The Third Space
ENGINEERING

Contents

This project takes place on the unceded traditional territories of the x▯m▯▯k▯▯y▯▯m (Musqueam), S▯wx▯wú7mesh (Squamish), and s▯lilw▯ta▯ (Tsleil-Waututh) Nations.

Third Space Commons is the result of interdisciplinary collaboration and creative engineering thinking. This building seamlessly combines systems to produce a resilient, adaptable, and low-carbon home.

Approach & Documentation

The engineering of Third Space Commons was guided by carbon minimalism, system minimalism, flexibility, resilience, and a vision of a living lab. These principles were used to assess systems and ensure a cohesive building concept. In past projects, our team has often over-engineered. However, with our key driver of carbon minimalism, we realized the value of simple engineering solutions which are often more elegant than current industry practices. This is evident in our structural and mechanical systems.

Our vision for this space was clear from the beginning: challenge the norms of construction to develop the most low-impact building possible. This targeted goal required breaking down the typical development process. Rather than starting with an architectural vision, developing that to schematic design, and then introducing engineers, we created a combined engineering and architecture team from the get-go. This integrated design methodology allowed our team to holistically evaluate project decisions.

Our team was split into architecture/building science, mechanical/electrical/energy, and structural/civil to facilitate overlapping conversations. Weekly meetings within these 'bubbles' along with full-team discussion meetings allowed for technical excellence and thoughtful integration. In the early stages of ideation, we used a weighted decision matrix to evaluate the optimum combination of building components, which we updated on a weekly basis until reaching our final concept. Instead of using a life-cycle analysis only as a tool to evaluate decisions after the fact, we performed carbon calculations throughout all stages of the project to choose the most environmentally friendly design options. Interdisciplinary meetings were carried out all the way through the design-build as we slowly integrated project partners including designers-of-record, contractors, and permitting bodies.

Our history of success as a team gave us the confidence to make this project truly student-led. Undergraduate students (with an average team age of 20) evaluated system options, conducted calculations, drafted documentation, and ensured construction compliance. With mentorship from our partners, students developed industry level designs, something that is still impressive to our project supporters. To achieve this, we had to grow strong design, modelling, and management skills within our engineering teams. We facilitated this through mentorship seminars with key design partners and iterative feedback cycles throughout the design process.

Our team also took the initiative to develop a 'directed studies' class at UBC where students across engineering disciplines on our team could collaborate on the energy modelling process for Third Space Commons. Led by our faculty advisor, students used the model as a tool to evaluate

Figure 1- Weekly Integrated Design Meeting

the energy performance of design choices and iterate to produce the most efficient building systems possible, given our specific context and constraints. The latest energy model, appended to the end of this document, analyses the performance of the building as constructed. Even after the competition, this model will grow and evolve as Third Space Commons becomes part of the campus as a living lab initiative at UBC, where actual building usage will be compared to the model and used to refine its assumptions.

Our students reached out to UBC professors during the early design process, who provided valuable feedback on features such as the foundation and rainwater capture. We also engaged students studying high performance buildings in the Masters in Engineering Leadership program, who had valuable industry experience. Their mentorship towards the undergraduate student designers brought us closer to producing professional-level drawings. As we continued to refine our work, we began to collaborate closely with local design firms. The architectural, mechanical, electrical, and civil drawings were designed and drafted entirely by students, with multiple cycles of reviews from the architect and engineers of record. Initial structural design and calculations were performed by students, but due to structural requirements in BC, the final drawings were drafted by RJC Engineers (including a co-op student from our team).

Our design and documentation required not just the approval of our consultants, but also the approval of UBC. Our engineering documentation surpasses typical standards of a single-family home by meeting institutional standards for the building's future life as a living lab.

When we began to bring on our construction manager, suppliers, and installers in spring 2022, they also provided design feedback, specifically in terms of cost and buildability. Guidance from contractors continued all the way through construction, as we have gone from building permit to issued-for-construction to as-built drawings. A 'digital twin' in Revit using BIM 360 is continuously being updated to reflect site changes which can be used in the future for research purposes.

Civil Design

Site Geology and Foundation

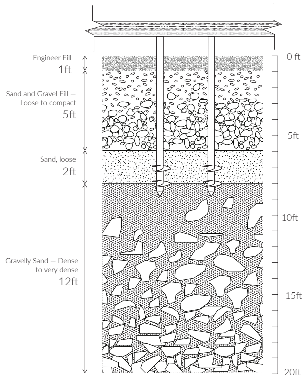


Figure 3- Foundation Diagram

A geotechnical desktop study was taken to inform early concept development and a later geotechnical site assessment confirmed our assumptions. Nearby sites consisted of around three to seven feet of sand and gravel fill, followed by up to thirty feet of dense glacial till, and a deep groundwater table. While several foundation options were considered, steel helical piles were selected as the best option. Helical piles are sufficient for dense silty sands and can withstand large gravity loads making them a good fit for the site. They can also be easily unscrewed at the end of the building's life with no prior excavation which allows for material reuse. Helical piles are not as carbon intensive as typical foundation materials like concrete, furthering the goal of making this site carbon neutral.

Site Servicing

The design of water, electricity, storm, and sanitary services went through numerous iterations due to unique challenges posed by our site. Sloped topography, far-away utility connection points, abundant trees, stone benches, nearby abandoned utilities, outdoor lighting, and multiple pathways impeded the routing of site services. The final design preserved all trees on site while maintaining proper pipe size, slope, and depth below grade as required by UBC Technical Guidelines and BC building code.

Structural Design

The building's wood framed structure is a celebration of British Columbia's strong lumber industry. We partnered with local wood product suppliers to develop a low carbon building that seeks to serve as the model for net-zero carbon developments. The team utilized iterative lifecycle analysis to assess the embodied carbon footprint of various structural system options. Lightwood framing significantly outperformed concrete, mass timber and other material systems which led us to the final structural design. Dimensional lumber systems significantly outperform mass timber products due to mass timber's glue content. The structural system is a perfect example of our engineering approach of minimal systems leading to low impact construction. 'Old-fashioned' construction methods are often less impact than newer, more manufactured structural products.

Third Space Commons is a primarily wood framed structure. Engineered wood trusses run flush against the bottom of the roof envelope before carrying loads to parallel strand lumber (PSL) girder beams. The PSL beams lay on built-up stud posts and PSL posts at the roof valleys. The building's bulkhead is framed with dimensional lumber at optimized spacing for MEP access before bearing onto PSL beams. The exterior stud walls carry both gravity and lateral loads from the roof and bulkhead framing. Floor live and dead loads are carried by engineered wood trusses in the floor system. Truss loads are carried to PSL exterior beams before transferring to the locally manufactured steel helical pile foundation system.

> The helical pile foundation system saves 10,439 kg C02 compared to a typical foundation for an equivalent building.

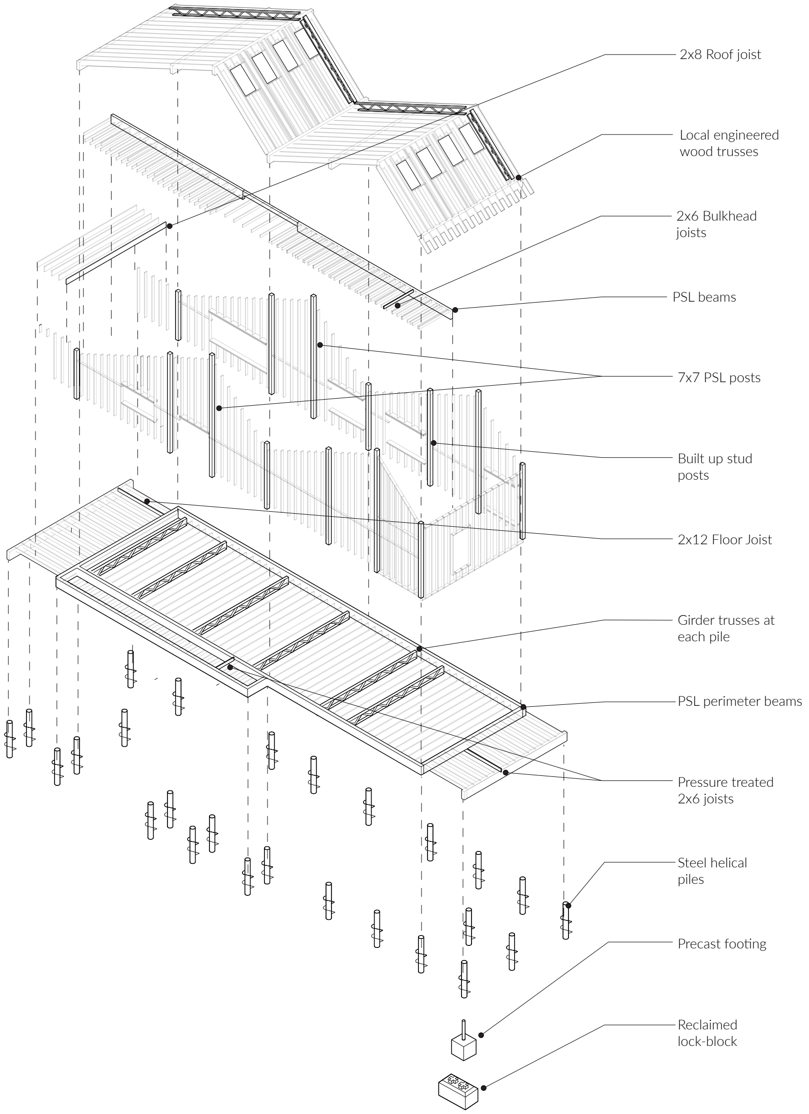


Figure 4- Structural Axo

All wood is sourced locally within 100km from the project site.

> 30% of the helical piles used for this project are re-used from other projects in BC.

All piles from this project can also be re-used for future projects.

The structure has been designed to efficiently resist both gravity and lateral loading. Shear stud walls, tie-back trusses between helical piles, and hold downs at main posts make up the building's seismic resiliency system.

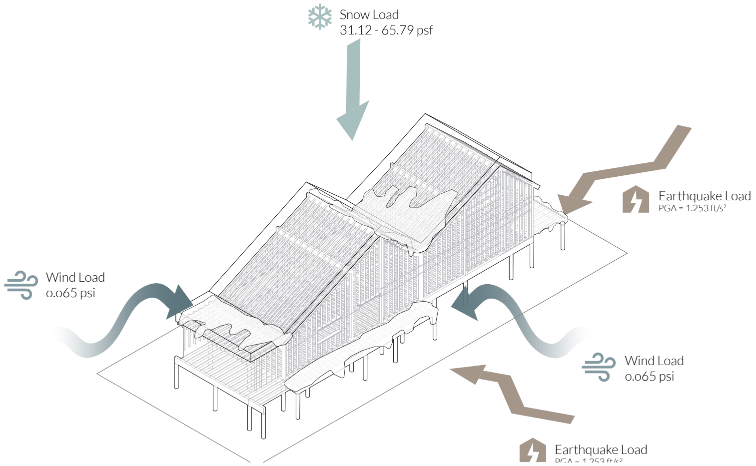


Figure 5- Loading Diagram

For the sunroom and decks, dimensional lumber is used to carry loads to smaller helical piles, cast-in-place concrete footings, and reclaimed lockblocks from other construction projects. Structural members outside of the building envelope are pressure-treated to maximize their lifespan and ensure dry-use condition. Although termites are not of concern at the project site, all structural members were kept above 150 mm from site grade which also ensured dry-use condition.

Envelope Design

Glazing and Doors

With the help of our industry partners, we were able to procure triple-paned glazing that would have otherwise gone to landfill. The skylights were manufactured by a local supplier. The windows on the west wall have PVC frames manufactured locally by Innotech, a Passive House-rated window manufacturer. The same supplier manufactured our north and south doors to be as high-performing as possible.

Insulation

Our building is insulated with hempcrete in the walls and low carbon blown-in cellulose in the ceiling and floors. Locally-sourced mineral wool batt was used to mitigate thermal bridges, while foam insulations and spray foam were avoided for their high embodied carbon.

The decision to build the walls with hempcrete was the biggest innovation in the envelope system, requiring adaptation of other design aspects from usual passive house methods. The **18” hempcrete walls** provide R-value and thermal mass all in one, enabling passive heating and cooling strategies. Hempcrete is a rare source of low carbon thermal mass, since it is bio-composite with sequestration potential. First, carbon dioxide is sequestered during the growing cycle of the hemp. When combined with lime and water to form hempcrete, additional carbon is sequestered during the chemical reaction as it cures.

This carbon-negative material is a key feature of our building and a cornerstone of our carbon minimalism principle. Its implementation posed many challenges, one of which being that it was unfamiliar to our project partners and therefore a source of concern. However, with careful engineering and consideration of how it impacted all aspects of the design, we were able to bring our industry team on board and successfully integrate this carbon-negative insulation into our envelope.

The structural system was heavily impacted by the choice of insulation in all places, as the cellulose relied on trusses in the roof and floor and the exterior plywood diaphragm provided shear resistance. It was vital that the moisture content of the hempcrete within the stud walls was kept below 19% to ensure dry-use condition and prevent decomposition. Thus, **we partnered with FP Innovations to conduct moisture content and density testing** on a full-sized test wall before framing began to determine how long the hempcrete insulation would need to cure for before closing the envelope. Wood framing also helped to reduce the concern of thermal bridges.

A lower value for R-value/inch was assumed for the hempcrete because there was no reliable data on the expected R-value of the mix ratio we used. In Third Space's future life as a living lab, there are plans to utilize temperature data to back calculate the R-value of the hempcrete walls, since this material has a highly variable R-value dependent on mix ratios and compaction during install. Overall, the living lab data collection will allow researchers to verify actual building energy performance and inform future decisions on appropriate energy-saving low carbon materials and system solutions.

Air Barrier System

Because of the use of hempcrete, the air barrier in the wall has an unconventional placement. The walls needed to be able to "breathe" and be exposed in certain places in the interior, so an exterior-facing air barrier system was implemented. The air barrier system is located on the exterior side of the envelope in the walls and on the interior side in the roof and floor, making the transitions between these structures key to a continuous system.

Integrated design reviews and careful construction sequencing allowed the connection details to be adequately continuous. The use of Soprema membranes in the roof, Siga membranes and tapes on the walls, floor and windows, and construction mentorship from both companies was essential to the successful installation of their products. The system was verified by a mid-construction blower door test provided by our building science consultant, RDH, and allowed the system to be fortified where necessary.

An atomized air sealing system, called the AeroBarrier solution provided by Aeroseal, was utilized to address air barrier deficiencies that could not be addressed through reconstruction because of constrained construction timeline.

Mechanical & Electrical Design

Electrical Design

Third Space Commons is supplied by a combination of on-site solar generation and electricity from BC Hydro's 97% renewable energy grid. The system consists of **eighteen 100W solar panels**, re-used from a house slated for demolition. We decided to forego battery back-up due to its high embodied carbon and toxic components. For improved resilience, a DC-coupled grid-tied system allows us to receive and send energy within UBC. The multimode inverter can switch into different operation modes for optimal performance. British Columbia aims to transition into 100% electric vehicle sales by 2040; as part of this goal, a Level 2 EV charger has been added.

Lighting Design

The lighting within Third Space is designed for ultimate occupant comfort, suitable for both working and living environments, while minimizing energy loads using natural daylighting methods. Daylight analysis was performed using location-based weather data and lighting simulation software to quantify the interaction between natural and artificial lighting. This allowed us to determine the ideal lighting layout, ensuring that baseline illumination levels of at least 300 lux were met throughout the space. To light the open work and living spaces, we used linear fixtures, surface-mounted inside an architectural reveal between the ceiling and west wall. These lights run along the entire length of the building, outputting up to 1000 lumens.

With Vancouver's ever-changing climate, we aimed to implement a lighting system that can be controlled using daylighting sensors to best suit day-to-day conditions. Daylight harvesting in the space will be achieved with continuously dimming circuits controlled by photocell sensors to detect natural light levels. Sensor data and commands to lighting will be fielded by **Home Assistant, our smart controls network**. Additionally, the lighting layout is separated into multiple zones to accommodate flexible space configurations. This ensures that optimal illumination levels are achieved per zone, whether it be a space for living or working.

Indoor Environmental Quality

Careful consideration was applied in designing an indoor space that would be comfortable for occupants year-round while minimizing lifecycle carbon. This process required consistent collaboration between design teams for a fresh and holistic approach.

To achieve exceptional fresh air quality during the heating season while minimizing energy expenditure, we chose to use a heat-recovery ventilator (HRV) for mechanical ventilation. The specified Oxygen8 Ventum unit has the ability to provide high flowrate at very high efficiencies of up to 87%, for luxurious air exchange rates at little cost to the heating system. Powerful but quiet electronically commutated motor (ECM) fans have the static pressure requirements to enable high-efficiency particulate absorbing (HEPA) filters for perfect air quality, even during forest fires. For most of the year, standard MERV13 filters are installed as default on the fresh air stream, providing excellent filtration at reduced fan energy loads when higher-level HEPA filtration is not needed.

Careful design of the ventilation supply system led to a minimized lower-carbon ductwork installation only within the bulkhead space. This bulkhead was the result of thorough collaboration between mechanical, electrical, and architecture teams to create a flexible and accessible space for installing systems while supporting the use of the second level as a creative additional floor area. A series of **CFD simulations** allowed the team to optimize and validate the mechanical ventilation delivery for the unique shape of our space. The results confirmed that concealed diffusers located on top of the bulkhead and directing airflow toward the peak of the roofs in both zones, with air returning through concealed grilles near the center valley and travelling through the bulkhead plenum, would allow for excellent distribution effectiveness across the range of designed supply temperatures and flowrates.

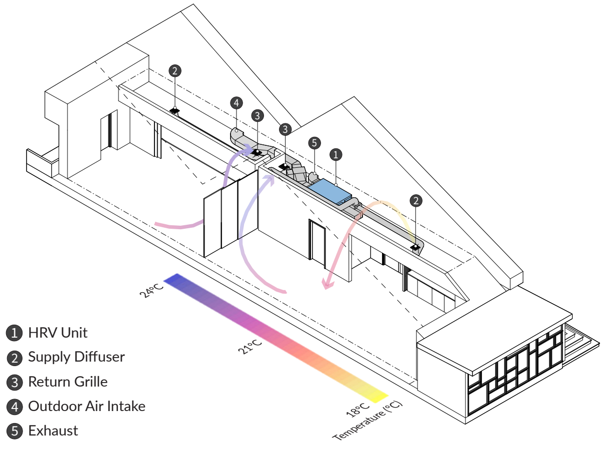


Figure 6- Mechanical Ventilation

In our mission to significantly reduce the lifecycle carbon of our mechanical systems, we opted out of an embodied carbon heavy active cooling system such as an air source heat pump. Instead, our building uses a simple but elegant combination of passive features to guarantee comfort in the hot summer months, even into the future of rising average temperatures due to climate change. The key to the passive thermal performance of the building is the strong natural stack and cross ventilation provided by large operable tilt-turn windows at the ground level and electrically operable skylights high in the roof. This natural ventilation performance was designed based on engineering judgement combined with static calculations based on the CIBSE AM10 guidelines and more flexible and thorough **simulations run through Climate Studio.** The window specifications and locations were also chosen in conjunction with nearby natural shading to minimize direct solar gains into the space. The hempcrete in the walls acts not only as insulation but also as low-carbon thermal mass, damping the daily temperature cycle by absorbing heat during the day and releasing it at night. Our nighttime cooling strategy combines thermal mass with airflow to flush out additional heat, using the high-elevation skylights and HRV bypass mode to avoid security risks. Structural and electrical rough-in has been provided for future ceiling fans which could be installed to enhance the cooling strategy. The standing seam roof and upper walls are painted white to reflect longwave solar radiation, a key driver of overheating during the summer. The west windows are also naturally shaded by blooming vegetation during the summer months, further preventing heat due to the sun.

Vancouver's climate typology is temperate and does not require active humidity control. The hempcrete insulation material in our walls has the potential to act as a humidity 'battery' and help naturally regulate the humidity of the space by absorbing and releasing moisture.

As the summer wanes and winter sets in, electric radiant heating mats in the floor provide abundant thermal comfort by keeping the space uniformly warm. When landing on this design choice, it was challenging to strike the right balance between operational efficiency and carbon; ironically, many of these elements are in opposition to one another when it comes to building engineering. Thin underfloor resistance heating mats were chosen because of their combination of extremely low embodied carbon and architectural appeal. Although heat-pump heating and cooling would have been higher efficiency, the embodied carbon of the system (particularly due to refrigerant leakage) overshadowed the energy savings when considering the context of our local renewable low carbon grid and even lower carbon reused PV panels.

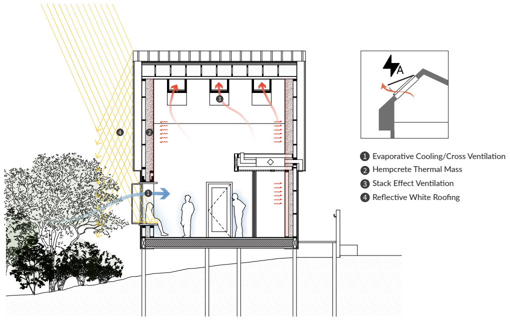


Figure 7- Summer Day

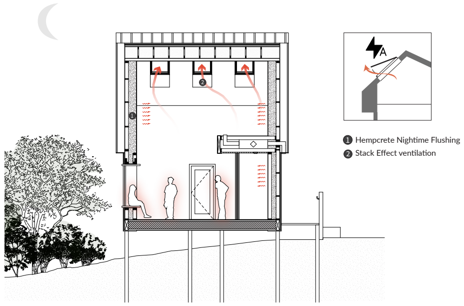


Figure 8- Summer Night

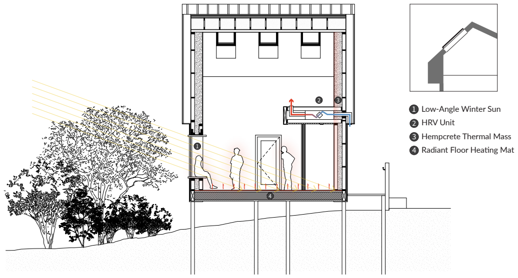


Figure 9- Winter Day

Water Systems

> The plumbing fixtures and appliances within Third Space Commons are all low-flow and reused.

They were sourced either from an existing building that was slated for demolition or from Vancouver locals to minimize embodied carbon and promote circularity.

To balance energy efficiency with embodied carbon for hot water supply, mini-tank domestic water heaters were chosen. These provide near-instant hot water to occupants while avoiding the standby energy losses and embodied carbon associated with larger tanks and the heavy electrical requirements of a tankless system.

In alignment with our resilience principle, rainwater is collected from the full roof catchment area and channeled through a large particle filter into a 1000L (220 gal) storage tank. This water can be used for manually irrigating plants during the growing season, offsetting the largest water use category in our region and reducing the risk of the system in comparison to domestic use. The design also includes provisions for future expansion of the system, with extra space for additional tanks or filtration systems to be implemented in its future life as a living lab.

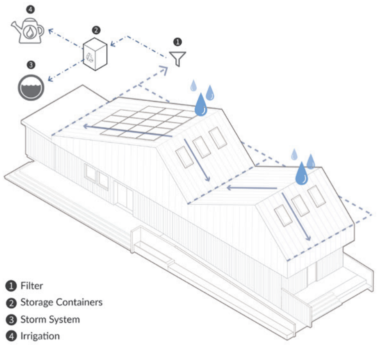


Figure 10- Rainwater Harvesting System

Smart Controls and Living Lab

Third Space Commons is part of UBC's Campus as a Living Lab initiative. After the Solar Decathlon competition, the space will be converted into an institutional building for engineering and architecture students and faculty to study, collaborate, and experiment on the building. From the very beginning, this shaped the design of Third Space. The clear ceiling in the bathroom reveals the HRV, encouraging occupants to think about what makes buildings tick. The mechanical and electrical bulkhead is fully accessible from above, allowing the curious to inspect the inner workings of our active systems.

> Access hatches and ample room within the bulkhead structure allow for easy modification of existing systems, or installation of additional components.

Third Space Commons is also equipped with a smart controls and data monitoring network hosted on the Home Assistant dashboard. Home Assistant is an open-source operative system that allows for home automation and local control of smart home devices via Zigbee, Wi-Fi, and Bluetooth protocols.

The above diagram shows some of the capabilities that will be integrated into the building: the monitoring network, for measuring a diverse set of performance indicators; and reactive controls, which shape building behavior depending on external and internal conditions. Control algorithms will interconnect components and automatically operate the home to be as efficient as possible. The user is always able to override these settings when necessary for occupant comfort and can also customize schedules, setpoints, and more through the Home Assistant dashboard.
To monitor the efficiency of the high-performance systems, a circuit-level energy monitoring system is installed on the electrical panel.

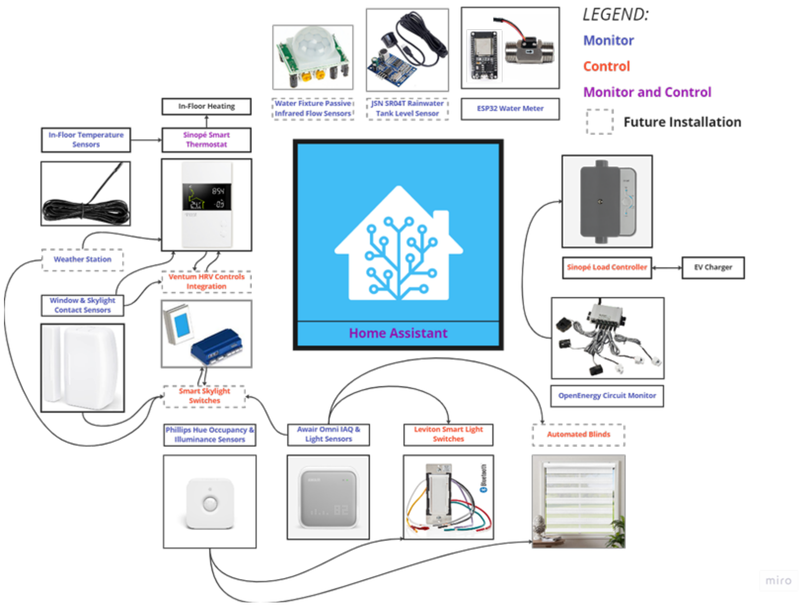


Figure 11- Smart Controls & Monitoring Network

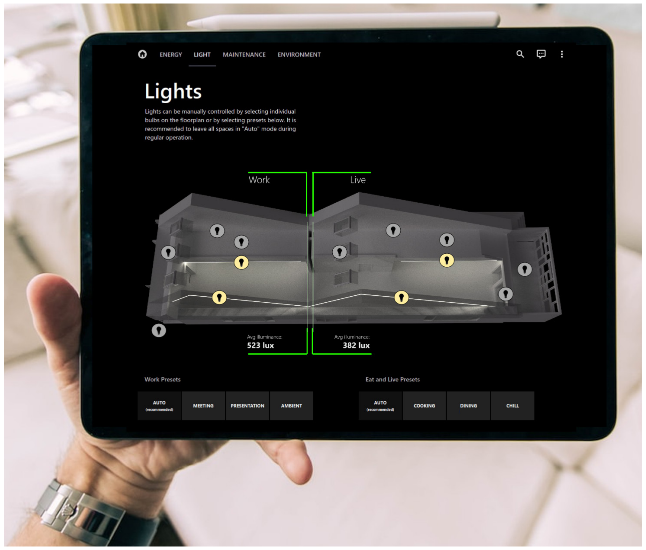
Occupants can view this information through Home Assistant to better understand how their energy is supplied and consumed. The smart water meter, in combination with sensors on each fixture, will allow the user to understand and optimize their water usage.

Illuminance and occupancy sensors will be connected to lighting controls via an algorithm that automatically dims lights according to human traffic and ambient light levels.

> Indoor air quality sensors that measure CO2, VOCs, and particulate matter will adjust the ventilation based on their concentrations.

A future weather station will be looped into the mixed-mode ventilation, heating, and cooling algorithms so that interior conditions can adjust accordingly. For instance, detection of rain will automatically close the skylights to prevent water ingress. As this building will be a test bed for faculty and students, various configurations and algorithms will be tested to explore implementations that allow for optimum comfort and efficiency.

Sensor test points in the hempcrete walls and in the wood studs were installed during construction to monitor moisture content, which are still accessible for data collection. Further experiments regarding its density, insulative performance, and carbon sequestration are of interest to our team and consultants, as it is a new material with limited information available. As a test bed, Third Space Commons is the perfect place to conduct experiments that facilitate our understanding of it, and therefore facilitate its future implementation.



Lights can be manually controlled by selecting individual bulbs on the floorplan or by selecting presets below. It is recommended to leave all spaces in "Auto" mode during regular operation.

Figure 12- Smart Controls UI

Energy Generation

Our current generation plan pairs on-site solar energy generation with BC Hydro’s renewable electrical grid.

Photo-voltaic panels were selected as the primary energy source for this build as they are visually unobtrusive, silent, and reliable during sunnier months. Other sources such as biofuel were ruled out due to their high emissions, while wind turbines were found to be not viable for the location of the build. Our system will consist of eighteen 300WPV (1023BTU/h) panels salvaged from an unused house on campus. Preventing the panels from going to waste brings us closer to our overall goal of reducing our environmental impact and achieving net-zero carbon.

In the rainy and winter seasons when there is minimal solar irradiation, an alternative energy source is required. For this purpose, we will be tapping into BC Hydro. Their energy is sourced from 32 hydroelectric facilities that provide clean, reliable, and cost-effective energy that is readily accessible within the province. Tying our PV system to the grid ensures that there is sufficient renewable energy supplied to our build year-round. British Columbia experiences significant periods of solar radiation during the summer; at this time, the building also has its lowest energy loads. Any excess solar energy generated during summer months can be returned to BC Hydro’s grid. This is crucial to maintaining our goal of 100% renewable energy. BC Hydro’s energy is 97% renewable, so by feeding back our own renewable solar energy, we will be able to offset the 3% of their energy that is produced by three natural gas-fueled power plants.

Our solar calculations indicate an approximate yearly energy yield of 5295kWh (18,067,000 BTU). This number is more than enough to account for the 3% of BC Hydro’s grid that is non-renewable. This calculation includes a 30% safety factor for shading and variable conditions throughout the year. See Figure 1 for a Sankey diagram of energy production and use (in kWh).

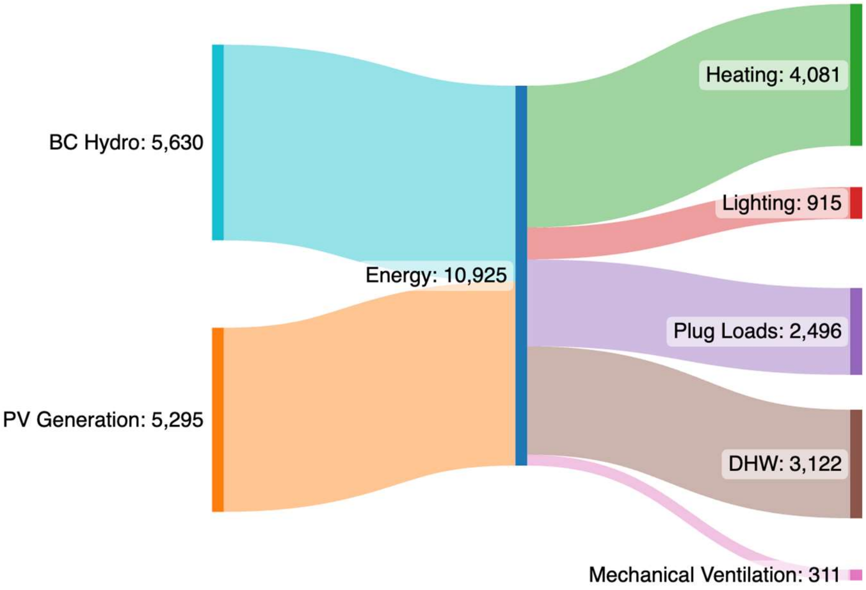


Figure 1: Sankey diagram

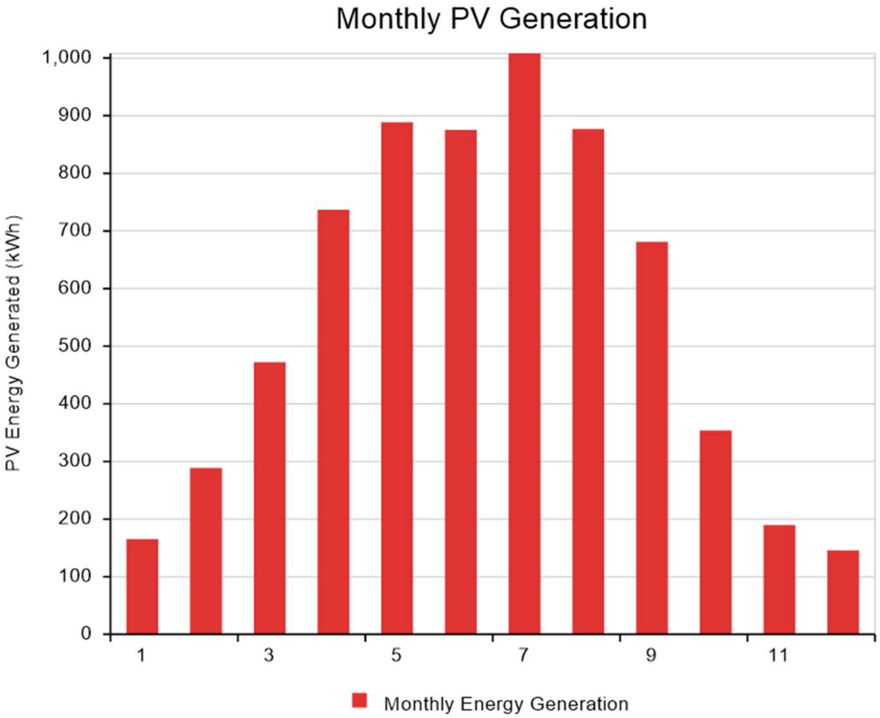


Figure 2: Energy production from PV panels on a monthly basis

Energy Model

The energy model was done in Rhino 7, via EnergyPlus modeling in ClimateStudio. The original building design was completed parametrically using Grasshopper, using ClimateStudio assemblies and loads based on our constructions and use case. Input data included expected occupancy, lighting, and equipment schedules. Assemblies required R-values, heat capacities, and embodied carbon of our building materials. The weather file used for the model is the Canadian Weather year for Energy Calculation (CWEC) 2016 file for Vancouver and can be found at http://climate.onebuilding.org/.

Table 1

Inputs	Value
People density	0.0032 people/ft^2 (0.035 people/m^2)
Lighting power density	1.6 BTU/hr/ft^2 (5 W/m^2)
Equipment power density	1.6 BTU/hr/ft^2 (5 W/m^2)
Heating set point	68 °F (20 °C)

Values in Table 1 were calculated using standard values from the City of Vancouver's energy modelling guidelines: https://vancouveer.ca/files/cov/guidelines-energy-modelling.pdf. Results show a site EUI of 32500 BTU/sqft (102.5 kWh/m2) annually, with a TEDI of 11410 BTU/sqft (36 kWh/m2). These values are within UBC Technical Guidelines for the 2020s as well as BC Energy Step Code 3. Figure 3 highlights the total energy breakdown for each month by end use.

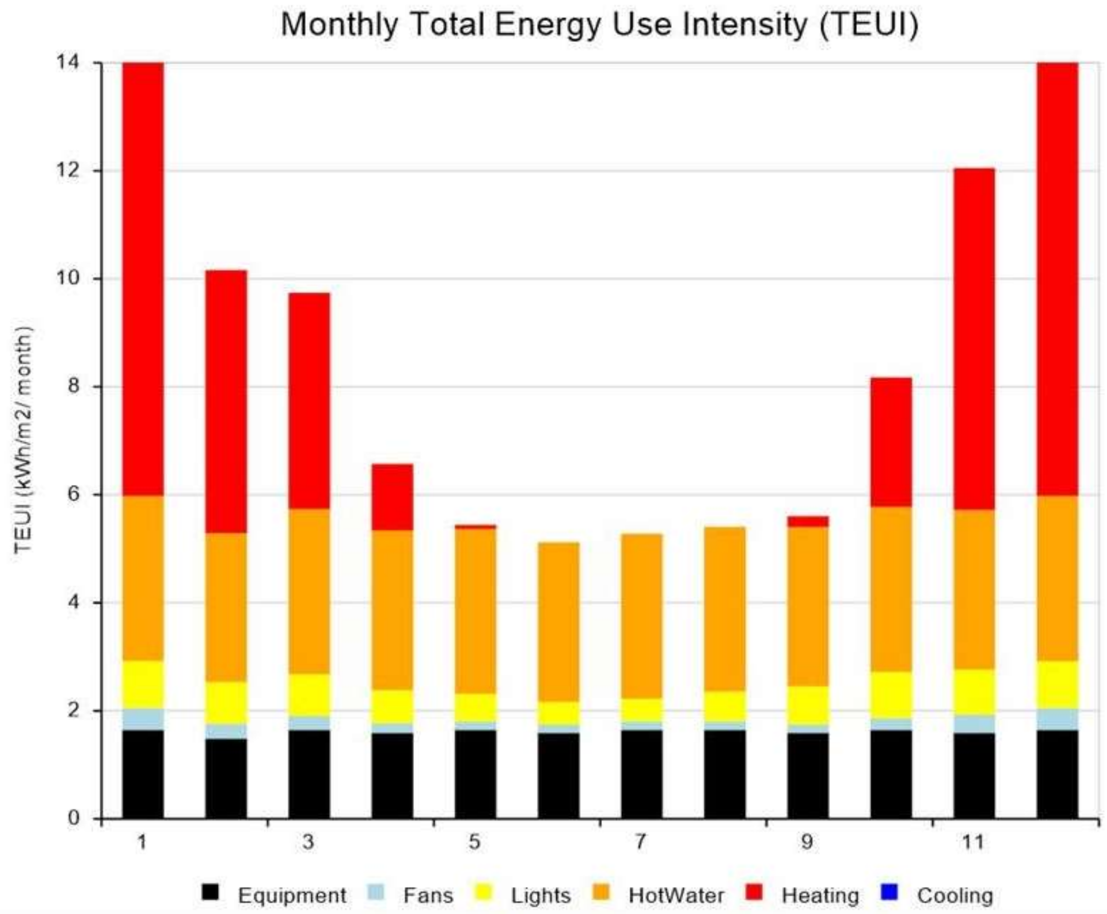


Figure 3: Monthly total energy use intensity (TEUI)

Modifications to our previous energy model allowed for more accurate calculations with regards to thermal bridging and infiltration, resulting in an overall increase in EUI. These include a decrease in floor area, which increased the people density.

Lighting loads vary seasonally depending on natural light levels using files containing information for local weather. These files contain the seasonal variations of the sunrise and sunset data, which factor in the hours the lighting is on. The equipment and plug loads are assumed to remain constant throughout the year, as indicated in Table 1.

The heating schedule is adjusted with occupancy, rather than letting it operate continuously. This energy-saving strategy is highlighted in Figure 4. In Figure 5, our temperature profiles indicate that the air and mean radiant temperatures in the interior space remain relatively constant due to the heating system and envelope. The sunroom is not included in the energy model or calculations, however in the built life of Third Space Commons it may be interesting to see the effect it may have on attenuating the temperature in our building as compared to the energy models.

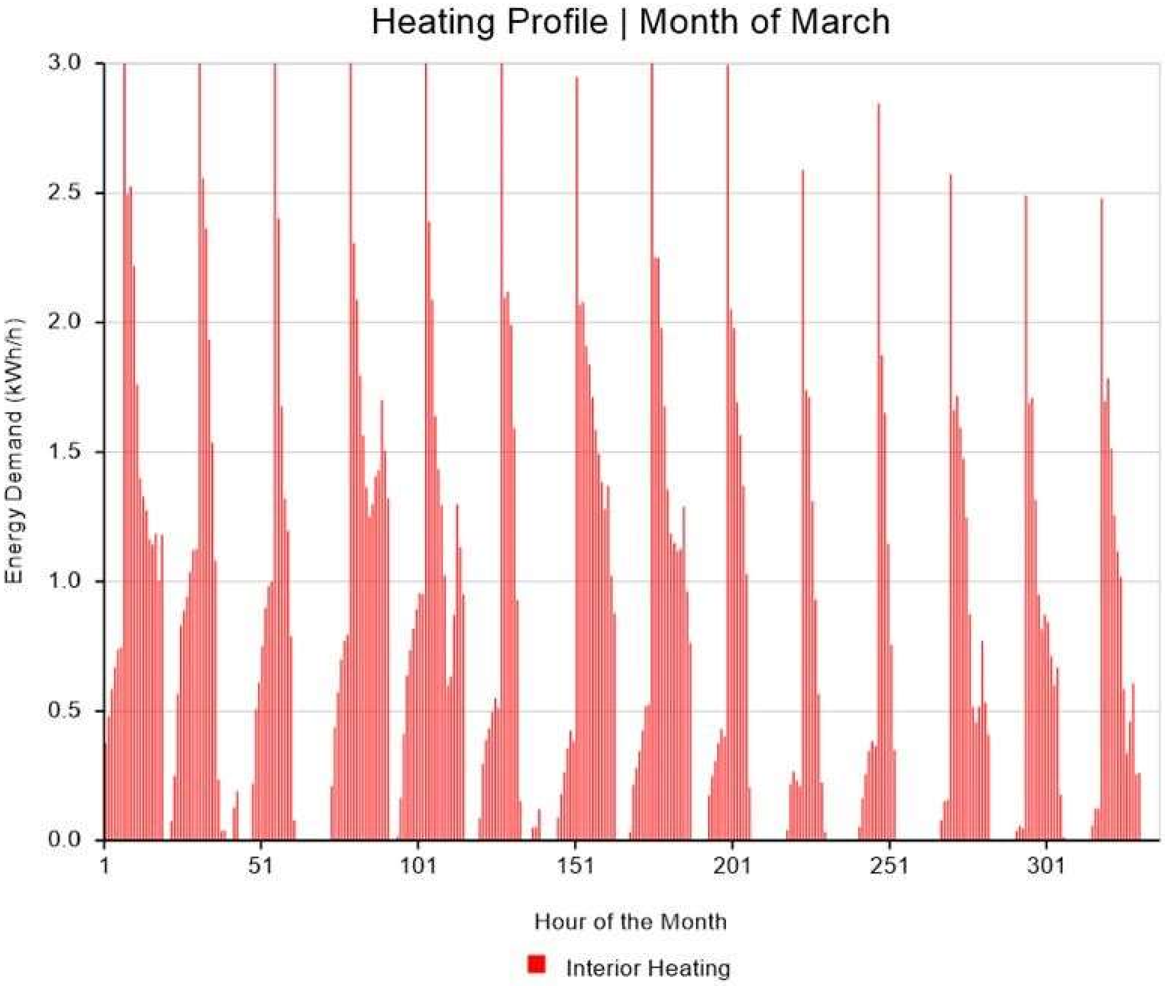


Figure 4: Heating profile for the month of March

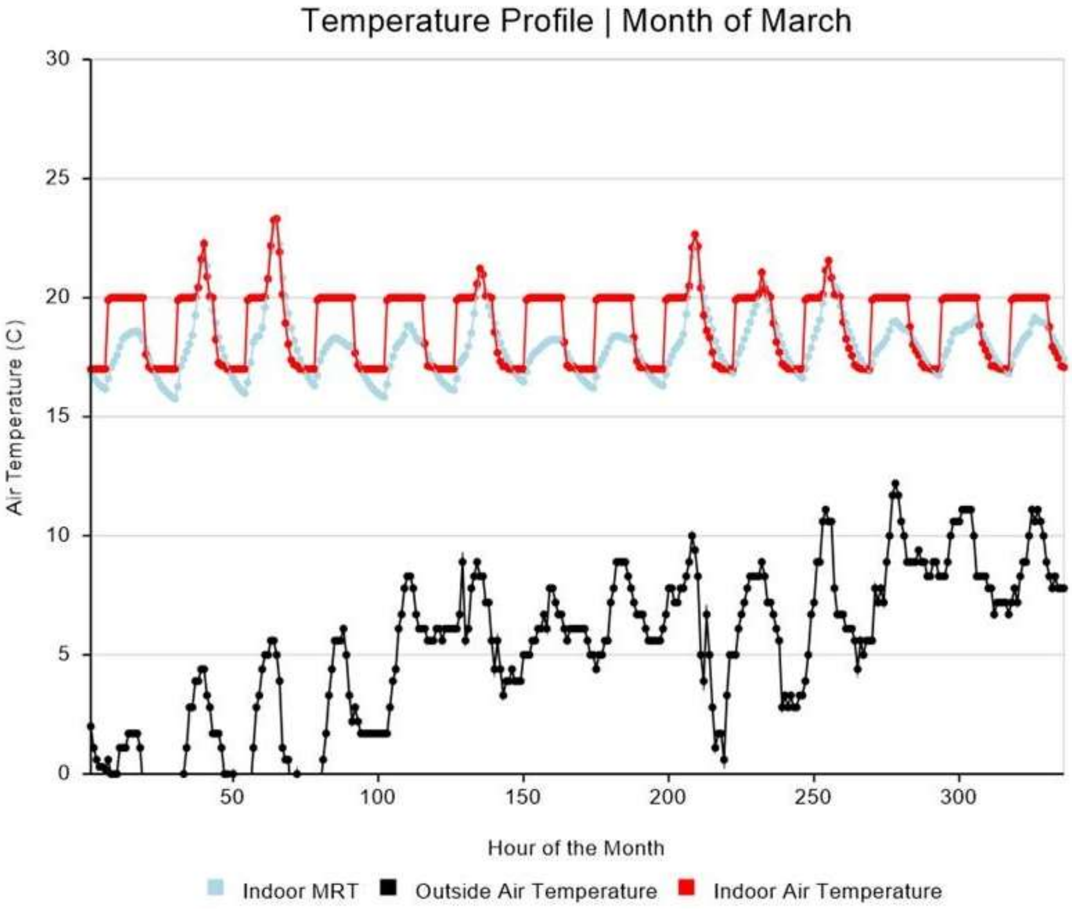


Figure 5: Temperature profile for the month of March

Passive Cooling

To ensure occupant comfort in the cooling season our building relies on passive design features only, without any active mechanical systems. This approach was chosen to minimize energy use and to showcase the effectiveness of these strategies within the context of our climate. With this project our team wishes to encourage designers and policymakers to think critically about what resilient and low-impact future housing could look like.

We began the design with the first principles approach of optimizing the placement of glazing to achieve excellent daylighting without excessive solar gains. Special attention was paid to make the building as permeable as possible while fielding reused windows from a variety of sources. A static stack effect calculation based on a 3C degree temperature difference was used to ensure the building had enough free area to achieve 8-10 ACH as a baseline. This airflow was made possible by electrically operable skylights high in the roof, and manually operated windows and casement vents at the ground level. Another key strategy was in using experimental hempcrete in the building's wall construction, thus allowing both thermal mass for attenuating temperature cycles, and insulation for controlling thermal exchange across the enclosure. Other supporting aspects of the design are the white painted reflective roof to reduce opaque solar gains and an HRV bypass for secure night purging.

For the evaluation of our passive performance in the summer we relied on targets from both ASHRAE 55 and the UBC Technical Guidelines in addition to expert engineering judgement from our faculty advisor and professional consultant partners. To validate our design, we built a thermal comfort model alongside our energy model using the Climate Studio software package and guidance from the UBC Energy Modelling Guidelines. This tool includes more detailed information for windows like the solar heat gain coefficient (SHGC) and effective free area, and for external shading sources such as surrounding landscaping and buildings in addition to 3D building geometry and enclosure constructions. The tool also calculates natural ventilation air exchanges and meticulously tracks internal and external gains. Our team simulated hourly thermal comfort for the building from May to August inclusive, using future weather data for 2011-2040 based on RCP8.5 warming predictions. The results from this simulation show that we are comfortably meeting ASHRAE 55 targets and approaching full compliance with UBC's Technical Guidelines.

Peak Heating Load

To guarantee comfort for occupants during the cold winter months, we created a steady-state peak heating load calculation spreadsheet to size our electric radiant heating system. This calculation accounted for heat losses through the enclosure, from infiltration, and from mechanical ventilation. The design day setup was based on BC Building Code specifications and cross-referenced with UBC Technical Guidelines requirements. Although by convention this calculation is designed to account for a worst-possible 1% scenario, with no accounting for any internal gains from equipment, lights, people, or solar, our team decided to use our judgement to avoid costly oversizing, both in dollars and embodied carbon. Additionally, our heating system is sized to account for internal gains from people, and thus with demand-control ventilation our peak load is when there are no occupants, and only baseline ventilation. The resulting peak heating load is 4298.8W (14,668BTU/hr), or 38W/m^2 (12BTU/hr*ft^2). Figure 7 shows the breakdown of heat losses, useful during our design process for identifying the areas that needed improvement.

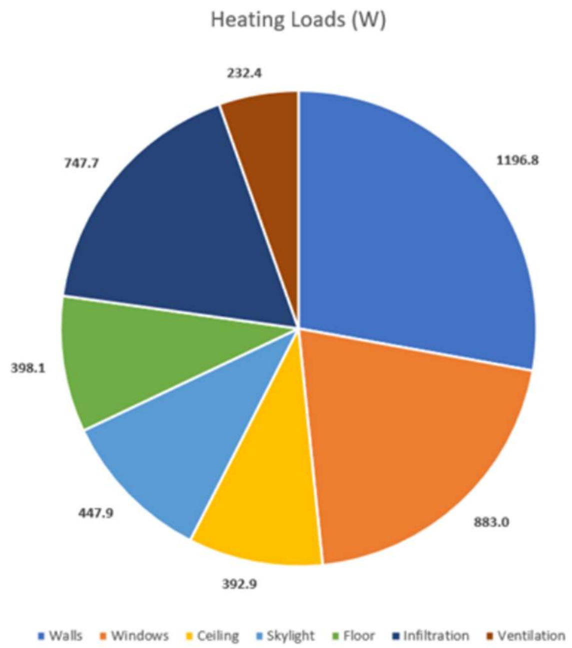


Figure 7: Heating loads for different uses