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Ryerson University
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Multifamily Residential Building
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Executive Summary

This project is the culmination of design decisions and extensive research developed by the Multifamily Residential Building team from Ryerson University. The site has a total floor area of 2800 m² and is located at the northeastern intersection of Dundas Street and Mutual Street in Toronto, Ontario, Canada. It features a five-story residential and commercial mixed-use building with very high-performance metrics, reaching Passive House levels in several criteria. This was achieved by preserving the existing commercial building, which is not accounted for in project data, and instead of building over and around, it is using a modular construction design. This form of construction allowed the team to create unique and efficient design choices without the need to account for carbon costs from complete demolition or renovating existing structures.

The team had many goals in mind for the project, with major ones being occupant comfort (IEQ, internal environmental quality), affordability, community support, durability, and resilience, low embodied carbon, energy efficiency, and many more. The modular prefabricated units would become the hallmark of achieving everything the team needed. This design choice allowed for each modular unit to be standardized with an air-tight and highly insulated facade, which is placed and set in a formation that allowed for green spaces and other amenities within the building itself.

Following the guidelines and Contests set by the 2022 Design Challenge Rules (U.S Department of Energy), this report follows a rigid structure in its presentation. Each category in this report is an attempt to explain and rationalize the decisions made according to the contest's challenge criteria.



Figure-1: Building from Mutual Street

1.0 Introduction

1.1 Location and Target Market

The project is a five-story multi-family housing building with commercial spaces at the street level, located in downtown Toronto, in the Church-Yonge neighborhood, at the north-eastern intersection of Dundas Street and Mutual Street. The area supports mid-rise to high-rise mixed-use buildings residential and commercial that serve the universities (Ryerson and the University of Toronto) and George Brown College. Therefore, the target market (occupants) of this project is mainly, students and small families of 2-3 people.

The site (152&153 Dundas St.) is within zoning by-law CR4.0(c2.0r4.0)SSI x1728. The site area is (2,800m²/30,139ft²), with dimensions of (82m x 34m, 269ft x 111.5ft).



Figure-2: Downtown Toronto



Figure-3: Site Location

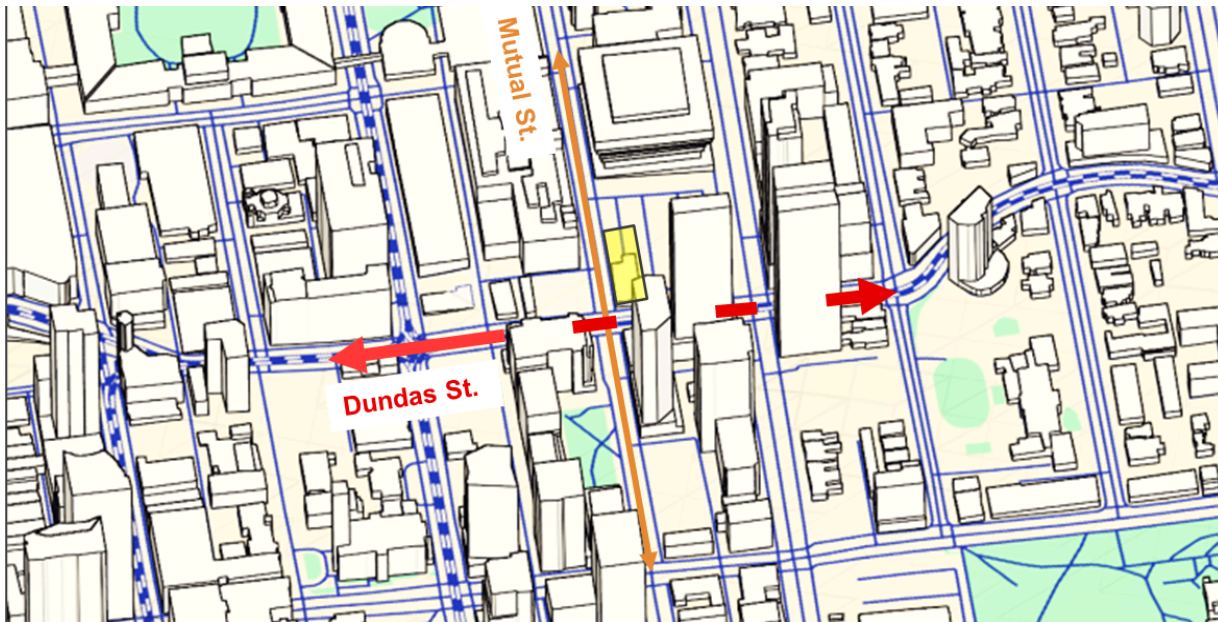


Figure-4: Mixed-use mid-to-highrise buildings surrounding



Figure-5: Approaches to the site from Dundas-West



Figure-6: Approaches to the site from Dundas-East



Figure-7: Approaches to the site from Mutual-North



Figure-8: Approaches to the site from Mutual-South

1.2 Climate

Toronto city is within the climatic zone 5A. Based on the climatic charts of Toronto, the following weather patterns mostly affect the design of the building:

1-Highest Temperatures are in July, lowest in January

2-The chance of rain is year-round, with the highest chance of 31% in mid-June, and the lowest in January when the chance of snow is the highest.

3-Comfort Humidity ranges between 55% to 75% (Mid-June to Mid September)

4-Wind Direction is mostly from the West at 50%, Hot wind from the South, and cold wind from the north

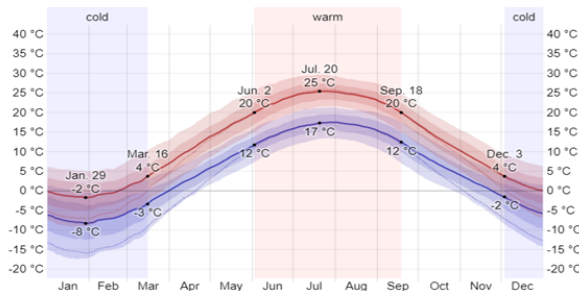


Figure-9: Temperature

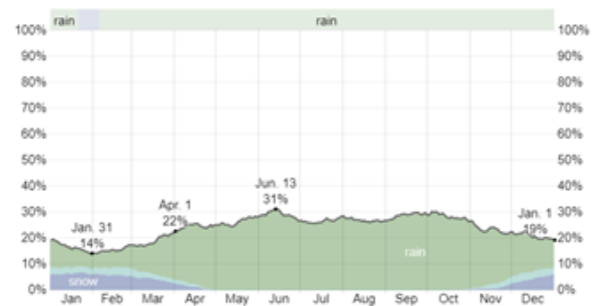


Figure-10: Rain

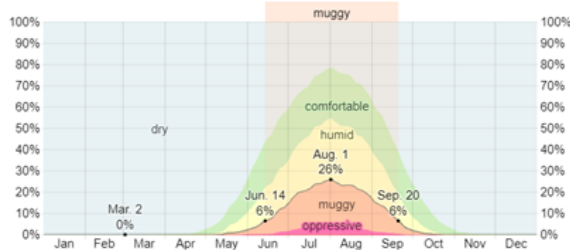


Figure-11: Humidity

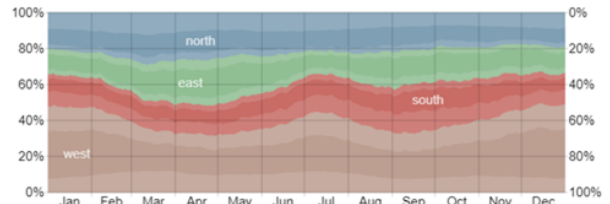


Figure-12: Wind Direction

1.3 Applicable Standards and Codes

1 - National Building Code of Canada

2 - Ontario Building Code

3 - City of Toronto - Zoning By-laws

4 - Canadian Standards Association (CSA)

5 - Toronto Green Standards (TGS) - Version 4

6 - National Energy Code of Canada for Buildings 2017 (NECB)

7 - Zero Carbon Building – Performance Standard Version 2 (ZCB-Performance v2)

2.0 Architecture

2.1 Project Objectives

- High performance with goals of zero net energy and positive embodied carbon over its lifecycle
- Relatively affordable compared to the overall expensive Toronto housing market
- Accessibility options of various kinds to public facilities and occupant units
- Proper installation practices, specific material choices, and safe transportation of module units were studied and used to ensure longevity and high durability
- A resilient site that could withstand numerous unprecedented events
- Supporting the community with the introduction of spaces for the general public

2.2 Example Challenges Encountered

- Adding new development on top of already existing infrastructure
- Managing construction on a high-traffic site while also reducing embodied carbon
- An aesthetically appealing exterior while maintaining high-performance metrics and occupant comfort
- Produce renewable energy onsite using our limited, relatively compact, roof area on a site shaded by high-rise buildings from the south

2.3 Our Solutions

- Opting for a modular design structure to make ease of construction and transportation while having very little to no intrusion into existing infrastructure
- A modular design structure also allowed for freedom in creating an aesthetically appealing facade for both the exterior and interior
- Self-contained and insulated residential units with amenities on site.
- Utilizing the latest technology of dual-axis tracking solar system (COGenerate) to maximize the energy production to cover required loads

2.4 Design Concept

- 1 - Preserving the existing building on site and integrating it within the new design.
- 2 - Building with modular, volumetric, prefabricated units to minimize the construction time on site, control the quality, and manage waste.
- 3 - Designing with sustainability and high performance in mind by targeting Zero-Energy and Zero-Carbon standards.
- 4 - Creating a central space at the street level for the community to interact with the commercial activities within the development.



Figure-13: Existing Building on site

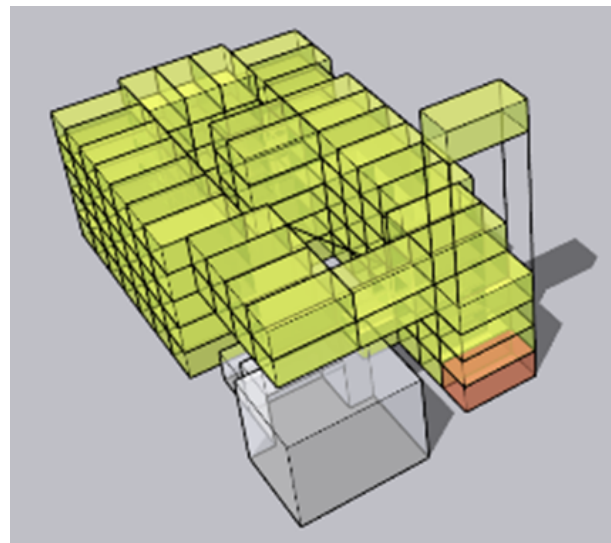


Figure-14: Modular volumetric prefab-units

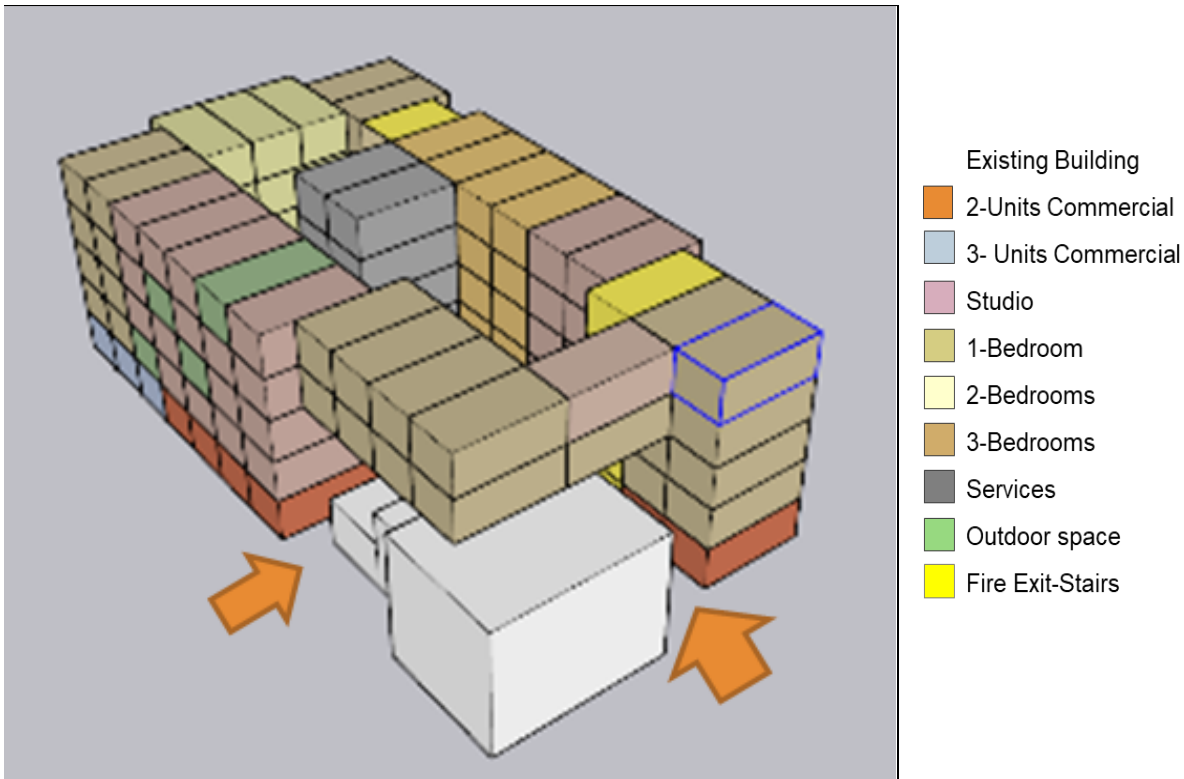


Figure-15: Modular volumetric prefab-units(Right) entrances to the public space at the street level next to the existing building

2.5 Project Program

The project building consists of five floors and a basement, for storage purposes, which total an area of **6705 m²**, and a footprint area of **1127 m²**. 61% of the proposed project will be built off-site in a controlled factory environment and brought to the site as a modular volumetric unit, each sized (4.2 x 8.4 x 3.4m/13.7 x 27.6 x 11.2ft) for installation. The other 39% includes the basement, shear walls, corridors, and staircases that will be built on-site.

The module is based on the minimum studio unit area of 35 m². 74% of the modular units are used for residential apartments, 17% for commercial units, and 9% for services on each floor, including the mechanical and electrical room, garbage room, and janitorial room. The project residential units consist of thirty studios (one prefab unit), 14 one-bedroom apartments (two prefab units), 4 two-bedroom apartments (three prefab units), and 4 three-bedroom apartments (four prefab units) as shown in Table-1.

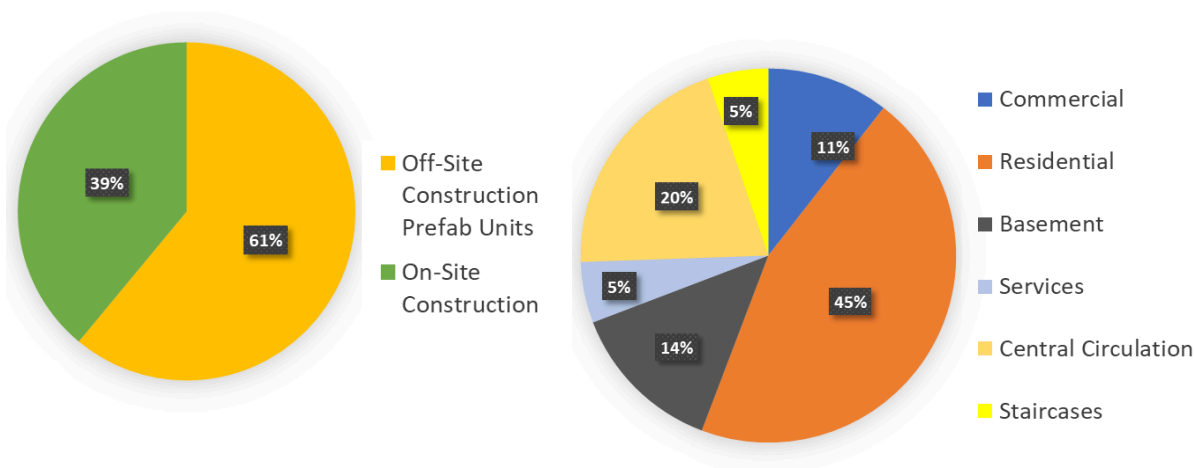


Figure-16: Off-Site Vs On-Site Construction

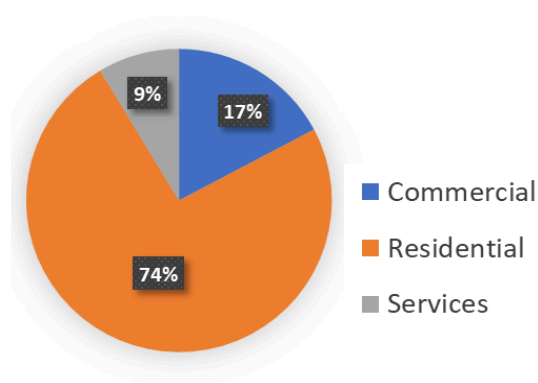


Figure-17: Mixed Use Breakdown

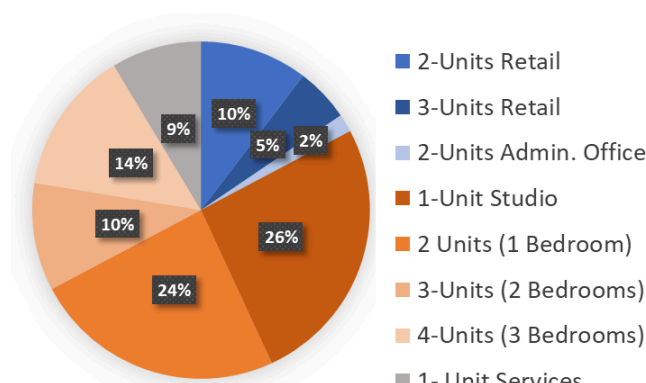


Figure-18: Modular Prefab Units per zone type

Figure-19: Modular Prefab Units Breakdown

Table-1: Project Areas

Space Type	Number	Number of Prefab Units	Area/Space (m2)	Type	Total Area (m2)
2-Units Retail	6	12	70.56	Commercial	423.36
3-Units Retail	2	6	105.84	Commercial	211.68
2-Units Admin. Office	1	2	70.56	Commercial	70.56
	9	20		Commercial	705.6
1-Unit Studio	30	30	35.28	Residential	1058.4
2 Units (1 Bedroom)	14	28	70.56	Residential	987.84
3-Units (2 Bedrooms)	4	12	105.84	Residential	423.36
4-Units (3 Bedrooms)	4	16	141.12	Residential	564.48
		86		Residential	3034.08
1- Unit Services	10	10	35.28	Services	352.8
	71	222		Off-Site Construction	4092.48
Basement			900		900
Public-Gr			350.677		350.677
Public-1-2			231.26		462.52
Public-3-4			273.85		547.7
Staircase			23.477		352.155
				On-Site Construction	2613.052
				Total Project Area	6705.532

2.6 Sustainability

The design of the project considers the triple bottom line of sustainability: people, planet, and profit. It is designed to be affordable for prospective homebuyers located in downtown Toronto who are also dependent on public transportation, such as students who attend post-graduate studies, young people working in the city center, seniors who prefer to live in an accessible building with short walking distances to essentials, small families of two to three, and families of four to six who prefer to live downtown. Moreover, the commercial activities at the street level are open to the public.

As for the planet, the project makes use of natural local resources at a low cost. FSC-Certified wood and solar panels are especially to note as they are used for generating electricity, which ultimately minimizes the overall carbon footprint and brings the development to net-zero energy.

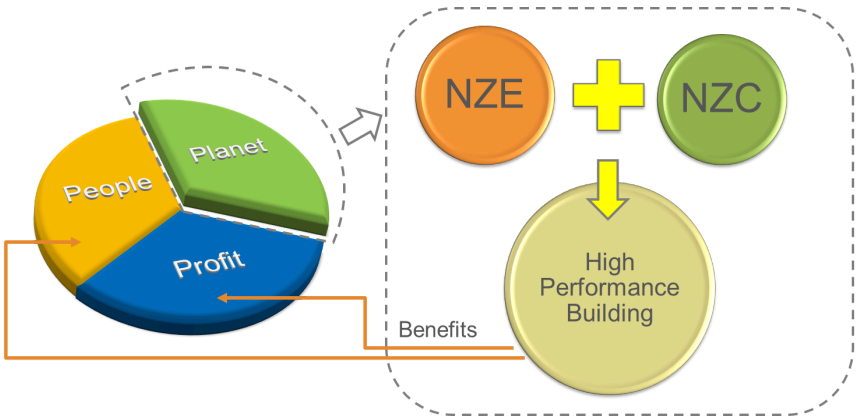


Figure 20: Sustainability and NETZERO as related to High-performance buildings

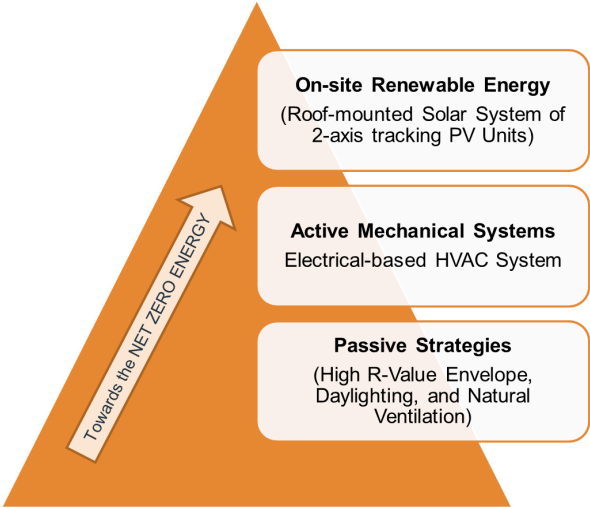


Figure 21: Net Zero Energy Framework

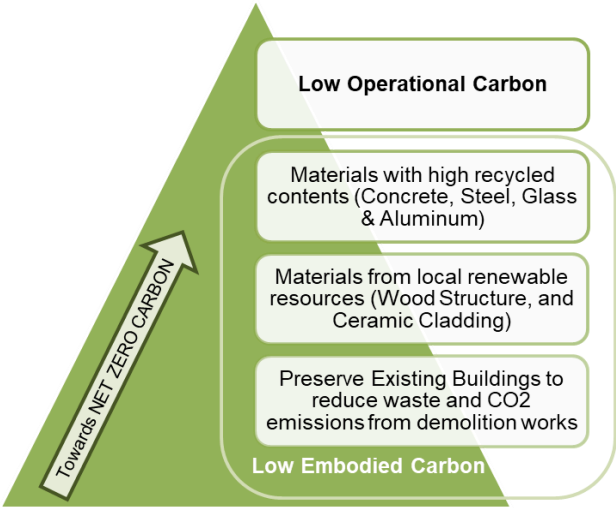


Figure 22: Net Zero Carbon Framework

2.6.1 Towards Net Zero Energy:

The design is based on maximizing the passive strategies related to the building envelope, natural daylight, natural ventilation, minimizing the use of mechanical systems, and generating the required energy on-site through a roof-mounted solar system.

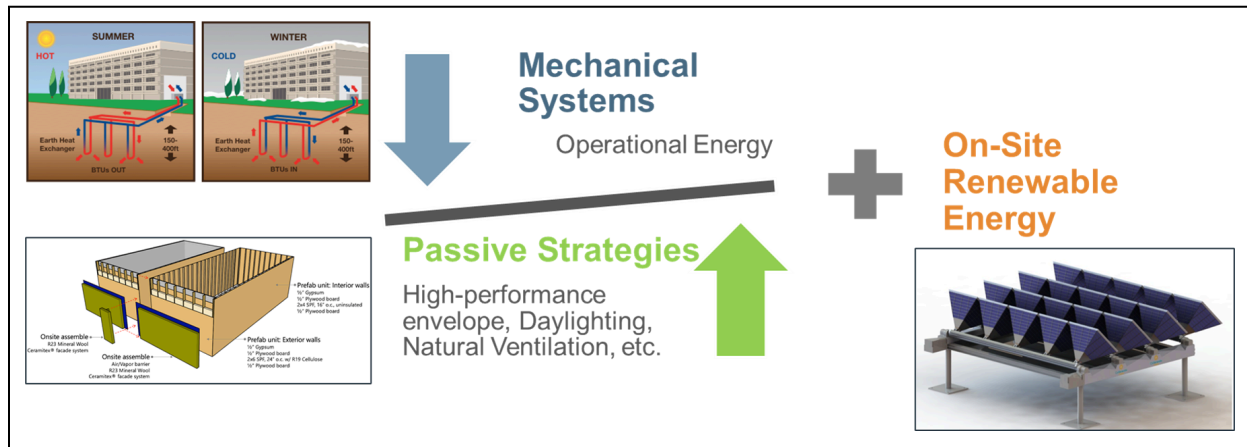


Figure 23: Net Zero Energy Framework¹

2.6.1.1 Passive Strategies

- 1 - Self-contained prefabricated units provide control of airtightness and heat transfer (R-Value) through the envelope.
- 2 - The atrium separates the residential thermal zone from the commercial thermal zones, circulates the air in the building, and provides daylight through north-facing clerestory windows on the roof.
- 3 - The existing building has a separate thermal zone and is not included in the current analysis. It might be upgraded in the future, but that is not within the scope of this project.
- 4 - Continuous insulation and ceramic cladding panels with high thermal mass wrap the building envelope
- 5 - Window-to-wall ratio (WWR) is 25% on the east, west, and north facades and 40% on the south facade.
- 6 - Windows and curtain walls are triple glazed and have an R-value of 7 ft²·°F·h/BTU
- 7 - Each window has an operable panel for natural ventilation in good weather
- 8 - Outdoor spaces on each floor with biophilic aspects to make up for the lack of balconies and to filter the air
- 9 - Shading canopies over the doors and commercial-level windows in the south, east and west facades to protect from sun and rain.
- 10 - Wood structure (FSC-certified) with a high thermal mass that preserves heat and requires less heating/cooling loads.

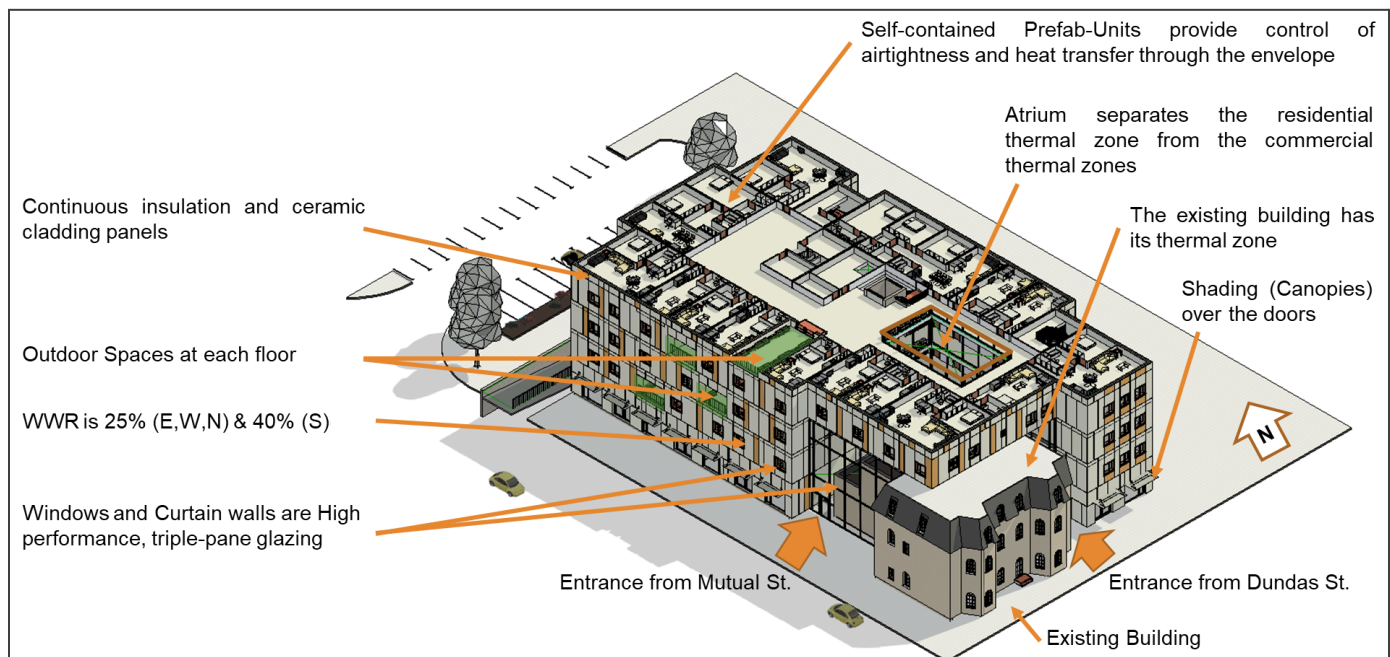


Figure 24: Summary of the passive strategies used

¹ <https://www.nachi.org/gallery/heating/ground-source-heat-pump-1>

2.6.1.2 Active Strategies (Mechanical Systems)

The interior space is divided into 5 main thermal zones: residential, commercial, central public space and atrium, the unconditioned basement and services, and the existing building zone that is separate and not part of the energy study.

A geo-exchange energy system will be utilized for the heating and cooling systems. Pipes will be installed under the parking lot along the eastern side of the building.

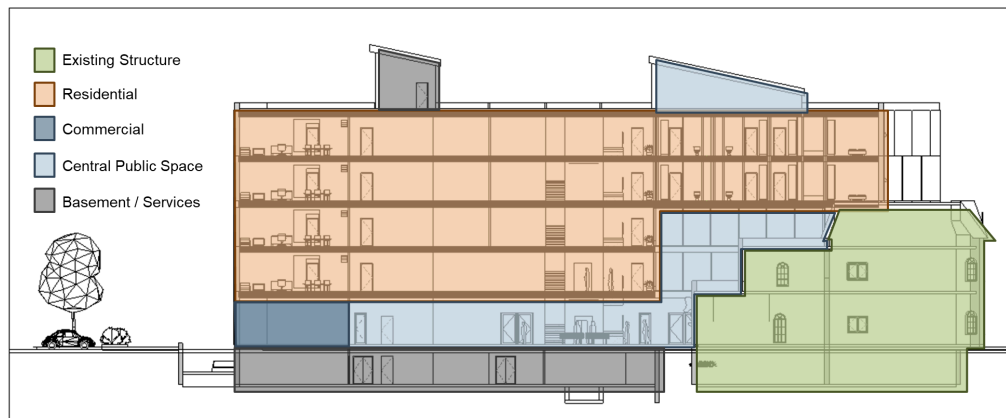
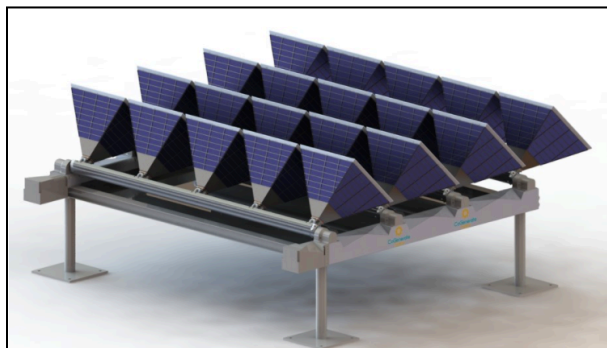


Figure 25: Thermal Zones

2.6.1.3 On-Site Renewable Energy

The project is located in downtown Toronto and is surrounded by high-rise buildings. The main facade that captures sunlight is shaded by a tall building from the south, so the patented dual-axis, micro-tracking technology with secondary optics of CoGenerate will be used to provide over 35% PV efficiency and 50% thermal efficiency. This technology captures 4 to 6 times more solar energy from the same rooftop compared to standard flat panels. Using the thermal energy captured for cooling cuts the demand for electricity by 30% in Ontario (CoGenerate, n.d.).



Figures 26 and 27: COGenerate Roof-mounted Solar System (CoGenerate, n.d.)

2.6.2 Towards Net Zero Carbon:

Achieving the Zero Carbon target depends on both the embodied carbon of the materials used in the project and the operational carbon throughout the building's life span.



Figure 28: Net Zero Carbon Framework ²

2.6.2.1 Low Embodied Carbon

Most of the materials used in the project are from renewable resources, such as:

- FSC-certified wood for the structure
- Cradle-to-cradle ceramic cladding
- Ceramic tiles for bathroom floor and shower walls
- Bamboo flooring for all the living spaces and bedrooms in the residential apartments
- High-quality ceramic tiles for the public circulation space

Other materials are of high-recycled contents, such as:

- ECOPact low-carbon concrete (LAFARGE, n.d.) for the foundation
- Aluminum for the curtain wall and window outer frames in Alu-wood systems, Aluwood is suggested for higher thermal efficiency, and to reduce the amount of aluminum by replacing the interior part of the frame with wood.
- All the exterior and interior glazing of the project should contain some recycled contents

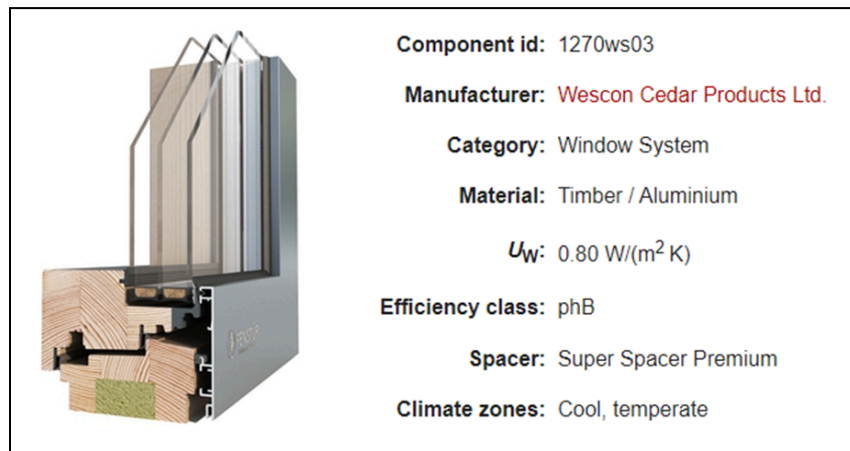


Figure 29: High-Performance windows of Alu-wood system (Passive House Component Database, n.d.a)

² <http://www.keepbanderabeautiful.org/photov3.jpg>
<http://www.cybermoja.byethost13.com/wp-content/uploads/2012/02/fsc-hardwood-shutters2.jpg?i=1>
<https://www.gannett-cdn.com/-mm-/6bd01fb943fc4c0479ab8c7947c572f7d77f803e/c=0-237-5184-3166/local/-/media/2017/09/05/NJGroup/AsburyPark/636402051449033252-bamboo.013.jpg?width=3200&height=1680&fit=crop>
<https://www.jdogjunkremoval.com/wp-content/uploads/2018/03/scrapmetal.jpg>
http://2.bp.blogspot.com/-DYN-sZz5T4A/Tdn9cYE_eGI/AAAAAAAAABk/-Uc7m6lcTU/s1600/concrete_building_material_recycling.jpg

2.6.2.2 Low Operational Carbon

The project is designed to achieve net-zero energy by minimizing energy loads and using natural energy resources, such as geo-exchange for heating and cooling. Solar energy will be used to offset the required energy, so no energy is pulled from the grid and no carbon will be emitted from the operational processes.

2.7 Parking Requirements

The number of parking spots required for the building is calculated as per the City of Toronto Zoning By-law 569-2013 (City of Toronto, 2021) as follows:

- (B) If a building has more than 12 dwelling units or 12-bed sitting rooms or is located on a lot that has a lot frontage greater than 12.5 meters, then parking spaces must be provided at a minimum rate of:
- (i) 1.0 for each 6 bed-sitting rooms; 28 unit = 5 cars
 - (ii) 0.5 for each bachelor and one-bedroom dwelling unit; 14=7 cars
 - (iii) 0.75 for each dwelling unit with two or more bedrooms; 8= 6 cars
 - (iv) 0.06 for each dwelling unit and used for visitor parking. [TO: 438-86; 4(3)] 46=3cars

The total required parking lots are 21 for (regular cars), the project offers 23 lots of which 2 are used for accessible spots.

2.8 Architectural Drawings

2.8.1 Site Plan & Views

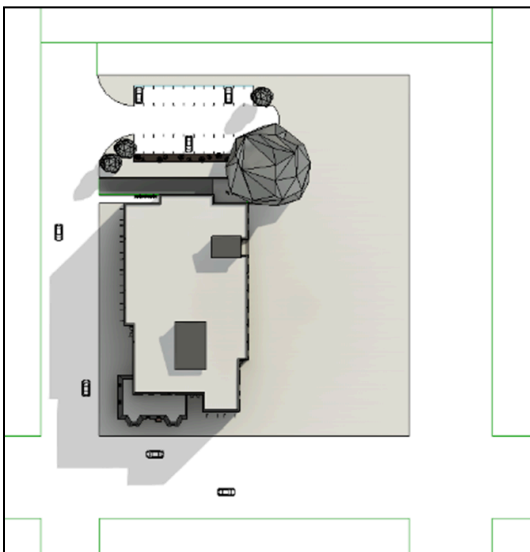


Figure-30: Site Plan



Figure-31: Image from Mutual Street- Back Corner

2.8.2 Floor Plan

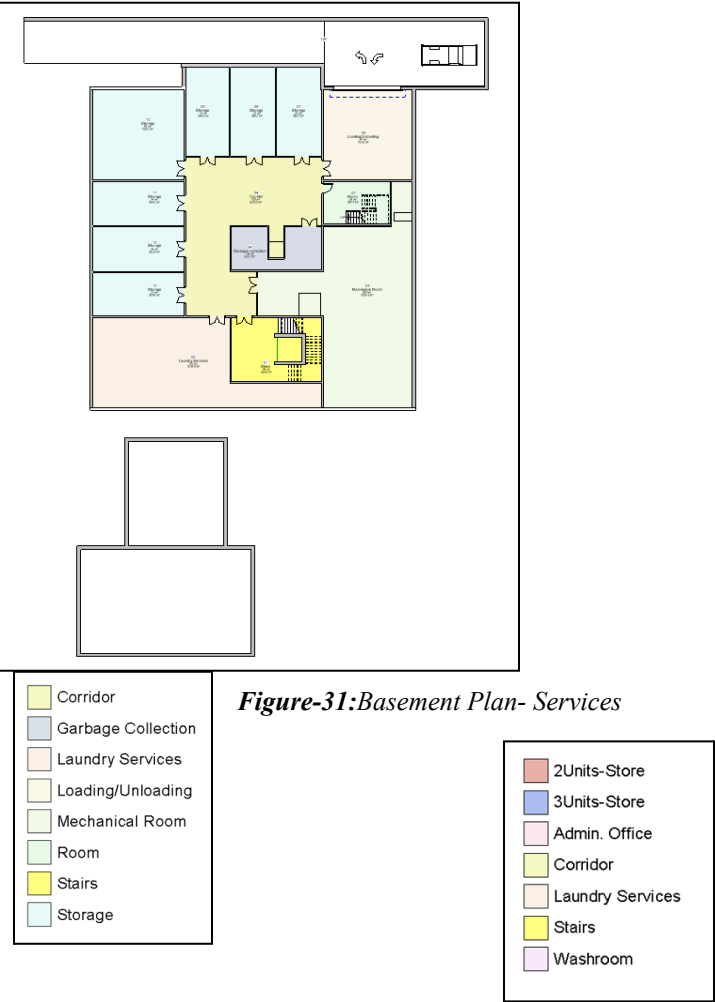


Figure-33: Ground Floor Plan- Commercial Zone

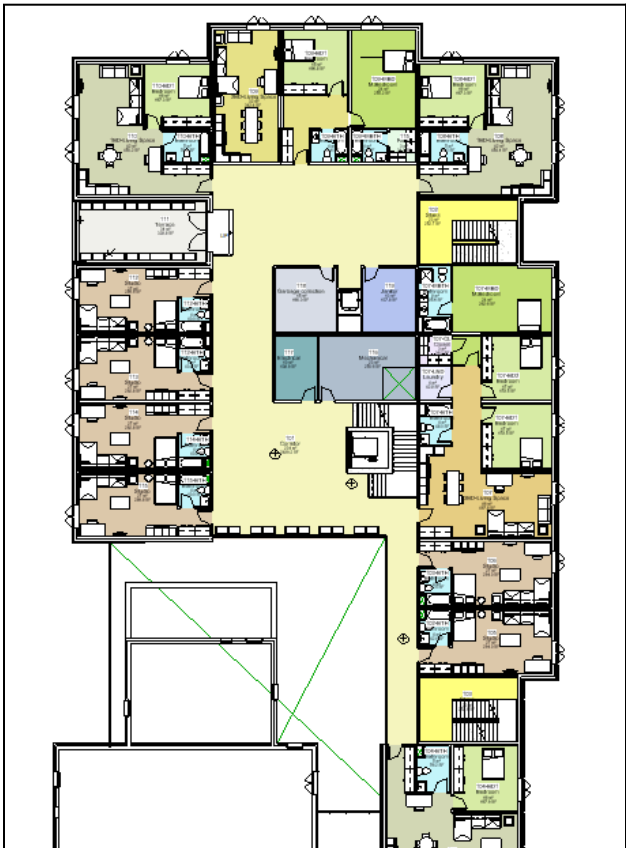
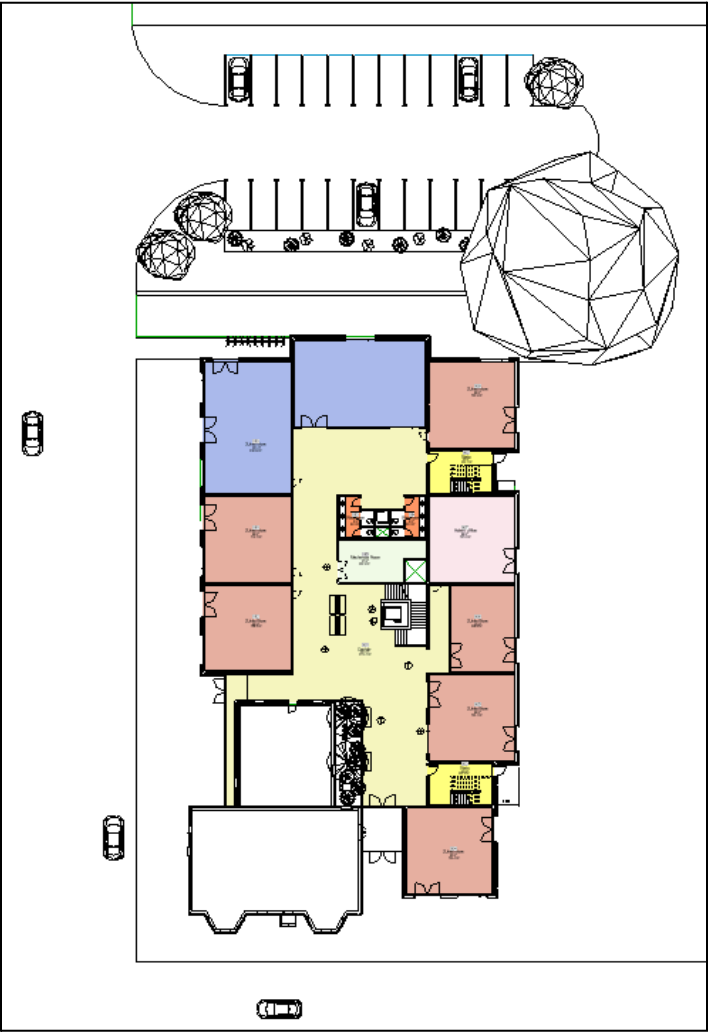


Figure-34: Levels 1&2 - Residential Zone

Figure-35: Levels 3&4 - Residential Zone

2.8.3 Residential Units- Space Layout

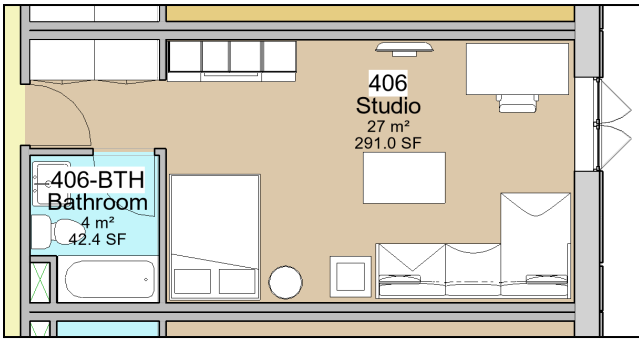


Figure-36: One-Bedroom Apartment layout

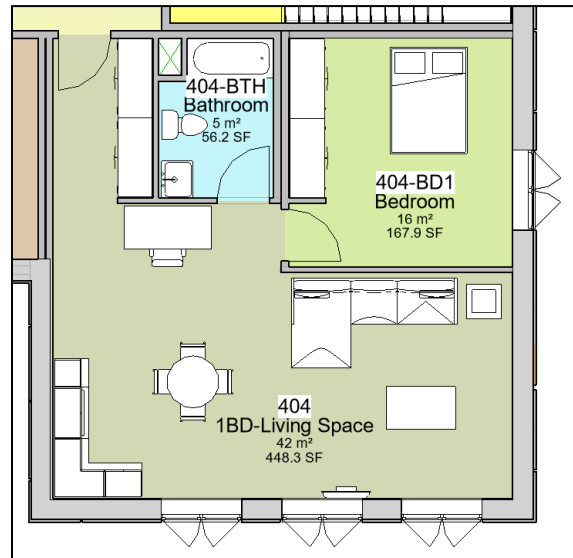


Figure-37: Studio Layout

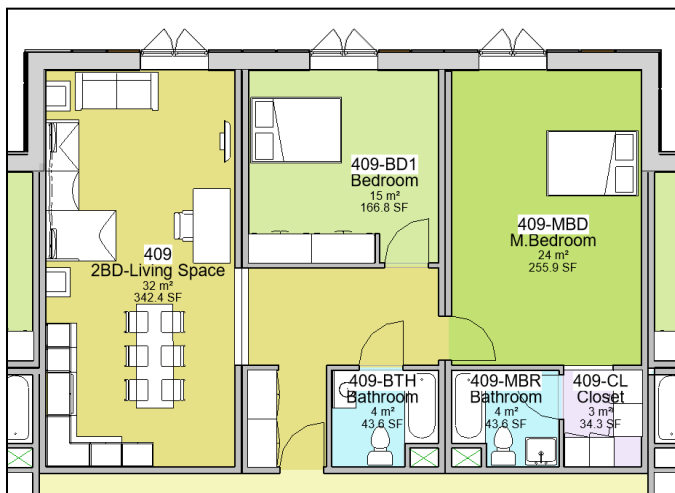
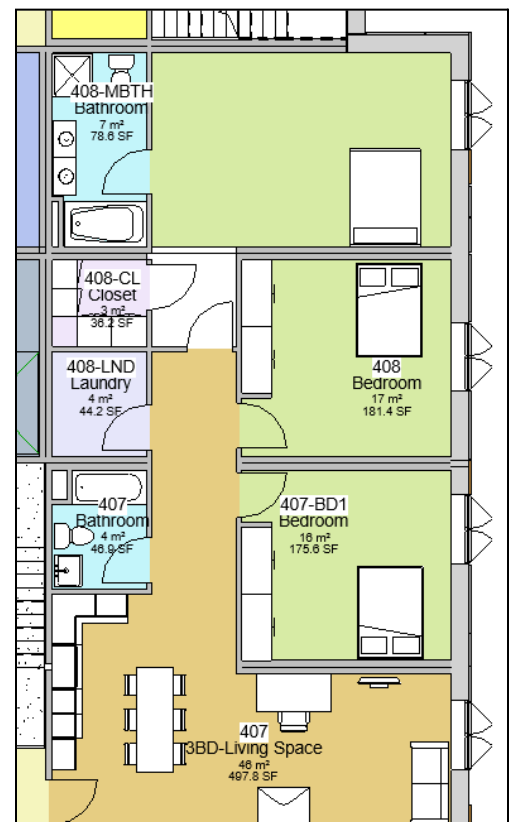


Figure-38: Two-Bedroom Apartment Layout



3. Engineering

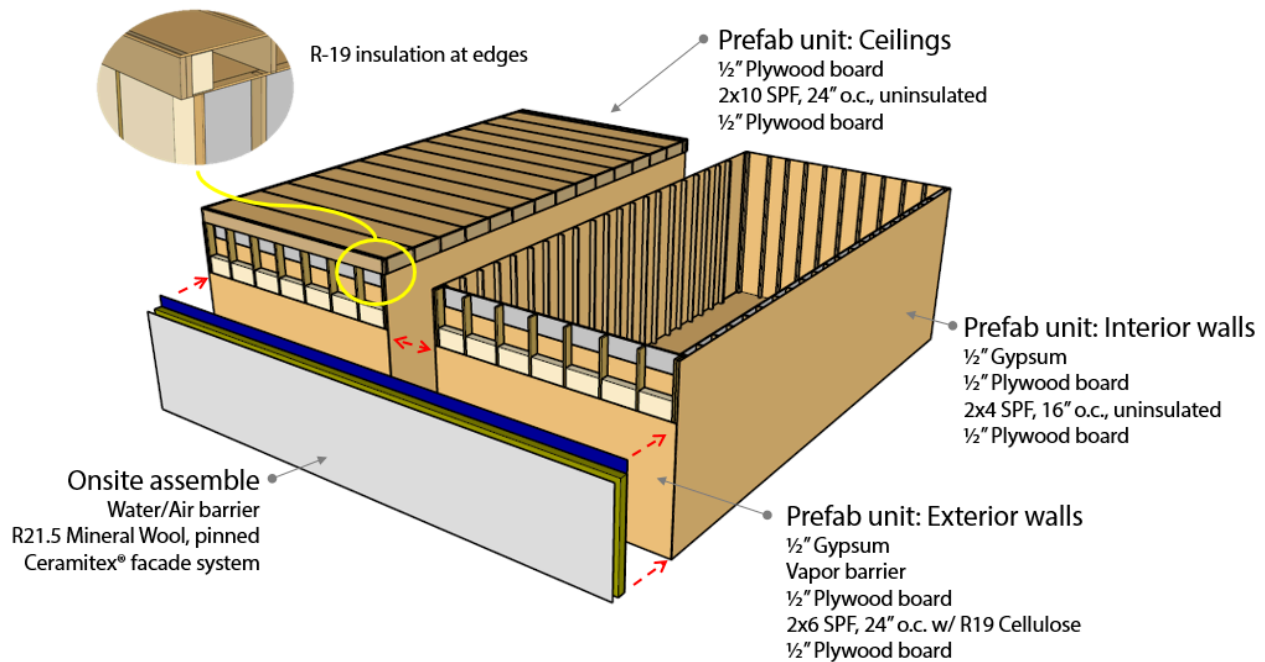
3.1 Building Envelope

3.1.1 Envelope Design

The thermal performance and airtightness of the building enclosure play significant roles in whole-building energy efficiency. Regarding Building Envelope Thermal Bridging Guide Version 1.6 and Passive House Component Library, the effective thermal resistance values (R-value) of the building envelope are designed as:

- Exterior walls: R-37.5
- Roof: R-62
- Foundation: R-22
- Windows: R-7
- Curtain walls: R-7

The figures below show the prefabricated units and the processes of vertical and horizontal assembling on-site.



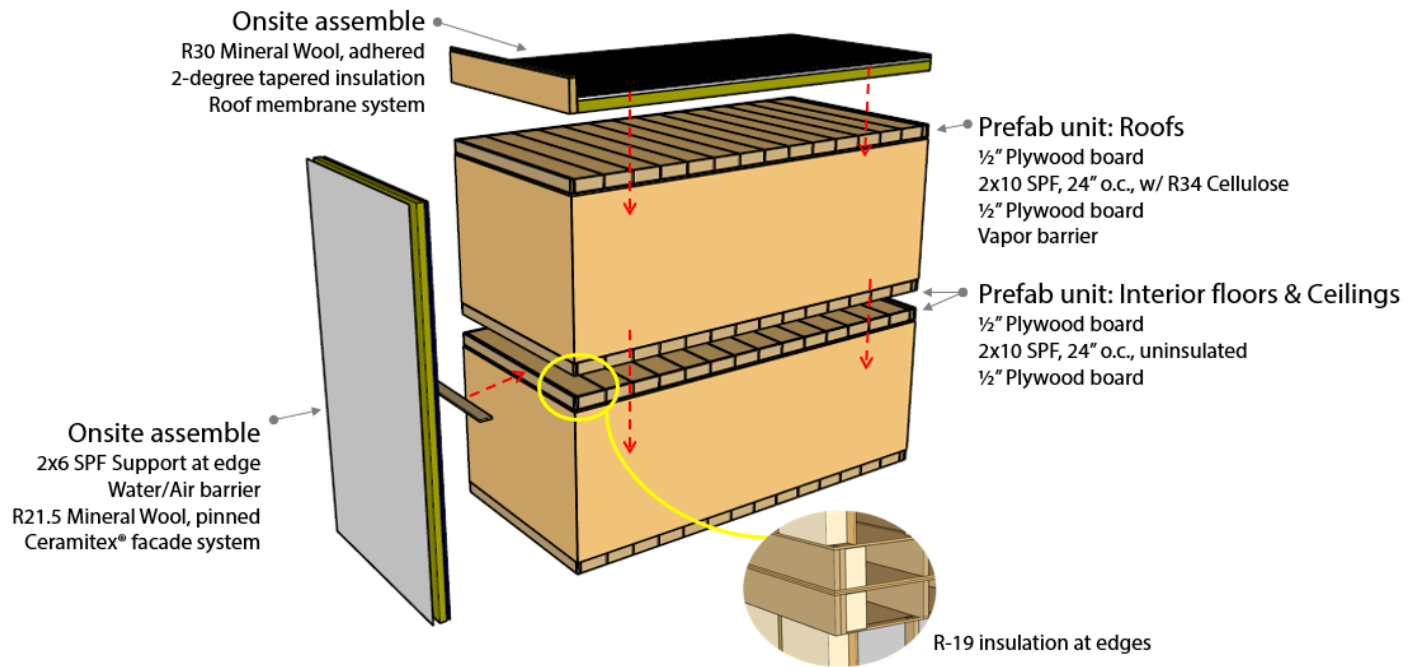


Figure-40 & 41: Horizontal, Vertical, and Roof Assemble of Prefabricated Units

Table 2- Envelope Components

Envelopes	Components
Exterior walls	- ½" Gypsum - ½" Plywood board - Vapor barrier - 2x6 SPF, 24" o.c. w/ R19 Cellulose - ½" Plywood board - Water/Air barrier - 5" Rockwool Cavityrock® (Rockwool, n.d.a) - ½" air cavity - Ceramitex® facade system (Elemex, n.d)
Interior walls	- ½" Gypsum - ½" Plywood board - 2x4 SPF, 16" o.c., uninsulated - ½" Plywood board - ¾" air cavity - ½" Plywood board - 2x4 SPF, 16" o.c., uninsulated - ½" Plywood board - ½" Gypsum
Roof	- ½" Gypsum - ½" Plywood board - 2x10 SPF, 24" o.c., w/ R34 Cellulose - ½" Plywood board - Vapor barrier - 8" Rockwool TOPROCK DD® (Rockwool, n.d.b) - 2-degree tapered insulation - Roof membrane system
Floor/Ceiling	- ½" Gypsum - ½" Plywood board - 2x10 SPF, 24" o.c., uninsulated, with R-19 at edges connected to exterior walls - ½" Plywood board

	- 1-½" air cavity - ½" Plywood board - 2x10 SPF, 24" o.c., uninsulated, with R-19 at edges connected to exterior walls - ½" Plywood board
Foundation	- 20" Concrete - R-20 XPS
Windows	- Triple glazed Wood-Alu Window with R-value of 7, manufactured in British Columbia (Passive House Component Library, n.d.a)
Curtain walls	- PHACTOR II Unitized CurtainWall by GAMMA with R-value of 7, manufactured in Ontario (Passive House Component Library, n.d.b)

Point thermal bridges from attaching the mineral wool insulation to the exterior wall substrate were estimated following Detail 8.1.8 from Building Envelope Thermal Bridging Guide Version 1.6. Point thermal bridges from the attachment of the Ceramitex® facade system are minimized by Thermally Broken EnviroClip®, a composite thermal clip system. The figure shows the concept of Thermally Broken EnviroClip® (Elemex, n.d.).

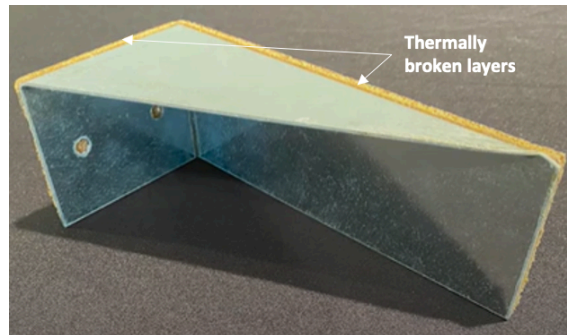


Figure-42: Thermally Broken EnviroClip® to install Ceramitex® Facade System (Elemex, n.d.)

3.1.2 Hygrothermal Performance

In Toronto, the east orientation of the building is subjected to the most driving rain and the south orientation of the building is subjected to the highest solar radiation. The hygrothermal performance of the exterior envelope on the east and south orientations was examined with WUFI for 5 years. Water absorbent materials, such as plywood, studs, and cellulose insulation all need to be kept dry to maintain their expected levels of performance. See the Figures below for water content variations of water-sensitive materials.

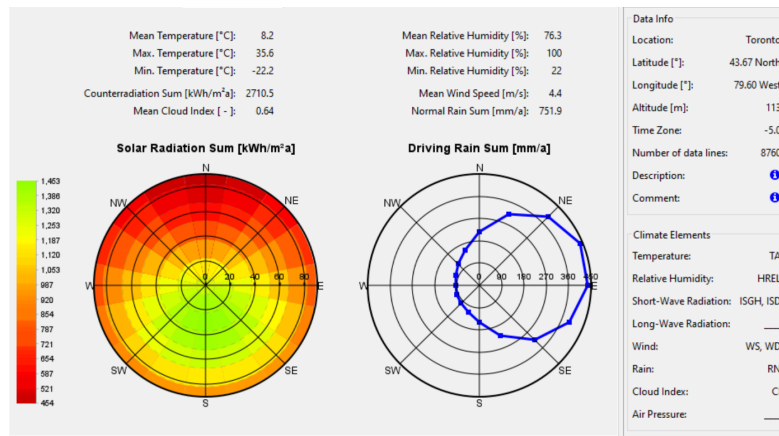


Figure 43: ASHRAE year 1 climate date from WUFI

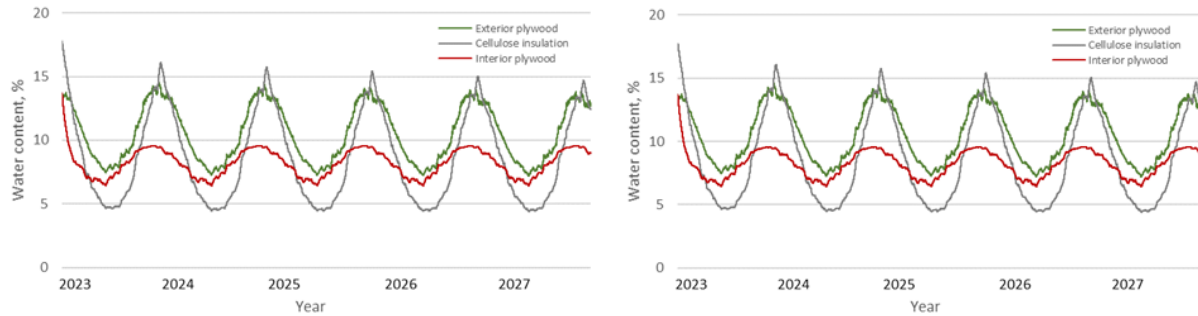


Figure-44a & 44b: Water content of materials on the east facade (left) and south facade (right) during 5 years

3.1.3 Airtightness and Waterproofing

Ensuring an air- and water-tight envelope is invaluable in maintaining a proper indoor environmental quality and mechanical system efficacy. To do this, continuous air and water barrier systems will be incorporated into the building envelope. Details of how fenestrations work with the barrier systems are shown in Figures 45 and 46 below.

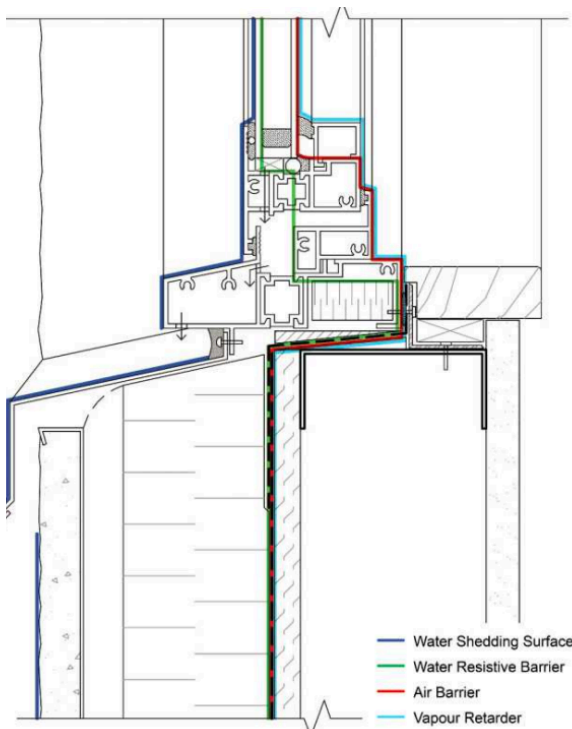


Figure 45: Barriers to a window (De Rose, 2022, p.9)

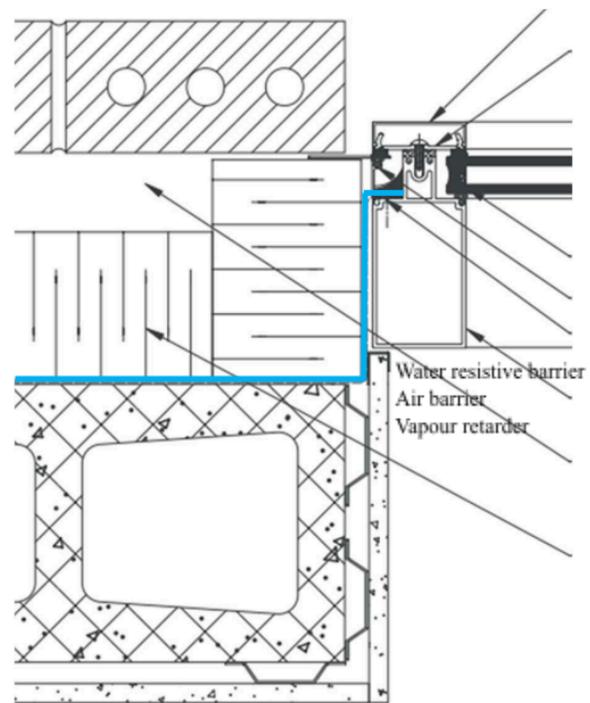
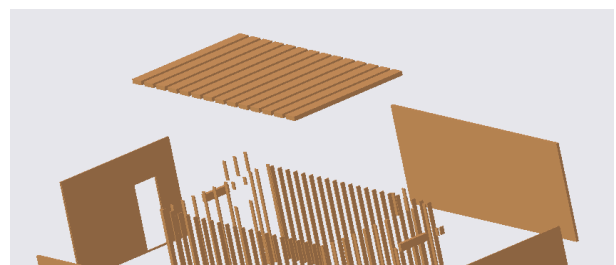
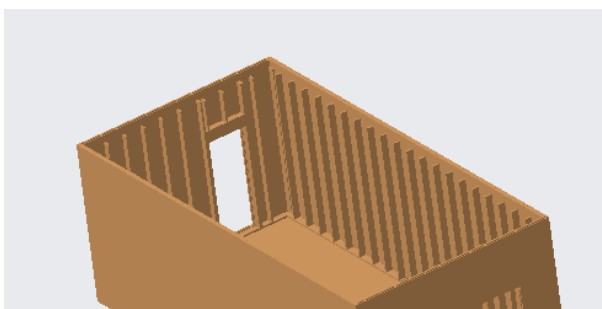


Figure 46: Barriers on a vertical curtain wall jamb (Canada Mortgage and Housing Corporation, 2004, p. 9)

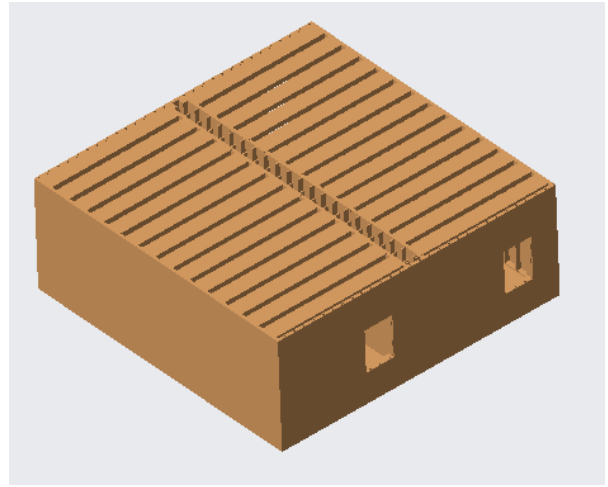
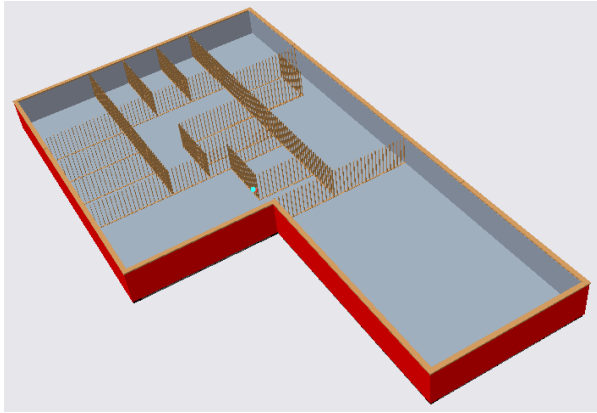
3.2 Structural Integrity

3.2.1 Assembly

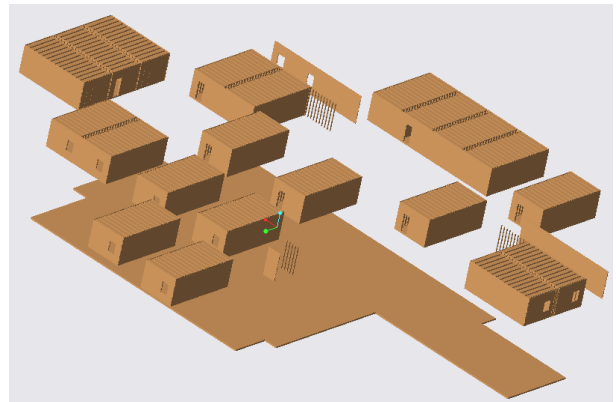
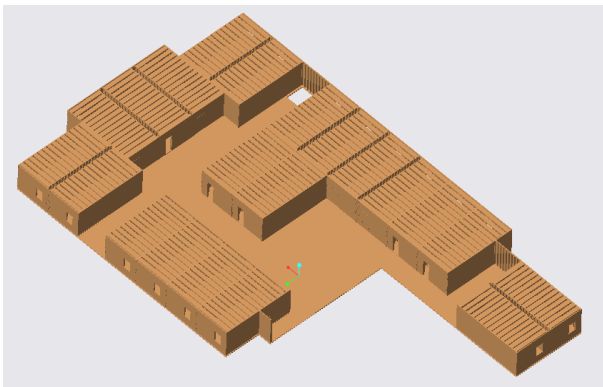
The structural assembly was created using PTC Creo, which allowed the model to be built up element by element. Each part was created in its file and assembled into gradually larger components of the building. The studs are 2"x4" glued laminated timber (glulam), the plywood is 3-layer cross-laminated timber (CLT), and the supportive beams and columns are 7"x7" glulam. The components which would be most devastating should they fail, the studio unit, which is then assembled into our larger units, and the third floor, were then analyzed using the finite element analysis software ANSYS.



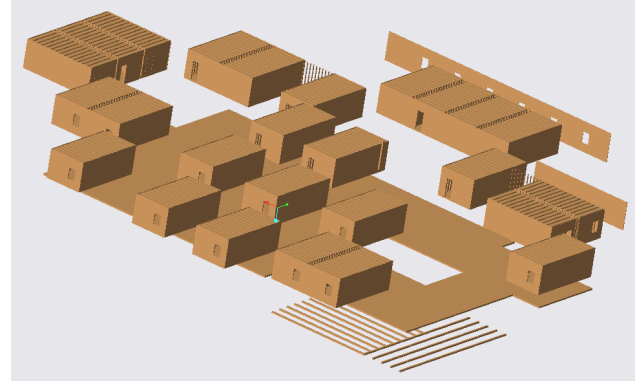
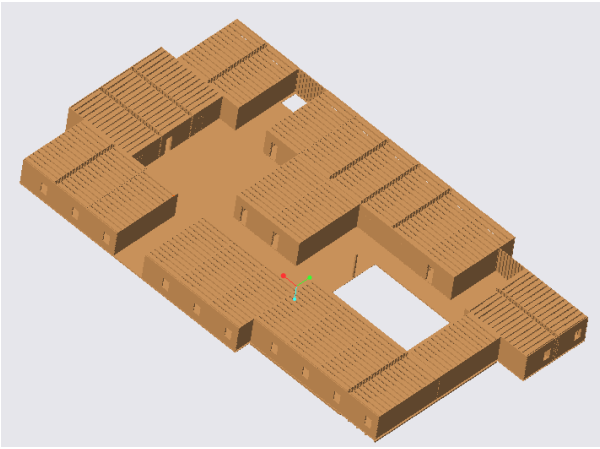
Figures 47 and 48: A perspective view and exploded view of the typical studio unit. The perspective view has no top to show the interior construction. Due to variations in the WWR and orientation, some units will have different window and door placements.



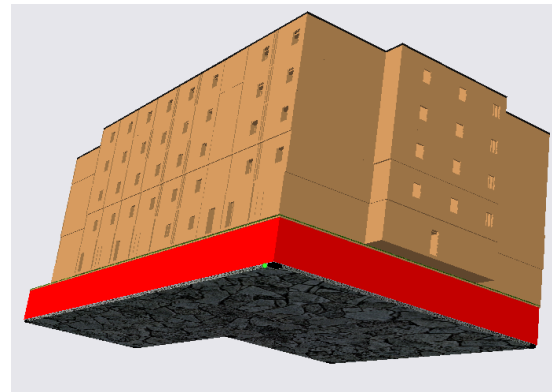
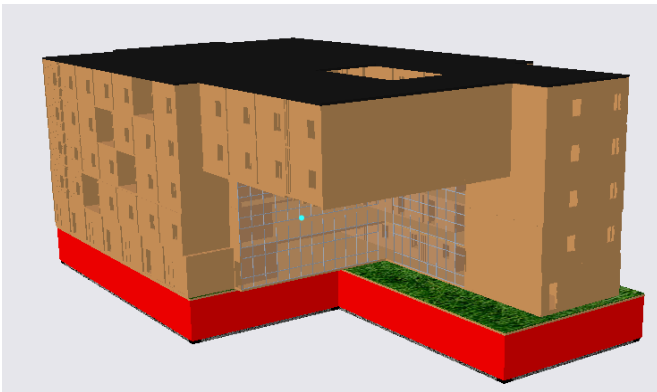
Figures 49 and 50: The layout of the basement and an assembled one-bedroom unit. The basement walls are reinforced with bamboo instead of traditional steel rebar. The concrete basement is reinforced with bamboo as a more carbon-efficient alternative to traditional steel rebar (Walker, 2014). It is assumed that bamboo is available in the same standard sizing as steel rebar; and Imperial size #14, and metric size #43, were used in the assembly.



Figures 51 and 52: A perspective view and an exploded view of the first residential floor



Figures 53 and 54: A perspective view and an exploded view of the third residential floor. The third floor has additional support, seen in Figure 49, to help support the cantilever over the existing building. These supports are 7"x7" glulam spaced 24 inches apart on-center.

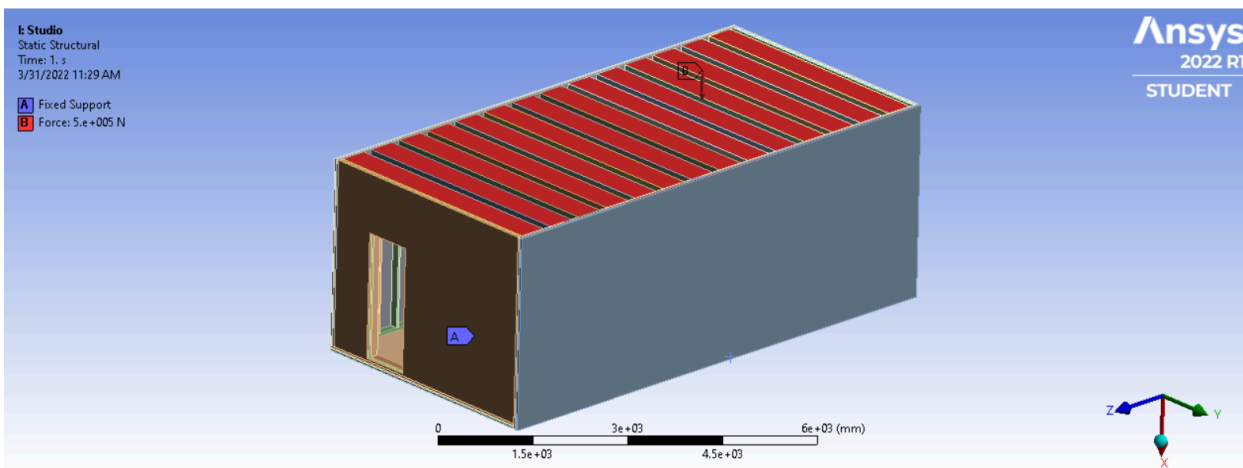


Figures 55 and 56: Perspective views of the front-top and back-bottom of the fully-assembled building. The curtain wall construction is based on Figure 2 from (Lee et. al., 2021)

3.2.2 Finite Element Analysis

Two key elements of the building were analyzed in ANSYS to ensure the structural stability of the building. All wood is modeled as bamboo. The layered nature of cross-laminated timber makes defining it in ANSYS very difficult, so choosing one consistent material makes the simulation run smoother.

3.2.2.1 Studio Unit



! Studio
 Total Deformation
 Type: Total Deformation
 Unit: mm
 Time: 1 s
 3/31/2022 12:01 PM

4.2265 Max
 3.7569
 3.2873
 2.8177
 2.3481
 1.8784
 1.4088
 0.93922
 0.46961
 0 Min

0 2e+03 4e+03 6e+03 8e+03 (mm)

Z
Y
X

ANSYS
2022 R1
STUDENT

ANSYS
2022 R1
STUDENT

I: Studio
Equivalent Stress
Type: Equivalent (von-Mises) Stress
Unit: MPa
Time: 1 s
3/31/2022 11:32 AM

18.695 Max
16.618
14.541
12.463
10.386
8.309
6.2317
4.1545
2.0772
8.935e-7 Min

0 3e+03 6e+03 (mm)
1.5e+03 4.5e+03

X Y Z

I: Studio
 Safety Factor
 Type: Safety Factor
 Time: 1
 3/31/2022 11:32 AM

15 Max
 10
 2.1235 Min
 0

0 3e+03 6e+03 (mm)
 1,5e+03 4,5e+03

X Y Z

Figure 60: The factor of safety does not fall below the threshold value of 1, which means that the studio, when loaded with 500,000 N, will not fail.

3.2.2.2 Third Floor Cantilever

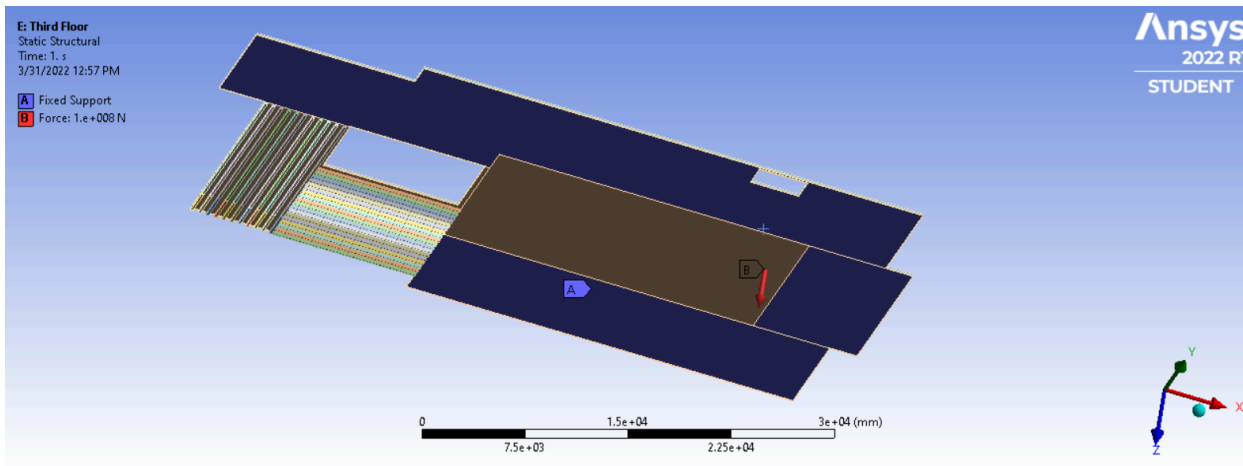


Figure 61: The support and force setup. The applied force is 100,000 kN (22,500 kip).

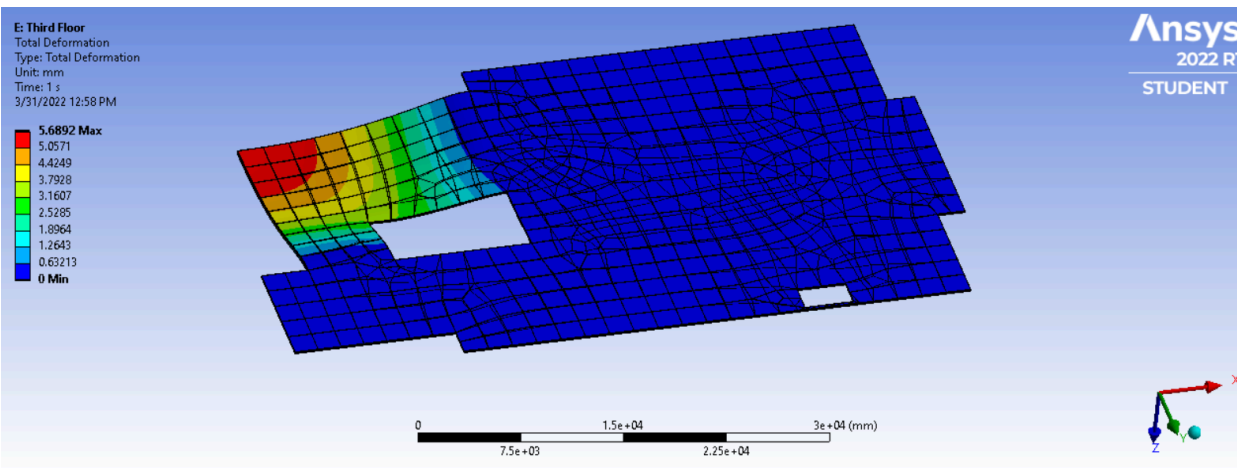


Figure 62: The total deformation is 5.6 mm (0.22 inches), located at the furthest part of the cantilever.

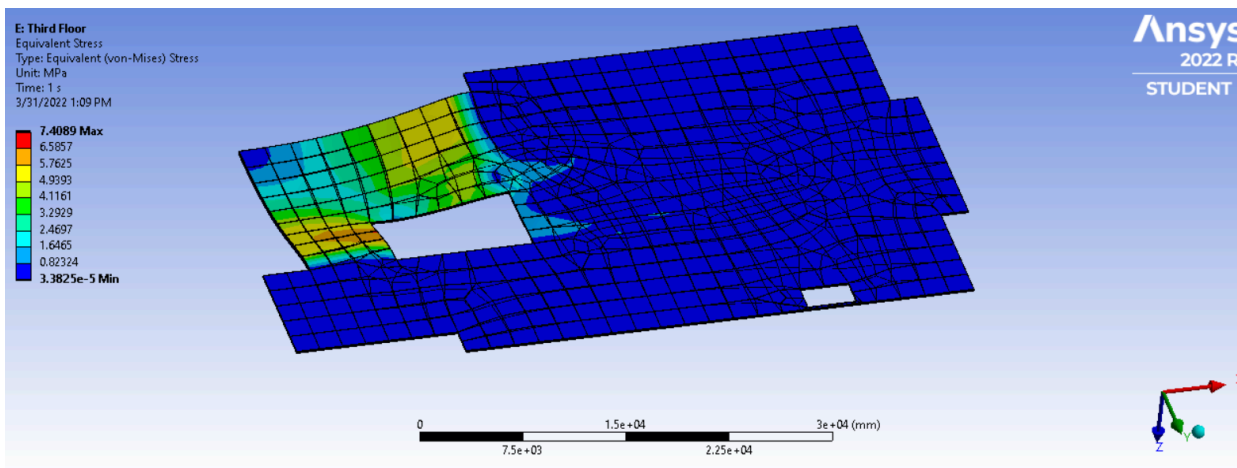


Figure 63: The maximum equivalent (Von-Mises) stress is 7 MPa (1 ksi).

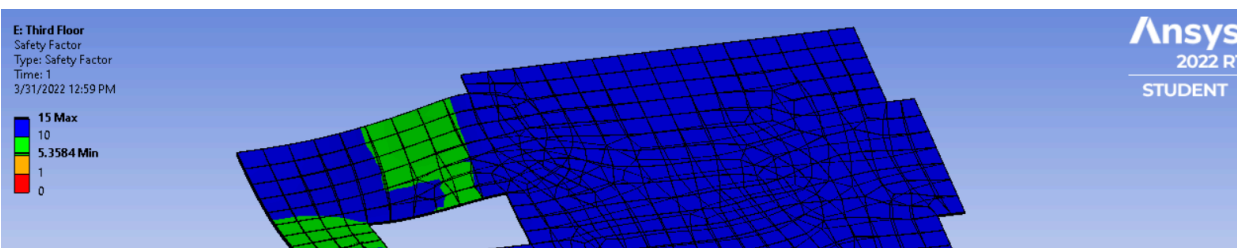
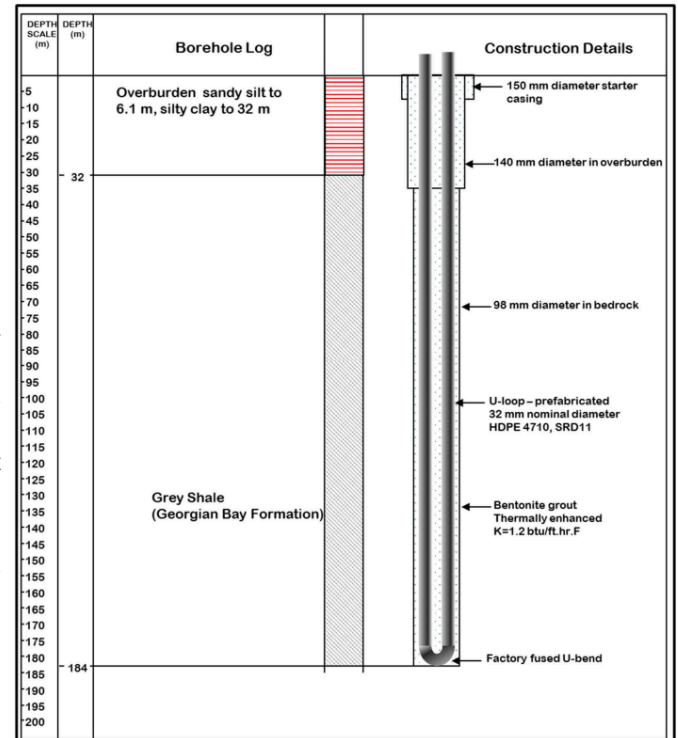


Figure 64: The minimum factor of safety is 5.7, 5 times the minimum threshold value of 1. The cantilever is at no risk of failing.

3.3 Electro-Mechanical Systems

3.3.1 HVAC

The HVAC system for this building is based on a ground-source heat exchanger (GSHX) system with vertical boreholes that will be drilled under the parking lot for easier maintenance access. The average length of GSHP boreholes in the Greater Toronto Area (GTA) is anywhere from 600 to 850 feet (183 to 260 meters) (Deweerd, 2022, p. 26). In Toronto, the frost line is anywhere from 3 to 5.5 feet (0.9 to 1.7 meters) below ground level, and the soil temperature ranges from 43°F to 52°F (6°C to 11°C) (Dittschlag & Dittschlag, 2020). A test was conducted at a property in Toronto at the end of October where a borehole was dug according to the diagram shown below. The team found that at a depth of 184 meters (603 feet), the soil was 52.6°F (11.4°C) and had a conductivity of 1.3 Btu/hr·ft·°F (2.25 W/m·K) (Reitsma, 2017, p. ii). For every 6 kW of power that is used by a building, one borehole is required (Ground Source Heat Pumps: How Much Space do you Need? n.d.). As determined by the Open Studio analysis in Part 10 of this report, this project uses 359,606 kW per year or 985 kW per day. With these numbers in mind, this project will require 165 boreholes minimum.



Indoor air quality (IAQ) has become a more important topic in building design in recent years, augmented by the COVID-19 pandemic. As such, maintaining proper ventilation is important to maintaining occupant safety by reducing the risk (Reitsma, 2017, p. 2) of virus transfer and lowering the number of airborne particulates. The ventilation requirements according to ASHRAE 62.2 are shown in the table below, and the relevant numbers for this project are circled in red. For this purpose, the studio apartment will be modeled as a one-bedroom apartment as that is its closest approximate.

The building's main ventilation is provided by an energy recovery ventilation (ERV) system. An ERV system incorporates an enthalpy exchanger into the larger air handling unit, which allows for the transfer of both sensible and latent heat between the inside and outside. An ERV is preferred to a heat recovery ventilation system (HRV) in a cold climate because it can pretreat the supply air to control both temperature and humidity. (Dieckmann, 2008)

TABLE 4.1b (SI) Ventilation Air Requirements, L/s

Floor Area, m ²	Bedrooms				
	1	2	3	4	5
<47	14	18	21	25	28
47–93	21	24	28	31	35
94–139	28	31	35	38	42
140–186	35	38	42	45	49
187–232	42	45	49	52	56
233–279	49	52	56	59	63
280–325	56	59	63	66	70
326–372	63	66	70	73	77
373–418	70	73	77	80	84
419–465	77	80	84	87	91

(American Society of Heating, Refrigeration,



Figure 65: HVAC System- 1st & 2nd floors- GSHP & In-suite ERVs

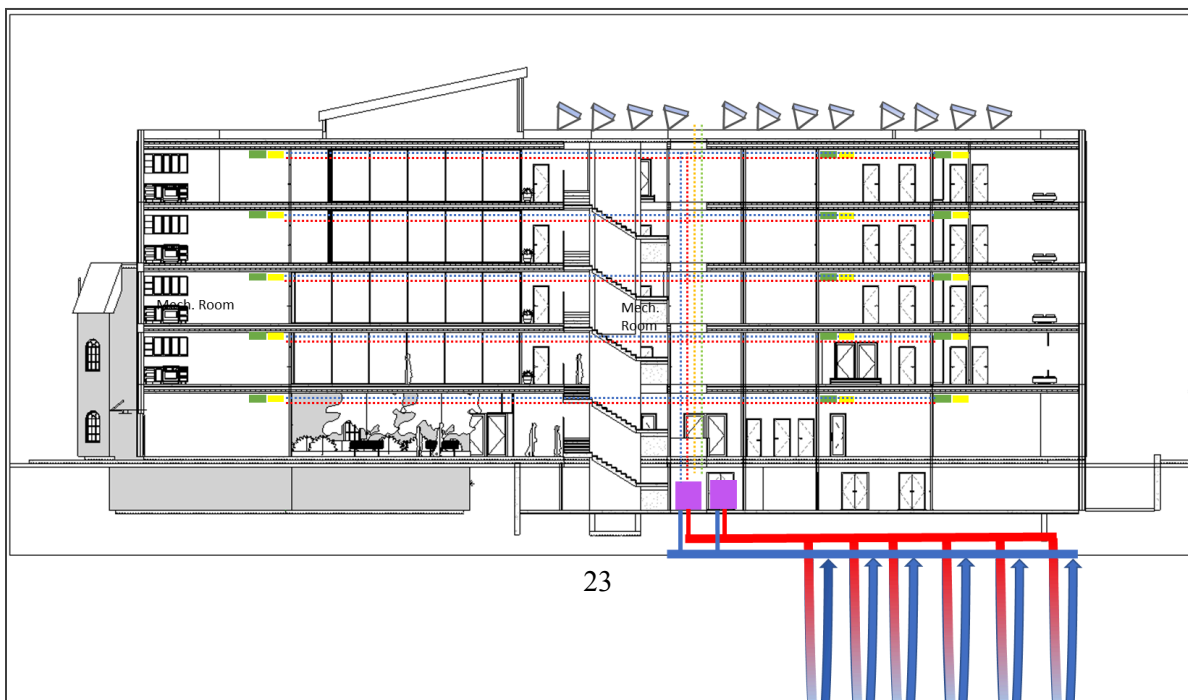


Figure 66: HVAC System- Section- GSHP & In-suite ERVs

3.3.2 Plumbing

The plumbing pipes for this building are made from PEX. There were four materials under consideration, PVC, CPVC, PEX, and copper. The benefits and drawbacks of each are as follows:

Table 3- Plumbing Materials, Pros, and Cons

Material	Pros	Cons
Polyvinyl Chloride (PVC)	- Corrosion-resistant - Cheap	- Made from natural gas - Not for hot water
Chlorinated Polyvinyl Chloride (CPVC)	- Hot and cold water - No chlorine damage - Corrosion-resistant - Insulated	Plastic
Cross-Linked Polyethylene (PEX)	- Hot and cold water - Flexible - Fewer leaks - Process energy is 26% of the total energy	- Plastic - Made from an oil byproduct
Copper	- Durable - Corrosion-resistant - Hot and cold water	- Expensive - Strip-mined 15% more water waste than plastic - Process energy is 97% of the total energy

(Plastic Pipe and Fittings Association, 2020); (Reddi Plumbing, 2019); (RWC, 2020)

Each washroom will be equipped with a recirculating shower system. This is a system that reuses water as the shower is run with real-time purification. The ShowerLoop is one such system that is open-source, so they have a lot of documentation online. Their system consists of five stages that remove increasingly small particles: a screen filter, a microfiber filter, sand, activated carbon, and ultraviolet light. After the shower is ended, the resulting greywater can be used in other places in the building, as shown in Figure # below (*How it Works*, n.d.). Compared to a conventional shower, a recirculating shower system uses 90% less water and 70-90% less energy for a ten-minute shower (*Home*, n.d.).

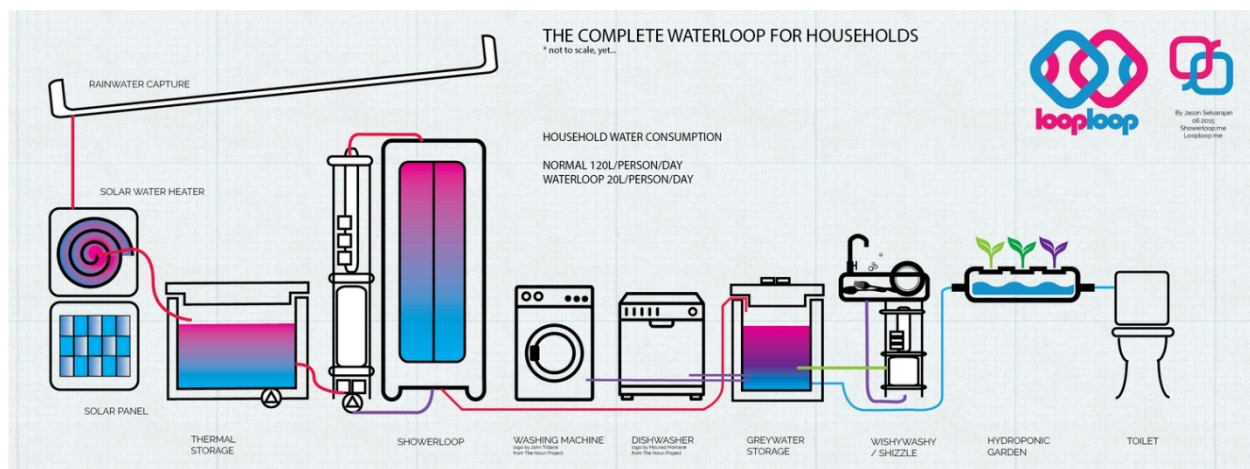


Figure 67: Example water loop system (*How it Works*, n.d.)

Since the whole building is wood, having an effective fire suppression system is vital. A sprayed water sprinkler system will be implemented in accordance with NFPA 15. (National Fire Protection Association, 2020)

3.3.3 Electrical



Electricity is integral to maintaining a high quality of life for the building's occupants. Figure 68 shows the locations of the plugs, light fixtures, and switches for one of the residential floors. The blue dots represent the plugs, the yellow dots are lights, and the green dots are switches. The plugs in Canada output 120 Volts and 60 Hertz and come in types A and B, all of which is the same as for the United States (*Plug, socket, and voltage by country*, 2022).

Figure 68: Approximate electrical layout for the first and second residential floors

4. Market Analysis

The modular concept employed in this project entails lighter construction with a chassis as part of the floor system; thus, as the name implies, it can be moved around easier than traditional buildings. This ease of transport coupled with zero on-site construction means cutting out many of the labor costs that usually follow projects such as this. To elaborate, since all modular units are created by one manufacturing facility, the construction of each unit is steadfast while also cheaper due to less time contracting workers among other reasons.

Market analysis is never as black and white as it seems. There are many programs in Canada dedicated to infrastructure support that can be utilized to assist some of the overall costs for our project. The *CMHC Rapid Housing Initiative* was used as a reference. The Government of Canada, through Canada Mortgage and Housing Corporation (CMHC), has launched the Rapid Housing Initiative (CMHC RHI or RHI). This \$1 billion program aims to help address the urgent housing needs of vulnerable Canadians through the rapid construction of affordable housing, which is particularly important in the context of COVID-19. While exact funding may be difficult to assess, it should still be noted that options such as this exist and apply to our project's situation.

Table 48 below represents the approximated total cost of the project throughout its design and construction phase. When comparing our proposed project to other code-compliant buildings in its surrounding, the material choices, HVAC systems, energy sourcing, finishes, and other building components have roughly the same overall costs. Where our project becomes more economical, however, is our transportation and contracting. As mentioned later in Section 5.1, the cost savings of steady workflow in a controlled manufacturing site becomes a major boon in reducing overall costs. With less time needed to construct each unit, labor costs naturally decrease for the project as a whole. While the foundation of the

project must still be laid out on-site and tie-ins for each module securely attached, a majority of the construction phase is located inside a controlled environment and thus can be worked upon year-round.

While Table 48 does not represent the operational or end-of-use phases of the project, due to maintenance and upkeep costs varying too widely, it should be noted that net positive energy would ultimately lead to much cheaper daily costs in comparison to its counterparts with higher energy and carbon requirements. These cost savings will come in the form of cheaper monthly fees for occupants, or exchange to city grids for energy generated on-site.

Table 4: Total Cost Estimation

Division	Description	Scope-of-work	Unit Rate	Amount	\$ Sum
1	General Conditions	Items related to Overall Logistics, safety, coordination and Permits and Workflow: process, payment, hoarding, cranes, permits, on-site facilities (e.g. W/Rs) Trailers, protections, Project Management, etc.	N/A	LS	3,850,872
2	Site Work	All aspects related to site preparation, civil, site services, excavation(s), earthworks, SWM	1	500,000	500,000
3	Concrete	Cast-in-place Concrete, Pre-cast concrete, formwork	600	1,000	600,000
4	Masonry	CMU, clay masonry	30	15,000	450,000
5	Metals	Structural Timber, Miscellaneous Metals, Structural Studs	350	18,000	6,300,000
6	Wood	Light frame wood, Heavy timber, millwork (finish carpentry)	150	18,000	2,700,000
7	Thermal & Moisture	Insulation, cladding, AVB, roof	500	4,500	2,250,000
7	Thermal & Moisture	Roof	350	4,000	1,400,000
8	Openings	Windows, doors, etc.	1,800	650	1,170,000
9	Finishes	Interiors: Gypsum Wall Board, tiles, Acoustical Ceiling Tiles, Linoleum	90	22,972	2,067,480
10	Specialties	Signage, toilet accessories (including partitions), display cabinets	30	10,000	300,000
11	Equipment	Equipments	1	500,000	500,000
12	Furnishings	Furniture, blinds	1	150,000	150,000
13	Special Construction	Clean rooms, cold storage room, EMI assembly shielding	4	25,000	100,000
14	Conveying Systems	Elevators	4	500,000	2,000,000
15	Mechanical	HVAC, fire protection, plumbing, controls	300	6,400	1,920,000
15	Mechanical	Geo-Exchange Systems - Borehole Array	12,000	150	1,800,000
16	Electrical	high-voltage & Transformers, distribution, panels, lighting	250	1,000	250,000
17	Electrical	PV sytem	4,500	270	1,215,000
	Sub-Total	Trades Total			25,672,480
	Total	Line 19 + Line 1			29,523,352

The estimated total materials cost for this project is \$29.5 million CAD (approx. \$23.6 million USD). The building has a total area of 6705 m² (72,200 ft²), so the unitized material cost is \$4400 CAD/m² (\$3500 USD/m²) or \$410 CAD/ft² (\$327 USD/ft²).

5. Durability and Resilience

5.1. Durability

To ensure solid durability, the team referenced *RDH Technical Bulletin No. 013*. It included the necessity of module-to-module tie-ins for the structural systems and insight on many other major roles such as the importance of water and air-resistive barriers for complete quality and durability control, as well as many others listed below. This approach to the project allowed flexibility in what the team could achieve. It is summed up nicely in the RDH technical bulletin

saying, “Modular construction is one solution to address the need for fast, affordable housing that also meets energy performance targets such as the BC Energy Step Code and Passive House.” (Henderson, 2020, page 2).

In terms of durability, a few key lessons were learned from case studies to allow for scaled-up projects, such as our own, to exist with minimal mistakes. The lessons implemented in our project are engagement, site selection, design and assembly, transportation, manufacturing, and tenant experience.

Engagement

- Hire a building inspector to investigate any outlying issues on a timely basis based on the size and purpose of the project.

Site Selection

- Not every site can utilize modular construction. Examples given are the proximity of power lines or lot line constraints. The location of the site can also cause worry as transportation of the modular units can be costly and complicated. This is solved by having early contact with contractors to ensure no problems arise later during transportation and assembly.
- Basement storage was implemented based on the suggestion “Consider each site’s capability for temporarily storing modules before craning, especially for remote sites or sites with more than one module delivered at a time.” (Henderson, 2020, page 5). Though storage on our site is designed mainly for occupants, it still can be used as temporary storage for modules and other components.

Design and Assembly

- Early planning can alleviate many of the problems that face modular construction. Our project will contact contractors early in development to ensure the permanent and completed details for air, water, thermal, and cladding (Figures 49, 50, and 51) are constructed properly. “Front-load the design work to determine all design details before manufacturing the modules” (Henderson, 2020, p. 9). The important note here is the continuity of structural support with the use of tie-ins.

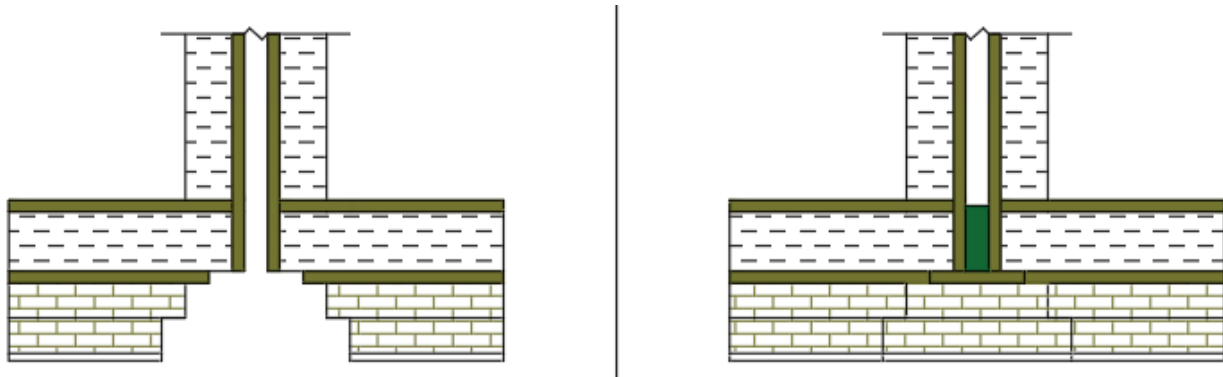


Figure 69: Example of detail for wall tie-in joints. Before site work on the left, and final continued details on the right.

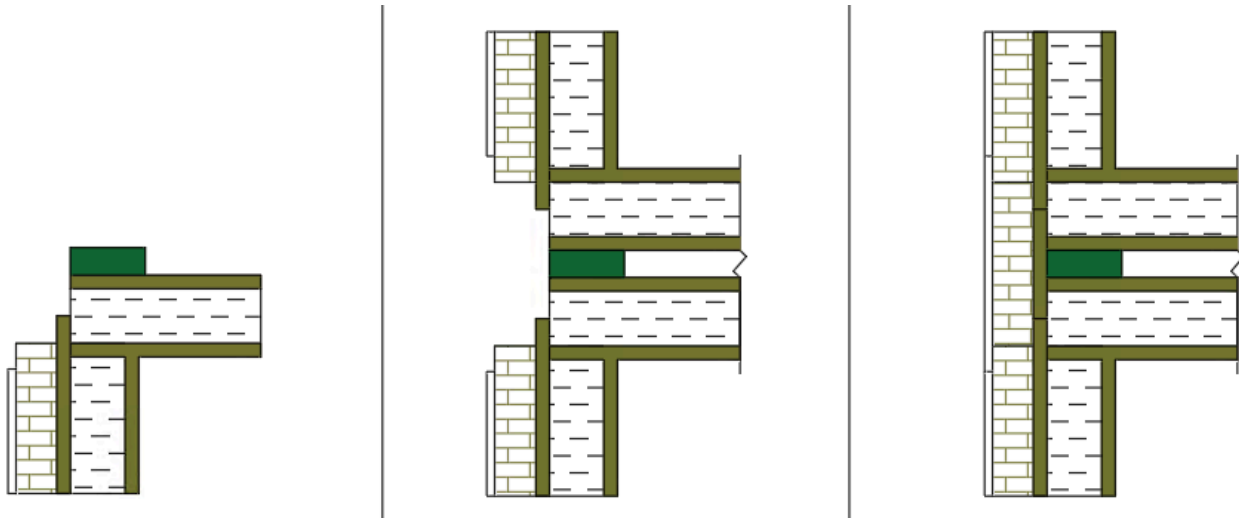


Figure 70: Example of detail for floor-to-ceiling connections. A single unit on the left, the addition of the second unit in the center, and the completed continuity of both units on the right.

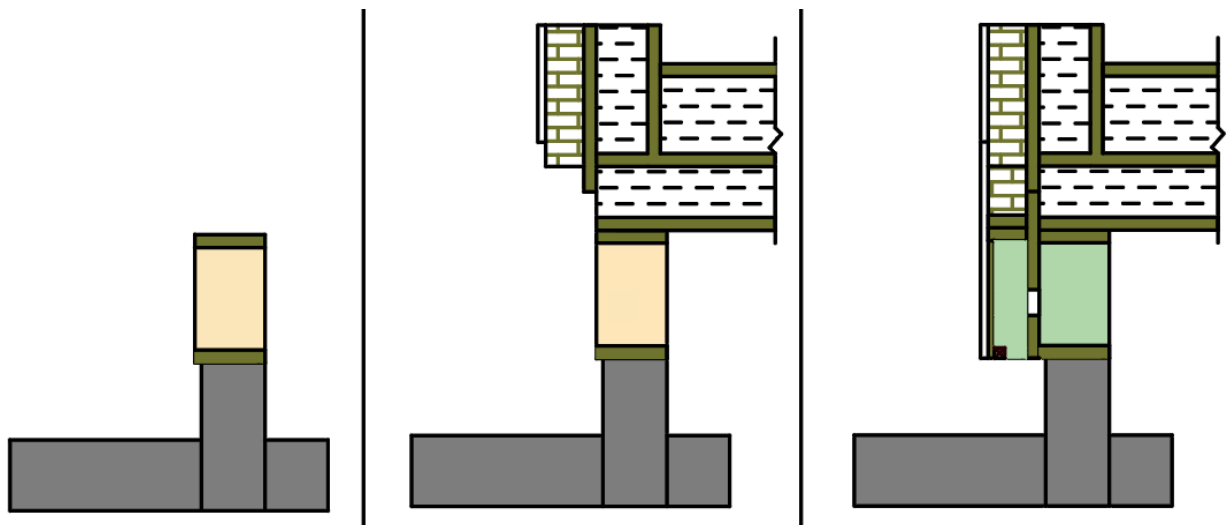


Figure 71: Example of the foundation stages. Prepared the basic foundation on the left, the addition of the modular unit in the center, and the completed foundation on the right with the protection of ventilated air cavity.

Transportation

- As noted in the RDH technical bulletin, “An extra 1 or 2 inches in width may trigger additional requirements for road safety... the units are often built to optimize their dimensional: ‘15’4” high once loaded onto a truck, under 70’ long and under 14’ to 15’ wide depending on the transport routes.” (Henderson, 2020, page 6). These dimensions were ensured during the design phase of our project.
- Transportation dimensions were important as the impact of just a few inches could lead to the project being unfeasible or requiring many more truck/ship deliveries, therefore increasing the overall embodied carbon of the project.

Manufacturing and Tenant Experience

- A modular building construction allowed for more varied material usage. This is due to construction being started and completed in a controlled environment, therefore eliminating the unpredictability of on-site construction. This gave the team liberty to choose nearly any material they thought best suited the needs of occupants and/or assisted in achieving higher performance metrics.
- General notes for modular construction as provided by "RDH Technical Bulletin No. 013" are as follows:
- “Take extra care for precise measurements since small errors may be compounded during the assembly of several modules, which may impact the component tie-ins”(Henderson, page 11).

- “The CAN/CSA-A277 standard may be used for quality assurance for portions of modular buildings that are constructed in the factory”(Henderson, 2020, page 11).

5.2. Resilience

Urban resilience is an astronomical topic to tackle. One definition of urban resilience is, “The ability of a city or urban system to withstand shocks and threats, to survive stresses, utilize them, reorganize, develop whilst retaining the essential same functions and identity, and to adapt to social, political, economic and environmental change” (Dodman et al, p. 98). With recent struggles caused by the pandemic, the weakness of cities is starting to show, they are much too fragile.

Resource efficiency, a term used by David Dodman, Loan Diep, and Sarah Colenbrander in their editorial *Making the case for the nexus between resilience and resource efficiency at the city scale*, was inspirational in our team's findings. They introduce the term resource efficiency, “reducing inputs required to produce the desired output,” which is desirable in urbanized areas. The main motivating question has always been how do we achieve this? Through home improvement, which includes retrofitting such as building tightness, ventilation, insulation, and solar paneling, we can greatly reduce our resource consumption. In the case of this project, we decided to further our solar capabilities through additional photovoltaic panels if needed, and extensive battery storage for prolonged outages or long durations of low energy generation

Photovoltaic panels can be laid over top parking lots if the extra energy demand is deemed needed. Solar parking canopies are becoming more common. Not only do they provide extra room for solar panels, but they also reduce the amount of snow that occupants will need to remove from their vehicles. Maintenance of these panels will be important as many obstacles stand in the way of consistent energy generation, such as heavy snowfall blocking solar radiation.

A major resilience issue we saw in our project was the potential for blackouts, or periods throughout the year where the energy gained through existing solar panels cannot support the occupants within. The team decided that significant battery storage located in the basement would suffice in alleviating this problem. We used the Living Building Challenge 4.0 as a reference to how much energy storage we needed on-site. The project building must be habitable for up to one week through batteries or other storage methods.

6. Embodied Environmental Impact

The following table is based on the One-Click LCA database or specific manufacturer Environmental Product Declarations. Assumptions include:

- “Total impacts for all life-cycle stages per material” (One-click Planetary LCA, n.d.)
- Generalized 100-kilometer transportation requirement by land-based methods
- All materials were chosen based on firstly the requirement to fulfill their purpose, then secondly on their low environmental impact in comparison to other competitors in the local area. For example, Our concrete choice, Ready-Mix Plant EcoPactMax35, was chosen due to its lower embodied carbon metrics in comparison to other local manufacturers while also maintaining adequate mechanical properties.
- Materials such as bamboo are chosen over conventional flooring and rebar materials not only because of their lower environmental impact but also due to their reusability and overall better end-of-life prospects.

Table 5- Total t CO₂e for materials used

Envelope Components	Quantity	Unit	Material selection (from OneClick LCA or Manufacturer EDP)	Total t CO ₂ e	Total kg CO ₂ e/m ²
Concrete	223	m ³	Ready-Mix Plant EcoPactMax35 Manufacturer - LafargeCanada 160 kg CO ₂ e/m ³ (Lafarge, 2021)	45.77 t CO ₂ e	16.35 kg CO ₂ e/m ²
Wood (studs, headers) and ply (subfloor, sheathing, roof)	3286	m ³	Glued Laminated Timber (Glulam), 544 kg/m ³ , 12% moisture content Manufacturer - Structurlam Mass Timber Corporation 0.21 kg CO ₂ e/kg 115.32 kg CO ₂ e/m ³	Approx. 387.94 t CO ₂ e	138.91 kg CO ₂ e/m ²

			Cross-Laminated Timber (CLT), 515 kg/m ³ , Nordic X-Lam Manufacturer - Nordic 0.2 kg CO ₂ e/kg 102.0 kg CO ₂ e/m ³		
XPS	56.99	m ³	XPS Insulation, Foamular XPS Manufacturer - Owens Corning 28.21 kg CO ₂ e/kg 586.73 kg CO ₂ e/m ³ 29.81 kg CO ₂ e/m ²	33.36 t CO ₂ e	11.93 kg CO ₂ e/m ²
Mineral wool	207	m ³	Rock Wool Insulation Batt, FabRock Batt - RockWool North America 0.87 kg CO ₂ e/kg 38.95 kg CO ₂ e/m ³ 0.99 kg CO ₂ e/m ²	4.90 t CO ₂ e	1.77 kg CO ₂ e/m ²
Cellulose insulation	194	m ³	Cellulose Insulation, blown (loose) Manufacturer - None (Generic) 0.22 kg CO ₂ e/kg 11.21 kg CO ₂ e/m ³ 1.12 kg CO ₂ e/m ²	1.82 t CO ₂ e	0.67 kg CO ₂ e/m ²
Gypsum (1/2")	138	m ³	Gypsum Plaster Board, Regular, Generic Manufacturer - None (Generic) 0.29 kg CO ₂ e/kg 248.14 kg CO ₂ e/m ³ 3.1 kg CO ₂ e/m ²	31.64 t CO ₂ e	11.32 kg CO ₂ e/m ²
Plywood (1/2")	532	m ³	Softwood Plywood, 9.5 mm, 484 kg/m ³ , 7% moisture content Manufacturer - American Wood Council, Canadian Wood Council 0.45 kg CO ₂ e/kg 219.32 kg CO ₂ e/m ³ 2.08 kg CO ₂ e/m ²	116.8 t CO ₂ e	41.7 kg CO ₂ e/m ²
Paint (on interior walls)	10,580	m ²	Recycled Latex Paints, for interior application, Coloured and White Manufacturer - Laurentide re/sources 0.66 kg CO ₂ e/kg 812.5 kg CO ₂ e/m ³ 0.13 kg CO ₂ e/m ²	1.5 t CO ₂ e	0.52 kg CO ₂ e/m ²
Roof membrane	1337	m ²	SPPR PVC Roofing Membrane Manufacturer - Chemical Fabrics and Film Association 3.68 kg CO ₂ e/kg 4133.86 kg CO ₂ e/m ³ 4.2 kg CO ₂ e/m ²	5.74 t CO ₂ e	2.04 kg CO ₂ e/m ²
Cladding	1477	m ²	Ceramitex®, Sintered Ceramic Facade System Manufacturer - Elemex® Approx. 0.73 kg CO ₂ e/kg 1436.07 kg CO ₂ e/m ³ 10.48 kg CO ₂ e/m ² (Elemex, 2022)	Approx. 0.16 t CO ₂ e	0.05 kg CO ₂ e/m ²
Bamboo Flooring	3034 8 24.3	m ² mm m ³	Dasso Traditional Bamboo Manufacturer - Zhejiang Daocheng Bamboo Industry Approx. 2.16 kg CO ₂ e/kg	Approx. 23.562 t CO ₂ e	8.47 kg CO ₂ e/m ²

			("dasso Traditional Bamboo", 2020)		
Ceramic tiles (Bathrooms' walls and floors)	776 12 9.3	m ² mm m ³	Ceramic Floor and Mosaic Tiles Manufacturer - Ragno 0.81 kg CO ₂ e/kg 14.1 kg CO ₂ e/m ²	1.84 t CO ₂ e	0.66 kg CO ₂ e/m ²
Ceramic (Public circulation)	1361 12 16.3	m ² mm m ³	Ceramic Floor and Mosaic Tiles Manufacturer - Ragno 0.81 kg CO ₂ e/kg 14.1 kg CO ₂ e/m ²	3.23 t CO ₂ e	1.15 kg CO ₂ e/m ²
Gypsum Ceilings	4092 12 49.1	m ² mm m ³	Gypsum Plaster Board, Regular, Generic Manufacturer - None (Generic) 0.29 kg CO ₂ e/kg 248.14 kg CO ₂ e/m ³ 3.1 kg CO ₂ e/m ²	11.21 t CO ₂ e	4 kg CO ₂ e/m ²
Bamboo Rebar	L=1 Ø=0.043 (Steel Rebar Sizes, n.d.)	m ³ m	Bamboo pole SSH 75 kg CO ₂ e/m ² (Escamilla et. al., 2018)	0.97 t CO ₂ e	0.34 kg CO ₂ e/m ²
Total kg CO₂e				Approx. 670.442 t CO₂e	Approx. 239.88 kg CO₂e/m²

Total t CO₂e

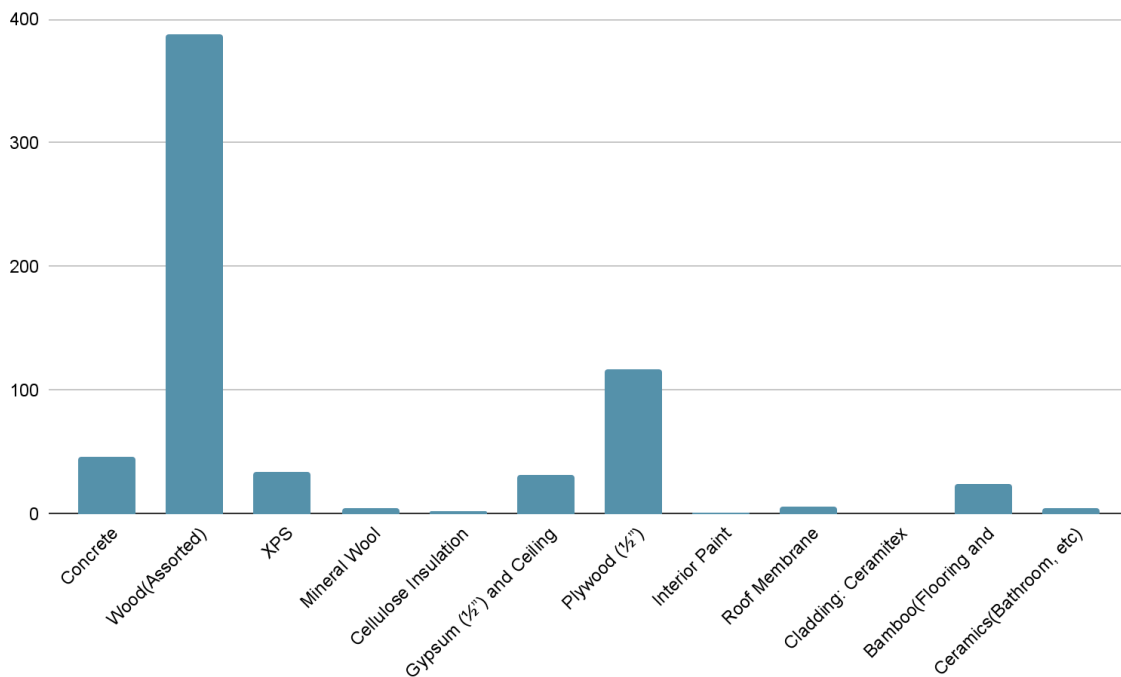


Figure-72: Total embodied carbon(t CO₂e) bar graph. Similar results were shown when seen in kg CO₂e/m².

7. Integrated Performance

A building automation system will be installed to incorporate information technology into the structure of the building to improve its functionality and efficiency and provide a better experience to occupants. The building will be partitioned with a local control function in each unit and a larger central building management system for a hierarchical automation

architecture design. The aspects of building functionality and monitoring that will be controlled using the automation system are as follows:

Temperature	Indoor air quality	Humidity	Lighting
Wireless internet	Energy use	Power quality	Building access

To satisfy the energy demand and resultant sizing requirements, an optimal sizing algorithm for the renewable energy system will be implemented. The goal is to minimize the system cost while ensuring the load demand is met. Load shifting is one of the technologies that has been introduced to get a distributed load profile and to reduce the entire system cost and CO₂ emissions (Kaufmann et al., 2016). The geo-exchange system will be sized to meet the building's heating demand, which due to Toronto's climate, will be larger than its cooling demand. The number of boreholes is fixed, but they will be turned on or off depending on the number needed to meet the energy demand.

Occupancy sensors will be used to increase the energy efficiency of the lighting and ventilation systems. These sensors will prevent the building from wasting energy on lighting and ventilating spaces that are not occupied or over-lighting and over-ventilating spaces that are not at capacity. The shades will be programmable by the occupants according to their daily schedules and when they want the most daylight. Our window-to-wall ratios are calculated to minimize the thermal bridging while optimizing the internal daylighting.

Water will be reused through different systems around the building to minimize the amount wasted. Potable water will be the input for the recirculating shower system and come out of the faucets. The greywater generated will then be used in the toilets, washing machines, and HVAC systems. Any blackwater and stormwater will be transported offsite for proper treatment.

8. Occupant Experience

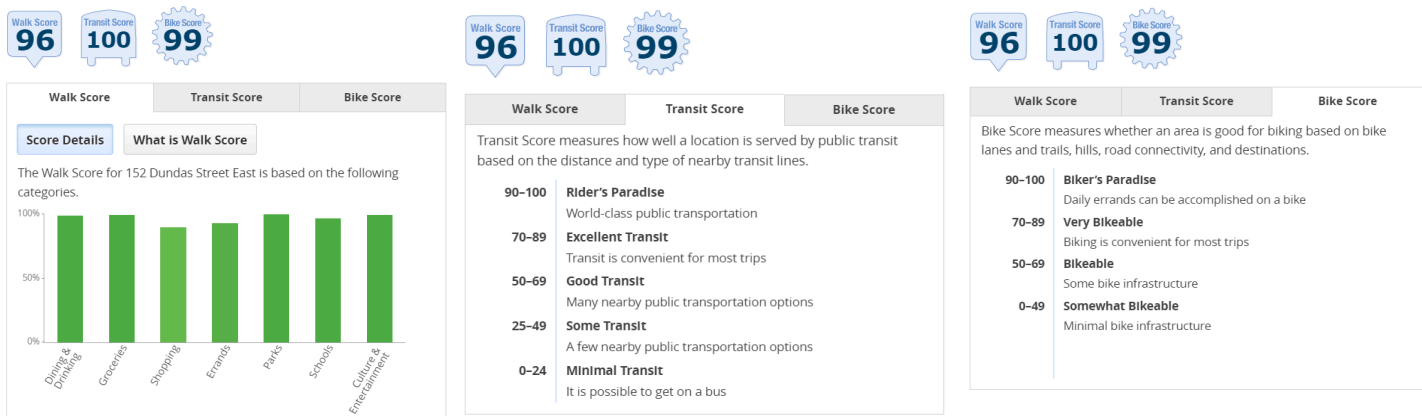
Occupant experience was one of the team's highest priorities, as it should be with all residential projects. One of the many features that support an excellent occupant experience is the incorporation of punched terraces throughout the building. The benefits of a terrace are innumerable, starting with natural and cross ventilation. For the project team, the main driving force behind the decision for a punched terrace was to support mental well-being and to allow natural daylighting to penetrate deep within the building.

Trees and creepers will be planted inside the atrium and around the building. The atrium will act as a small community park that provides access to nature, and a post-occupancy survey will be provided to the occupants to evaluate indoor environmental quality each year. The building is designed with benches outside for occupants to sit under the shades of trees.

The building has incorporated direct and indirect biophilic strategies, and design concepts mimicking nature through colors, textures, organic shapes, and patterns to reduce stress, enhance thought clarity, and overall improve the well-being of the occupants (Terrapin Bright Green, 2014). The elements of biophilia not only improve the aesthetic view of the building but also connect the built form with nature. The following are the elements included: indoor planters, flooring, wall decor, mini gardens, natural artworks, furniture fabrics, living walls, acoustic panels, aromatherapy, eco cleaning policies, and soundscapes (Biofilico, n.d.).

The building was designed with bike stations on the peripheral sides of the building. The atrium inside the building will provide space for occupants to gather and increase occupants' socialization and interactions within the community. Two bike and storage stations will be installed from Bike Share Toronto which offers 24/7 convenient access for commuting and exploring the city (Bike Share Toronto, 2021).

A mobile phone app and website for sharing resources and information amongst occupants will be developed for carpooling, bike-sharing, public transit real-time updates, and a marketplace to buy or sell any items. There will also be a link to the front desk with a desktop app portal that will enable the front desk to assist occupants with their needs. which not only utilizes the resources efficiently but also reduces the requirement of virgin materials to produce these products and reduces carbon footprint. A periodic occupants survey will be conducted. The building's transport accessibility scores are shown below.



Figures 73-75: Project Site Movement Scores (152 Dundas St. East, n.d.)

The design team also recognizes the need for water conservation, from both an environmental and operational cost perspective. WaterSense building guides help facility managers reduce water usage with the following process to reduce potable water by 20 to 60% and use it efficiently (EPA, 2021b).

EPA recommended process:

- 1 - Water management planning: making a commitment, assessing facility water use, setting and communicating goals, creating an action plan, implementing the action plan, evaluating progress, and recognizing achievement
- 2 - Water use monitoring and education: metering and submetering, leak detection and repair, user education and facility outreach, codes and standards, and voluntary programs for water efficiency (EPA, 2021b).
- 3 - Indoor sanitary fixtures and equipment: toilets, urinals, faucets, showerheads, laundry equipment with sensor-operated WaterSense labeled models for all the floors. Outdoor water-efficient use: In-Ground Grey Water Irrigation System design will effectively utilize the greywater for irrigation and also the Inground design reduces the amount of water required for irrigation.
- 4 - Integrating energy efficiency methods for heating and cooling will reduce the amount of water needed, and maintaining indoor thermal comfort will increase the efficiency of heating and cooling equipment (EPA, 2021b). Implementing energy-efficient measures will reduce the need for equipment cooling and heating, which will reduce the amount of water required by these systems. By adhering to the above EPA recommended process, the building will save approximately 50% of its regular consumption compared with a typical baseline model.

The building will use Manufactured Treatment Devices (MTDs) based on pre-development hydrology and current ecological conditions. MTDs are proprietary devices used in stormwater management to treat and remove pollutants from stormwater runoff, the treated water can be stored at the basement level and used for dishwashers, toilets, urinals, and landscape irrigation (City of Toronto, 2021). To reduce the stormwater runoff on-site, rainwater harvesting methods will be implemented. As part of the resilience, enough water will be stored in air-tight containers in the basement for all regular occupants for a week in case of an emergency.

To reduce the amount of blackwater, all the toilets will be high-efficiency, low-flush toilets. These offer an environmentally friendly and odor-free method of dealing with human waste. The water to flush these toilets will be greywater generated from the recirculating shower system and rainwater gathered from the rainwater collection system.

The appliances that will be provided in the residential units were chosen for their energy efficiency, and the dishwasher and washing machine were given the additional limitation of low water consumption. The final chosen appliances are as follows:

Table 6- Breakdown of devices used

Category	Product	Efficiency	Other	Source
LED light bulbs		10 W/bulb	700-850 lumens	(4 Types of Light Bulbs, 2020)
Refrigerator	Beko - BFBF2414WH	286 kWh/yr	11.4 ft ³ (0.32 m ³)	(EnergyStar, Beko, 2019)
Microwave	Impecca CM-0674W	0.016 W standby	0.6 ft ³ (17 L)	(Energy, n.d.)
Range (stove/oven)	Samsung HIIP054C	345 kWh/yr	4.9 ft ³ (140 L)	(EnerGuide, n.d.)
Dishwasher	Miele - G 6835 SCi	199 kWh/yr	3.2 gal/cycle (23.2 L/cycle)	(Energy Star, Miele, n.d.)
Washing machine	Bosch - WAW285H1UC	84 kWh/yr	2379 gal/yr (9000 L/yr)	(Energy Star, Bosch - WAW285H1UC, 2020)
Dryer	Bosch - WTW87NH1UC	125 kWh/yr	4 ft ³ (0.11m ³)	(Energy Star, Bosch - WTW87NH1UC, 2020)

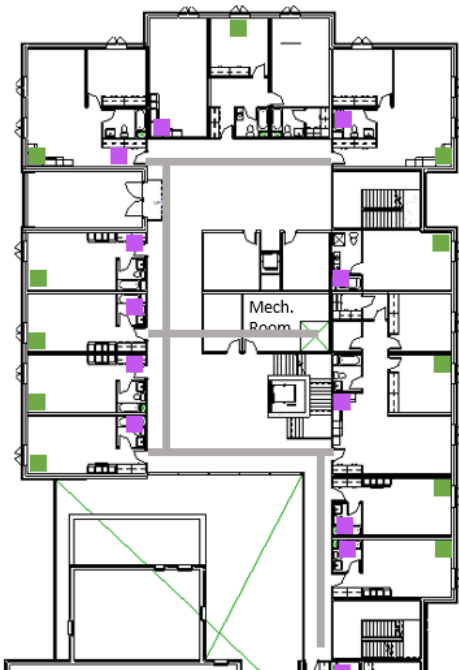
9. Comfort and Environmental Quality

Smoking and vaping within nine meters of building entrances are prohibited, as per the Smoke-Free Ontario Act. Each space will be retrofitted to maximize access to fresh air, natural views, and automated window shades. Each unit will have a HEPA-grade filter incorporated into the ventilation system to minimize the transmission of the COVID-19 virus and to reduce allergens in the air (Thompson, 2021).

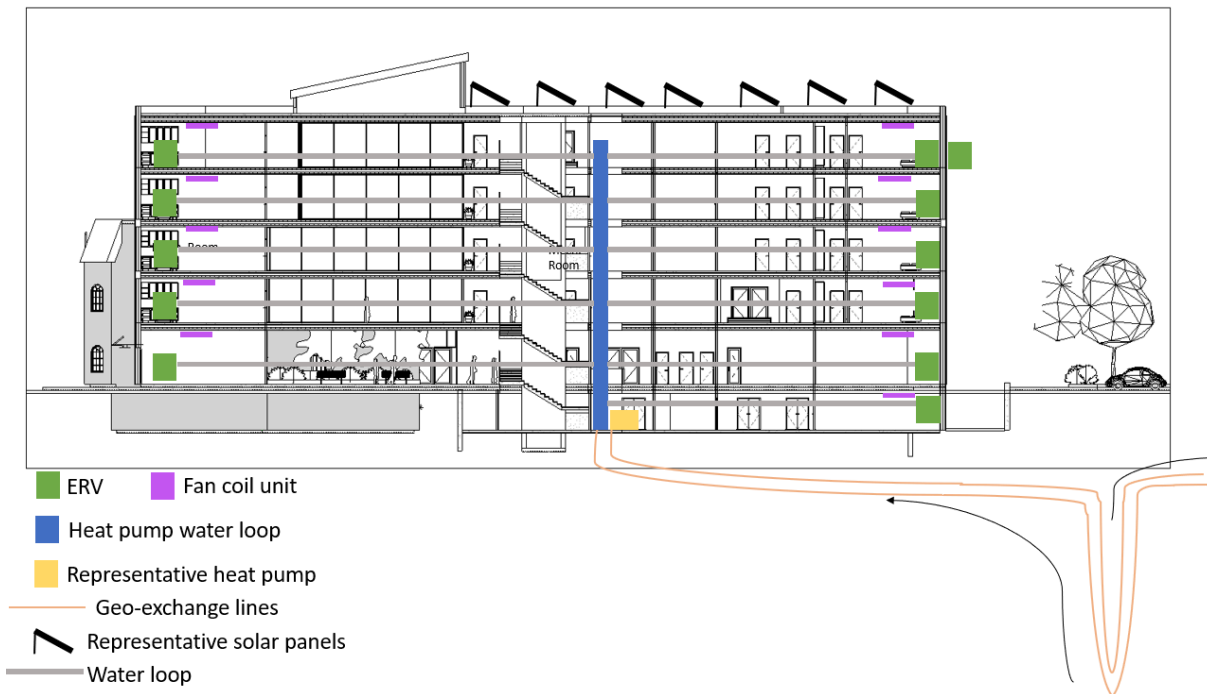
Operable windows will be included to bring in more fresh air. The glazing around the building provides occupants with visual relief and engages them with the outdoor environment. A dedicated exhaust will be fitted for the restrooms, which will be part of the composting toilet system and be exhausted by the rooftop fans. The IAQ (Indoor air quality) test will be carried out at regular intervals to meet the guidelines of the building code. All the cleaning supplies will be 100% organic without any volatile organic compounds (VOCs) and will comply with the EPA's Safer Choice label. The entrance vestibules will be retrofitted with air curtains above the interior doors to stop outside air from entering the building.

Smoke detectors and CO sensors will be placed at all levels of the common area, basement, and individual units to check the safety and will be tested every month to comply with ASHRAE standards. Advanced flooring entrance matting systems with polypropylene inserts will create a slip-resistant and moisture-absorbent barrier and remove dirt from the building.

Keeping a safe and comfortable indoor environment is crucial for maintaining occupants' health and happiness. Two major factors in a comfortable environment are temperature and relative humidity, which are controlled by the HVAC system. The active pieces of the HVAC system in this building are a geo-exchange loop located under the parking lot, individual ERVs and fan coil units (FCUs) in every unit, a system of heat pumps in the basement mechanical room, and pipes running through the building to connect everything. These systems and devices will work with the passive systems and the building automation system to keep the interior at whatever setpoints the occupants want. Approximate active system diagrams can be found in Figures 58 and 59.



Figures 76 and 77: Layout of the active HVAC systems from the top (58) and side (59). The legend in Figure 59 applies to both figures.



10. Energy Performance

The team used OpenStudio, a whole building energy modeling software incorporating EnergyPlus as the simulation engine, as an iterative design tool to get a critical understanding of the variables associated with energy consumption and energy efficiency, to test out the proposed envelope and HVAC systems throughout the preliminary design process, and subsequently to help with making informed decisions on forming our net-zero energy building. The team has run 27 individual simulations to investigate the most optimized site energy use intensity (EUI) out of multiple design features. The finalized project obtained a site EUI of 19.24 kBtu/ft² (60.7 kWh/m²), which is 73% better than the Canadian multifamily housing average (ENERGY STAR Portfolio Manager, 2021). Such performance was achieved by a combination of an air-tight, highly-insulated envelope system, efficient HVAC system coupled with dedicated operational schedules, and efficient lighting and appliance loads that were promoted by Toronto Green Standard (City of Toronto, 2018). Following the net-zero energy framework, the project’s annual energy consumption was offset by solar energy harvested through the PV system covering the rooftop and a portion of the parking area.

10.1 Simulation Results

The EUI of the energy model is 19.24 kBtu/ft² (60.7 kWh/m²). The thermal energy demand intensity (TEDI) is 5.48 kBtu/ft² (17.3 kWh/m²) calculated as the heating outputs per conditioned floor area. Settings in Open Studio can be found in the appendix. The table below shows the results summary. The pi-chart breaks down the energy end-use.

Table 7- Total site energy, EUI, and TEDI

Total site energy	1,479,533	kBtu
	433,608	kWh

Total site EUI	19.24	kBtu/ft2
	60.7	kWh/m2
TEDI	5.48	kBtu/ft2
	17.3	kWh/m ²

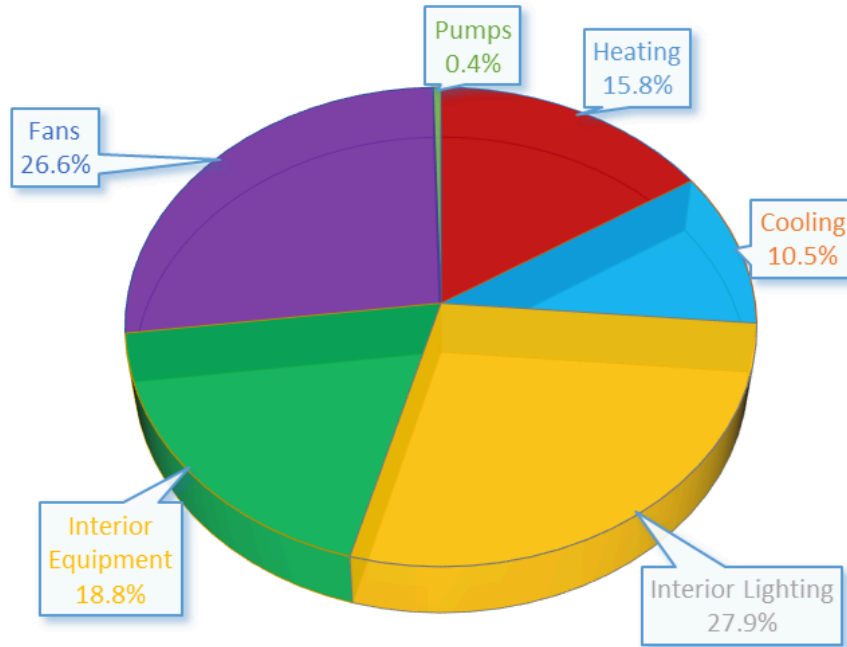


Figure 78: Electricity End-Use According to OpenStudio

Through energy modeling, the team learned that the current design with a ground-source heat exchanger (GSHX) system would lead to slightly unbalanced heating and cooling. It was proposed that a reserve capacity in the geothermal loop should be installed and regulated by the building automation systems so that the whole system can be activated during the heating season, whereas a partially activated system on a concentrated heating geo-zone can be used during the cooling season. In this way, heating seasons won't overdraw on the geo loop.

10.2 On-site Renewable Energy

In Helioscope, the simulated PV system in the baseline scenario 1a consisted of 359 modules of fixed-tilt racking HT-ASSE HT66-18X-480 Bifacial (480W), 18 degrees tilted. The row spacing has defaulted as 0.6m, and the setback from the roof parapet was 1.2m.

With CoGenerate Solar, a PV system utilizing dual-axis micro-tracking technologies, covering a suitable rooftop area, and fixed-tilt racking HT-ASSE HT66-18X-480 Bifacial (480W) system covering approximately 660m² of the parking lot area, the PV system proposed can supply 100% of the simulated annual site energy. The annual operational carbon saved from such on-site renewable systems is 15.6 tCO₂e, calculated from an emission factor of 36 gCO₂e/kWh for electricity used in Toronto (City of Toronto, 2017). The table below shows our team's proposed photovoltaic system.

Table 8- Proposed photovoltaic system

Target	Propose	Percentage
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Total Site Energy (MWh)	Scenarios	Annual Production (MWh)	
433.6	Scenario 1a: 172kW default PV covering suitable rooftop area	184.5	43%
	Scenario 1b: CoGenerate Solar system with 80% more efficiency	332.1	77%
	Scenario 2: 102 kW default PV covering 660m ² parking area (3m from the ground)	435	100%

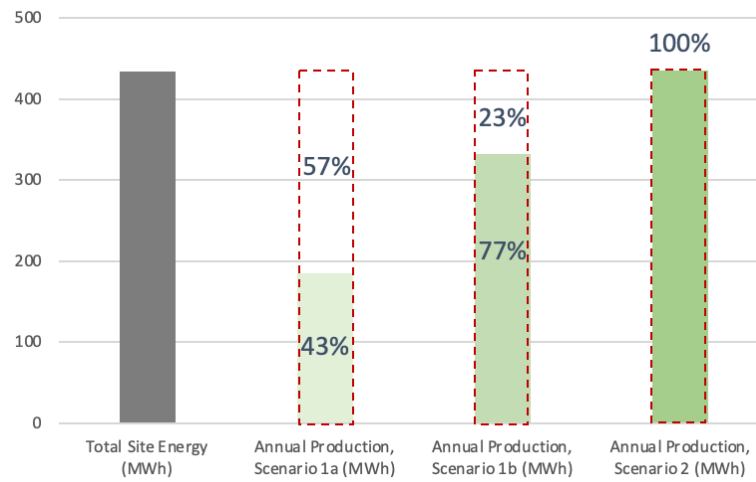


Figure 79: Comparison of Total Site Energy and PV Annual Production

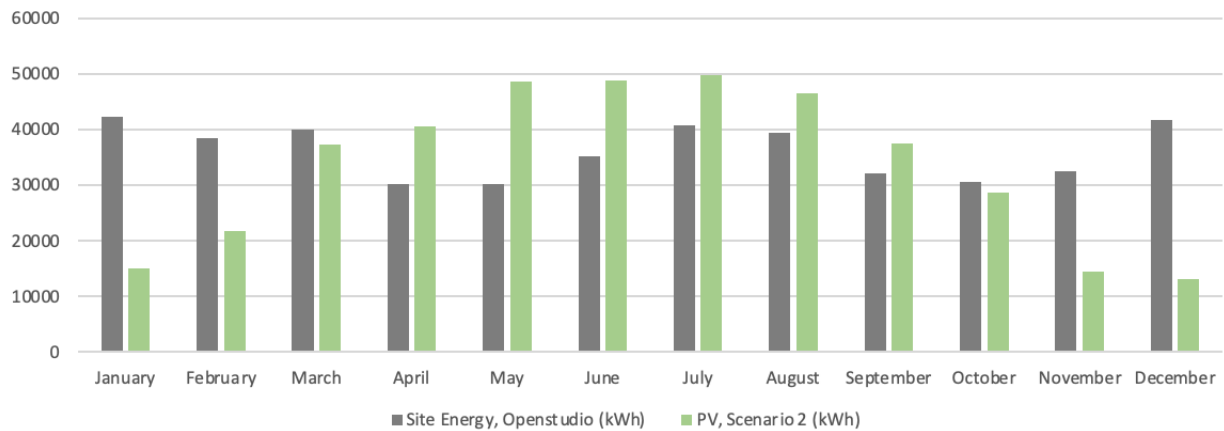


Figure 80: Monthly Comparison

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12. Appendix

12.1 Appendix A: Architectural Drawings

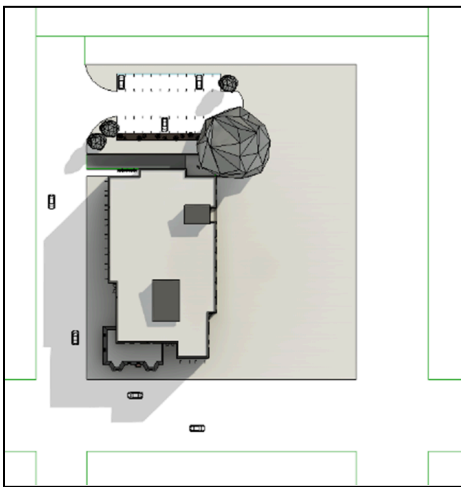


Figure 81: Site Plan



Figure-82: Image from Mutual Street- Back Corner



Figure-83:Image from the corner of Dundas Street and Mutual Street



Figure-84:Basement Plan- Services

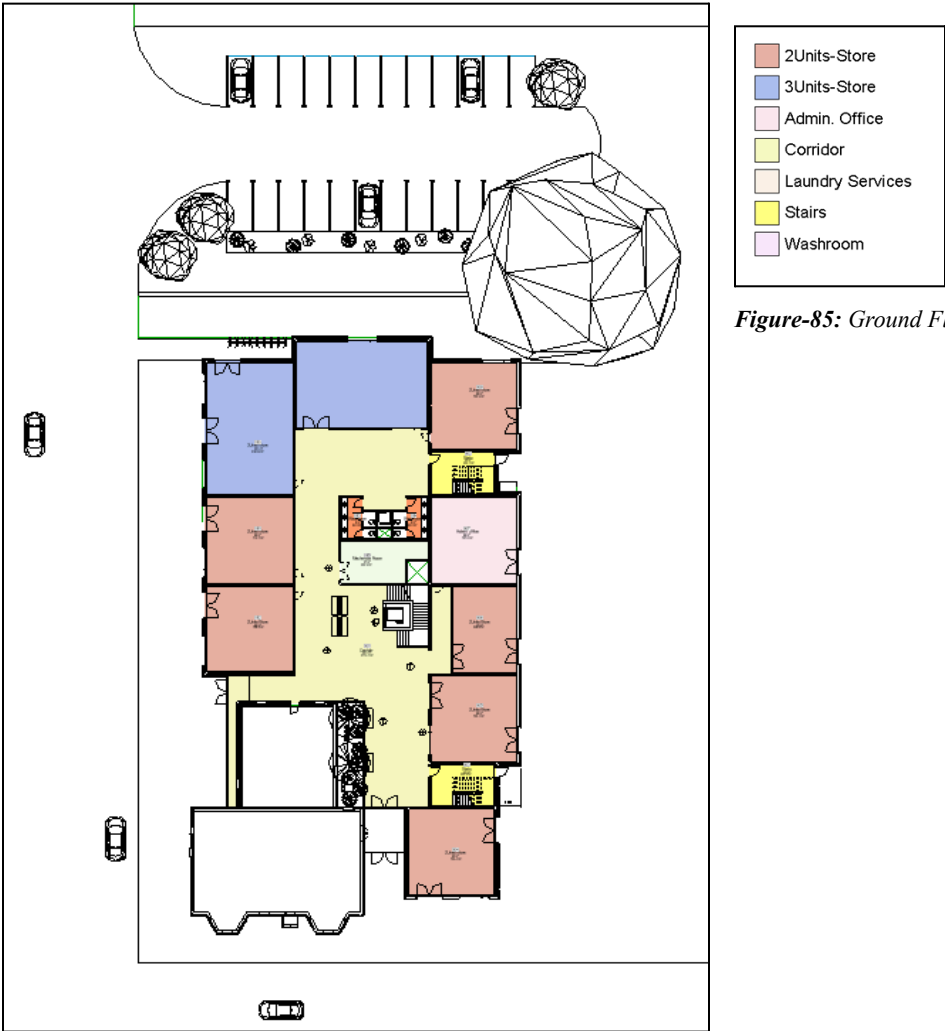


Figure-85: Ground Floor Plan- Commercial Zone

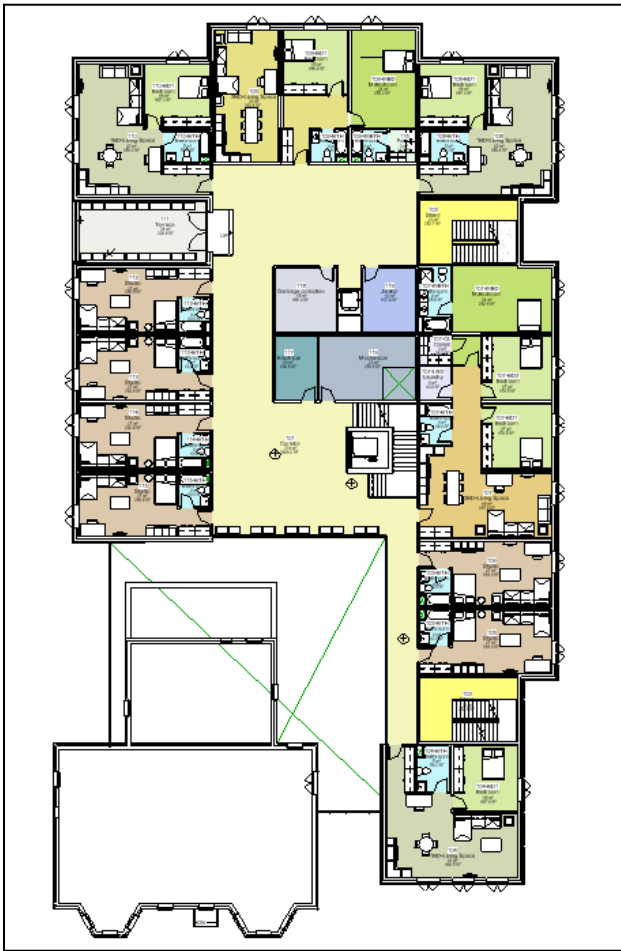


Figure-86: Levels 1&2 - Residential Zone



Figure-87: Levels 3&4 - Residential Zone

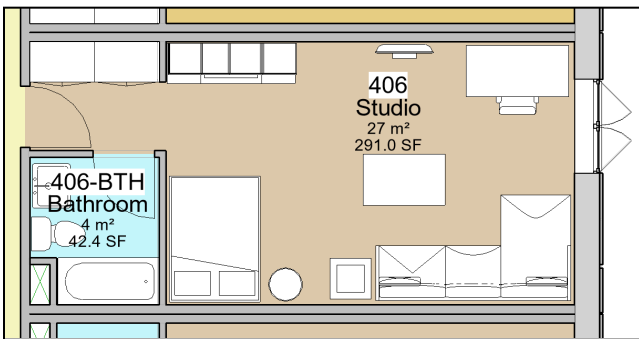


Figure-88: Studio Layout

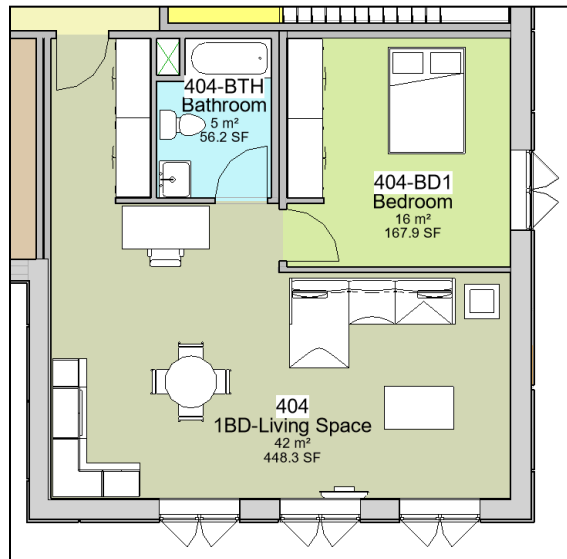


Figure-89: One-Bedroom Apartment layout

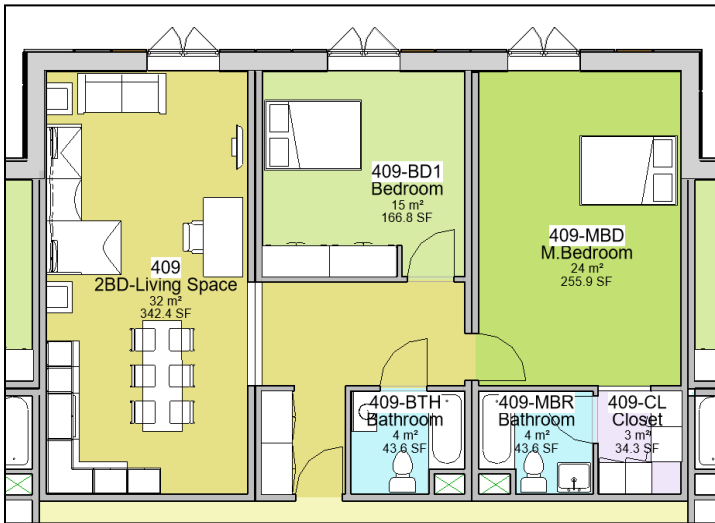


Figure-90: Two-Bedroom Apartment Layout

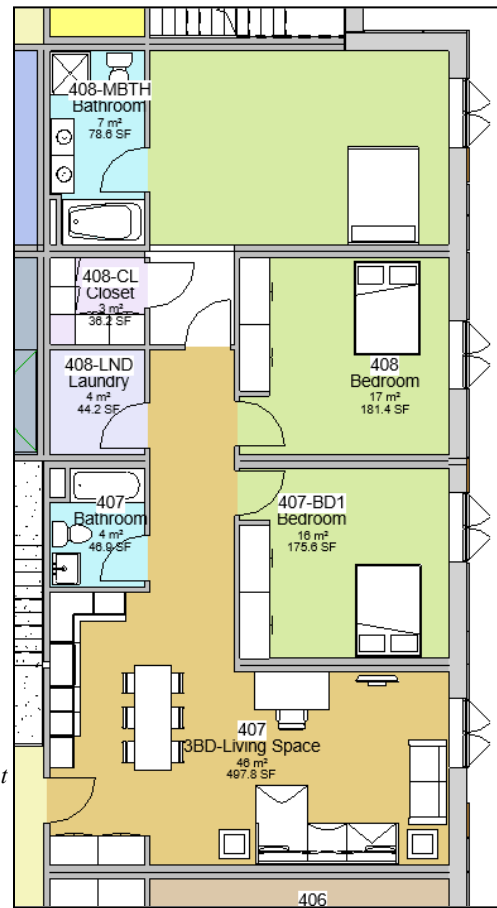


Figure-91: Three-Bedroom Apartment layout



Figure-92: Section-A

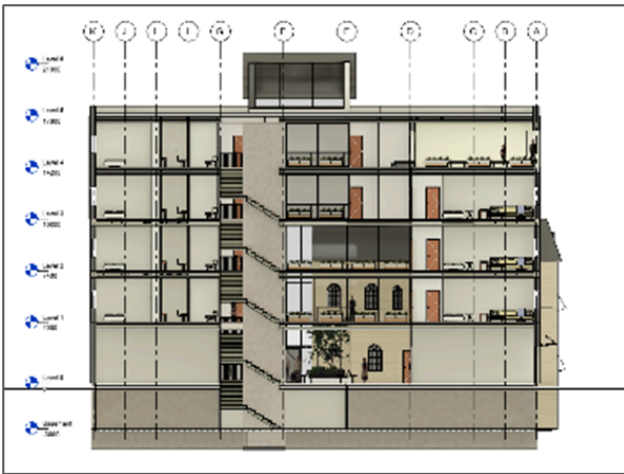


Figure-93: Section-C

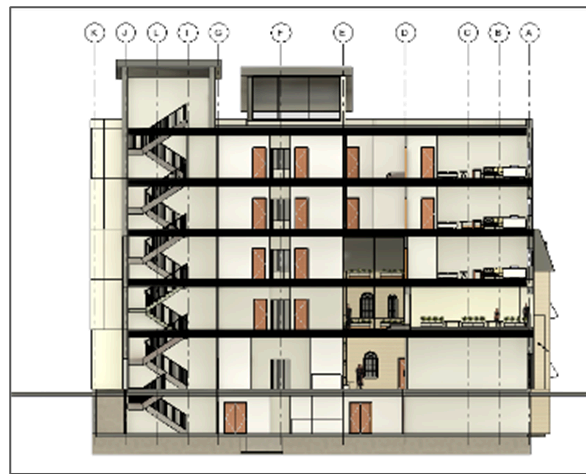


Figure-94: Section-B



Figure-95: Section-D



Figure-96: South Elevation (Dundas Street)



Figure-97: North Elevation



Figure-98: West Elevation (Mutual Street)



Figure-99: East Elevation



Figure-100: Elevator's Hall (Ground Floor)



Figure-101: Elevator's Hall (First Floor)



Figure-102: Entrance from Dundas Street



Figure-103: 3 Bedrooms apartment- Living space

12.2 Appendix B: EUI Target Documentation Summary

Table 9: Envelope Characteristics

Construction	Materials	Reference
Exterior walls	$\frac{1}{2}$ " Gypsum, k-value of 0.16 W/m·K $\frac{1}{2}$ " Plywood board, k-value of 0.15 W/m·K Vapor barrier, N/A 2x6 SPF, 24" o.c. w/ R19 Cellulose, k-value of 0.0392 W/m·K $\frac{1}{2}$ " Plywood board, k-value of 0.15 W/m·K R-21.5 mineral wool, k-value of 0.034 W/m·K Water/Air barrier, N/A Air cavity, N/A Ceramitex® facade system, N/A	(Morrison Hershfield, 2021)
Roofs	$\frac{1}{2}$ " Gypsum, k-value of 0.16 W/m·K $\frac{1}{2}$ " Plywood board, k-value of 0.15 W/m·K 2x10 SPF, 24" o.c., w/ R34 Cellulose, k-value of 0.0415 W/m·K $\frac{1}{2}$ " Plywood board, the k value of 0.15 W/m·K Vapor barrier, N/A R-30 mineral wool, k-value of 0.037 W/m·K 2-degree tapered insulation, N/A Roof membrane system, N/A	

Interior walls	$\frac{1}{2}$ " Gypsum, k-value of 0.16 W/m·K $\frac{1}{2}$ " Plywood board, k-value of 0.15 W/m·K 2x4 SPF, 16" o.c., uninsulated, k-value of 0.137 W/m·K $\frac{1}{2}$ " Plywood board, k-value of 0.15 W/m·K $\frac{3}{4}$ " air cavity, N/A $\frac{1}{2}$ " Plywood board, k-value of 0.15 W/m·K 2x4 SPF, 16" o.c., uninsulated, k-value of 0.137 W/m·K $\frac{1}{2}$ " Plywood board, k-value of 0.15 W/m·K $\frac{1}{2}$ " Gypsum, k-value of 0.16 W/m·K	
Interior Floors & Ceilings	$\frac{1}{2}$ " Gypsum, k-value of 0.16 W/m·K $\frac{1}{2}$ " Plywood board, k-value of 0.15 W/m·K 2x10 SPF, 24" o.c., uninsulated, k-value of 0.367 W/m·K $\frac{1}{2}$ " Plywood board, k-value of 0.15 W/m·K 1- $\frac{1}{2}$ " air cavity, N/A $\frac{1}{2}$ " Plywood board, k-value of 0.15 W/m·K 2x10 SPF, 24" o.c., uninsulated, k-value of 0.367 W/m·K $\frac{1}{2}$ " Plywood board, k-value of 0.15 W/m·K	
Foundation slabs	20" Concrete, k-value of 1.7296 W/m·K R-20 XPS, k-value of 0.029 W/m·K	WUFI North America Database
Foundation walls	12" Concrete, k-value of 1.7296 W/m·K R-20 XPS, k-value of 0.029 W/m·K	
Basement ceiling	$\frac{1}{2}$ " Plywood board, k-value of 0.15 W/m·K 2x10 SPF, 24" o.c., w/ R34 Cellulose, k-value of 0.0415 W/m·K $\frac{1}{2}$ " Plywood board, k value of 0.15 W/m·K	(Morrison Hershfield, 2021)
F-factor (basement)	0.97	(Winkelmann, 1998)
F-factor (slab-on-grade)	0.52	

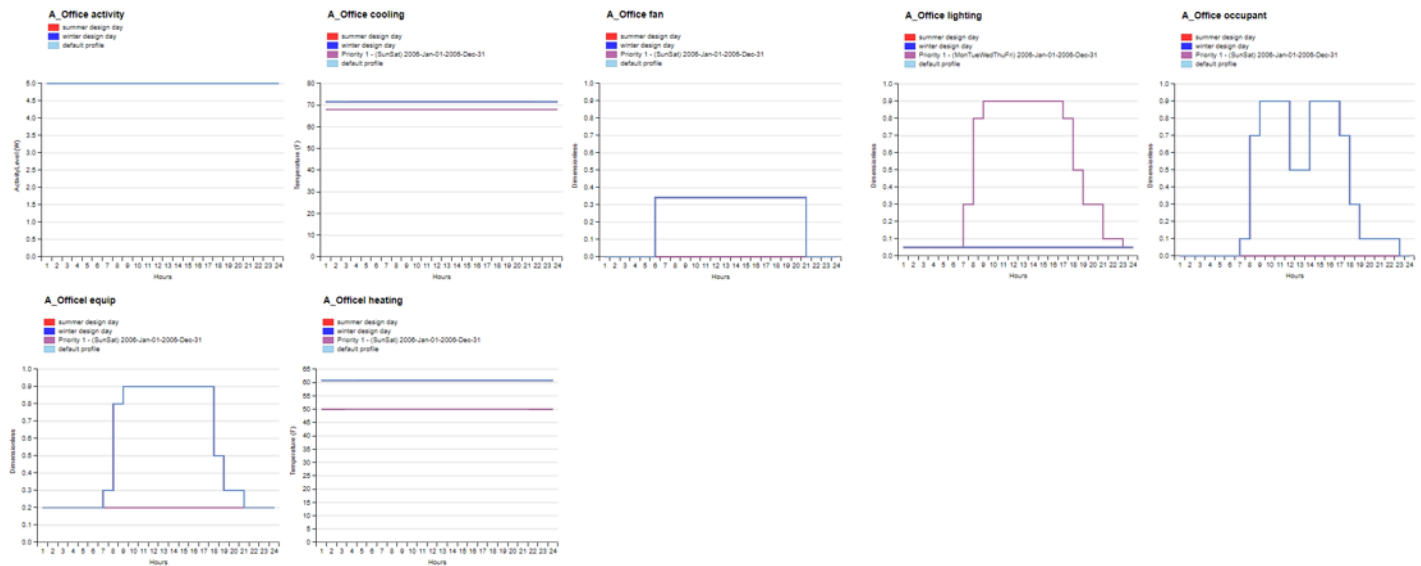
Table 10: Definitions: people, lights, and plug load per space types

Space Types	People Definitions		Lights Definitions		Equipment Definitions	
	people/m ²	people/ft ²	W/m ²	BTU/h·ft ²	W/m ²	BTU/h·ft ²
Commercial	0.033	0.003	13.1	4.2	3.7	1.2
Corridor	0.01	0.0009	6.9	2.2	-	-
Atrium	0.1	0.009	7.3	2.3	-	-
Washroom	0.033	0.003	13.1	4.2	7.6	2.4
Office	0.05	0.005	10	3.2	8.3	2.6
Stair	0.005	0.0005	6.2	2.0	-	-
Residential	0.04	0.004	5.0	1.6	5.0	1.6
Storage	0.001	0.00009	7.8	2.5	-	-
Mechanical room	0.005	0.005	4.6	1.5	2.9	0.9
Laundry	0.05	0.005	4.6	1.5	2.9	0.9
Loading area	0.002	0.0002	6.2	2.0	-	-
Reference	(National Research Council of Canada, 2017)		(City of Toronto, 2018; National Research Council of Canada, 2017)		(City of Toronto, 2018; COMNET, n.d.)	

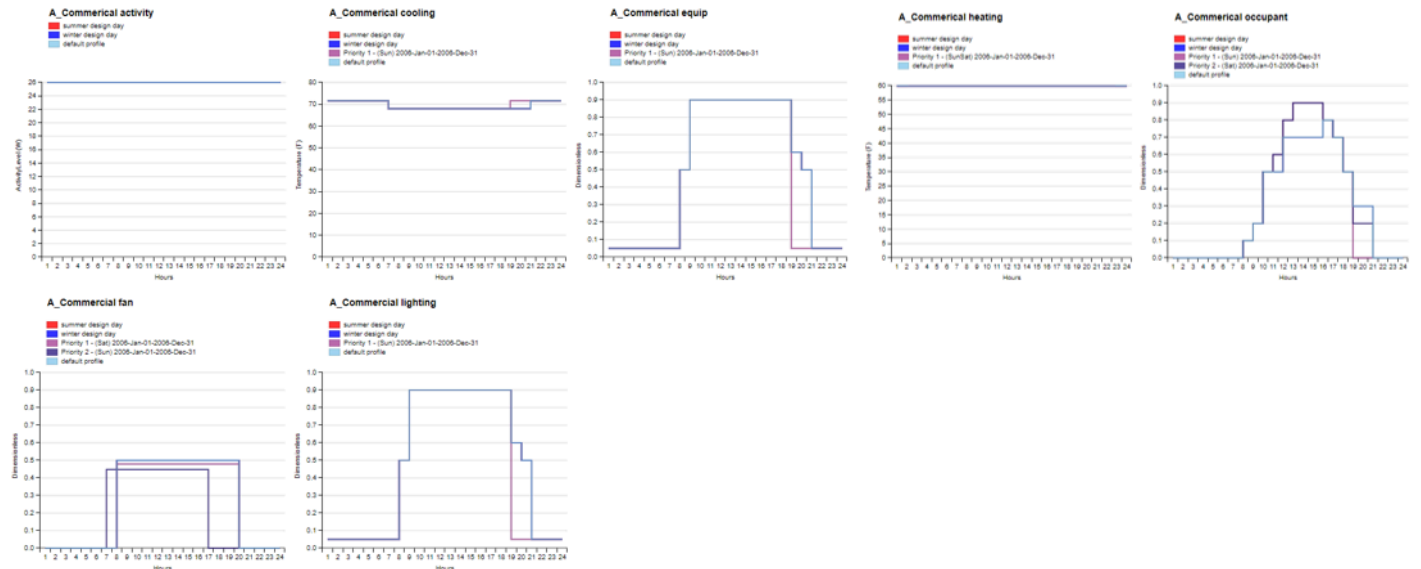
Table 11: Schedules

Schedule sets	Spaces types	Reference
Operating schedule A	Office	Modified from National Research Council of Canada, 2017
Operating schedule C	Commercial; Laundry	
Operating schedule G	Atrium; Corridor; Mechanical Room; Residential; Stair; Storage; Washroom	
Operating schedule H	Loading Area	

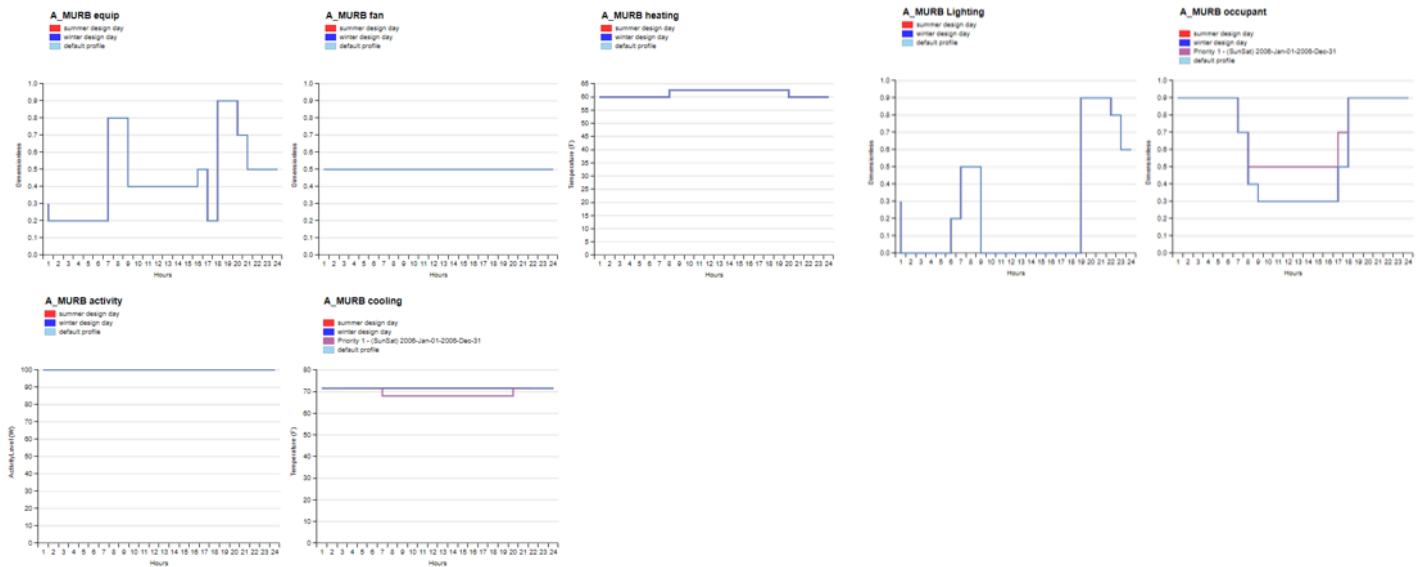
Operating schedule A



Operating schedule C



Operating schedule G



Operating schedule H

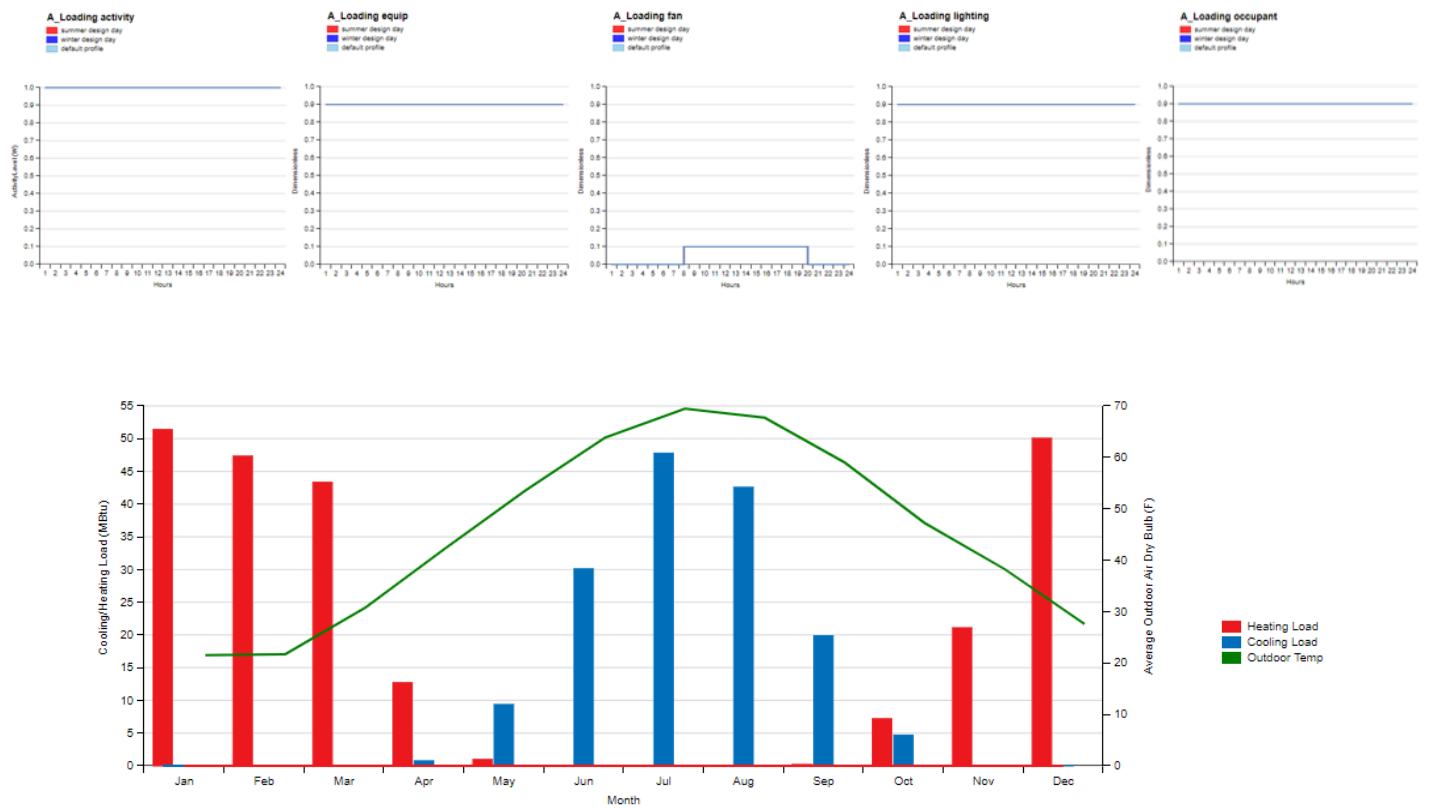


Figure 104:Monthly Heating and Cooling Profile

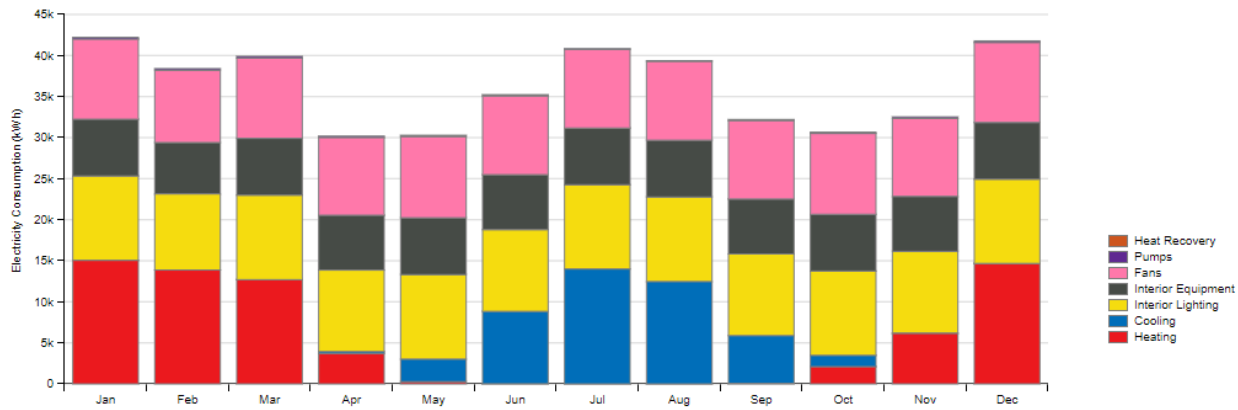


Figure 105: Monthly electricity consumption

12.3 Appendix C: PV System for Renewable Energy Generation

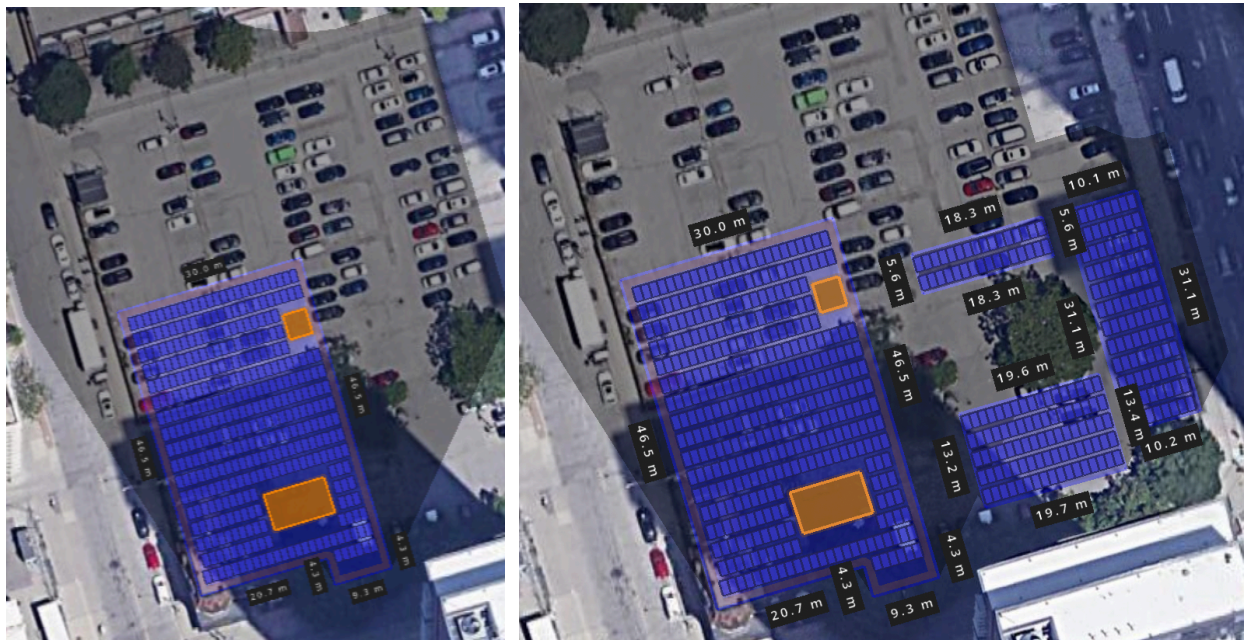


Figure 106: Helioscope simulation for scenarios 1a and 2