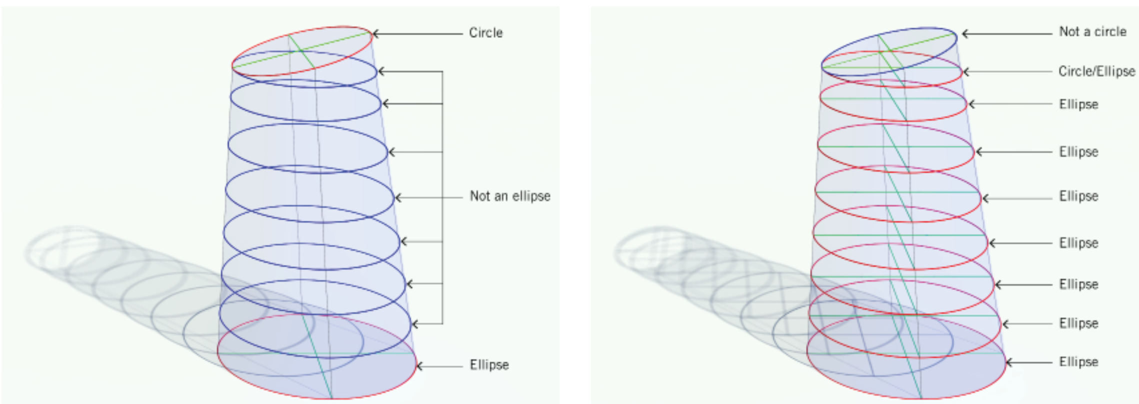

Figure 25: Terrarium geometry schemes - Ellipse and circle (left); Stacked ellipse (right).

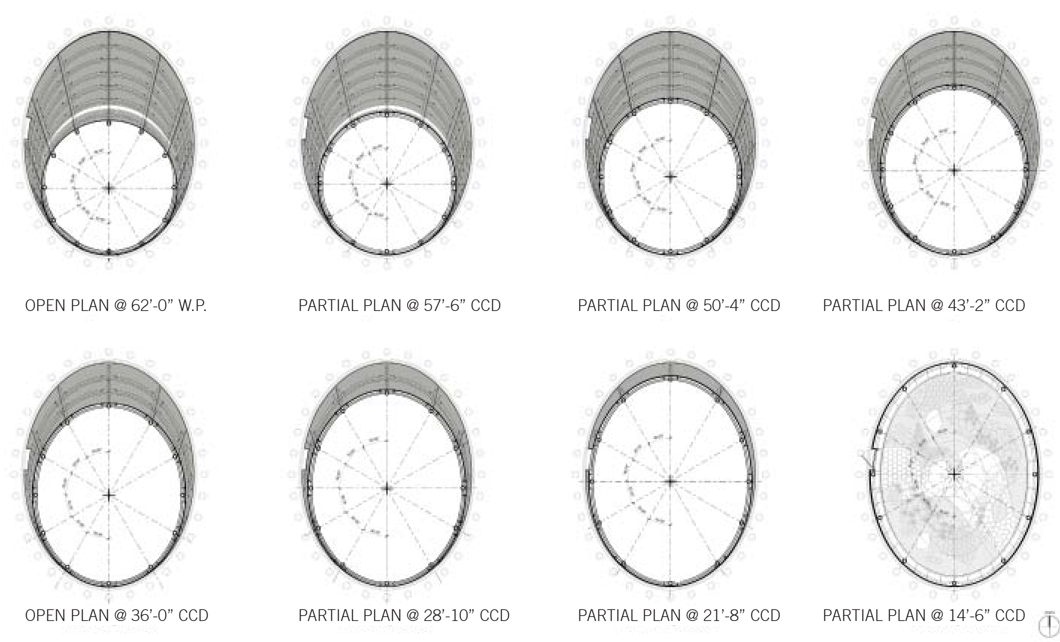

Figure 26: Horizontal terrarium plan along its height.

3.2 Technical Challenges

3.2.1 Inverted Curtain Wall

The terrarium's curtain wall is inverted compared to a normal curtain wall, as its structure is located at the exterior space rather than interior. Generally, the internal volume of a form is its interior space and outside of the form is the exterior environment. As the terrarium is open at the top, this is actually reversed and the internal volume is now outside. Therefore, the structure of the terrarium curtain wall including the tubes and the fittings are located outside. At the same time, they must resist weather, water, snow and ice. The sealant joint that usually faces outside now faces inside. All these factors were taken into account designing the structure members that are exposed to the outdoor environmental elements.

The components of the curtain wall support system were first pre-assembled off-site similar to ladders shown in Figure 27. Then, these components were erected at the site and the glass elements in-between the ladders were installed and connected.

Figure 27: Structural ladders (left); Assembly of the ladders to create the terrarium form (right).

3.2.2 Location and Structural Load Transfer

The terrarium is located on top of the junction of the Atrium Building and the Tower basement. The terrarium is located right at the spot where the two buildings come together. Below the terrarium lies the only usable pathway for service and transportation of materials between the loading dock and the Atrium Building and west side of the campus. There is a 4hr fire-rated vestibule at the basement below the Entry Pavilion that separates the dock from the Atrium Building. This path could not be disrupted, changed or reduced in size and foundations could not be placed in this area.

As the terrarium is large and has significant weight, providing structural support was a major challenge. The existing foundations could not take this additional load since more than half of the Entry Pavilion is situated on top of the existing Atrium Building basement. All these reasons precluded the terrarium to be supported on its columns.

The terrarium was considered to be placed on a platform. The solution was a structural concrete mat slab with micro-pile foundations supporting the terrarium. Structural steel beams running in two directions were embedded in the light-weight concrete. The mat has its own columns near the corners avoiding the logistic circulation path and foundations are drilled through the floor of the basement of the Atrium Building.

3.2.3 Roof Connection

The terrarium was totally disengaged from the Entry Pavilion's roof structure, and there is no structural connection between the Entry Pavilion roof and the terrarium. Any kind of structural connection would interrupt the glass layer of terrarium, which would require this area to be sealed for water-tightness.

The terrarium enclosure is made of glass without interruptions as it rises through the roof. Careful attention was given to the roof interface detail in order to maintain

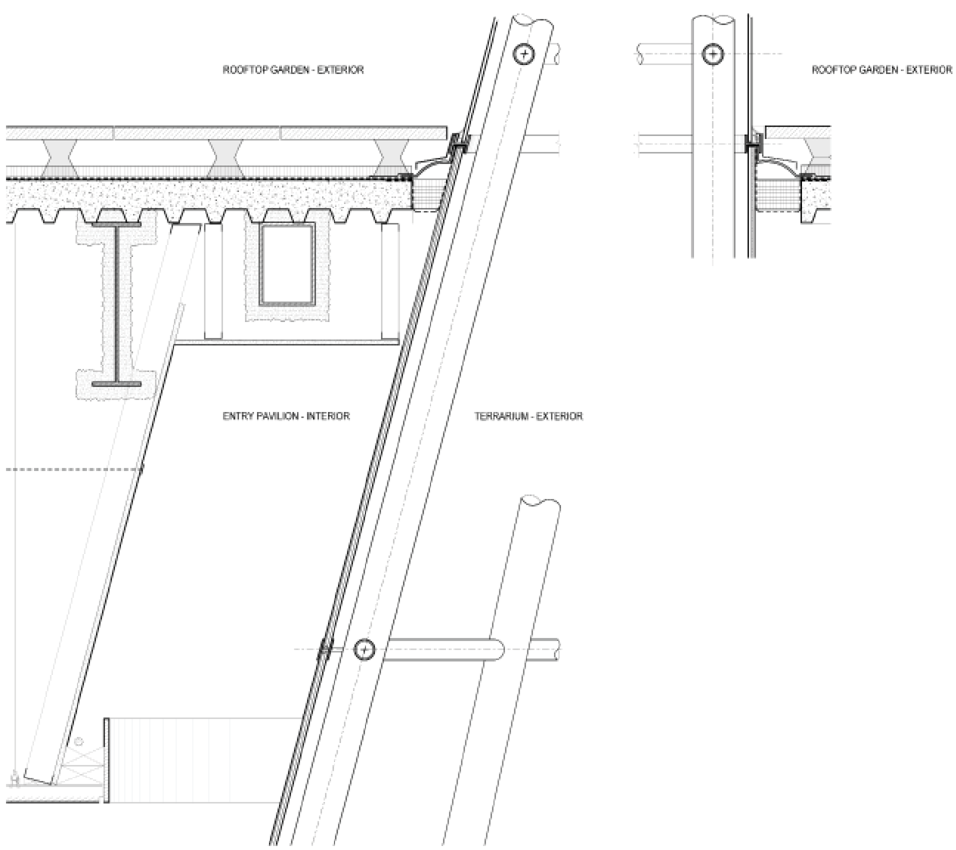

Figure 28: Detail at the roof connection.

the design intent of a pure form punching through the roof deck. One option that was studied was a perimeter skylight, but was rejected because it would create a barrier for occupants on the roof. Also, simulations and modeling preformed during the design indicated that the two large skylights provided sufficient daylight to the interior space, therefore, the additional perimeter skylight would be redundant.

The solution to this issue was introduced, which included a twisting “H” shaped channel at the roof level. It is vertical at one edge of the terrarium, tilted at the opposite end and twisted in between. As the roof of the Entry Pavilion is a sloping deck and meets the irregular geometric shape of the terrarium, the channel has to change profile constantly around the terrarium. A flexible gasket was attached to the channel to cover the gap between Entry Pavilion roof opening and terrarium glass surface and to allow three dimensional movements. The glass of the terrarium surface changes from insulated at the bottom part of the terrarium to laminated above the roof line. This allowed some extra space so that the “H” shaped channel and gasket are not visible at the rooftop.

3.3 Materials and Components

3.3.1 Glazing Units

The terrarium glass pieces measure 7’-2” in height and their width varies around six feet. Although the terrarium is symmetrical along its long axis, the opposite corresponding pieces are not the same in terms of dimensions. The terrarium is composed of total 84 unique shapes of glass (42 on each side). Insulated glass panels were used with laminated glass on both sides with air space between. Each glass panel consists of four panes of glass in this order: glass, PVB inner layer, glass, air space, glass, PVB inner layer and glass. This composition increased the thickness of the overall glass panels as well as their weight. The structural load was analyzed to make sure that it will not impart too much additional load to the underlying structure.

3.3.2 Patch Fittings

To show the corner joint, the terrarium glass panels were designed to be attached with small size patch fittings at the both sides of the vertical corner joint. These were later changed to a comparatively bigger size patch fittings at the corners, seen in Figure 29.

Figure 29: Patch fittings at the corner of glass units (left); Terrarium after construction (right). Photo credit Steve Hall © Hedrich Blessing Photographers.

3.3.3 Terrarium Access Door

In general, the terrarium has to be sealed, but, there is a need for an access point for maintenance. It was difficult to design a door in a complex geometric shape. The solution was to design a vertical, flat glass door with steel plate jambs at both sides. This would allow access to the terrarium through a weather-tight door, seen in Figure 30.

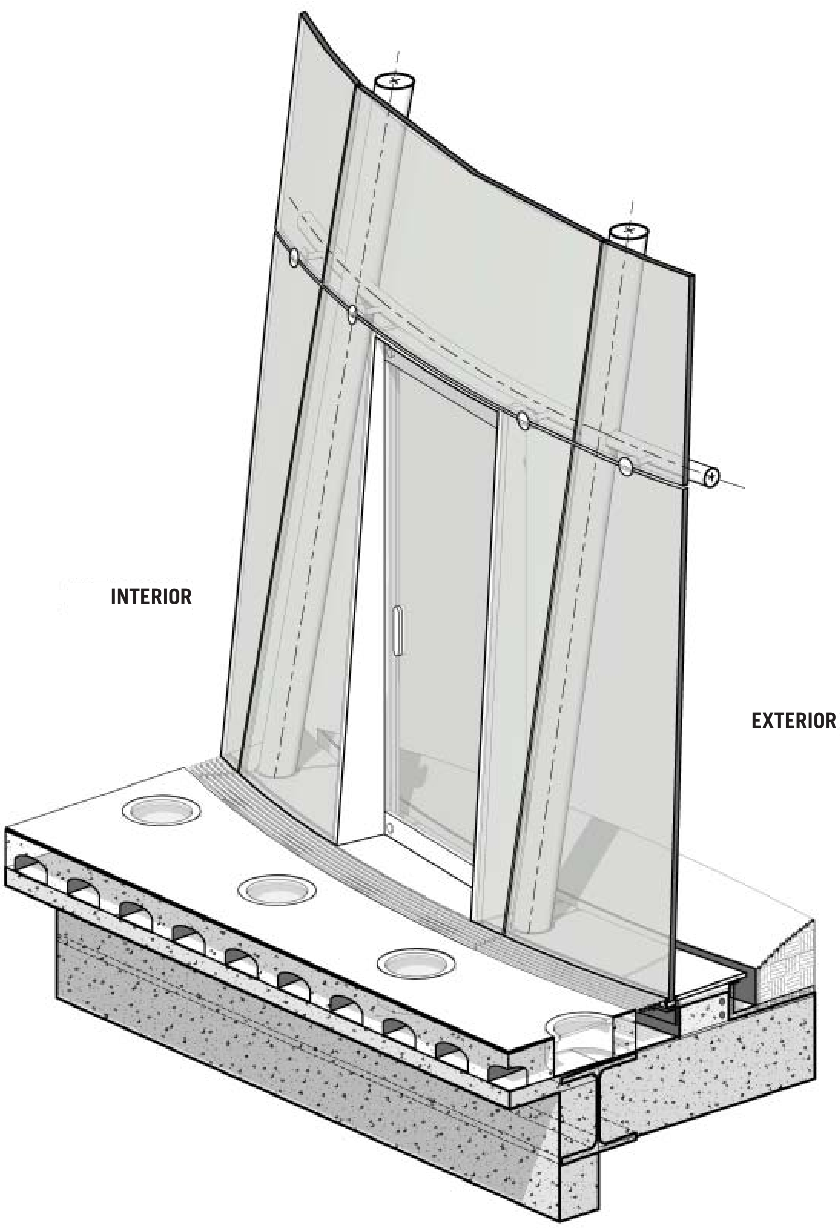

Figure 30: Terrarium access door.

4.0 CONCLUSION

This article reviewed in detail the design, building performance analyses and solutions to technical challenges that were encountered during the design of the Entry Pavilion. Sustainable design strategies, which were identified as a possible method for meeting the Living Building Challenge, were discussed in detail in the second part of the article. Also, different building performance studies that were performed during the design process were presented. These included solar exposure studies for the roof garden of the Entry Pavilion, double skin facade analysis, investigation of solar access for different facades and daylighting analysis for the terrarium and the interior space of the Entry Pavilion. The last part of the article discussed technical challenges that were encountered during the design of the terrarium due to its complex, unique geometry and location within the Entry Pavilion.

Complex facilities that are being designed and constructed today require integrated design, research, analysis and smart approach for solving technical issues. With environmentally-friendly use of resources and architecture that enhances the experience of those who inhabit and use it every day, the new Rush University Medical Center campus has transformed into an exciting new setting for the delivery of 21st century healthcare. The Entry Pavilion is the front door of this medical campus and was designed to provide an exceptional experience to the patients, visitors and medical staff. The unique design features of the Entry Pavilion, such as the roof garden, terrarium and large open space are meant to provide welcoming, healing environment to the patients and an improved working environment for the medical employees. These design features were intended to improve building performance, but also satisfaction, productivity and performance of building occupants. Further research would be required to analyze actual occupants' satisfaction and performance by administering post-occupancy evaluations.

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