March 24, 2023

Nathan Splinter
Queen's Facilities
355 King Street West
Kingston, Ontario

Dear Mr. Splinter:
cc: David Gerrish, Alexandra Rae Peet

Please find enclosed Shady Consulting's final report for the Queen's University CIVL460 Design Project titled Solar Shading Solution for Mitchell Hall.

This report contains the detailed process that Shady Consulting followed to complete the Solar Shading project for Mitchell Hall, including the final design selected, and process decisions made to complete an effective design. This report describes the project scope, constraints, stakeholders, background information, and research on the site. It also outlines different detailed design alternatives and the evaluation method used to select a final design. The final design was expanded to entail a plan for implementation, including a design layout, selected materials, and cost analysis. This report will also touch on risk assessment and mitigation, as well as climate considerations. Finally, this report includes the completed project timeline and recommendations for future improvement.

We hope you find this report satisfactory. We thank you for your time and look forward to discussing this project with you again soon. Should you have any comments, questions, or concerns after reading through this document, please do not hesitate to contact us through our communication lead Roy Wang (18cw54@queensu.ca).

Sincerely,

Cameron Gravelle
On behalf of Shady Consulting

Shady Consulting
334 University Ave
Kingston, Ontario

Solar Shading Solution for Mitchell Hall

CIVL460 FINAL REPORT

Shady Consulting
334 University Ave,
Kingston, ON
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Queen's University | Faculty of Engineering and Applied Science

Cameron Gravelle
Evelyn Batson
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Final Report

Presented to Sean Watt and Esmé Hirsch

CIVL460

Civil Engineering

Faculty of Applied Science

Queen's University

Prepared by Shady Consulting

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Due March 24th, 2023

Statement of Originality

Our signatures below attest that this submission is our original work.
Following professional engineering practice, we bear the burden of proof for original work. We have read the Policy on Academic Integrity posted on the Faculty of Engineering and Applied Science web site (http://engineering.queensu.ca/policy/Honesty.html) and confirm that this work is in accordance with the Policy.

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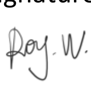

Disclaimer

This report was prepared by Shady Consulting for Queen's Facilities. Shady Consulting is a group of fourth-year civil engineering students at Queen's University, as such, there should be no reliance on this report for any real engineering, consulting, or construction purposes. The material in this report reflects Shady Consulting's best judgment considering the information available at the time of preparation. This report should only be distributed to the Faculty of Civil Engineering or Facilities at Queen's University. Any use that a third party makes of this report, and any reliance on or decision made based on it, are the responsibility of the third party. Shady Consulting accepts no responsibility for any damages, whether personal or property, suffered by any third party because of decisions made or actions completed based on this report.

Executive Summary

The objective of this project is to propose, select, and design a solar shading technology for Queen's Facilities to reduce excess heat uptake in Mitchell Hall. Shady Consulting has been selected by Queen's Facilities to complete this project. Mitchell Hall is part of Queen's University's larger wellness facility in Kingston, ON, and has two large glass curtain walls on the south and east-facing portions of the building. Since construction, it has become apparent that these curtain walls allow excess heat to enter the building. The purpose of this project is to decrease the heat uptake and therefore energy used to regulate the temperature in Mitchell Hall, decrease utility costs, and improve the user experience in the building. The deliverables of this project have been a work plan report, a progress report, a poster presentation, an oral presentation, a Queen's Building Standards document, and this final project report. As requested by the client, Shady Consulting also gave a short presentation to Queen's Facilities on November 23rd, 2022, and a final client presentation.

This report outlines the decision process that Shady Consulting followed to select and design a solution, implementation plan, and risk assessment, along with the rationale behind these decisions. Initially, different possible solutions were brainstormed; keeping the status quo, implementing a structural frame, solar glass, or utilizing trees and blinds. These design alternatives were evaluated using a weighted evaluation matrix, with the final solution chosen to be trees and blinds. The major factors considered during the evaluation process were cost, solution lifetime, construction time, environmental impact, effectiveness, and aesthetics; the client's preference towards environmentally friendly and effective solutions was considered, as well as stakeholder interest. The process decisions made after conducting primary research were evaluating alternative solutions, selecting a solution, developing a conceptual and detailed final design, and a project cost breakdown.

After researching the effects and advantages of each proposed solution, Shady Consulting selected planting trees outside of Mitchell Hall in tandem with the existing double-blind system as the best solution for this project. This report includes a thorough technical analysis of the chosen solution including final design drawings, a detailed project budget, a timeline to implement, and the anticipated decrease in energy usage Queen's facilities can expect. Shady consulting opted for a final solar shading design layout along the South wall of Mitchell Hall using two Shantung Maple Trees, for an estimated material cost of $1400.

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1.0 Introduction

1.1 Problem Statement

Queen's Facilities has awarded Shady Consulting with a contract to research and propose solar shading alternatives to be implemented on the east and south facing glass curtain walls of Mitchell Hall at Queen's University in Kingston, Ontario. The purpose of solar shading is to control the amount of heat admitted from the sun into the building during the summer months to decrease the amount of air conditioning and, therefore, energy required to cool the building. The shading will help decrease energy costs associated with cooling the building as well as decrease energy consumption, improving the building's environmental footprint. Shady Consulting will work closely with the client, Queen's Facilities, to create a solution that meets their functionality, aesthetic, cost, and energy goals.

1.2 Project Scope

The south and east facing curtain walls receive direct sunlight in the summer months. Queen's Facilities would like to incorporate solar shading to reduce the level of heat gain in Mitchell Hall due to sunlight. To accomplish this, Shady Consulting aims to design a solar shading option for the glass curtain walls that will reduce the amount of sunlight, and therefore heat, permitted into the building. Shady Consulting will research and review the existing glass curtain walls, including conducting a structural review of the curtain walls, to determine a method and approach to incorporate the solar shading. A cost estimate for implementing the solar shading will also be conducted, including an estimation for potential cost savings and greenhouse gas reductions. Shady Consulting predicts that the use of solar shading will reduce energy consumption and related energy costs. Lastly, Shady Consulting has been tasked with taking the final solution and incorporating it into a standard approach to be integrated into the Queen's Building Standards for future projects. Mitchell Hall has two south-facing glass walls (Figure 1), one on the east and one on the west side of the building. Due to time limitations, solar shading solutions will only be researched and proposed for the glass curtain walls on the east side of the building. This is because the glass curtain walls on the east side collect light and heat from both the south and east directions, meaning that this side of the building experiences the highest amount of heat gain. As such, the focus will be on the south and east facing glass curtain walls of Mitchell Hall, shown in Figure 2. Additionally, Shady Consulting will mainly focus the solar shading solution on the south-facing glass wall in the south-east corner. It is anticipated that the final solution proposed for the east side of the building may be incorporated into the Queen's Building Standards and eventually, based on evaluation and success, be implemented onto the west and east side of the building as well.

Figure 1: Mitchell Hall's South acing glass walls on both the East and West side of the building (Google Maps, 2022).

Figure 2: Mitchell Hall's South and East facing glass curtain walls on the South-East corner (Google Maps, 2022).

1.3 Stakeholders

The primary stakeholders consist of Queen's University, the students, and the faculty. Mitchell Hall is owned by Queen's University and run by the Queen's Facilities department. Students and faculty are the primary users of the facility and will experience the effects of solar shading firsthand. The intended purpose of solar shading is to reduce heat gain during the summer, creating a more comfortable environment in the building. The potential stakeholders' section includes two possible companies/groups that may provide funding, as discussed during a client meeting (Splinter, personal communication, October 2022). The full list of stakeholders is provided in Table 1; please note that Table 1 is not ordered in terms of importance.

Table 1: List of Stakeholders and Reasoning.

Stakeholder	Reason
Queen's Facilities (Queen's University)	Mitchell Hall is owned by Queen's University and is run by Queen's Facilities.
Students and Faculty	Primary users of the space.
Kingston Community	Potential community events are held in the building. May hold opinions on the aesthetic of the building.
Tourists	University tours. Building aesthetic and indoor comfortability.
Indigenous Peoples	Queen's is situated on traditional Anishinaabe and Haudenosaunee territory.
Shady Consulting	Providing design of the solar shading.
Project Manager (TA)	Project manager providing guidance.
Potential Stakeholders	**Reason**
Kingston Utilities	Possibly providing funding.
External Environmental Funding Group	Possibly providing funding.

Students and faculty are primary stakeholders because they are the primary users of the building. They are interested in having a comfortable and appealing place to learn and work. Solar shading would help to make Mitchell Hall a more comfortable space for its users through decreasing the heat that comes through the windows in the summer months. Indigenous Peoples are stakeholders because Mitchell Hall is situated on traditional Anishinaabe and Haudenosaunee territory. Indigenous Peoples believe strongly that the natural world is sacred, that humans should live in balance with and have respect for nature. As such, Indigenous leaders are keen to reinforce that action must be taken to reduce pollution and to improve the ways in which the natural environment is protected (Canada n.d.). Therefore, a solution that would lower Mitchell Hall's environmental footprint is in their interest. Shady Consulting is a stakeholder because they are providing the research and design for the solar shading solution, and the project manager (TA) is a stakeholder because they are invested in ensuring that Shady Consulting remains on-track and produces the best possible solution for the problem at hand.

As for potential stakeholders, although not yet confirmed, it is possible that Kingston Utilities and an external environmental funding group would provide funding for this project. This project is in their best interest as the result of the solar shading design is projected to reduce both utilities usage and the building's environmental footprint.

1.4 Project Plan

Shady Consulting worked to maintain a balanced and reasonable work schedule throughout the 2022/2023 academic year to complete the final deliverable for CIVL460. Throughout the year, technical skills learned throughout different civil engineering courses were integrated into the project, everywhere from structural engineering applications to environmental engineering applications. The plan for this project revolved heavily around the engineering design process, which included asking questions, researching the problem, imagining possible solutions, planning the design, selecting a design, and iterating the design to improve the final solution. One of the main goals of this project was to work as a team to provide the client with a creative, innovative, economical, and environmentally friendly solution. The stakeholders, constraints, and legal ramifications for completing this project were considered throughout the process. A detailed schedule was created to facilitate the project throughout the year, including the use of a Gantt Chart and a work breakdown structure (WBS). A responsibility assignment matrix (RAM) was also created to keep track of the project tasks and which team member was responsible for them. The updated project schedule can be seen detailed in Section 10 of this report and the updated Gantt Chart, WBS, and RAM for the final report can be seen in Appendix B. Additionally, a team dynamics and project plan updates section has been added and can be seen in Appendix E. The team dynamics section outlines group member roles and how the team worked together to complete the project. The project plan updates section outlines which parts of the original project plan were adjusted or omitted to complete the solar shading design on schedule.

1.5 Final Deliverable

By early April 2023, a final report will be drafted for Queen's Facilities outlining a detailed design plan of the chosen solar shading solution for Mitchell Hall. This report includes updates and new material since the progress report that was submitted to the client in November 2022.

2.0 Background Information and Research

To complete this project, Shady Consulting must understand the standards and regulations that govern design and construction in Ontario. It is also important to become familiar with the structural properties of Mitchell Hall's glass curtain walls. The preliminary research conducted is described below, along with available figures and material specifications. Some of the information about Mitchell Hall was collected from meetings with Queen's Facilities and a preliminary site visit.

2.1 Standards and Regulations

2.1.1 A Note on Ethics

Professional Engineers Ontario (PEO) has a Code of Ethics that serves as a guide for professional conduct and imposes duties on practitioners with respect to society, clients, colleagues, the engineering profession and him or herself (*Professional Engineers Act*, R.S.O. 1990, c. P.28.). As such, Shady Consulting will demonstrate fairness and loyalty to the client and other associates, faithfulness to public need, personal honour and professional integrity, and competence in the performance of the services being provided (*Professional Engineers Act*, R.S.O. 1990, c. P.28.). Shady Consulting regards public safety as paramount and regards all client information as confidential.

2.1.2 The Ontario Building Code

The Ontario Building Code details the specifications by which constructed or renovated buildings in Ontario are governed. The Ontario Building Code is based on the National Building Code of Canada (NBCC), but with more specific modifications and additions relevant to the Province of Ontario, therefore, Shady Consulting will refer to the OBC for this project. This will be useful for any structural components of the solutions designed for Mitchell Hall. When designing external structural components on the curtain glass walls, Shady Consulting referred to section 4.1.5.5. of the building code, which deals with loading on external areas, including snow, wind, and seismic loads (*The Ontario Building Code, Section 4.1.5.5.* n.d.). Section 9.6.1.4. of the building code deals with types of glass and the protection of glass, which may also be relevant for any structural designs in this case (*The Ontario Building Code, Section 9.1.6.4.*, 2018).

2.1.3 Queen's Building Design Standards

The Queen's Building Design Standards aid consultants and contractors during the planning, design, and construction phases of the University's maintenance, renovations, and new capital projects (*Queen's Building Design Standards* 2022). As such, Shady Consulting must consider the Queen's Building Design Standards in addition to the Ontario Building Code throughout the solar shading design process. It is especially important as Queen's Facilities has requested that the solar shading design selected in this project be generally implemented into 'Division 01 – General Requirements' of the Queen's Building Design Standards.

There are at least three Divisions that may be relevant to the design and implementation of potential solar shading solutions. Firstly, 'Division 01 – General Requirements' is relevant in that it outlines the expected summary of work for any project, as well as outlining LEED Requirements and Sustainable Requirements for all on-campus buildings. The Standard states that all new buildings or major renovations are to target LEED Gold certification or higher. A LEED certificate recognizes the design, construction, and operation of high-performance green buildings or neighbourhoods (U.S. Green Building Council 2020). In addition to aiming for LEED certification, the design should also aim to be sustainable in areas such as rainwater management, heat island reduction, process water use, enhanced indoor air quality strategies, interior lighting, and more. The Standard also outlines different Sustainable Requirements, including ensuring that all new buildings and renovations maintain the look-and-feel of Queen's campus heritage landscape through the inclusion of natural greenspace. There are also specifications for energy and utility usage, including capacities on thermal energy usage and specifications on modelling and costing, including expectations for assessing and documenting greenhouse gas emissions and energy costs.

The second Division that may be relevant to this project is 'Division 32 – Exterior Improvements', which details how landscaping, planting preparation, plants, and planting accessories may be included in any new project or renovation on campus. This section outlines how trees on campus must be protected, specifications for tree planter dimensions, and specifications for precast tree gates in the case that a tree be surrounded by a concrete walkway or sidewalk. This Division may be especially relevant should trees be selected as part of a design alternative for this project.

Lastly, 'Division 23 – Heating, Ventilation, and Air Conditioning (HVAC)' is generally relevant to this project as it details heating and cooling requirements, air handling units related to air conditioning, and water chillers related to air conditioning.

2.2 The Site

2.2.1 Location and History

Mitchell Hall is in Kingston, Ontario on the Queen's University main campus, as seen in Figure 3. More specifically, Mitchell Hall is located on the corner of Union Street and Division Street. It is approximately 190,000 square feet (17,650 square meters) and was first opened in December 2018 (Queen's University 2022). The modern, sleek building was an $85 million project designed to house engineering research and learning, innovation, entrepreneurship, and wellness facilities (Queen's University 2022). The focus will remain on the south and east-facing glass curtain walls of Mitchell Hall, shown in Figure 2.

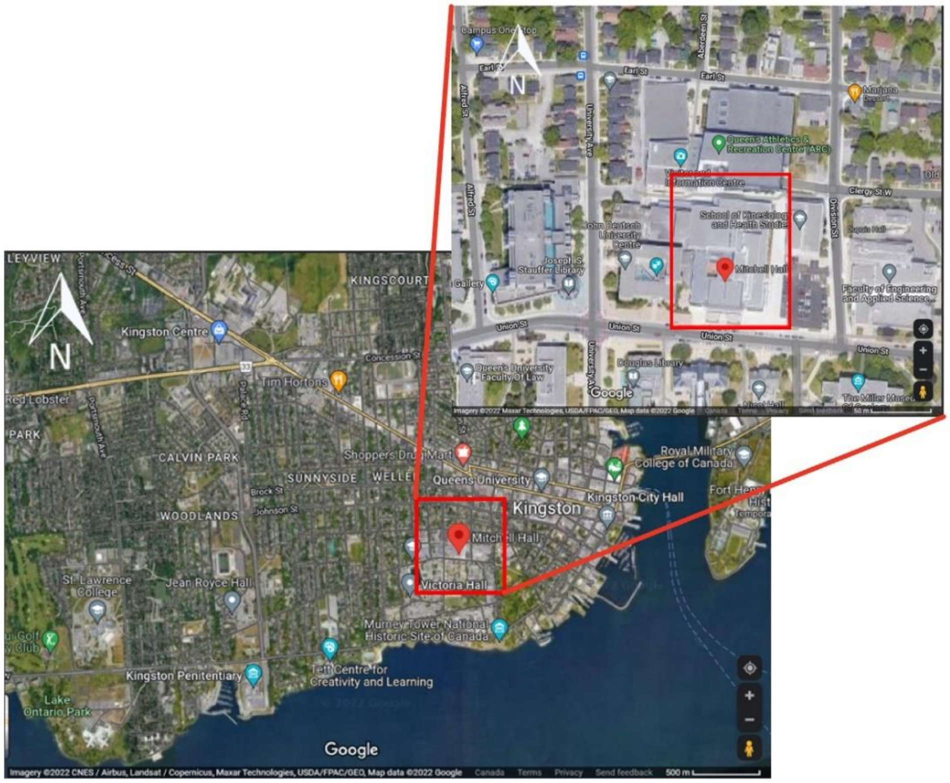


Figure 3: Satellite image of the Mitchell Hall location at Queen's University within Kingston, ON (Google Maps, 2022).

2.2.2 Site Investigation

Shady Consulting conducted a site visit on November 8, 2022. The site visit was intended to familiarize the consultants with the existing conditions, the structural components of the walls, the functionality of the existing solar shading, and to investigate possible boundaries or constraints. The existing solar shading will be described in Section 2.2.3. The glass curtain walls are panelized and span three floors, from the ground floor up to the roof. The curtain wall is secured to the interior floor slabs. As the curtain wall essentially "hangs" from the floor slabs on the building, it is non-load bearing (Kovach 2018).

A view of the east glass-curtain wall, as seen looking west from the outside, can be seen in Figure 4. The south-facing glass curtain wall on the east side of the building is like the east-facing wall. The glass curtain wall, as seen facing east from the inside, can be seen in Figure 5. The load-bearing columns and beams for the building itself are located inside of the windows, away from the curtain walls, as seen in Figure 5. This information confirms that the curtain walls do not have any load-bearing capacity.

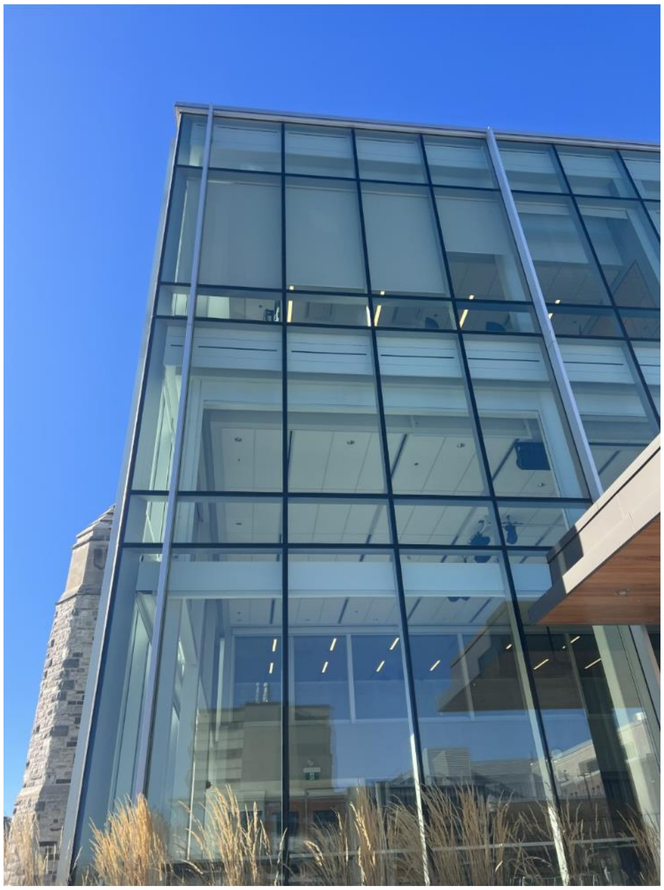


Figure 4: Mitchell Hall's glass curtain walls as seen from outside.

Figure 5: Mitchell Hall's glass curtain walls as seen from inside.

2.2.3 Existing Solar Shading

Mitchell Hall currently has a fully automated, interior double-blind system that is installed on the south and east-facing glass curtain walls. As shown in Figure 7, one set of blinds provides partial shading, and the other serves as blackout shading. The partial shading is made from a medium weight, flame-retardant sunscreen fabric that is white/grey in colour. As described in the Window Shades Specification Sheet, provided by Queen's Facilities (personal communication, October 20, 2022), under the Product section, it states that the south-facing partial blinds have a 3% exposure (97% UV blockage), and those on the east have a 5% exposure (95% UV blockage). The second set of shades, however, are designed to block out all sunlight. They are made from black-out material, where the fabric is coated in fiberglass to achieve room darkening. This fabric is 12 mils thick, washable, and appears white/grey in colour. Each roller shade has a 120V AC motor, and there are wall switches (1 for each bank of blinds) located inside of Mitchell Hall that connect to each roller shade system (east and south), allowing for the double-blind system to be fully automated.

Figure 6: Existing Fully Automated Double-Blind System at Mitchell Hall.

2.2.4 Current Energy Usage and Cooling Demand

Currently, Mitchell Hall is heated with steam and cooled using chillers (A. Rae Peet, personal communication, November 16, 2022). Monthly steam usage can be seen in Appendix A of this report. The energy usage from heating the building translates to monthly utility costs as shown in Appendix A. From the heating data, it was determined that steam usage is mostly limited to the winter months, meaning that the energy used to heat the building occurs from October through May. The highest heating costs are also seen only in the winter months. It was not possible to obtain cooling energy data that is exclusive to Mitchell Hall, as the chillers are also used to cool two other buildings on Queen's campus (A. Rae Peet, personal communication, November 16, 2022). However, Queen's Facilities was able to provide data on the state of a cooling valve in one of Mitchell Hall's air handling units, which provides a sense of demand throughout the year. The data represents the percentage open of the cooling valve throughout the year. The cooling data provided spans from the end of February 2022 to the middle of November of 2022. The average value of percent open of the cooling valve in Mitchell Hall for each month can be seen in Figure 7. This demonstrates that Mitchell Hall has the highest cooling demand in the summer months, from May to September, as expected. Currently, Shady Consulting has not been provided with any costs associated with this cooling information.

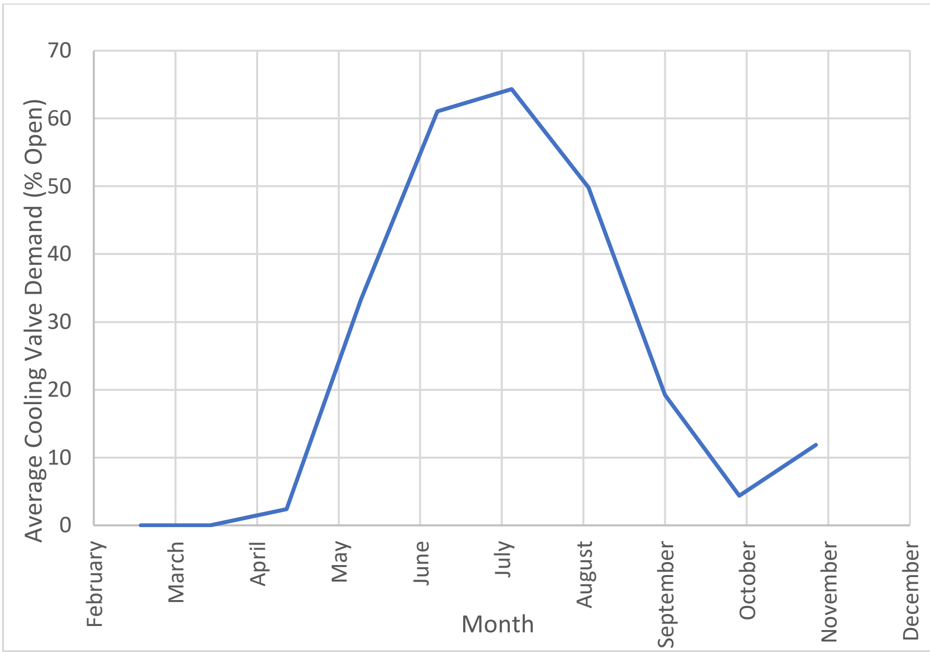


Figure 7: Cooling demand for one of the cooling valves in the air handling unit of Mitchell Hall.

3.0 Design Considerations

Before selecting a solution and developing a conceptual design, multiple alternative solutions need to be explored and considered. To brainstorm different design options, Shady Consulting used the information provided by the client and researched current and upcoming solar shading techniques used in the industry. These ideas are illustrated below in Figure 8. Shady Consulting have identified four different solutions: keeping the status quo, an external structural design, implementing solar glass, and planting trees. It is important to define the current conditions to effectively see the effect that each alternative will have, which is why the status quo option was considered. A structural design will likely be technically intensive but may be highly effective, which is why it is being considered. Solar glass is also being considered because it could be a relatively simple design to solve the problem, although it could prove costly. Finally, planting trees in conjunction with utilizing the existing blind system is the fourth option. This will involve a different range of technical analyses, from tree selection to planting requirements. This section of the report is designed to describe the advantages and disadvantages associated with each alternative, and any technical analysis needed for each. This section also outlines the iterative design approach used to identify the solutions with the most potential.

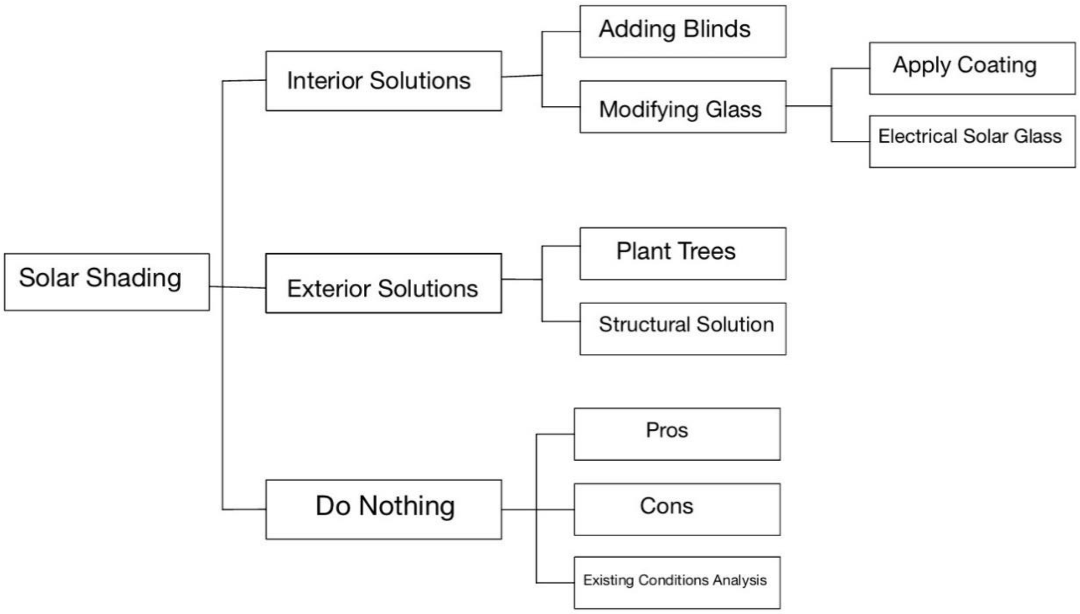


Figure 8: Project Mind Map.

3.1 Status Quo

The first solution to be considered is retaining the existing automated double-blind system in place at Mitchell Hall. If no further measures are taken to improve the excess heat uptake in Mitchell Hall, monthly energy usage will remain at current levels, and associated utility costs will not decrease.
The advantage of the current system is that the windows can be shaded at the user's convenience to either partial or complete shading. This allows for the excess heat intake to be roughly regulated throughout the day. The disadvantage of this is that when blackout curtains are used, the curtain walls do not function like windows, and more artificial light needs to be used inside the building. This solution does not offer improvement but may be considered in tandem with other solutions.

3.2 Trees as Solar Shading

The second solution to be analyzed is to plant trees outside of Mitchell Hall, in conjunction with the existing double-blind system. This idea has potential to be relatively environmentally friendly, cost effective, and is in use across Queen's campus currently.

3.2.1 Relevant Regulations

For Mitchell Hall, the Ontario Landscape Tree Planting Guide (McGrath et al. 2019) is the most relevant documentation for planting trees. This guide is a comprehensive revision of "A Reference Guide for Developing Planting Details." The intent of this guide is to give professionals an understanding of commonly used horticulture terms, tree attributes, and planting requirements. For this project, the guide's information about environmental site assessment, soil assessment, and site preparation will be applicable, as detailed below.

An environmental site assessment of Mitchell Hall will help determine if planting trees is a feasible and suitable solution for this location. This process is summarized as follows:

1. Identify the hardiness zone where trees will be planted. This zone can be located by using one of two main methods: the Canadian plant hardiness method, and the USDA method.
2. Observe the amount of sunlight new plantings will receive throughout the growing season. This is categorized into either full, partial, or no sunlight. This parameter depends on several factors including planting location, height, and the number of surrounding buildings.
3. Determine the distance between the planting site and surrounding hard surfaces like roads and concrete. This is to monitor heat reflected from these surfaces onto the trees. This is important to consider because if the trees experience prolonged periods of high temperatures, it can cause death.
4. Ensure the crown of the mature trees will fit the space requirements. This means checking the distance to any surrounding objects, buildings, other trees, and setbacks from utility lines.
5. Select tree species whose mature crowns and heights will fit the space requirements of the location.
6. Determine the distance between the planting site and areas where de-icers will be applied. This is because de-icers can cause harm to trees.
7. Identify root system spacing requirements and check these against the space available at the site, including any necessary setbacks from existing underground infrastructure, including utilities.
8. Identify the wind direction and potential wind effects on tress at the planting site.

After identifying the environmental site constraints, a soil assessment will identify the type, texture, and drainage of the soil at Mitchell Hall. The soil assessment process is as follows:

1. Categorize the soil type and texture, via laboratory analysis or the hand texture method, into fine or course-grained soil, loam, or silt loam.
2. Categorize the drainage characteristics of the site as poor, moderate, or excessive via a drainage test.
3. Consider any necessary interventions if soil type/texture/drainage is unsuitable for trees.
4. Check the compaction level at the site by using a probing wire test. If insufficient, compaction measures may be taken to mitigate.
5. Determine the organic matter in the soil via laboratory tests. If less than 5 percent of the soil is organic matter, soil modification will be needed.
6. Find the pH of the soil at the site. This is important because it helps to identify potential pH-related nutrient deficiencies in the soil. These may affect tree growth and health.
7. Estimate the useable soil volume for each tree planting location.

The third process, detailed below, is site preparation. This is important because it describes the measures needed that will allow planted trees to survive and thrive.

1. Determine if mechanical de-compaction is required at the site.

2. Install any soil or drainage modifications identified through the environmental and soil assessments.

3. Ensure utility locates are completed and setbacks are followed.

3.2.2 Tree Shadow Calculations

Evaluating the quantity of shade provided by planting trees is crucial to this project and will determine the effectiveness of this proposed solution. The direct way to test the quantity of shade provided is to calculate the shadow length from the trees.

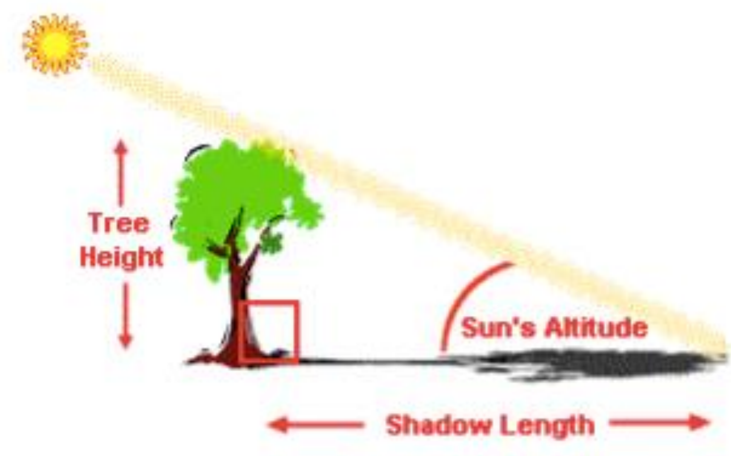


Figure 9: Tree Shadow Length Diagram (Skellern 2005)

Figure 9, shown above, describes the parameters needed to solve this problem. This problem resembles a right-angle triangle, which simplifies the necessary calculations. The mature height of the trees can be estimated. The sun's altitude can be calculated using the sun's declination throughout the day/year, latitude, angular velocity of the earth's rotation, and time displacement from solar noon. This calculation is shown below, in Equation 1. Then the tangent rule ratio will yield the shadow length (Equation 2).

$$Sin(altitude) = Sin(Dec) * Sin(latitide) + \cos(latitude) * \cos(Dec) * \cos\,(AV * T)$$

Equation 1: Sun's Altitude Calculation.

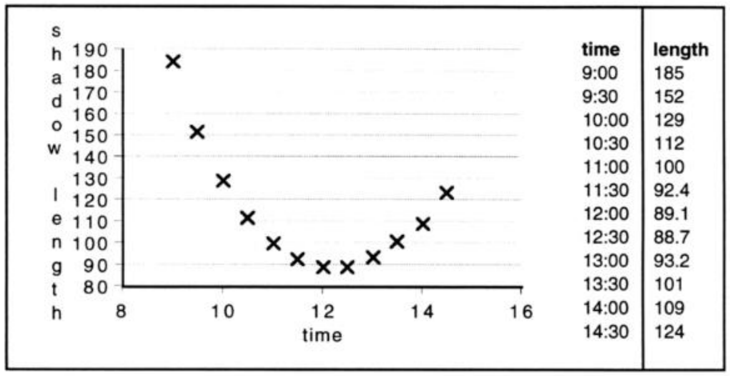
Dec, The sun's declination for that day/ month.

AV, Angular velocity of the earth's rotation.

T, +/- Time displacement from solar noon.

$$Shadow\ Length\ = \frac{Tree\ Height}{\tan(altitude)}$$

Equation 2: Shadow Length Calculation



Graph of Shadow Length over a Day

Figure 10: Graph of shadow length over a day (MVHS n.d.).

By observing Figure 10, shadow length changes throughout the day. Based on the graph, the shortest shadow length occurs around noon, meaning that the shade from planted trees will be the least effective at noon each day. Therefore, to optimize the design solution, the assistance of internal shading technology may be required. Thus, utilizing the existing double-blind system in tandem with planting trees would be ideal, as the blinds may be used at the time of day when the trees provide the least solar shading assistance.

3.2.4 Heat Transfer Calculations

Once daily shadow length information is estimated, the next step is to identify the amount of heat being passed through the glass curtain walls at Mitchell Hall. To find this, it is necessary to complete heat transfer calculations. Solar heat gain depends on a series of factors: the direction that the windows face, time of day, month, latitude, whether there are interior partition walls, type of floor covering, and internal shading devices. The heat gain of the glass can be calculated using four factors: the solar heat gain factor, the total surface area of the glass, the shading coefficient of the window, and the cooling load factor. This calculation has been simplified below in Equation 3 (Hes et al. 2011).

$$BH_{glass} = SHGF * A * SC * CLF$$

Equation 3: The equation used to predict the solar heat gain (radiation) through glass.

BH, Heat gain by solar radiation through glass, (Btu/hr).

SHGF, Solar heat gain factor, (Btu/hr*(ft^2)).

A, Total surface area of the glass, (ft^2).

SC, Shading coefficient of the window, dimensionless.

CLF, Cooling load factor, dimensionless.

The first of the four parameters to be calculated is the shading coefficient. This will be done using Equations 4 and 5, as shown below. This equation has been proven effective in the study of estimating the heat flux transmission of green walls (Hes et al. 2011).The benefit of using a shading coefficient is that it allows existing predictive modelling tools to be applied. The remaining three parameters needed to calculate heat gain have not yet been considered by Shady Consulting but will be included in the final report deliverable.

$$T_e = T_0 + (\frac{\alpha * E_t}{h_0})$$

Equation 4: Sol-Air Temperature for Vertical Surface Equation

T_0, Outdoor air temperature

A, Absorptance of surface for solar radiation

E_t, Total solar radiation incident on surface

H_0, Outside air convective heat transfer coefficient.

Equation 4 above can be rewritten to calculate the sol-air temperature for a wall with shading. Sol-air temperature is used to find the cooling load of a building and determine the total heat gain through exterior building surfaces.

$$T_{es} = T_0 + (\frac{\alpha * E_t * (1 - SC)}{h_0})$$

Equation 5: Sol-Air Equation for Shaded Wall

T_{es} = Sol-air temperature for a wall with shading, degrees Celsius

SC = Shading coefficient

The shading coefficient, SC, can be calculated by combining Equation 4 and Equation 5, shown as follows:

$$SC = 1 - (\frac{T_{es} - T_0}{T_e - T_0})$$

Equation 6: Shading Coefficient Equation

The absorption of solar radiation needs to be adjusted according to different shading coefficients present throughout the day and for different seasons. The solar absorptance equation can be seen in Equation 7.

$$Adjusted\ Solar\ Absorptance = 0.6 * (1 - shading\ coefficient)$$

Equation 7: Solar Absorptance Equation

Aside from the equations described above, calculating heat flux and heat rate is another method employed to determine heat transfer. The formula used to calculate heat flux is shown below in Equation 8. The thermal conductivity, thickness, and temperature difference across a sheet of rigid extruded insulation are all known. To simplify the question, a few assumptions are needed. The first assumption is that the heat transfer process is one-dimensional. The second is that the heat transfer process remains steady state. The third assumption is that the sheet of rigid extruded insulation has constant properties. The process of calculating heat transfer also includes solving for the heat rate, shown in Equation 9 (Bergman et al. 2011).

$$q_x = (-k) * \left(\frac{dT}{dx}\right) = (k) * (\frac{T1 - T2}{L})$$

Equation 8: Heat Flux Equation

q_x, the heat flux in x-direction, (W/m^2)

k, thermal conductivity, (W/m*K)

dT, changing temperature in x-direction (K)

dx, the changing distance or controlled distance (m)

T1, initial temperature, (K)

T2, updated temperature (K)

L, controlled length (m)

$$q'_x = q_x * A$$

Equation 9: Heat Rate

q_x', the heat rate in x-direction, (W)

A, the total surface area, (m^2)

All the equations from this section outline the parameters that Shady Consulting will calculate and use to evaluate the effectiveness of planting trees.

3.2.5 Carbon Footprint Consideration

To grasp the environmental impact of this solution, the carbon footprint was considered. Carbon cycle evaluation is one of the most important factors to consider for an environmental project. Shady Consulting values sustainability in this project, because reducing carbon emissions and decreasing the rate of global warming is a large-scale design objective indicated by the client. One of the key features of trees is performing carbon dioxide sequestration. The sections below will identify what this process is, illustrate simple caron dioxide sequestration calculations, and explain the relationship between planting trees and sustainability.

3.2.5.1 Carbon Dioxide Sequestration

Carbon dioxide sequestration is the process wherein carbon in the atmosphere is captured and stored via photosynthesis. This process transfers carbon atoms from the gas phase to the solid phase. Carbon dioxide sequestration can be categorized into two types: biological carbon dioxide sequestration and geological carbon dioxide sequestration (Clear Center 2019). Providing solar shading by planting trees involves using soils and creating a more plant-rich environment, therefore it is considered biological carbon dioxide sequestration.

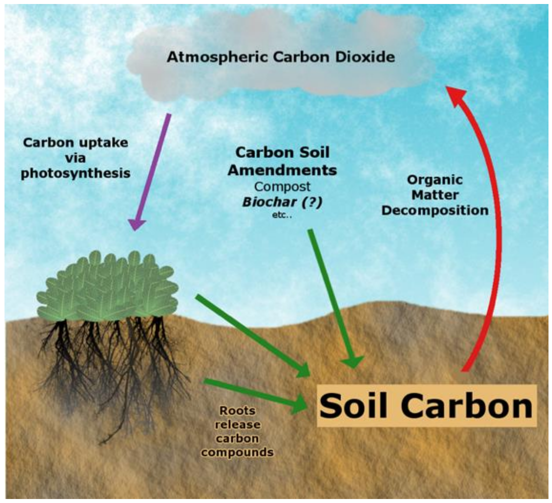


Figure 11: The process of carbon dioxide sequestration through soil (Cooperman 2016).

Figure 11 shows the basic process of carbon dioxide sequestration in soil. Atmospheric carbon dioxide is transferred into soil organic carbon through the process of photosynthesis. Soil organic carbon levels can be degraded and depleted by agroecosystem, where carbon is used by organisms in the soil. Carbon can also be stored and sequestrated in the form of carbonate; carbonate is a product when carbon dioxide dissolves into water, and it can percolate the soil, which may take thousands of years (Cooperman 2016).

3.2.5.2 Carbon Dioxide Sequestration Calculation

To calculate the carbon sequestered from planting trees, the first step is to determine the total green weight of the trees, which is related to the weight of the trees (Fransen 2019).The formulas needed to find this are shown below in Equations 10 and 11.

$$W_{above-ground} = 0.25 * D^2 * H$$

Equation 10: Green Weight for Diameters less than 11 inches.

$$W_{above-ground} = 0.15 * D^2 * H$$

Equation 11: Green Weight for Diameters more than 11 inches.

$W_{above\text{-}ground}$, the green weight above the ground, in pounds.

D, the tree trunk diameter, in inch.

H, the tree's height, in feet.

The formulas above demonstrate green weight contributed from the part of the tree that is above ground, but the root system must also be accounted for. The roots equal about 20 percent of the weight above ground, so the total green weight of the tree is approximately 1.2 times the green weight above the ground, as shown below in Equation 12.

$$W_{total\ weight} = 1.2 * W_{above-ground}$$

Equation 12: Total Green Weight.

The second step to calculate carbon sequestration is to find the dry weight of the trees. This step requires information about the moisture content of each type of tree. The formula needed to find this parameter is shown below in Equation 13.

$$W_{dryweight} = (1 - moisture\ content) * W_{total\ weight}$$

Equation 13: Dry Green Weight.

The third step is to determine the weight of carbon in the trees. This requires research or knowledge about the carbon content in the dry weight of the trees, as shown below in Equation 14.

$$W_{carbon} = (carbon\ content) * W_{dryweight}$$

Equation 14: Carbon Weight.

The last step is to determine the carbon dioxide sequestrated in the tree by using the atomic weight ratio between carbon dioxide and carbon. According to the periodic table, carbon's atomic unit weight is 12 (u), and oxygen's atomic unit weight is 16 (u). Equation 15 demonstrates the atomic weight of carbon dioxide, and Equation 16 shows the atomic weight ratio between carbon dioxide and carbon. This allows Equation 17 to be used to calculate the weight of carbon sequestered by the trees.

$$Total\ atomic\ weight = (2 * 16) + 12 = 44(u)$$

Equation 15: Carbon Dioxide Atomic Weight.

$$Ratio = \frac{44}{12} = 3.67$$

Equation 16: Calculation of Atomic Weight Ratio.

$$W_{carbon-dioxide} = 3.67 * W_{carbon}$$

Equation 17: Carbon Dioxide Sequestered and Carbon Weight in the Trees.

3.2.5.3 Sustainability Discussion

On a broad scale, planting trees can positively impact climate change by providing shade, regulating temperature extremes, increasing animal habitat, and preventing flooding. On a smaller scale, it can also improve soil-water conversion, store carbon, and moderate local climate change (Weeden 2020). It has been shown that healthy trees absorb and store harmful pollutants and greenhouse gases to cool down the planet, and an average mature tree can absorb and store nearly 22 pounds of carbon dioxide (Weeden 2020). Furthermore, planting trees using local seeding in appropriate geological conditions can counteract soil and biodiversity loss (Weeden 2020) . So, utilizing this solution would not only provide solar shading but would also serve as an environmentally friendly addition to Queen's campus.

Planting trees can effectively reach 'Broad and Strong Sustainability'. According to the Ethics for Engineers textbook, "'Broad and Strong Sustainability' can be achieved only by ensuring no significant long-term depletion of natural, economic, or social resources and gains in other dimensions cannot compensate for the loss in another dimension" (Peterson 2019). It also states that "plants can heal land degradation" and "there is no long term significant economic loss from planting trees due to the positive impact on environmental and social sustainability" (Peterson 2019). From these excerpts, it is clear this solution is aligned with long-term sustainability.

Planting trees also can effectively reach 'Seven Generations Sustainability'. 'Seven Generations Sustainability' refers to the notion of sustainability that can last for seven generations (Peterson 2019). Since there is no time limit on how long the positive impact of planting trees will last, it can be assumed that the positive impact can last seven generations. Furthermore, aiming to reach 'Seven Generations Sustainability' shows that Shady Consulting values empathy, integrity, reputation, and responsibility.

3.2.8 Innovation

Using trees as a solar shading design option is unique in that it uses a natural solution to provide shade for the building. The design is innovative in that it does not require any major renovation or construction to implement but could meet each design objective. It is also an innovative solution because of its seasonal effectiveness; both the summer and winter seasons would be idealized in terms of energy use. In the summer, the trees will be full of leaves, which provide solar shading to decrease the amount of air conditioning required to cool the building. In the winter, the trees will be bare, allowing more sunlight to penetrate the glass curtain walls, helping to decrease the amount of steam required to heat the building. Therefore, utilizing trees as a solar shading solution may help to decrease energy usage and associated energy costs year-round.

3.3 Structural Option

Solar shading can be accomplished through various structural solutions. Fixed solar shading solutions include overhangs, vertical fins, balconies, canopies, awnings, external louvres, and more. These devices can be excellent architectural features for certain buildings. Architectural sun control can improve natural lighting and reduce heat gain within a building (Enviroscreen 2020). In terms of structural solutions, overhangs and vertical fins are potential solutions for Mitchell Hall's south and east facing glass curtain walls.

3.3.1 Overhang

An overhang consists of a structural roof extending out from the building to block the sun's heat energy from entering the windows. The physical dimensions of the overhang are an important element since the overhang will not accomplish its purpose if enough shade is not provided. Many variables, including latitude, sun angle, and window angle need to be determined for the specific site to properly size the overhang (Inspectapedia n.d.). The design of overhangs is important as you want them to admit as much heat and light as possible in the winter, while limiting heat gain in the summer.

The first step in designing an overhang for Mitchell Hall is determining the angle of the sun during the warmest part of the year. The angle of the sun at noon during the summer solstice can be calculated using Equation 18 (Triangle Gardener 2015).

$$\propto = 90 - L + D$$

Equation 18: Sun angle calculation.

Where L is Kingston's latitude, and D is the tilt of the Earth. Using values of 44.213˚ and 23.5˚ for latitude and tilt angle, respectively, Equation 18 yields a sun angle of 69.287˚. The next step is determining the window size. The shop drawing of the south curtain wall, provided by Queen's Facilities, was used to determine the location of the overhang, as well as the window size. The annotated shop drawing can be seen in Figure 12, where the red horizontal lines represent the overhang location. The window heights are dimensioned on the right side of the drawing spanning between overhangs.

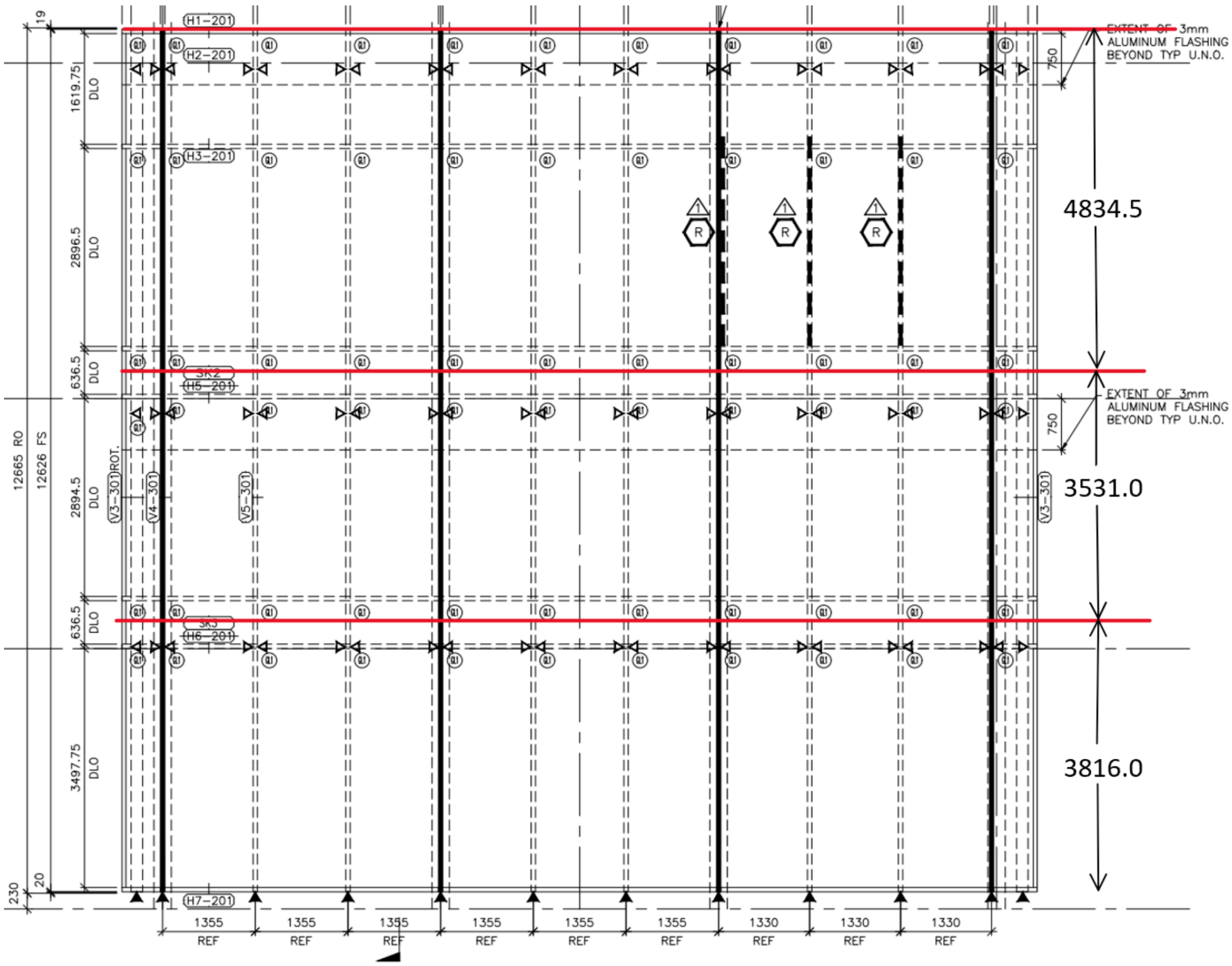


Figure 12: Shop drawing of south facing curtain wall with proposed solar shading location.

The required length of horizontal overhang perpendicular to the glass curtain wall can be calculated using Equation 19, relating the height of the window (H) to length of the overhang (L).

$$L = H \times \tan{(90 - 69.287)}$$

Equation 19: Length of overhang.

The calculation for the length of overhang can be visualized in Figure 13. The three overhang lengths for the south facing glass curtain wall were determined to be 1442.9 mm, 1335.2 mm, and 1828.1 mm. The east facing glass curtain wall can be analyzed following the same steps.

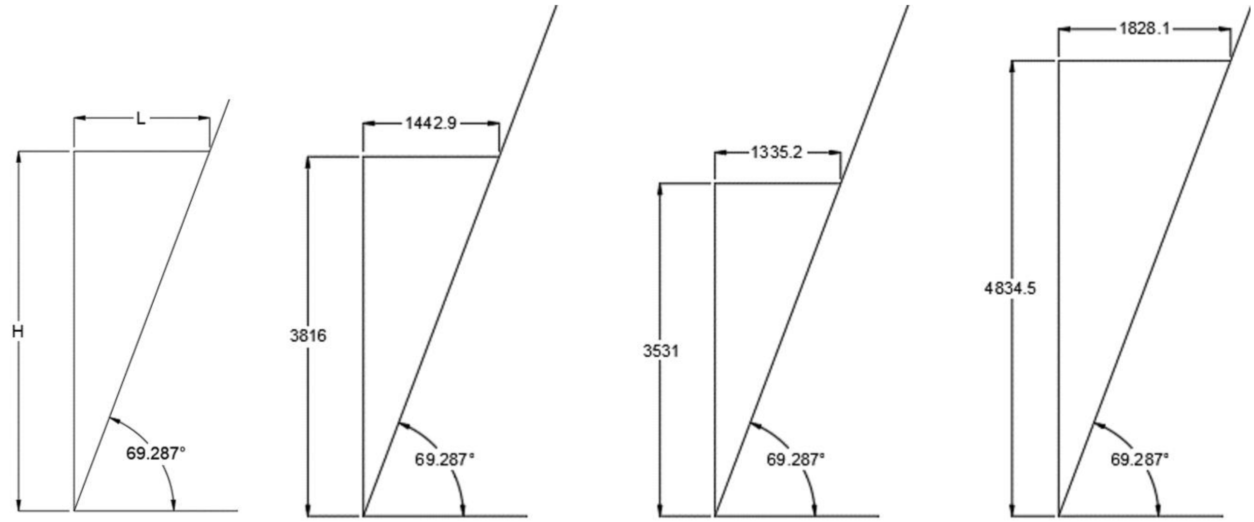


Figure 13: Overhang length calculation diagrams.

With the positioning and the length of the overhangs determined, the final step is to determine the type of overhang. The overhang installed at Goodes Hall on the Queen's University campus would be the ideal overhang design for Mitchell Hall. The Goodes Hall overhang is shown in Figure 14. The slitted design prevents snow accumulation, as well as reduces uplift caused by winds, while also remaining lightweight due to reduced material volume.

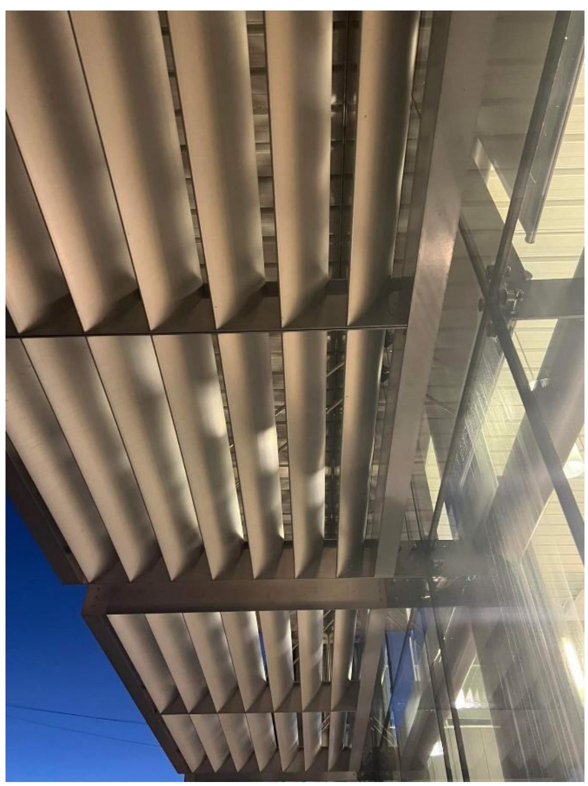


Figure 14: Goodes Hall overhang design.

3.3.2 Vertical Fins

Vertical fins are a type of vertical solar shading that consist of evenly spaced thin vertical members spanning the height of the windows. An example of vertical fins as a solar shading device can be seen in Figure 15 (Fairconditioning n.d.).

Figure 15: Vertical fins example (Fairconditioning n.d.).

The idea of using vertical fins as a solar shading device for Mitchell Hall was generated during the brainstorming process. After further thought and discussion, Shady Consulting has determined that vertical fins will not be an appropriate solar shading solution for Mitchell Hall. The primary reason for this decision is that the vertical fins would cover too much of the glass curtain walls. The vertical fins would greatly reduce vision into and out of the building and would make the interior space seem darker. They would also take away from the aesthetic appeal of the glass curtain walls, rendering the architectural features of the building redundant. Due to these reasons, no further analysis of vertical fin systems will be completed.

3.3.3 Frame Innovative Solution

Observations gathered from a site visit to Mitchell Hall, as well as discussion with Dr. Woods of Queen's University, Department of Civil Engineering, concluded that it is not possible to secure a structural solution directly to the glass curtain walls due to the lack of external structural members. To overcome this, Shady Consulting proposes the innovative idea of designing an external frame for the east and south walls. The frame would be slightly offset from the wall and would be fixed to the ground through a footing system. To prevent moments from developing in the top of the frame, the frame could also be fixed to the roof of Mitchell Hall.

Figure 16 shows a simplified diagram of the proposed frame design for the south facing glass curtain wall. The columns are spaced so that they line up with the existing interior columns to maintain current sightlines from the interior of the building.

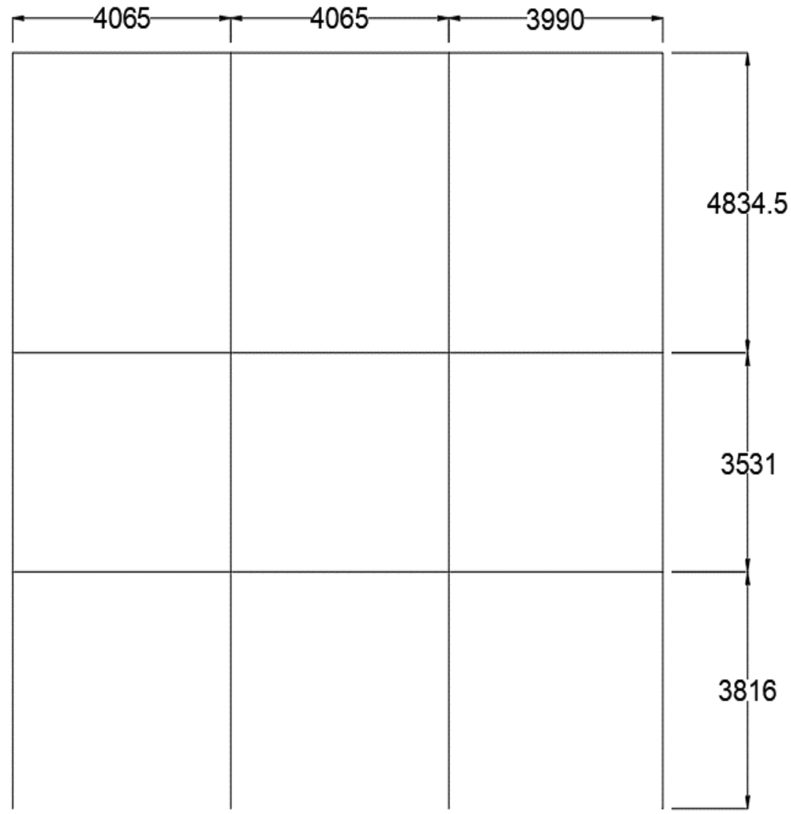


Figure 16: Simple frame diagram for south facing glass curtain wall. All dimensions in mm.

The next step in designing the frame would be sizing the structural members. The size of the members would depend on the loading applied to the frame. The weight of the overhangs discussed previously would be the primary source of loading. Further analysis can be done using structural modelling software, such as SAP2000.

3.3.3.1 Frame Disadvantages

The frame solution has many disadvantages. The bulky exterior frame would greatly take away from the aesthetics of the glass curtain walls. It would also have a negative impact on the architecture feeling of the building. The purpose of glass walls is to generate an open feel to the building, while the structural frame on the outside would cause the building to feel more closed off. Another disadvantage is the potential carbon footprint of the structural members used to construct the frame. The primary method of producing structural steel uses 13.8% scrap and produces 1.987 tonnes of carbon dioxide per tonne of steel (NSC 2010). Assuming a standard W150X30 structural steel section, the mass of the structure would be approximately 2553 kg. The mass of the structure was calculated by multiplying the weight of the structural members per meter by the total length of all members. The weight of a W150X30 member is 30 kg/m, and the frame consists of 85.086 meters of structural members. Assuming the structural steel is produced using the primary method, the frame would produce 5.07 tonnes of carbon dioxide emissions.

3.3.3.2 Further Innovation

The frame is an innovative solution in that it overcomes the structural limitations of the glass curtain walls. Further innovation can be applied using green engineering materials. A possible green solution would be to use glulam structural members. Glulam is a highly innovative construction material. Glulam members are stress-rated engineered wood beams composed of wood laminations that are bonded together with durable, moisture-resistant adhesives. Glulam is versatile, ranging from simple, straight beams to complex, curved members. Glulam offers greater strength and stiffness than similar sized timber members (The Engineered Wood Association n.d.). Glulam also produces significantly less greenhouse gases. A comparative life cycle carbon footprint study compared the carbon dioxide emissions of constructing two identical buildings, one made of structural steel and the other made of glulam. It was calculated that the glulam structure emitted one quarter of the total GHG emissions of the steel structure (Laurent et al. 2018).

3.4 Solar Glass

Using electrical solar glass is one of the design alternatives for the solar shading project. The following sections explain the basic principles of electrical window shading, along with its advantages and disadvantages.

3.4.1 Electrical Window Shading Description

Electrical window shading is widely used in various areas including residential, commercial, retail, healthcare, hospitality, and banking (Sage Glass n.d.). The main functions of electrical window shading include blocking direct sunlight and providing privacy. The most common type of glass used is electrochromic glass, which consists of five layers of ceramic material coated on a thin piece of glass. Then, a small electrical charge is applied, which causes lithium ions to transfer between layers. Followed by that, the tint is removed by reversing the polarity to return the glass to its transparent state.

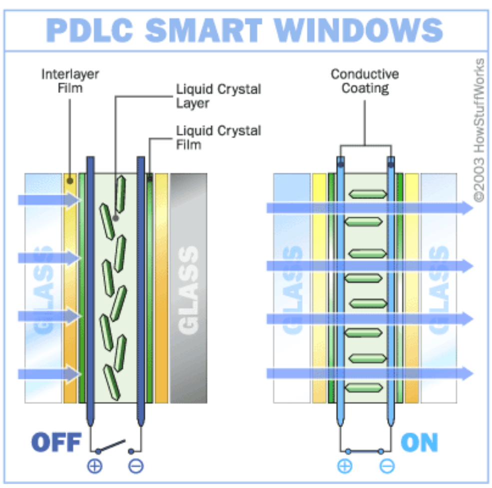


Figure 17: Visual identification on how the electrical glass works.

Using electrical window shading adds to the use of the building. When the glass is clear, it can increase natural light and energy efficiency in the winter time (Dash Door n.d.). The technology can also switch the glass from transparent to an opaque translucent state with the simple flip of a switch, tap of an app, or wave of a hand. When the switch is on, the glass is clear. When the power is turned off, liquid crystal molecules that are randomly oriented within the glass layers will scatter light, making the glass opaque. The liquid crystal molecules will line up and the incidental light will pass through, causing the glass to become clear when electric current is being applied to the system.

3.4.2 Advantages and Disadvantages

There are several advantages for using electrical solar window. The first benefit is the decrease in indoor heat gain during the summer season (Dream Civil 2022). Secondly, it decreases power usage generated from cooling the building, which in turn lowers utility bills. The electrical solar glass can also reduce ultraviolet radiation passing through the glass. Additionally, it can provide user privacy and decrease glare within the building. Lastly, it has a low maintenance cost and effectively reduces the carbon footprint of the building through increased energy savings.

There are disadvantages to using electrical solar windows. The first disadvantage is that electrical solar windows are more expensive than normal windows because they require more advanced technology and take longer to manufacture. In addition to that, the disposal of solar windows at the end of their lifespans may be harmful to the environment, and the aesthetic appeal of opaque windows would not be desirable for this project.

4.0 Evaluation Process

Given the open-ended nature of this project, Shady Consulting evaluated multiple design alternatives before beginning to develop a final conceptual design. To compare the solutions, an evaluation matrix was used. Each solution from Section 3 of this report was considered in the evaluation process.

4.1 Design Criteria

An evaluation matrix was used to evaluate the alternatives because it allows each solution to be ranked by its ability to meet multiple design criteria, independent of the other alternative solutions. This method also allows for quick comparison within one criteria category and can have certain criteria weighed more heavily depending on their importance. The selected criteria for consideration are listed below, as well as the rationale guiding the scoring in the evaluation matrix. The evaluation criteria were chosen based on the design constraints provided by the client, and the purpose of the project.

1. **<u>Effectiveness:</u>** To choose a solar shading solution, the relative effectiveness of the proposed solutions must be considered, because the purpose of this project is to reduce excess heat uptake in Mitchell Hall. This criterion will be scored qualitatively based on the expected excess heat uptake reduction from each solution.
2. **<u>Environmental Impact:</u>** The second criterion for this project is the impact that different solutions will have on the environment. This includes any carbon sinking the solution would contribute, footprint of the materials needed, and construction required. This is important in this project because choosing a solution that is as environmentally friendly as feasible aligns with Queen’s facilities goals to reduce the footprint of their facilities.
3. **<u>Cost:</u>** As with any project, cost plays a key role. Cost is important to minimize in this project because it will determine how economically feasible the various solutions are. The cost is also important because the future savings made from each solution will need to be compared with the upfront investment by Queen’s facilities.

4. **Solution Lifetime:** The fourth criterion to be considered is how long the alternatives will remain functional. This is important because balancing the longevity of the chosen solution will impact the cost to Queen's facilities and the quality of the project with time.
5. **Constructability:** Choosing a solution that can be implemented quickly and with minimal disturbance to the surrounding area would be preferable for this project. This criterion includes considering the level of construction required and the time to complete installation. This also includes considering the amount of time after installation until the solution becomes effective.
6. **Aesthetics:** Finally, it must be considered that this project will be highly visible on Queen's campus and should be cohesive with the surrounding buildings. The aesthetic appeal of each solution will be considered in this section, relative to the other alternatives.

4.2 Design Criteria Evaluation

Before ranking each alternative solution for the design criteria, the evaluation rubric and scale for each factor need to be clearly identified. The following section lays out the rationale used to scale and rank each design criteria.

1. **Effectiveness:** Given that the purpose of this project is to decrease excess heat intake, a ranking scale of one to five will be used, one being the worst, and five being the best. This category will be ranked qualitatively by estimating the reduction in sunlight passing through the glass curtain walls. Along with this, the seasonal effectiveness will also be considered – solutions that can allow sunlight in the winter will be favoured qualitatively. These factors are laid out in Table 2 below.

Table 2: Effectiveness Scoring Rubric

Effectiveness Scoring Rubric	
Score	Rationale
1	The solution does not decrease excess heat intake in summer months.
2	The solution decreases excess heat in take minimally in summer months.
3	The solution decreases excess heat intake in the summer months but does not allow sunlight in the winter months.
4	The solution slightly decreases excess heat intake in the summer months and allows sunlight in the winter months.
5	The solution decreases excess heat intake in summer months and allows sunlight in winter months.

2. **Environmental Impact:** The environmental impact of the design alternatives will be considered on a scale of one to five, as shown below in Table 3. This category will be ranked qualitatively because the scale of the solution's carbon footprint and the degree of construction required will

be considered. If more information on the carbon footprint of each solution becomes available, more quantitative analysis will be conducted.

Table 3: Environmental Impact Scoring Rubric

Environmental Impact Scoring Rubric	
Score	Rationale
1	The solution poses a large carbon footprint from materials and construction, with no carbon-sinking potential.
2	The solution poses a large carbon footprint from materials and construction, with carbon sinking potential.
3	The solution poses a moderate carbon footprint, with no carbon-sinking potential.
4	The solution poses a minimal carbon footprint from materials construction.
5	The solution poses a minimal carbon footprint from materials construction and has carbon-sinking potential.

3. **Cost:** The cost criteria will be scored on a scale of one to five; one being the worst and five being the best. This category will be ranked quantitatively by dollar amount. Table 4 below described the rationale used.

Table 4: Cost Scoring Rubric

Cost Scoring Rubric	
Score	Rationale
1	The solution will be very expensive with significant maintenance requirements.
2	The solution be expensive with minimal maintenance requirements.
3	The solution will be moderately expensive with moderate maintenance requirements.
4	The solution will be inexpensive with moderate maintenance requirements.
5	The solution will be inexpensive with minimal maintenance requirements.

4. **Solution Lifetime:** The lifetime of the alternative solutions will be ranked quantitatively on a scale from one to five; one being the worst, and three being the best. This criterion will be considered based on the serviceability lifetime of the solution, as shown in Table 5.

Table 5: Solution Lifetime Scoring Rubric

Solution Lifetime Scoring Rubric	
Score	Rationale
1	The solution remains serviceable for 0-15 years.

2	The solution remains serviceable for 15-25 years.
3	The solution remains serviceable for 25-35 years.
4	The solution remains serviceable for 35-50 years.
5	The solution remains serviceable for 50+ years.

5. **Constructability:** The constructability of the solutions will be ranked on a scale of one to five; one being the worst and three being the best. This will be a relatively qualitative scoring, as shown below in Table 6.

Table 6: Constructability Scoring Rubric

Constructability Scoring Rubric	
Score	Rationale
1	The solution requires considerable construction time and intensity.
2	The solution requires moderate construction time and considerable intensity.
3	The solution requires moderate construction time.
4	The solution requires minimal construction time and moderate disturbance to the surrounding area.
5	The solution requires minimal construction time and minimal disturbance to the surrounding area.

6. **Aesthetics:** The final criterion will be qualitatively ranked on a scale of one, three, and five; one being the worst and five being the best. This scoring scale was adopted to ensure the category weight was not impacted by having fewer scoring classes. As shown below in Table 7, the rationale for scoring aesthetics depends on the ability of the glass curtain walls to function as windows.

Table 7: Aesthetics Scoring Rubric

Aesthetics Scoring Rubric	
Score	Rationale
1	The solution does not allow the glass curtain walls to function as windows.
3	The solution allows the function of curtain walls as windows.
5	The solution allows the function of curtain walls as windows and improves the aesthetic appeal of the building.

4.3 Design Alternative Evaluation

Now that the rubrics for each criterion have been clearly described, the alternative solutions can be evaluated. The section below illustrates the scoring and rationale for each solution with respect to the design criteria.

Option A: Status Quo

Table 8: Status Quo Evaluation

Status Quo Evaluation		
Criteria	Score	Rationale
Effectiveness	4	The blinds can be closed in the summer and opened in the winter.
Environmental Impact	3	The solution does not pose an additional carbon footprint but has no carbon sinking potential.
Cost	5	This solution requires no additional cost.
Solution Lifetime	1	The existing blinds should remain functional for up to 15 years.
Constructability	5	This solution requires no construction.
Aesthetics	1	This solution does not allow the curtain walls to function as windows.
Total Score:	19	

Option B: Structural Option

Table 9: Structural Option Evaluation.

Structural 1 Evaluation		
Criteria	Score	Rationale
Effectiveness	3	An overhang would decrease heat in the summer but would not allow excess heat in the winter.
Environmental Impact	1	A structural solution would pose a large carbon footprint with no carbon sinking potential.
Cost	2	This solution would be expensive with low maintenance costs.
Solution Lifetime	5	This solution would remain serviceable for 50+ years.
Constructability	3	This solution would require moderate construction.
Aesthetics	1	This solution would decrease the functioning of the curtain walls as windows.
Total Score:	15	

Option C: Solar Glass

Table 10: Solar Glass Evaluation.

Solar Glass Evaluation		
Criteria	Score	Rationale
Effectiveness	5	This solution would decrease excess heat in the summer and allow heat uptake in the winter.
Environmental Impact	3	This solution would pose a moderate carbon footprint with no carbon-sinking potential.
Cost	1	This solution would be very expensive.
Solution Lifetime	3	This solution would remain serviceable for 15-50 years.
Constructability	1	Solar glass would require considerable construction time and intensity to complete.
Aesthetics	5	This solution would improve the function of the curtain walls as windows.
Total Score:	18	

Option D: Trees & Blinds

Table 11: Trees and Blinds Evaluation.

Trees & Blinds Evaluation		
Criteria	Score	Rationale
Effectiveness	5	This solution would significantly decrease excess heat uptake in the summer and allow heat uptake in the winter months.
Environmental Impact	5	Trees would pose a minimal carbon footprint and have a carbon-sinking potential.
Cost	4	This solution would be relatively inexpensive but require moderate maintenance.
Solution Lifetime	5	This solution should last 50+ years.
Constructability	3	This solution would require moderate construction.
Aesthetics	5	This solution would improve the functioning of the curtain walls as windows and the aesthetics of the building.
Total Score:	27	

4.4 Evaluation Matrix

As a disclaimer, Shady Consulting must acknowledge the bias present when ranking the different design alternatives. Engineering judgment depends on both objectivity and experience, and in this process, each member of the Shady Consulting team contributed with this in mind. In the matrix, each solution was numerically ranked for each criterion; these rankings were prescribed by the evaluation criteria in sections 8.2 and 8.3. These category rankings were then multiplied by a category factor so that the most important factors were considered more strongly.

When designing the decision matrix for this project, the relative importance of each factor needed to be considered. Therefore, each criterion was given a weight value, the higher the value, the more important the factor. As stated by the client, the effectiveness of the solution is the highest-ranking factor, which is why its weight is two and a half, instead of one. Environmental impact is the second most important factor, which is the reason for weighing it at two. This is because this factor was identified by the client as a key goal for this project. The lifetime, time to implement, cost, and aesthetics factors have all been given a weight of one. This is because they are important but are not the critical factors identified in the problem description and by the client but will impact the design. The options shown below represent the following solutions:

- Option A: Status Quo
- Option B: Structural
- Option C: Solar Glass
- Option D: Trees and Blinds

Table 12: Evaluation Matrix.

Criteria	Weight	Option A	Option B	Option C	Option D
Effectiveness	2.5	4	3	5	5
Environmental Impact	2.0	3	1	3	5
Lifetime	1.0	5	2	1	4
Time to Implement	1.0	1	5	3	5
Cost	1.0	5	3	1	3
Aesthetics	1.0	1	1	5	5
Total Weighted Score:		28	20.5	28.5	39.5

Based on the evaluation matrix above, Shady Consulting has selected Option D: planting trees in tandem with the existing double-blind system as the solution moving forward. The following sections of this report outline this solution in detail, including implementation cost and a detailed final design.

5.0 Design Solution

Shady Consulting has researched each facet of the selected design to ensure it can be implemented in a feasible, economical, and effective manner. This section of the report will outline the research conducted to select an appropriate species of tree, the planting mechanism, the design layout, and information on material accessibility. The relevant regulations and documentation needed for this project have also been included, along with engineering drawings of the proposed final solution layout. At each step of the design process, Shady Consulting considered effectiveness, cost, and environmental impact as the most important factors – as specified in the evaluation process and stakeholder sections of this report.

5.1 Tree Species Research

A critical step in the design of the final solution is selecting an appropriate tree species to plant. The following sections in this report outline the research conducted to facilitate the species selection process; the research conducted followed the Ontario Landscape Tree Planting Guideline (McGrath et al. 2019). This research will be used to evaluate the different species for their suitability to Kingston's climate, their aesthetic contribution to Queen's campus, and the amount of shading provided by each species.

5.1.1 Alternative Species

Shady Consulting decided to consider different types of Maple trees for the final design solution because Maples are a pervasive genus of trees in Kingston that are well-suited to the local climate. Out of the 150 known Maple tree species, seven types are compatible with Ontario's environment. Due to the scope of the project, Shady Consulting will focus the evaluation on the four most common Maple tree types in Ontario: the Shantung Maple tree, Red Maple tree, Silver Maple tree, and Striped Maple tree (Environment Canada n.d.).

Figure 18: The figure above shows a picture of a Shantung Maple tree, Red Maple tree, Silver Maple tree and striped Maple tree (Urban Program Bexar County 2007).

Figure 18 shows each of the four species considered for the final design solution; this figure provides a reference for the aesthetic qualities of each tree type. Each type of Maple considered has its own qualities. For example, Red Maple trees provide shade and moisture for the environment and can be easily transplanted and adapted to many climates. Silver Maples are convenient because they are fast-growing (Environment Canada n.d.). The Shantung Maple tree is an outstanding tree type for a relatively small area, and it can tolerate alkaline soils, drought, and windy situations (Urban Program Bexar County 2007).

5.1.2 Cold Acclimation

Cold acclimation is defined as the ability of a plant to survive in extremely cold environments; understanding this concept is crucial for species selection because Kingston experiences cold winters. Cold acclimation is determined by the ability to tolerate low and freezing temperatures. The most vulnerable part of trees to freezing is the shoot tissue, comprising the foliage and branches. The plant's survival through extreme cold weather depends on the hardest part of the tree, the root system (Borden 1999). The root hardness is classified by Agriculture Canada, and the US Department of Agriculture, to identify species based on their ability to handle colder climates. The extreme temperature ranges in Canada that are considered in the USDA classification system range from negative 23 to positive 28 degrees Celsius (Alladin 2022).

Table 13: Tree Species USDA Classifications.

Tree Species	USDA Classification
Shantung Maple Tree	4-8
Red Maple Tree	3-9
Silver Maple Tree	3-9
Striped Maple Tree	3-6

Table 13 displays tree species and their associated USDA class (Tree Canada n.d.). The listed information can be used as a reference for evaluating cold acclimation during the tree selection process.

5.1.3 Habitat Comparison

One facet of evaluating the alternative tree species considered is by looking at the habitat requirements of each tree type. This information provides a qualitative look at each tree type.

Red Maple trees have strong adaptation mechanisms, making them one of Ontario's most common trees. Red Maple trees can survive through various soil conditions in terms of soil types, textures, and elevations. One study showed that it grows the best in a moderately well-drained, moist soil at lower elevations (Walters and Yawney n.d.). Silver Maple trees have a narrower range of suitable soil conditions. The allowable range of soil pH for a Silver Maple is 2.2 to 3.3. Silver Maple trees tend to grow better when they are located near a water source, such as near a stream or lake (Gabriel n.d.). Striped Maple trees are more fragile than Red Maple trees and tend to grow better in densely wooded areas. Striped Maple trees do not grow well in full sunlight, and prefer well-drained, acidic soil conditions (Adirondacks Forever Wild n.d.). Shantung Maple trees can survive in both full and partial sunlight and display colourful foliage in the fall. Shantung Maples grow easily in a variety of soil conditions, ideally in moist soil with good drainage. The pH tolerance for Shantung Maple trees is flexible, with an acidic, neutral, and slightly alkaline acceptance level. They can survive across a wide range of temperatures, and do not require fertilization to grow (Engles n.d.).

5.1.4 Shadow Length Analysis and Comparison

Different tree species provide different amounts of shade based on their size and shape. The amount of shade they provide is impacted by many factors, one of them being their shadow length. Shadow length refers to the length of shadow that extends on the ground at different times of day. The results from performing shadow length calculations, as described in section 3.2.2 of this report, on each alternative species can be seen in Figure 19 and Figure 20. Figure 21 illustrates how shadow length varies throughout the year; these results show that summer months have the shortest shadow lengths. This figure identifies that Silver Maple trees have the greatest shadow length, and Shantung Maples have the shortest shadow length.

Figure 19: Winter Shadow Lengths

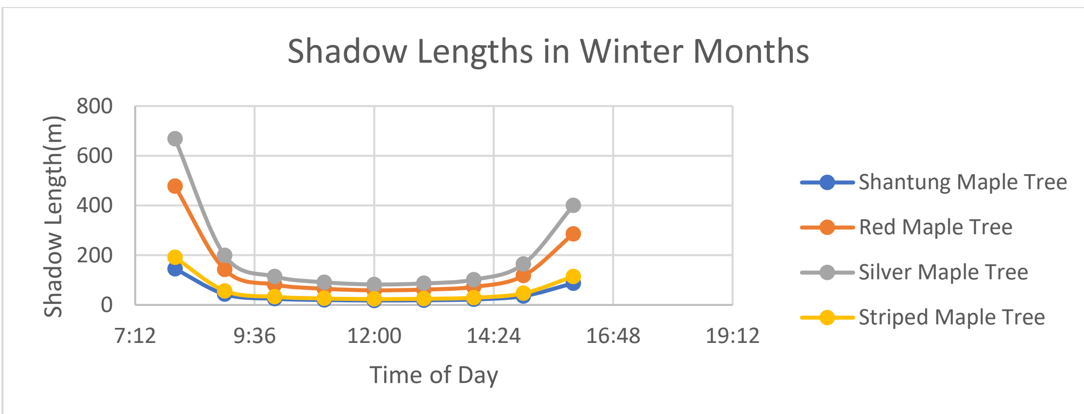


Figure 19: Winter Shadow Lengths

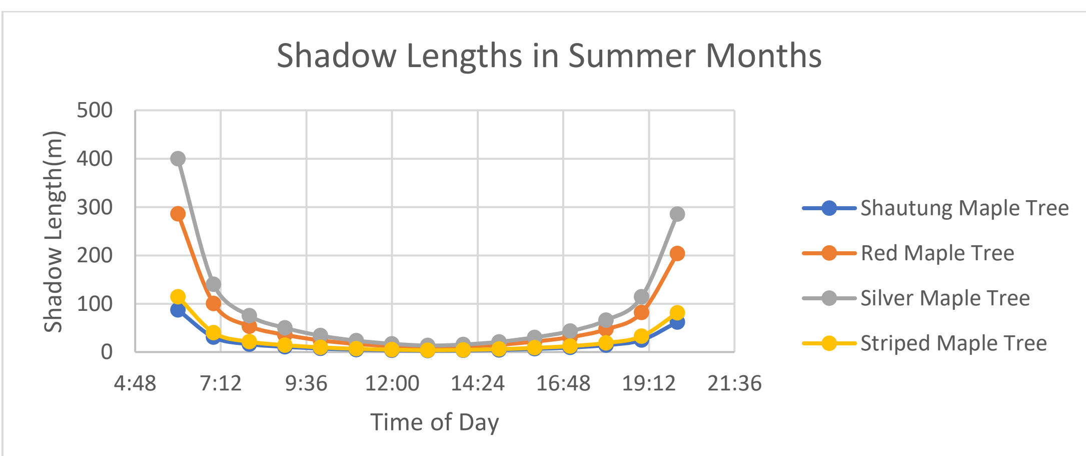


Figure 20: Summer Shadow Lengths

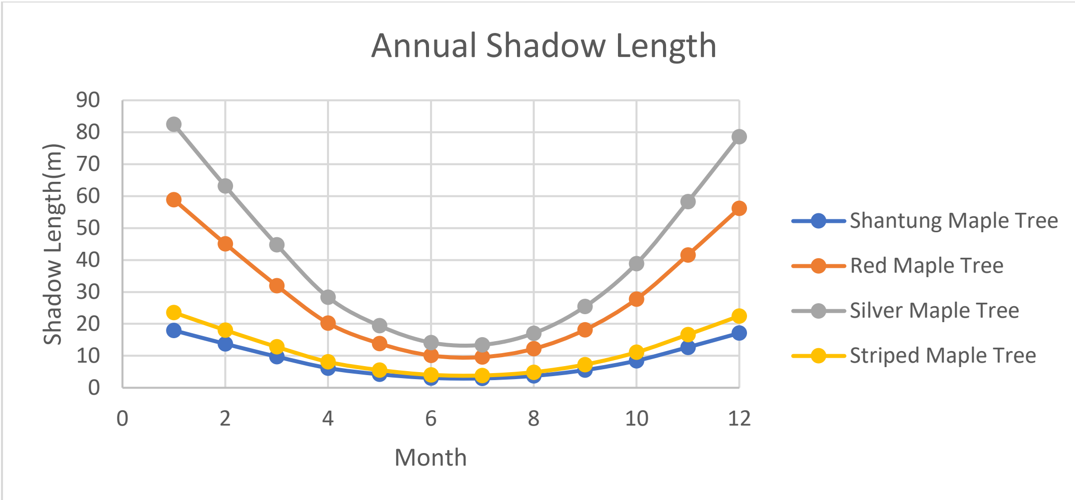


Figure 21: Annual Shadow Length

Shadow length may be used as a design parameter, especially if the trees are planted at a distance from any structure. For this project, the Shantung Maple trees are to be planted near the glass curtain walls of Mitchell Hall, making shadow length less pertinent in comparison to the spread of the tree. The shaded area for each tree species can be seen summarized in Section 5.1.5.

5.1.5 Species Maximum Shaded Area

One important quality for each tree species considered is the amount of shade they can provide. To estimate this, the average height and spread of each species was researched and used to calculate the maximum possible shaded area; this was done by multiplying the spread by the height of each tree (Tree Canada n.d.). These values are displayed below in Table 14.

Table 14: Tree Species Maximum Shaded Areas

Species	Average Spread (m)	Average Height (m)	Maximum Shaded Area (m2)
Shantung Maple	6.0	7.6	45.6
Red Maple	15	21	315
Silver Maple	15.2	23.3	352.6
Striped Maple	9.45	15.2	143.6

The more shade that can be provided, the more effective the solution may be. However, there is a tradeoff between shaded area and the size of tree. Generally, the bigger the tree, the bigger the shaded area. The size of the tree had to be limited for this project, as the space surrounding Mitchell Hall is not large enough to support a large tree species. Medium trees, such as the Shantung Maple tree, are a reasonable size to plant in front of Mitchell Hall. Therefore, even though the Shantung Maple tree has the smallest maximum shaded area, it is a more reasonable size of tree to be used in this project.

5.1.6 Time to Maturity and Life Span

Table 15 lists the time to maturity for the different tree species under consideration. The time to reach maturity for the four types of trees ranges between 10 to 25 years (Germane 2023). After the tree is planted, it takes time for the trees to grow to achieve their maximum shading effect. Identifying the time to reach maturity for each type of tree is crucial because it is one of the evaluation criteria, the shorter the time to maturity, the better.

Table 15: Tree Species Time to Maturity

Tree Species	Time to Maturity
Shantung Maple Tree	Around 10 years
Red Maple Tree	Around 25 years
Silver Maple Tree	Around 20 years
Striped Maple Tree	Around 10 years

Table 16 lists the life span for the different tree species under consideration. The life span of the four types of trees ranges from 80 to 100 years. Identifying the life span is crucial because it directly impacts the lifespan of the project. Picking a tree species that has a longer life span may reduce the future cost for replanting.

Table 16: Tree Species Lifespan

Tree Species	Lifespan
Shantung Maple Tree	100 years or more (Metro Maples n.d.)
Red Maple Tree	80 to 100 years (National Wildlife Federation n.d.)
Silver Maple Tree	130 years or more (Gabriel n.d.)
Striped Maple Tree	80 to 100 years (Adirondacks Forever Wild n.d.)

5.2 Tree Species Evaluation Processes

The following sections outline the evaluation process followed to select an appropriate tree species for the selected final design. This entailed defining the selection criteria, how these criteria would be evaluated, completing evaluations of each species considered, and comparing these results in an evaluation matrix. This process was completed to select a tree species that would be feasible to implement, could survive in Kingston, and provide adequate shading for Mitchell Hall.

5.2.1 Tree Species Selection Criteria

To evaluate the various research tree species to select the best option, a similar approach to the design solution selection was implemented. Shady Consulting used an evaluation matrix because it allows each tree species to be independently evaluated against the design criteria. The selected criteria for consideration are listed below, as well as the rationale guiding the scoring in the evaluation matrix. The evaluation criteria were chosen based on the design constraints provided by the client, and the purpose of the project. The criteria used are as follows:

1. **Effectiveness:** To choose a tree species, the relative effectiveness of each species must be considered, because the purpose of this project is to reduce excess heat uptake in Mitchell Hall. This criterion will be quantified by an estimated amount of shade provided in the summer months, from the maximum shade area previously calculated for each species.
2. **Time to Mature:** After being planted, there will be a period before the trees reach maturity and provide their maximum potential shading effect. Choosing a species that grows relatively quickly is advantageous because it reduces this time of lowered heat reduction.
3. **Lifespan:** The lifespan of each tree species is important to consider because it directly affects the lifetime of the project before it would need to be re-started by planting new trees. Choosing a species with a long lifetime is advantageous because it reduces future costs required to replant trees and following time for the tree to mature.
4. **Habitat Suitability:** The final factor considered will be each species' suitability to the local climate. Choosing a species that will be able to thrive in the local climate will directly impact the success of the project, as it will increase the chances of the trees' survival.

5.2.2 Criteria Evaluation

To rank the alternative species against the design criteria, the evaluation rubric needs to be clearly identified. The following section lays out the rationale used to score each option.

1. **Effectiveness:** This category will be ranked by estimating the amount of shading provided by each tree. This will be quantified by estimating the maximum shaded area each tree can provide using the values from Table 14. Given that the objective of this project is to decrease excess heat intake, a ranking scale of one to three will be used, one being the worst, and three being the best. The criterion for each score is described below in Table 17.

Table 17: Tree Species Effectiveness Scoring Rubric

Tree Species Effectiveness Scoring Rubric	
Score	Rationale
1	The species provides a maximum shaded area of ≤ 150 m^2
2	The species has a maximum shaded area of 150 – 250 m^2
3	The species has a maximum shaded area of ≥ 250 m^2

2. **Time to Mature:** The time each species takes to mature will be ranked quantitatively by estimating the time in years for the trees to reach maturity. This factor is critical as it directly impacts the effectiveness of the design solution; a ranking scale of one to three will be employed, with one being the worst and three being the best. These criteria are laid out in Table 18.

Table 18: Tree Species Time to Mature Scoring Rubric

Tree Species Time to Mature Scoring Rubric	
Score	Rationale
1	The species requires a long period to mature, 25 ≤ years.
2	The species requires a moderate period to mature, 10-25 years.
3	The species requires a short period to mature, 10 ≥ years.

3. **<u>Lifespan:</u>** The lifespan of each tree species will not only impact the effectiveness of the design solution, but also the future costs associated with the project. Ideally, a species with a long lifespan will be selected to increase the time Mitchell Hall can experience decreased heat uptake before re-planting is needed. This factor will be ranked in a similar fashion to the previous two: quantitatively based on the tree lifespan, with one being the worst and three being the best. This scoring is described below in Table 19.

Table 19: Tree Species Lifespan Scoring Rubric

Tree Species Lifespan Scoring Rubric	
Score	Rationale
1	The species has a relatively low life span, 75 ≥ years.
2	The species has a moderate lifespan, 75-100 years.
3	The species has a long lifespan, 100 ≤ years.

4. **<u>Habitat Suitability:</u>** The suitability of each tree species will affect the level of shading provided by the design solution, and future costs related to the project; replanting the trees due to poor suitability would be costly and negate any shading provided. This factor will be measured qualitatively by considering if the species are invasive, their ability to acclimate to cold weather, and their general suitability based on soil and sunlight conditions. Given that the purpose of this project is to decrease excess heat intake, a ranking scale of one to three will be used, one being the worst, and three being the best. The criterion for each score is described below in Table 20.

Table 20: Tree Species Habitat Suitability Scoring Rubric

Tree Species Habitat Suitability Scoring Rubric	
Score	Rationale
1	The species is poorly suited to Kingston’s climate.
2	The species is well-suited to Kingston’s climate.

3	The species is non-invasive and well-suited to Kingston’s climate.

5.2.3 Alternative Species Evaluation

All the species can now be evaluated; the following section illustrates the scoring and rationale for each solution with respect to the design criteria.

Species A: Shantung Maple

Table 21: Shantung Evaluation

Shantung Maple Evaluation		
Criteria	Score	Rationale
Effectiveness	1	This species provides a maximum shade area less than 150 m^2
Time to Mature	3	Shantung Maples take 10 ≤ years to reach maturity.
Lifespan	3	This species has an average lifespan 100 ≤ years.
Habitat Suitability	3	This species has flexible pH, moisture, and soil requirements, and can survive in direct sunlight.
Total Score:	10	

Species B: Red Maple

Table 22: Species B Evaluation

Species B Evaluation		
Criteria	Score	Rationale
Effectiveness	3	This species provides a maximum shade area greater than 250 m^2
Time to Mature	1	This species takes 25 ≤ years to reach maturity.
Lifespan	2	This species has an average lifespan of 80-100 years.
Habitat Suitability	3	This species has flexible pH, moisture, and soil requirements, it can survive in direct sunlight, and is minimally invasive.
Total Score:	9	

Species C: Silver Maple

Table 23: Species C Evaluation

Species C Evaluation		
Criteria	Score	Rationale
Effectiveness	3	This species provides a maximum shade area greater than 250 m^2
Time to Mature	2	This species takes a moderate amount of time to mature, around 20 years.
Lifespan	3	This species has a long lifespan, 130 ≤ years.
Habitat Suitability	1	Silver Maples have specific soil pH, moisture, and sunlight requirements not suited for the Mitchell Hall location.
Total Score:	9	

Species D: Striped Maple

Table 24: Species D Evaluation

Species D Evaluation		
Criteria	Score	Rationale
Effectiveness	1	This species provides a maximum shade area less than 150 m^2
Time to Mature	3	This species takes about 10 years to reach maturity.
Lifespan	2	This species has an average lifespan of 80-100 years.
Habitat Suitability	1	Silver Maples have specific soil pH, moisture, and sunlight requirements not suited for the Mitchell Hall location.
Total Score:	7	

5.2.4 Tree Species Evaluation Matrix

As with the design solution evaluation, Shady Consulting acknowledges the bias present during the ranking of the tree species. Each member of the Shady Consulting team contributed using their engineering judgment and acknowledging their own biases. In the matrix, each solution was numerically ranked for each criterion; these rankings were prescribed by the evaluation criteria in sections 5.2 and

5.3. These category rankings were totaled to provide a quantitative comparison between each species option, with the highest-ranking species being selected.

The evaluation criteria for this matrix were weighted equally – at a factor of one; this is because each factor will contribute to the success of the project equitably. Selecting a tree species with high enough shading is important because that will determine the ability of the solution to decrease excess heat uptake in Mitchell Hall, which is the main purpose of the project. Choosing a tree species that will mature relatively quickly will also directly impact the success of the project because it determines when the design will become effective. Likewise, the lifetime of the selected tree species will determine the longevity of the solutions' effectiveness, and the future costs associated with replanting the trees. Finally, the habitat suitability of the selected species is imperative in ensuring that the trees can mature, live for their expected lifespan, and provide effective shading at Mitchell Hall. If this factor is not considered, then the future costs of the project will increase if the trees need to be replanted. Since each factor in the matrix directly impacts the success of the project, each factor has been given an equal factor weighting of one.

- Species A: Shantung Maple
- Species B: Red Maple
- Species C: Silver Maple
- Species D: Striped Maple

Table 25: Tree Species Evaluation Matrix

Criteria	Species A	Species B	Species C	Species D
Effectiveness	1	3	3	2
Time to Mature	3	1	2	3
Lifespan	3	2	3	2
Habitat Suitability	3	3	1	1
Total Score:	10	9	9	7

Based on the results of the matrix in Table 25, Shady Consulting has selected the Shantung Maple as the tree species to be implemented in the final design solution. The following sections of this report detail the planting mechanisms and design layout that this species will be used in.

5.3 Planting Mechanisms

Tree roots can pose a significant threat to the stability and longevity of surrounding structures and landscapes. Without proper precautions, growing roots can cause damage to hardscapes, utilities, and foundations. These risks can be mitigated using various measures. One of the most effective methods for controlling roots is the use of a root barrier system. Root barriers consist of sheets of high-density polyethylene that are placed around the perimeter of the tree, preventing the roots from expanding and causing damage. These barriers can also be installed laterally beneath concrete landscapes to prevent the roots from upheaving the hardscape, a common problem in urban areas. In addition to their root-controlling properties, root barriers also serve as a waterproof seal, helping to maintain moisture levels in the soil and promote healthy tree growth (Felecia 2019). For this project, the trees will be planted in above ground planter boxes to reduce the depth of the roots, and it is recommended that the described root barrier systems be implemented. This also reduces the depth that needs to be excavated, which can prevent any excavating accidents involving underground utilities.

5.4 Design Layout Selection

To select an effective design layout for this project, consideration needs to be given to the use of Mitchell Hall and its surrounding infrastructure. This site has high levels of pedestrian and vehicular traffic, so minimizing the footprint of proposed structures while maintaining effectiveness is ideal. Two proposed design layouts have been prepared and are detailed below. It is important to note that both designs maintain the current double-blind system and will ignore the shading effects from the blinds when comparing effectiveness of the designs.

Layout Option 1: South Wall Only

The first design layout proposed for this project is illustrated below in Figure 22. This design layout uses a planter box along the south glass curtain wall, which involves extending the existing planter boxes present. This design layout would use two Shantung Maple trees and provide about 33.7% of shading for Mitchell Hall's glass curtain walls once the trees reach maturity.

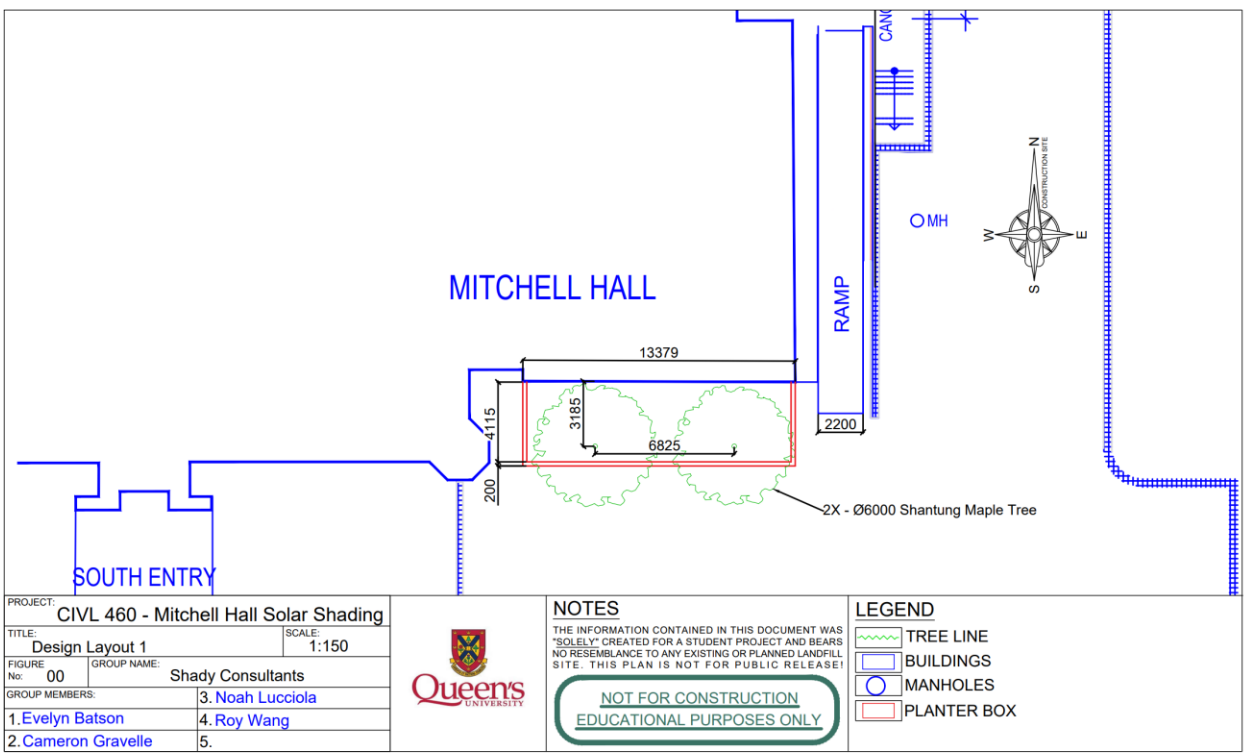


Figure 22: Design Layout 1.

Layout Option 2: South and East Walls

The second design layout proposed for this project is shown below in Figure 23. This option will require more construction than option 1 because a second planter box would need to be constructed for the east glass curtain wall. For the trees planted to provide shade to the east wall, they need to be close enough to the building for their shadows to fall against the glass. This would require the removal and relocation of the existing stairs and ramp to build planter boxes for the trees. The current canopy that runs along the east wall must be removed or shortened to only cover the entrance way. The accessibility ramp width must also be reduced from 2.2 metres to 1.6 metres due to space restrictions imposed by the existing manhole. The revised 1.6 metre ramp width still exceeds the minimum width of 0.9 metres as stated in section 3.8.3.4 of the Ontario Building Code ("The Ontario Building Code | Ramps" n.d.). The decreased ramp width may decrease accessibility to the building, as it decreases the number of people or objects that can use the ramp at once, but it remains within code. Option 2 would provide more shade than option 1, but this comes at a higher cost due to increased construction time, greater material needs, and more complex engineering design. Therefore, while this design layout is more complicated and costly to construct, it would be more effective at shading the glass curtain walls. This design option would require five Shantung Maple trees and would shade 60.2% of Mitchell Hall's curtain walls when the trees reach maturity.

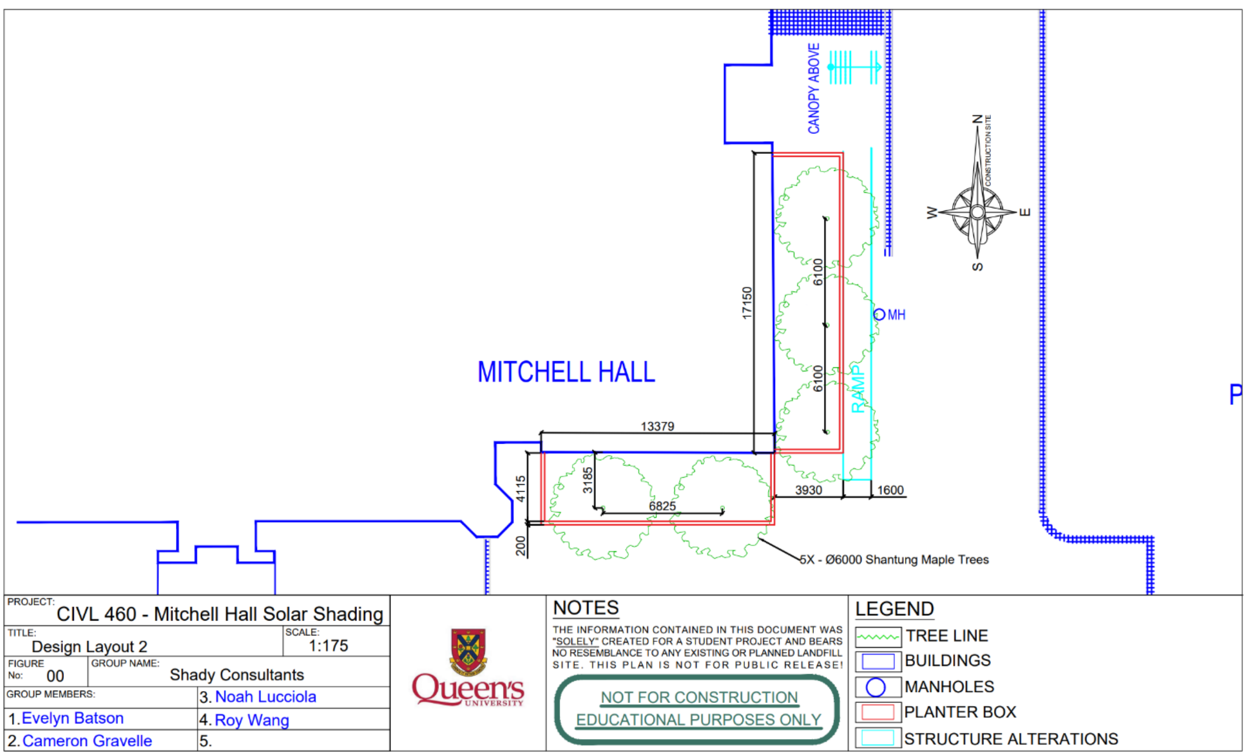


Figure 23: Design Layout 2.

5.4.1 Shade Calculations

To evaluate the shading effectiveness of each design layout, the percentage of area being shaded was calculated. In design layout 1, the Shantung Maple trees provide shading for the south wall while the existing canopy provides shading for the east wall. Figure 24 shows the shaded and unshaded areas for design layout 1. The unshaded area is visualized with diagonal hatching.

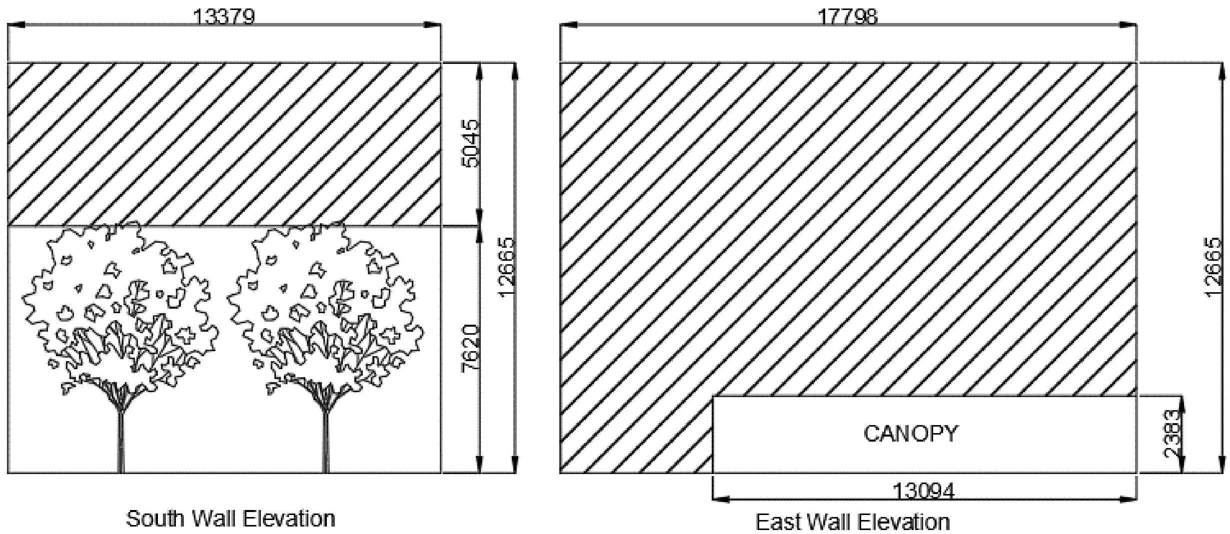


Figure 24: Elevation drawings of the east and south walls showing shaded area provided by design layout 1.

Design layout 1 provides shading for 33.7% of the glass curtain walls. The detailed calculations are shown below.

$$\%\ Area\ Shaded = \frac{Area\ Shaded}{Total\ Area} \times 100 = \frac{(7620\ mm \times 13379\ mm) + (2383\ mm \times 13094\ mm)}{(13379\ mm + 17798\ mm)(12665\ mm)} \times 100$$

$$\%\ Area\ Shaded = 33.7$$

In design layout 2, the Shantung Maple trees provide shading for both curtain walls. Figure 25 shows the shaded and unshaded areas for design layout 2. The Shantung Maple trees provide much greater shaded area than the existing east wall canopy.

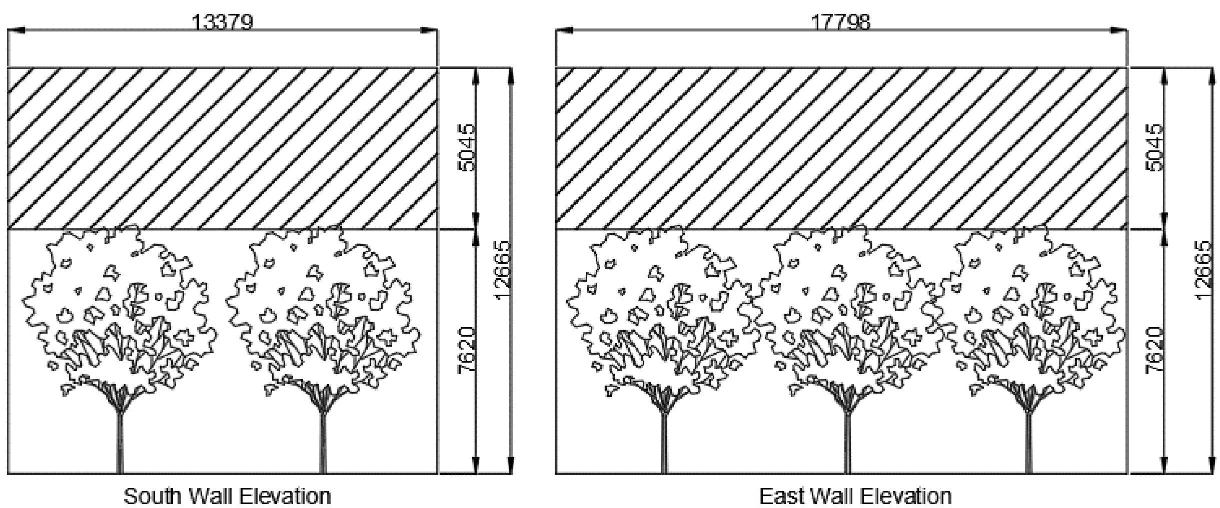


Figure 25: Elevation drawings of the east and south walls showing shaded area provided by design layout 2.

Design layout 2 provides shading for 60.2% of the glass curtain walls. The detailed calculations are shown below.

$$\% \, Area \, Shaded = \frac{Area \, Shaded}{Total \, Area} \times 100 = \frac{(7620 \, mm \times 13379 \, mm) + (7620 \, mm \times 17798 \, mm)}{(13379 \, mm + 17798 \, mm)(12665 \, mm)} \times 100$$

$$\% \, Area \, Shaded = 60.2$$

5.4.2 Design Layout Selection

After carefully considering the two design options presented, Shady Consulting has selected design option 1 as the preferred design. This design features two Shantung Maple trees along the south wall of the building, while leaving the east wall untouched. Option 1 was calculated to provide shade to 33.7% of the wall area. A visual representation of the design can be seen in Figure 26 below. Option 1 is not only cheaper but also requires significantly less construction than option 2. Option 2 features five Shantung Maple trees in total, with two along the south wall and three along the east wall. However, to accommodate the additional trees along the east wall, the accessibility ramp would need to be relocated, and its width reduced from 2 meters to 1.6 meters. While this width is still within guidelines, it is undesirable. This option also involves removing or shortening the existing canopy and relocating the existing stairs, which requires extensive and expensive construction. Despite option 2 shading 60.2% of the wall area, we have chosen option 1 due to its practicality, cost-effectiveness, and less construction, making it a more sustainable option. Option 1 does not provide any additional shading to the east facing wall, but it is important to note that due to the location of Mitchell Hall, the south facing wall experiences sun for a longer period during the day. The east wall only experiences sun until noon when the sun becomes overhead and continues moving west. The south wall experiences sun for most of the day due to the sun always being located south of the building. Therefore, providing shading to the south wall is significantly more effective than providing shading to the east wall. Selecting option 1 as the preferred design, does not eliminate the possibility of implementing design option 2, since design option 2 incorporates design option 1.

Figure 26: Visual Representation of Design Layout 1.

5.5 Transport, On-Site Handling, and Inspection

The Ontario tree planting guide provides general information about transportation and handling techniques planting trees. Accessibility considerations should start with using the Ontario tree guide as a reference. The critical materials needed for transportation, onsite handling, and inspection include a record of trees ordered, a water source and hose, bags to protect bare roots, trees, and equipment required to move large trees (McGrath et al. 2019).

To ensure that the tree transportation process and material handling is successful all the trees should be covered during transportation to site. The tree foliage and root balls should be handled carefully to avoid damage. Maintaining adequate moisture on the roots by watering during any prolonged periods of transportation is important.

On-site inspection of the tree planting process is a key step to ensure they are planted correctly. This should include inspecting the delivered trees for any scarring, broken branches, and damaged root balls. The trees should also be checked to make sure the leaf size, colour and appearance are reasonable according to the time of the year and the stage of growth. Any bare root trees should have least three well-distributed roots to survive after planting, so this is worth checking on the recommended Shantung Maples. Once the trees are planted, they should be regularly watered – this is especially important while the trees are freshly planted as they will be establishing new root systems.

5.6 Carbon Sequestration Analysis of the Final Design

Figure 27, shown below, illustrates the carbon sequestration analysis for the Shantung Maple trees across a 25-year period. This figure shows that carbon being sequestered increases non-linearly across time (as the tree grows), and each tree can collect up to 2500 pounds of carbon over 25 years. The principle of this analysis is described in section 3.2.5.2. of this report.

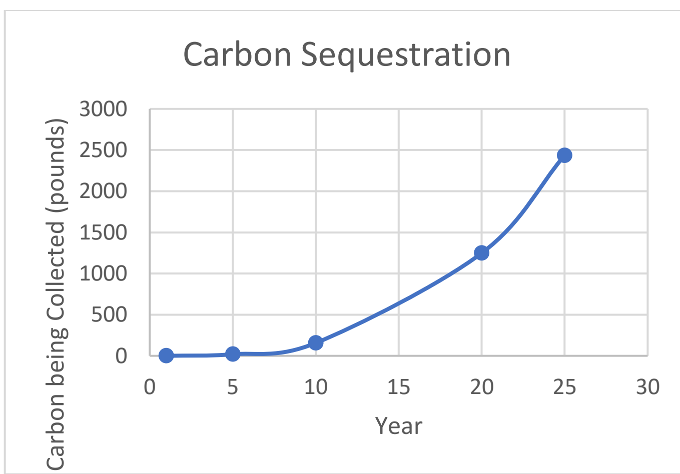


Figure 27: The figure above shows the carbon sequestration analysis for Shantung maple tree.

6.0 Energy Saving Innovation

Shady Consulting suggests that Queen’s Facilities can improve the design solution in terms of energy efficiency through the application of a metal oxide coating on the glass curtain walls. Improving energy efficiency is not only part of the client's request but is also part of the universal objective to increase energy efficiency. There are several benefits that come from improving energy efficiency. Firstly, it will reduce greenhouse emissions and other pollutants indirectly through the reduction of electricity usage. Additionally, reducing energy expenditure can effectively reduce utility bills. With decreased utility bills, the increase in energy efficiency may stabilize electricity prices for the University. Decreasing the energy demand may allow the University to shift away from investing in electricity generation and transmission infrastructure. Lastly, energy efficiency may minimize the uncertainty related to fluctuating heat prices (US EPA 2017). All the windows on Queen's campus have adopted double glazing technology because it is the most common and standard energy efficiency practice for glass. The implementation of a glass coating could be a unique feature that only Mitchell Hall would possess across the Queen's campus. Glass coating could be a milestone for Queen's in terms of energy saving and global sustainability. However, the implementation may also pose some challenges, including delaying the project timeline and making the project more labour and cost intensive.

6.1 Glass Coating Energy Working Mechanism

Once glass is coated with metal oxide, it is known as low energy glass; this coating is microscopically thin and transparent (Vitro Architectural Glass n.d.). Figure 2828 shows the principal mechanism of metal oxide coated glass. The layer of coating is responsible for blocking short wave solar energy and long wave-infrared, which are UV rays and heat. The only type of light that can pass through metal oxide coating in both directions is visible light (Champion Window n.d.).

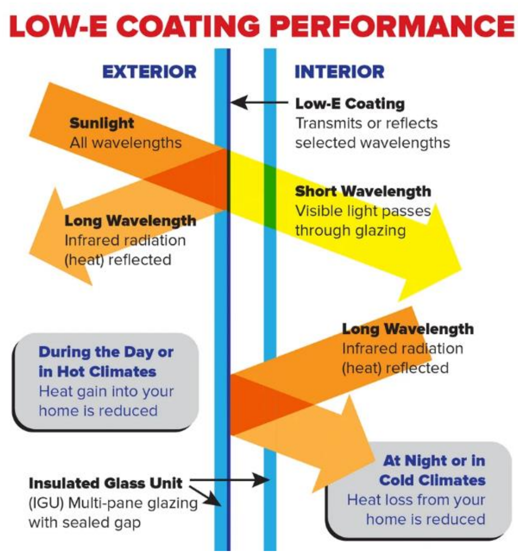


Figure 28: E-Coating on Glass (Champion Window n.d.).

6.2 Advantages of Glass Coating

There are several benefits to using metal oxide as a coating for glass. The coating reduces the susceptibility of the glass being damaged or scratched. This coating also blocks UV rays from entering buildings and increases the lifetime of the glass. Coated glass lowers the glare from light sources compared to un-coated glass. Coated glass works to maintain a comfortable temperature in buildings, minimizing the amount of heat and air-conditioning required throughout the year (Bality 2022).

6.3 Relevant Calculations and Analysis

The following section outlines the U factor and solar heat gain coefficient calculation completed as part of the energy savings analysis.

6.3.1 U factor

U factor analysis is one way to evaluate the insulating properties of specific building elements. Lower U values correspond to better insulation qualities. The purpose of calculating U for this section is to compare the thermal insulation provided by double glazed glass and low energy glass. These calculations require the use of R values (Kingspan 2017). R values depends on thickness and thermal conductivity of the material (Armacell 2022). For simplicity, the value of R has be identified directly through research as 2.084 for double glazed glass and 4.783 for double glazed glass with two layers of metal oxide coating, or low energy glass (All Weather Windows n.d.).

Double glazed glass:

Equation 20: The equation below shows the typical value of R for double glazed glass.

$$R = 2.084$$

Equation 21: The equation below shows the formula for calculating U value (Kingspan 2017).

$$U = \frac{1}{R}$$

Equation 22: The equation below shows the process of calculating U for double glazed glass and the result for U value.

$$U = \frac{1}{2.084} = 0.4798$$

Low energy glass:

Equation 23: The equation below shows the typical value of R for double glazed glass with two layers of metal oxide coating.

$$R = 4.783$$

Equation 24: The equation below shows the process of calculating U for improved glass and result for U value.

$$U = \frac{1}{4.783} = 0.2091$$

To conclude, the double-glazed glass with addition of metal oxide coating (low energy glass) provides better thermal insulation than just double-glazed glass, because the glass with the coating has a smaller U value.

6.3.2 Solar Heat Gain Coefficient

A solar heat gain coefficient is defined as the fraction of solar radiation admitted through a medium which includes windows, doors, or skylights. The transmission can be processed directly or through absorption while releasing the heat subsequently. Research dictates that the lower the solar heat gain coefficient, the better shading ability the material can provide; the greater the shading capacity, the less solar heat gets transmitted. (U.S. Department of Energy n.d.).

Double glazed glass:

Equation 25: The equation below shows the formula for calculating SHGC (Etheridge 2010).

$$SHGC = SC * 0.87$$

Equation 26: The equation below shows the value of shading coefficient of the double-glazed glass (Stephenson 1968).

$$SC = 0.5$$

Equation 27: The equation below shows the process of calculating SHGC value and the result value for SHGC.

$$SHGC = 0.5 * 0.87 = 0.435$$

Low energy glass:

Equation 28: The equation below shows the value of shading coefficient of double-glazed glass with metal oxide coating (Durabuilt n.d.).

$$SC = 0.43$$

Equation 29: The equation below shows the process of calculating SHGC value and the value for SHGC.

$$SHGC = 0.43 * 0.87 = 0.3741$$

According to the calculations, double glazed glass with metal oxide coating has lower SHGC, which indicates it has a stronger ability to provide shading. This also shows addition of metal oxide coating can achieve the goal of saving energy.

7.0 Economic Analysis

The following sections outline each component of the financial analysis completed for this project. This process included defining the client budget, a preliminary value judgment, and a cost analysis breakdown.

7.1 Client Budget

Queen's Facilities does not have a specific budget for this project, although they typically will use a cost per metric tonne and project payback model to evaluate project design budgets. Currently, they are only looking for the most cost-effective and environmentally friendly solution.

7.2 Preliminary Value Judgment (Triple Bottom Line Considerations)

The triple bottom lines accounts for the social, environmental, and financial impacts of implementing a design. Implementing a solar shading solution will decrease energy consumption and costs related to cooling the building due to heat gain from sun exposure. The solution will therefore not only save money but the reduction in energy will decrease Mitchell Hall's overall environmental footprint. The solution will also benefit the students and other faculty who intend to use the building, specifically in the room containing the south and east facing glass walls. It will help keep the temperature inside the building comfortable for all students, staff, faculty, and visitors. The room containing the glass walls is often used for presentations, which rely on a projector for visual aid. For the projector to work, the room cannot have full sun exposure, or else the image from the projector cannot be seen on the screen. The shade from the solar shading solution may allow for better screen visibility during the day. The reduction in energy will decrease Mitchell Hall's overall environmental footprint. Overall, the implementation of a solution meets triple bottom line goals as the implementation would have a positive financial, social, and environmental impact.

7.3 Cost Estimate

A cost estimate for the final design will be outlined in this section. It is a semi-detailed estimate because the project is currently in the conceptual design/detailed engineering phase. It is important to note that the cost is variable, it may change at any given time due to price fluctuation or upon the availability of materials. Shady Consulting may only provide an estimate, and in no way can guarantee that the estimate will reflect the cost at the time that the project is being developed (during the construction phase). It is recommended that a more detailed and precise cost estimation be conducted prior to the construction phase of the project.

There are some elements of cost that will be relevant despite the solution. Using RSMeans Data for Building Construction Costs (2020), Shady Consulting may provide more insight into what costs Queen's Facilities may face with the implementation of the final solution. Table 26 contains RSMeans Data with costs for engineering fees, permit fees, contingency fees, and insurance fees. All the fees listed in Table 26 are based on a percentage of the total cost. As such, these fees will increase with an increased final cost. These fees are considered relevant for this project.

Table 26: Potential costs as a percentage of total cost.

Task or Requirement	Description	Percentage of Total Cost (%)
Engineering Fee	Planning consultant fee	0.5
Engineering Fee	Landscaping and site development engineering fee	2.50
Engineering Fee	Structural engineering fee	1
Contingencies	Conceptual stage contingency fee	20
Regulatory Requirements	Permits	0.5
Insurance	Public Liability	2.02

A contingency fee, especially in construction, is the amount of money allocated to pay for unexpected costs during a construction or renovation project. Since this project is still in the preliminary stages, the contingency fee remains a relatively high percentage of total cost, as there are still many unknowns. Public liability insurance will protect Queen's Facilities and Shady Consulting against liability claims for bodily injury and property damage related to the site or to the implementation of the final solution. The construction and engineering fees in Table 26 are an estimate of how much these services will cost as a percentage of total cost, however, these are subject to change depending on how that service is used. RSMeans also estimates that permits for the project, such as a site alteration permit, may cost up to 0.5% of the total project cost.

7.3.1 Bill of Materials

This section contains a bill of materials containing the immediate materials required to implement the physical solution. It details the type of material, the location from which it can be purchased, the quantity required, and the estimated total cost. Shady Consulting tried to source materials from Canadian-located companies to support Canadian businesses, decrease transportation costs, and decrease the amount of time it would take to attain the materials.

The cost of the Shantung Maple tree is dependent on the size of sapling that is purchased. Purchasing a younger, shorter sapling is less expensive but buying an older, taller sapling will decrease the time required to grow to maturity. The cost estimate for the Shantung Maple tree (Acer truncatum) sapling was estimated using the cost of its sister species, the Native Maple (Acer rubrum) tree sapling. The soil cost is also dependent on the type of soil required. The Queen's Building Design Standards 'Division 32 – Exterior Improvements', 'Section 93 – Plants', specifies that planting mixture should be 3 parts topsoil, 1-part sterilized mushroom compost, 1-part peat moss, free of weeds, roots, stones, and similar material, placed in layers of not more than 150 mm at a time (Queen's Building Design Standards 2022). As a general cost comparison, a readily available grading topsoil will be used to estimate soil cost. The root management system will comprise of a polyethylene sheet that acts to protect the hardscape surrounding the trees (such as the building foundation and sidewalk) and utilities from root or water damage. The root barrier system utilized will be enough to cover the perimeter of the planter box to ensure maximum protection of the surrounding hardscape.

Table 27: Bill of Materials.

Material	Location	Qty	Est. Cost per Unit	Est. Cost
Shantung Maple Tree (Sapling)	Home Depot	2	$105	$210
Soil (1 Cubic Yard Grading Topsoil - Bulk Bag)	Home Depot	2	$209	$418
Root Management System (Dual Purpose Root and Water Barrier 18in. D x 120 in. L)	Home Depot	8	$40.37	$323
Concrete (20 Mpa)	Dufferin Concrete	1.3m^3	$217	$285
			Estimated Total Cost of Materials	**$1,236**
			Estimated Total Cost of Materials (HST incl.)	**$1,397**

7.3.2 Implementation Cost Considerations

In addition to material costs, Queen's Facilities will face costs associated with the implementation of the project. Implementation costs to consider include transportation costs, landscaping costs, engineering costs, and more. Possible costs associated with the implementation of the design will be considered in this section.

7.3.2.1 Transportation Costs

It is important to consider transportation costs in this estimation. Transportation costs may include the shipping and handling of the materials required for this project. These materials may include, but are not limited to, Shantung Maple tree saplings, soil, root management solution, and the concrete for constructing the tree planters.

7.3.2.2 Landscaping Costs

Landscaping plays a large role in this project because the solution requires creating space for new trees along the south side of Mitchell Hall. The landscaping requirements include the construction of a new tree planter. Currently, it is difficult to determine the exact cost of labour that would be required to complete this project. Landscaping costs depend on many factors, including the size of the project, the complexity of the design, and the different materials used. It is also dependent on the labour required. The cost of materials was considered in Section 7.3.1. In this case, the landscape architecture has been conducted by Shady Consulting, where the proposed design can be seen in Section 5.5. As such, the remaining landscaping cost would be for the landscaper, who is the contractor that will do the physical work to implement the design. The hourly labour cost for a landscaper lies between $30 to $75 an hour (average of $53 an hour) with an average cost per square foot being approximately $11 (Murphy and Allen 2022). A rough estimate can then be conducted using an estimate for the number of hours required to complete the project. However, for this specific project, it is recommended by Shady Consulting that Queen's Facilities obtain a quote from a landscaping company within the Kingston area, such as Drake's Landscaping or Bayridge Landscaping, both of which offer landscaping construction (including hardscaping and tree planting) and maintenance. Queen's Facilities may also opt to do the landscaping and construction internally, which may allow them to save money.

Since Queen's University operates year-round, and there are staff and students that use or walk by Mitchell Hall frequently every day, it is important to put fencing and signage up around the construction site for public safety. There may be a cost associated with the rental of such equipment, however, it is likely to be included in the cost of landscaping, or in the case that Queen's Facilities takes on the construction themselves, they are likely to already have such equipment. The same can be true for the equipment required to physically implement the solution.

7.3.2.3 Other Costs

Queen's Facilities will need to consider the cost for the engineering aspect of this project. Shady Consulting put time and effort into creating an extensive report outlining a solution for their solar shading inquiry. There is a cost for creating AutoCAD renditions of potential solutions for the client, and Queen's Facilities can expect to pay a fee for each CAD rendition of a potential solution. The fee depends on the complexity of the drawing and the time taken to complete it. Further, as per QBDS 'Division 32 – Exterior Improvements,' 'Section 93 – Plants,', planting should be inspected by a project manager at all stages of installation. As such, there is a fee to maintain a project manager throughout the entire design and implementation phase of this project. This fee is based on the time it takes to complete the project and whether Queen's Facilities uses an internal or external project manager.

In terms of maintenance costs, the solution is cost effective. The only maintenance the trees would require would be pruning and watering if necessary. Queen's Facilities can expect to spend a short amount of time pruning these trees to conform to the shape they wish and to ensure that any dead limbs are taken off to benefit the overall health of the tree. It is important to consider that the trees may require watering periodically throughout their lifespan, and consequently, Queen's Facilities may face additional utilities charges. It is recommended that the Shantung Maple be watered consistently at least until it is established (1-2 years after planting), especially in dry weather conditions. Once established, the only time the trees would need watering would be if drought conditions occur. As such, the solution only requires regular utilities costs (in this case, water) until the sapling is established, and this cost would be small in comparison to the University's regular water usage.

Other potential cost considerations that Queen's Facilities should be aware of are risk management costs, uncertainty and risk, and taxes. All materials purchased are subject to a 13% harmonized sales tax (HST) in Ontario. This tax has been added to the estimated total cost of materials in Table 17.

7.3.2.4 Energy Savings Return

Queen's Facilities may expect an energy savings return from this project. The idea is that with the implementation of solar shading Mitchell Hall will use less energy to cool the building in the summer months, essentially saving on energy costs in the long-term. The innovative solution of using trees also helps to reduce energy costs associated with heating the building in the winter, offering more energy savings. The energy savings return is not possible to estimate at this stage of the project. Shady Consulting recommends that in the future, Queen's Facilities should compare the energy costs associated with cooling/heating Mitchell Hall prior to the implementation of the solution with the costs associated with cooling/heating Mitchell Hall after the solution is implemented, especially once the trees have matured. This comparison can be used to determine how effective the solution was in creating an energy savings return.

7.3.3 Cost Estimate Summary

In the current phase of the project, Shady Consulting is only able to provide a semi-detailed cost estimate, as well as suggest other cost considerations that the client should consider prior to the construction phase of the project. The estimated cost of materials was determined to be approximately $1400 including tax. Other costs that Queen's Facilities may face are transportation costs, landscaping/construction costs, engineering/project management costs, and operation and maintenance costs. Additionally, Queen's Facilities may expect energy cost savings in the future with the implementation of the final design.

8.0 Risk Assessment

As part of the comprehensive design solution being proposed by Shady Consulting, a risk assessment for this project has been detailed below. This assessment considers the practical risks associated with construction at Mitchell Hall due to site usage, pedestrian traffic, and more general construction hazards. Steps to mitigate these factors have been included, as well as references to specified regulations within the City of Kingston.

8.1 Construction

It is important that Shady Consulting considers the risks associated with the construction of the chosen solution to ensure that the design will be safe and feasible to complete. Construction sites can have many risks, therefore, developing robust safety practices on construction sites is an ongoing topic in public discourse (NorthBridge and Insurance 2018). For this project, it would be impractical to close Mitchell Hall or the surrounding area during construction. This means that students, faculty members, other staff members, and visitors are also stakeholders facing potential risk during the construction phase. While construction workers are equipped with industry knowledge and are required to wear personal protective equipment, members of the public are not. This means that they will face a higher risk of accidental injury on or near the site. The major threats to safety may include broken ground, exposed underground utility lines, and heavy equipment. There are three important steps to reduce safety hazards. The first step is to control the site by using the right equipment, procedures, and protocols. The second step is to focus on clear communication between workers and to use effective signage around the site. The last step is to be diligent around the site with respect to safety and education measures.

The first step, which entails controlling the construction site, can be further broken down. A key component is establishing who can access the job site, as well as when and how they can do so. This includes excluding members of the public from having access to the job site. Furthermore, physical barriers and warnings such as alarms, motion sensors, fencing, and other building enclosures may be employed if necessary. Eliminating obvious safety hazards where possible and integrating extra protection in areas where visitors could be hurt should be considered. Ensuring that exposed holes and excavation sites are fenced off at the end of each workday is another standard precaution to take on a construction site. Lastly, exits to balconies, higher floors, or roofs should be marked or fenced off.

The second step focuses on clear communication and signage. Better communication starts by letting the purchaser, subcontractors, and suppliers know who has access to the job site along with when, where, and how they can enter. The second step is to develop a better understanding of the client's needs, desires, and vision for the building and provide updates and progress reports regularly. In addition to that, informing the public about the dangers and rules surrounding the worksite before and during construction should be considered. The best way to communicate with the public is through proper signage.

Developing a brochure outlining the job site's policies and distributing it to all affected parties before construction would be a good idea for this project. Also, referencing the Workplace Health and Safety Act may be relevant for the Mitchell Hall project construction. Including this document would also protect Queen's Facilities from liability if someone were injured on the job site. Lastly, proposing an agreement to sign a Site Visit Policy would both encourage safety diligence by all visiting parties and relinquish Queen's Facilities of liability.

8.2 City of Kingston By-Law

To complete the construction of this project, it is important to follow the relevant guidelines and procedures for the City of Kingston. The City of Kingston clearly outlines the conditions when a building permit is required for construction; constructing planter boxes outside of a building does not require a permit (City of Kingston - Bylaw 2005-99). For the duration of the construction phase, however, stringent safety measures including adequate signage and fencing should be implemented. The on-site signage should include the expected duration of construction, hazards present, and personal protective equipment required on site. The City of Kingston has a by-law document outlining the relevant fencing and signage requirements for construction sites (City of Kingston - Bylaw 2005-99).

8.3 OHSA

As a risk management tool for the construction phase of this project, referencing relevant documentation is useful. The provincial legislation surrounding workplace health and safety is the Occupational Health and Safety Act (OHSA). This document applies to this project as both the client and contractors are required to comply with the outlined regulations and recommendations (Occupational Health and Safety Act). This document may be referenced for:

- Workplace hazard management measures and procedures to follow.
- Legal route to enforce safety rules when not followed voluntarily.

8.4 Environmental Threats to Trees

One risk associated with this project is the possible losses if the trees die due to external influences. Re-planting the trees outside of Mitchell Hall would incur costs for necessary equipment mobilization, manual labor, tree sourcing, and transportation. This would also cause an increase in heat uptake in Mitchell Hall, leading to increased cooling costs. Understanding what trees need to survive in urban settings, and any preventative measures to ensure the health of the trees for this project will greatly decrease the risk of premature tree death. The City of Kingston provides the public with information about environmental and tree health hazards that apply to this area. This document identifies three main categories of threat to trees planted in Kingston: Spongy Moth infestation, tree pests, and tree diseases (Threats to Trees n.d.). In addition to this, extreme weather events such as drought and high winds pose a threat to the longevity of the trees in this project.

8.4.1 Spongy Moth

Spongy Moth is an invasive species of caterpillar that has caused considerable damage to trees across Southwestern Ontario in past years (Threats to Trees n.d.). They prey on many deciduous and coniferous tree species native to Kingston, including Oak, Birch, Elm, and Maple (Threats to Trees n.d.). This species of caterpillar harms trees by eating the foliage and preventing the tree from photosynthesizing. Trees can usually survive one season with Spongy Moth, but two or more years consecutively can kill most species (Threats to Trees n.d.). They can be deterred using different mechanisms throughout the growing season as follows:

- September – April: Manually scrape egg masses off affected trees and soak them in soapy water for 2 days before discarding them. An example of an egg mass is shown below in Figure 29:

Figure 29: Spongy Moth Egg Nest.

- April-May: Applying a 10 cm wide strip of double-sided tape to the tree trunk at approximately chest height will prevent the caterpillars from moving up the tree; the tape should be removed at the end of the growing season.
- Mid-May: Spraying trees foliage during this time with insecticides containing BTk (Bacillus thuringiensis kurstaki) compound is an effective means to kill and deter Spongy Moth.
- May-August: Placing burlap mats and the trunk of trees and discarding caterpillars that fall is an extra method during the later season to remove Spongy Moth caterpillars (Threats to Trees n.d.).

8.4.2 Tree Pests

There are a variety of different tree pests present in Kingston that can damage trees, including insects and larger animals like squirrels (Threats to Trees n.d.). The main species identified by the City of Kingston as threats to Shantung Maples are the European Gypsy Moth and Forest Tent caterpillars. To mitigate the risks of damage from insect and animal activity in this project, regularly checking the trees is recommended. If these species are identified, follow the same removal procedures as described above for Spongy Moth caterpillars (Threats to Trees n.d.).

8.4.3 Tree Diseases

The City of Kingston also has information available on prominent tree diseases in the greater Kingston area. Identification of tree diseases can be difficult but noting the symptoms, like foliage and bark discolouration, leaf dropping, and partial tree death, can allow for diagnosis and treatment (Threats to Trees n.d.).

8.4.4 Extreme Weather

Trees, especially those planted in above-ground planter boxes, are vulnerable to extreme weather events such as drought and high winds (Wpx_cairns 2020). To mitigate the risk of drought damage to the trees in this project, checking the soil for dryness during the summer months and watering accordingly is recommended. Since these trees will be relying on rainfall to keep the planter box moist, they will likely need extra watering, because there is no groundwater supply for the deep roots to use. The trees in this project may also be vulnerable to damage from high winds (especially while they are small) during storms because their root system will be contained to the planter boxes built, and they will be very out in the open against Mitchell Hall. To manage this risk, the planter boxes to be implemented were designed to be larger than necessary to allow the trees to form larger root systems. To further mitigate this risk, preventative measures can be taken such as implementing stakes on either side of the trees when they are small, and applying burlap covers to the foliage if needed (Wpx_cairns 2020).

8.5 Glass Coating

One of the key risks for implementing the glass coating is the exposure to metal oxide. The following section will explain the importance of following the safety data sheet, potential risk of exposure to metal oxide, and risk mitigation measures for this product.

8.5.1 Zinc Oxide

Zinc oxide is one of the most common coatings used for low energy glass. To reduce the scope to a reasonable level, the risk assessment for this product will focus on the potential risk of exposure to zinc oxide and its prevention. Zinc oxide can affect people's breathing; exposure to zinc oxide can cause a condition called "metal fume fever." Metal fume fever can be described as an illness with symptoms of metallic taste in the mouth, which leads to headaches, fever, chills, chest tightness and cough. This risk makes safety precautions for this project especially important (New Jersey Department of Health and Senior Services 2007).

Safety data sheets (SDS) are an important source to gather information about eliminating and minimizing the risks associated with the handling and use of hazardous chemicals. It is highly recommended that all operators that will handle metal oxide review the SDS and WHMIS material for zinc oxide (Workplace Health and Safety Queensland 2020).

To reduce the exposure of zinc dioxide, ventilation systems should be used during the process of application. The applicator must have all necessary personal protective equipment including safety glasses, masks, and protective clothing. Additionally, anyone encountering the coating during application is strongly recommended to take a shower directly after task completion. Clear site signage and product labelling for hazardous materials reduces incident risk, as well as continuing regular workplace education and training in workplace safety (New Jersey Department of Health and Senior Services 2007).

9.0 Queen's Building Design Standards Document

Queen's Facilities requested that solar shading be implemented into the Queen's Building Design Standards (QBDS). A short section on the incorporation of solar shading is to be added to 'Division 01 – General Requirements' within the QBDS. The section outlines how solar shading should be implemented, different solar shading options, design requirements, and other general information. The draft for 'Section 01 93 00 Solar Shading' can be seen in Appendix F.

10.0 Climate Considerations

Climate change refers to the long-term change in temperature and weather patterns around the world. Since climate change is becoming an increasingly important parameter, it is important that the climate be considered when designing and implementing any new engineering and construction project. The design and implementation of solar shading has a goal to reduce energy usage and greenhouse gas emissions in that the solution would decrease the amount of energy needed to cool the building throughout the summer months.

The climate was considered throughout the design and construction phases of this project. Firstly, it was important to think about how the materials used might impact the climate. If trees were to be planted and used as solar shading, it would be considered a carbon sink as opposed to a structural solution, which may be considered a carbon source, depending on the material used. If a structural solution were to be implemented, things to consider when choosing a material would include: the manufacturing process, recyclability, and/or carbon emissions. For example, wood is typically a single-use material, where at the end of its life, the wood would be land filled or incinerated, essentially returning any stored carbon back into the atmosphere, contributing to greenhouse gas emissions (Canadian Institute of Steel Construction 2019). Alternatively, steel is known as the world's most recyclable material, so although the material may take more energy to make initially, it can be continually recycled into new materials with no loss in quality, resulting in fewer emissions released long term (Canadian Institute of Steel Construction 2019). The design option of planting trees would act as a carbon sink during their service life; when the trees die, they will not be recyclable but would not have any negative carbon impact.

This project considered environmental implications throughout the entire design process. It was important to both Shady Consulting and Queen's Facilities that the design and implementation of the design have a low environmental impact. The design chosen (planting trees) is an environmentally friendly solution because the trees act as a carbon sink throughout their lifetime by taking in carbon dioxide (CO_2) and releasing oxygen (O_2) through photosynthesis.

11.0 Schedule

The following sections describe the mechanisms Shady Consulting has used to track progress and keep the project on schedule for completion. This includes the work completed as well as recommendations for future work to build on the selected design solution.

11.1 Gantt Chart and Work Breakdown Structure

An updated Gantt chart and work breakdown structure (WBS) can be found in Appendix B. The updated Gantt chart contains the completed timeline to finish the project. An updated work breakdown structure outlining all tasks completed to date, and those remaining in the course, are included in this figure. The tasks have been distributed to each teammate based on individual experiences, interests, and team roles. In addition, the Gantt chart was designed so that the weekly hours worked by each team member do not exceed ten hours. The Gantt chart includes accommodations for holiday breaks, such as Christmas and Family Day.

Additionally, an updated responsibility assignment matrix (RAM), in the form of a RACI matrix, has been included in Appendix B. The RAM ensures fair participation among team members, as well as a reference to see which team member is responsible for which task. It describes the participation and various roles of each team member in completing the deliverables for the project. Each team member was responsible and/or accountable for each part of each deliverable.

11.2 Next Steps and Recommendations

Moving forward, Queen's Facilities could consider building upon the recommended solution included in this report. One opportunity to increase the effectiveness of the design solution would be to implement a planter box on the south facing glass wall of Mitchell Hall, as described by *Design Layout Option* 2 in section 5.5 of this report. This option was not recommended as the chosen design solution because it was costly and would require a higher level of construction than the selected design layout along the east glass curtain wall. Implementing the second design option in the future would increase the shading on Mitchell Hall and decrease excess heat uptake in Mitchell Hall if desired by Queen's Facilities.

Another means to build on the contents of this report would be to conduct a more detailed cost estimation for the project. This could be accomplished by submitting requests for quotes (RFQ) for the design project construction to contractors in the Kingston area, for a more accurate cost estimate for the construction works. Material and labour costs are subject to changes in the economy, and time, and should be updated before the commencement of the project to ensure an accurate cost estimate.

12.0 Conclusions

This report outlined the final design solution proposed by Shady Consulting, along with the design and decision-making process followed to complete this work. Initially, Shady Consulting defined the scope, conducted extensive background research, determined design alternatives, and developed an evaluation process to select a preferred design alternative. The background research included conducting a site investigation, determining the structural integrity of the glass curtain walls, and understanding the standards and regulations that govern different designs. The existing conditions were examined, and the building's cooling demand was investigated.

After conducting background research, four different design alternatives were defined in detail. The first alternative was to continue with the status quo, meaning to do nothing and leave the fully automated double-blind system in place. The second alternative entailed planting trees to use as solar shading, which may be combined with the use of the existing double-blind system. The third alternative involved implementing a structural frame, which would be placed on the outside of the curtain wall, which may be used to place a structural overhang to be used for solar shading. The last proposed design alternative was to use solar glass instead of the current glass in the glass curtain wall system. A risk assessment was developed for the implementation of the design. After evaluating these alternatives, Shady Consulting selected to plant trees in tandem with the existing double-blind system for the final design solution.

This final design solution was further researched, with more process decisions being made as follows: tree species selection, number of trees needed, planting mechanism to be used, design layout selection and drafting, and final cost estimates. This report detailed the project budget, and a cost estimation was developed for the design solution, comprised of the potential costs that the client may face in the development and implementation phases of the final design. Shady Consulting also included information on climate considerations that should that were considered throughout the design process. Finally, this final report, prepared by Shady Consulting for Queen's Facilities, details a thorough risk assessment and mitigation measures, as well as details the incorporation of solar shading design into the Queen's Building Design Standards.

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Appendix A: Queen's Facilities Steam Data

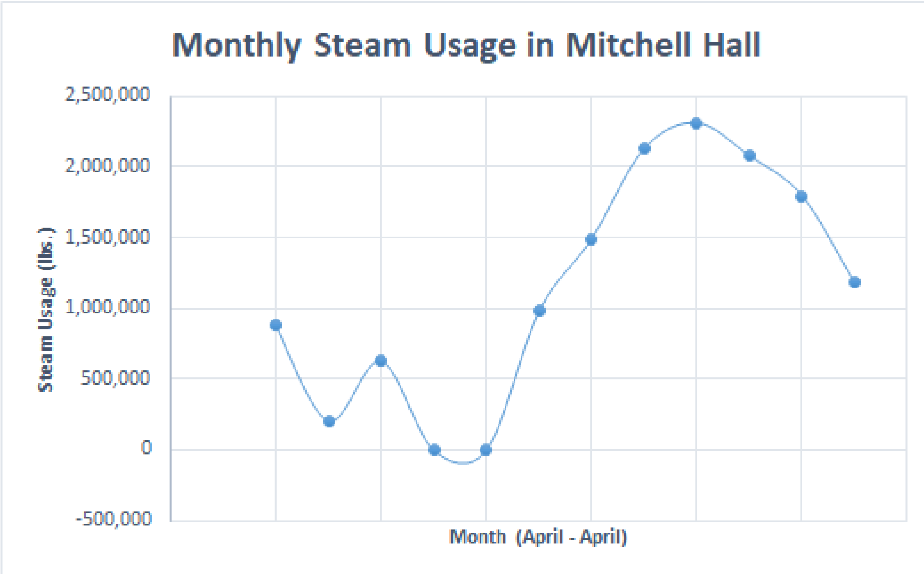

Figure 30: Mitchell Hall's Monthly Steam Usage (Copy of Mitchell Hall Steam Log, 2022).

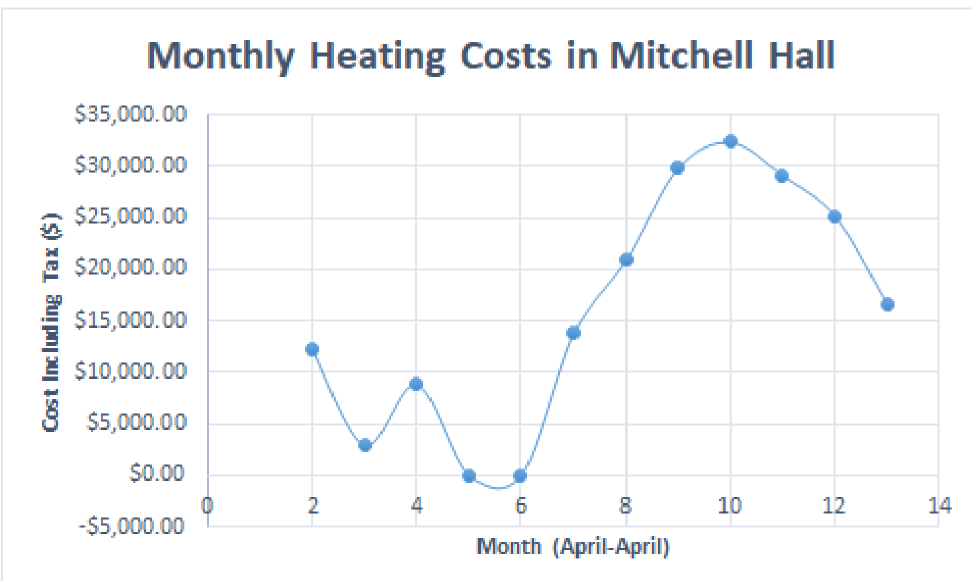

Figure 31: Mitchell Hall's Monthly Heating Costs (Copy of Mitchell Hall Steam Log, 2022).

Appendix B: Project Plan

Updated Gantt Chart

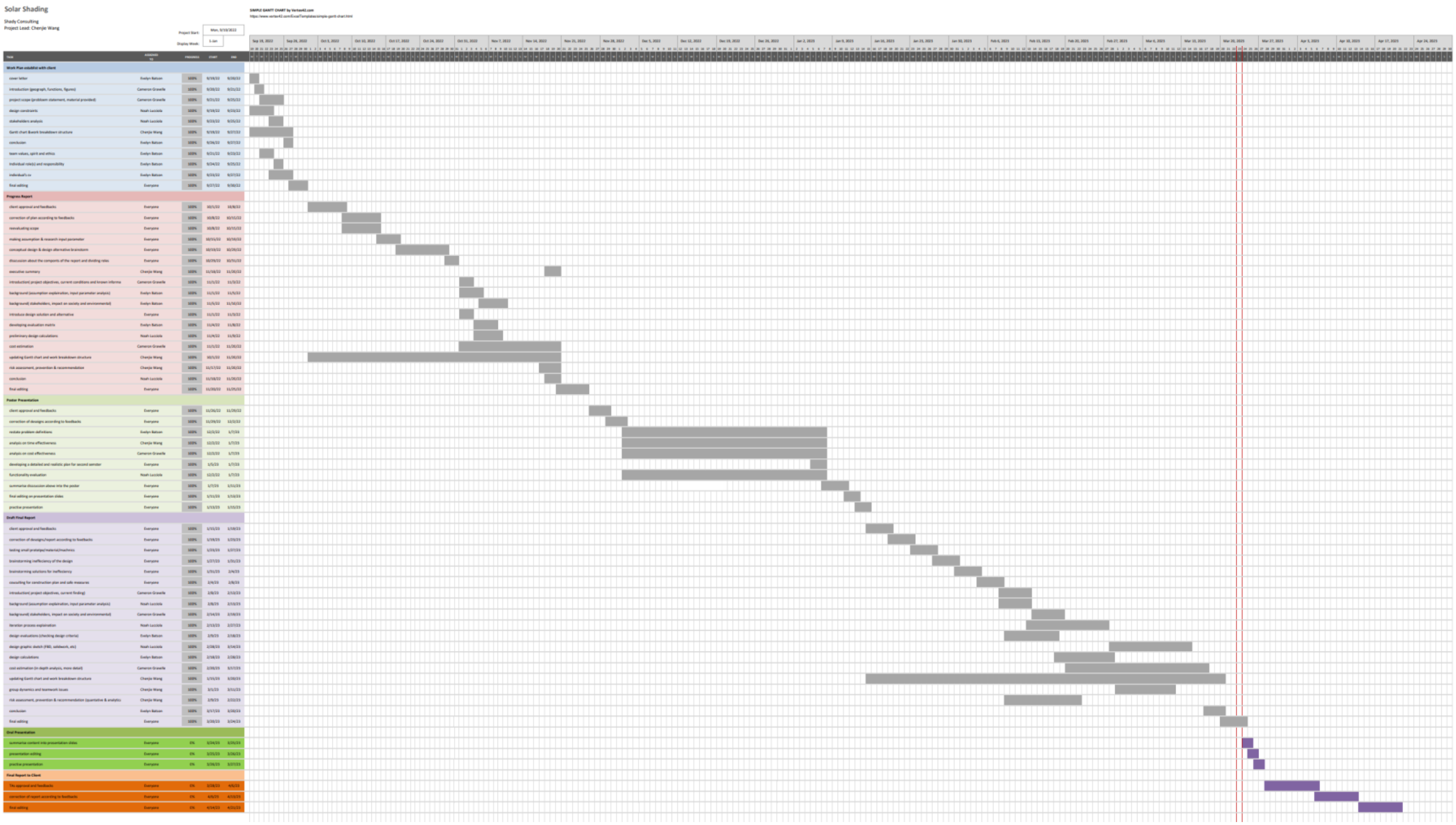

Figure 32: Updated Gantt Chart.

Updated Work Breakdown Structure

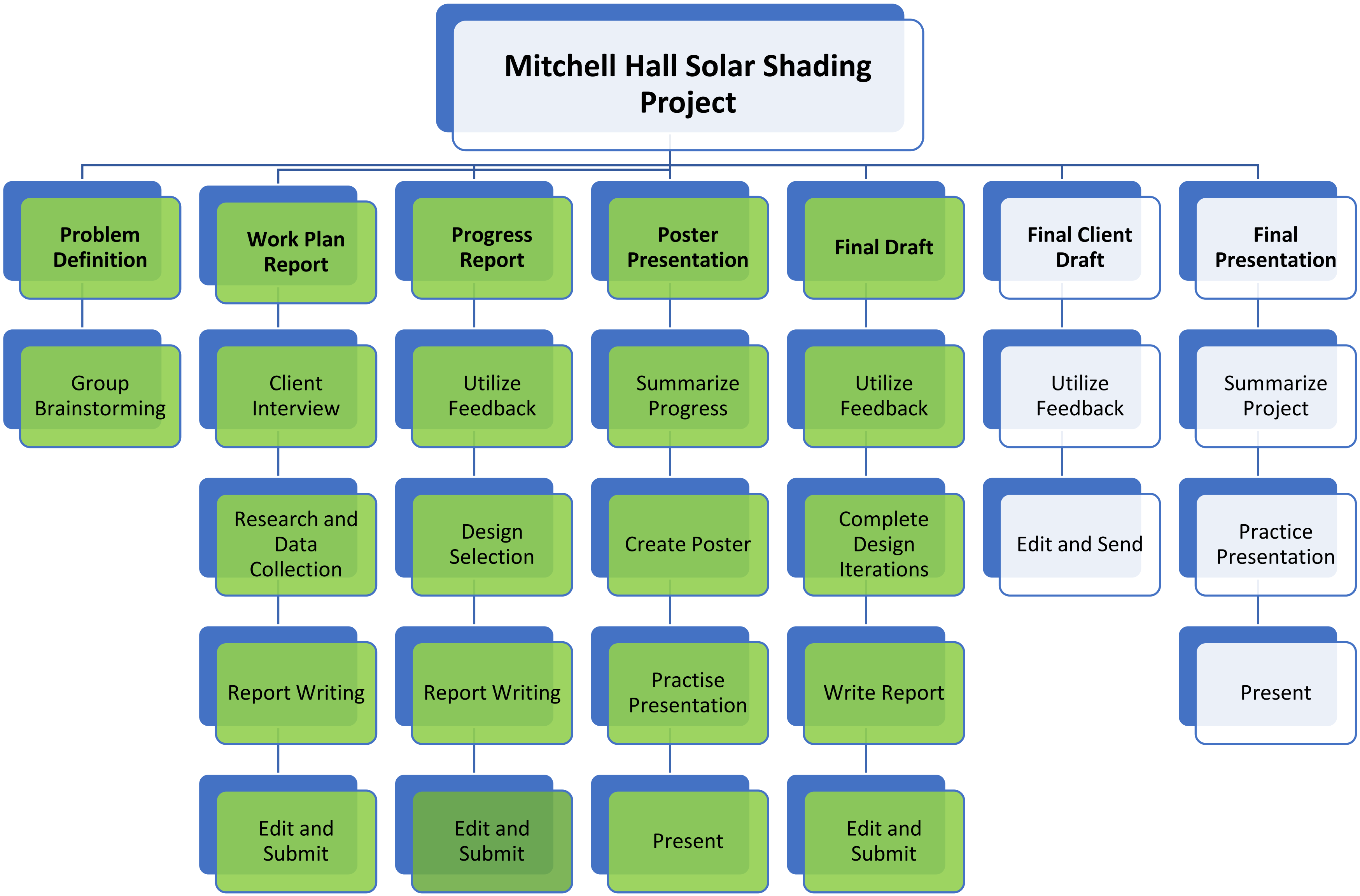

Figure 33: Updated Work Breakdown Structure (Green Means Completed Task)

Updated Responsibility Assignment Matrix (RAM)

R, A, C, and I stand for responsible, accountable, consulted, and informed. The RACI chart lists all the group members and their level of involvement in each task, denoted with the letters R, A, C, and/or I. Please note that this RAM is subject to change as Shady Consulting sees fit, in both the assignment of roles and the roles themselves.

Table 28: Responsibility Assignment Matrix.

Project Tasks	Evelyn Batson	Cameron Gravelle	Noah Lucciola	Chenjie Wang
Progress Report				
Client Approval and Feedback	R	R	R	R
Letter of Transmittal	A	R	A	A
Title Page and Disclaimer	A	R	A	A
Table of Contents, List of Tables, and List of Figures				
Introduction (Problem Statement, Problem Scope)	A	R	A	A
Constraints and Stakeholders	A	A	R	A
Background Research	R	R	R	R
Design Alternatives	A	A	R	R
Evaluation Process	R	A	A	A
Climate Change	A	R	A	A
Risk Assessment	A	A	A	R
Schedule (Gantt chart and WBS)	A	A	A	R
RAM	A	R	A	A

Project Tasks	Evelyn Batson	Cameron Gravelle	Noah Lucciola	Chenjie Wang
Budget and Cost	A	R	A	A
Conclusions	A	R	A	A
Appendices	R	R	R	R
Formatting and Editing	R	R	R	R
		Poster Presentation		
Client Approval and Feedback	R	R	R	R
Corrections to Designs Based on Feedback	R	R	R	R
Restate Problem Definition	A	R	A	A
Analysis on Time Effectiveness	A	A	A	R
Analysis on Cost-Effectiveness	A	R	A	A
Developing a New Plan	R	R	R	R
Functionality Evaluation	A	A	R	A
Summarize Discussion onto a Poster	R	R	R	R
Final Editing of Presentation Slides	R	R	R	R
Practice Presentation	R	R	R	R
		Draft Final Report		
Client Approval and Feedback	R	R	R	R

Project Tasks	Evelyn Batson	Cameron Gravelle	Noah Lucciola	Chenjie Wang
Correction of Designs and Report	R	R	R	R
Consulting for Construction Plans and Safety Measures	R	R	R	R
Introduction (Problem Statement, Problem Scope)	A	R	A	A
Constraints and Stakeholders	A	A	R	A
Background Research	R	R	R	R
Conceptual Design	A	A	R	R
Iteration Process Explanations	R	A	A	A
Design Sketch/Graphic	A	A	R	A
Design Calculations	A	R	R	R
Cost Estimation	A	R	A	A
Update Gantt Chart and WBS	R	A	A	A
Group Dynamics	R	A	A	A
Risk Assessment	R	A	A	A
Conclusion	R	A	A	A
Final Editing	R	R	R	R
		Oral Presentation		
Summarize Content	R	R	R	R

Project Tasks	Evelyn Batson	Cameron Gravelle	Noah Lucciola	Chenjie Wang
Edit Presentation	R	R	R	R
Practice Presentation	R	R	R	R
		Final Draft for Client		
Editing based on Faculty and Client Feedback	R	R	R	R

Appendix C: Relevant Meeting Minutes

CIVL460: CLIENT MEETING FOR PROGRESS REPORT

Meeting Minutes

Location:	BMH (and on Zoom)
Date:	October 19, 2022
Time:	2:30 p.m.
Attendees:	Evelyn Batson, Cameron Gravelle (Minute-taker), Noah Lucciola, Chenjie Wang, Nathan Splinter, David Gerrish, and Alex Rae Peet.

Discussion items

1. Discussed the scope of the project. Due to time constraints, the focus should be on establishing a solar shading solution only for the southeast side of Mitchell Hall (ignore the southwest side).
2. Asked client, Queen's Facilities, to send Shady Consulting Mitchell Hall shop drawings and product specification sheets for the glass curtain walls, windows, and current blind system.
3. Discussed the Project Work Plan. The client had not yet had the chance to view it in depth.
4. Discussed how CMPAC provides oversight to development on campus.
5. Discussed expectations for the upcoming Progress Report. Would like to see the alternatives, pros/cons, cost, and timeline for each solution IF FEASIBLE. Look at qualitative and quantitative benefits. Look at embodied carbon for each solution (incorporate into evaluation matrix?).
6. How to incorporate the solution into the design standard? Can be general when implementing solar shading into the design standard.

Action items	By	Deadline	Status
Begin brainstorming and background research for progress report	Everyone	N/A	In progress
Fill in hour logger	Everyone	N/A	N/A

CIVL460 PROGRESS REPORT MEETING #1

Meeting Minutes

Location:	BMH
Date:	November 9, 2022
Time:	2:30 p.m.
Attendees:	Evelyn Batson (Virtual), Cameron Gravelle (Minute-taker), Noah Lucciola, Chenjie Wang, and Esmé Hirsch (TA)

Discussion items

1. Discussed progress so far in the semester.
2. Discussed how the group is to incorporate possible solutions, even if they do not seem feasible.
3. Discussed expectations for technical analysis and other such sections for the progress report.
4. Discussed how the team can (and should) create soft deadlines for each project deliverable. Esmé will be available to review submissions prior to the deadline, given she has the time.
5. Discussed expectations for including meeting minutes and e-mail correspondence for the progress report.
6. When creating the scope for the progress report submission, it may be subject to change over the course of the year. The scope may change depending on time and resources.

Action items	By	Deadline	Status
Continue working on Progress Report	Everyone	N/A	In progress
Soft Deadline for Progress Report	Everyone	November 18	In progress
Fill in hour logger	Everyone	N/A	N/A

CIVL460 PROGRESS REPORT MEETING #2

Meeting Minutes

Location:	BMH
Date:	November 16, 2022
Time:	2:30 p.m.
Attendees:	Evelyn Batson (Virtual), Cameron Gravelle (Minute-taker), Noah Lucciola, Chenjie Wang, and Esmé Hirsch (TA)

Discussion items

1. Discussed progress made on progress report.
2. Discussed how the group should submit a rough draft of the progress report by November 20 at the latest.
3. Discussed expectations for technical analysis and innovation within the report.
4. Discussed the evaluation process thus far.
5. Discussed energy data that was sent to Shady Consulting from Queen's Facilities and how to incorporate it into the report.
6. Discussed expectations for having individual sections done in order to send a rough copy to Esme to review before next week's meeting.

Action items	By	Deadline	Status
Continue working on Progress Report	Everyone	N/A	In progress
Soft Deadline for Progress Report Rough Draft	Everyone	November 20	In progress
Fill in hour logger	Everyone	N/A	N/A

CIVL460 PROGRESS REPORT MEETING #3

Meeting Minutes

Location: BMH
Date: November 23, 2022
Time: 2:40 p.m.
Attendees: Evelyn Batson (Virtual), Cameron Gravelle (Minute-taker), Noah Lucciola, and Esmé Hirsch (TA)

Discussion items

1. Discussed progress report rough draft that was sent to Esmé on November 20.
2. Discussed how the group will not be able to get to the design evaluation phase of the report.
3. Discussed expectations for risk assessment and climate considerations portion of report.
4. Edited the progress report based on feedback.
5. Discussed further meeting times and final editing that needs to be done to finish the report.
6. Had another discussion on how the scope for the progress report submission may be subject to change over the course of the year. The scope may change depending on time and resources.

Action items	By	Deadline	Status
Continue working on Progress Report	Everyone	N/A	In progress
Aim to submit progress report by Nov. 24	Everyone	November 25	In progress
Fill in and attach hour log to final report	Everyone	N/A	N/A

CIVL460 CLIENT MEETING #2 (W23)

Meeting Minutes

Location:	Virtual (Zoom)
Date:	January 27, 2022
Time:	1:30 p.m.
Attendees:	Evelyn Batson, Cameron Gravelle (Minute-taker), Noah Lucciola, Chenjie Wang, Alex Rae Peet and David Gerrish

Discussion items

1. Progress report – thoughts and feedback. David and Alex have e-mailed their thoughts and feedback.
2. Discussed chosen final solution, thoughts and feedback, comments and advice. Client approves and likes the idea to implement landscaping/trees as a solar shading solution. They like that the solution would be carbon negative (could come up with creative solution for planters other than concrete?).
3. Client approves a compare/contrast for also designing structural option alongside the landscaping/tree options?
4. Discussed the landscaping process. Cables, pipes, and communications throughout underground at Queen's both city and Queen's infrastructure. Client will provide drawings/maps of these facilities.
5. Discussed the idea of creating alternative layouts/designs for landscaping to show client for their approval and preference options.
6. Client would like to see more calculations about how much the trees would actually block the sunlight. May depend on tree species. Think about sun, rainfall, shading, roots, root sizes and depths, maintenance. What about a vine wall? Something to think about.
7. No further questions or comments so far on our project.

Action items	By	Deadline	Status
Create outline for Final Report	Roy	N/A	In progress
Create Soft Deadlines for Final Report Drafts	Everyone	N/A	In progress
Research chosen final solution	Everyone	N/A	In Progress
Create and edit Final Report Document	Cameron	N/A	In Progress
Fill in hour logger	Everyone	N/A	N/A

CIVL460 CLIENT MEETING #3 (W23)

Meeting Minutes

Location:	Virtual (Zoom)
Date:	March 3, 2023
Time:	1:30 p.m.
Attendees:	Evelyn Batson, Cameron Gravelle (Minute-taker), Noah Lucciola, Chenjie Wang, Alex Rae Peet and David Gerrish

Discussion items

1. Asking client for AutoCAD editable DWG file to create detailed drawings of proposed solutions. Asked for site plan. Client stated that they would send over DWG files.
2. Specifics for building standard. Succinct, short, clear, for solar shading. Optimized for seasonal use, selecting solar shading option, general for selecting a solar shading option. Building standard keep it short, clear, and easy to read. Could expand on tree solution etc in our own report.
3. Design layouts – two general layout options. Will make on AutoCAD. Proposed neglecting the East facing wall to reduce cost vs the higher construction and landscaping cost for shading both south and east facing walls. Client would suggest choosing one solution and moving forward with that for a detailed final solution.
4. Discussed timing for a final presentation to the client. Discussed that the final client presentation could be in week eleven or week 12 (end of March, early April).
5. Team continues to think about technical aspects of project. Including calculations about how much the trees would actually block the sunlight. May depend on tree species. Think about sun, rainfall, shading, roots, root sizes and depths, maintenance. What about a vine wall? Something to think about.
6. No further questions or comments so far on our project.

Action items	By	Deadline	Status
Create outline for Final Report	Roy	N/A	Done
Create Soft Deadlines for Final Report Drafts	Everyone	March 12	In progress
Research chosen final solution	Everyone	N/A	Done
Create and edit Final Report Document	Everyone	N/A	In Progress
Fill in hour logger	Everyone	N/A	N/A
Work on assigned project tasks	Everyone	N/A	N/A

Appendix D: Hour Logs

Appendix D contains the pie-chart hour logs for each team member.

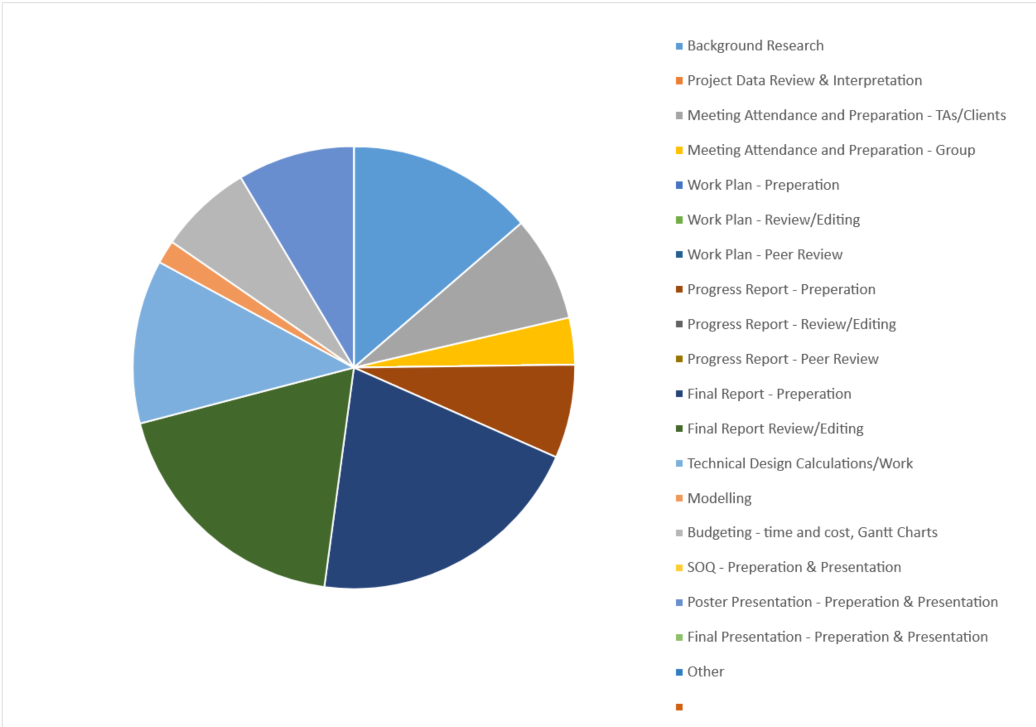

Figure 34: Chenjie Wang Hour Log

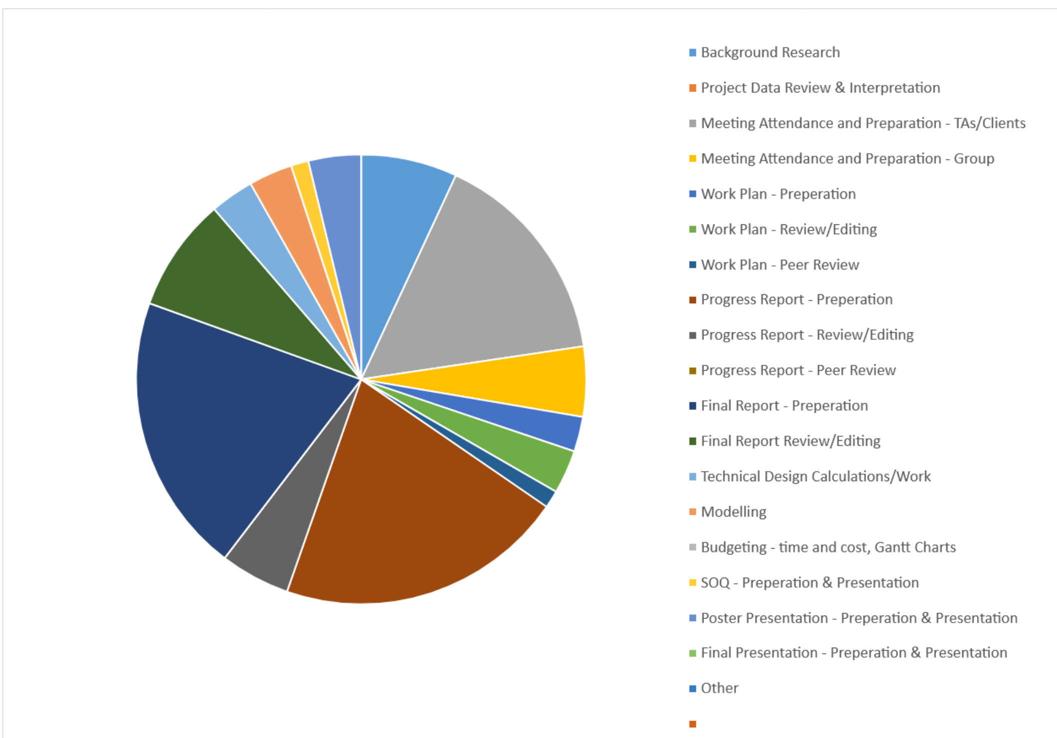

Figure 35: Noah Lucciola Hour Log

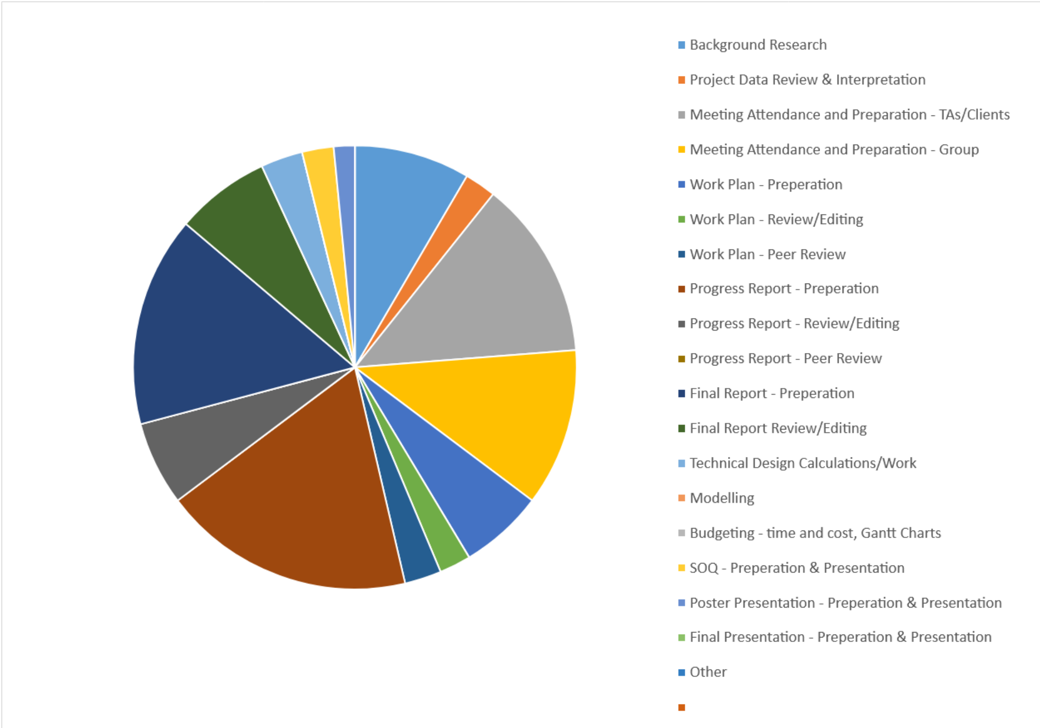

Figure 36: Cameron Gravelle Hour Log

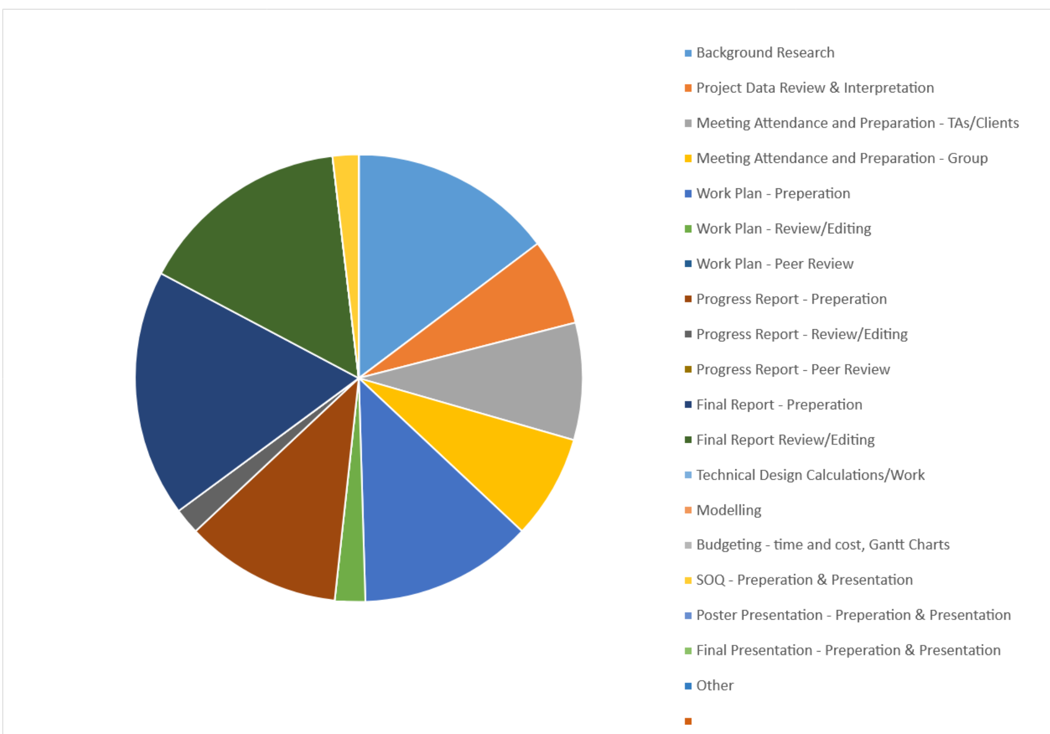

Figure 37: Evelyn Batson Hour Log

Appendix E: Project Plan Updates

Project Update

During this project, Shady Consultants deviated from the original project plan, when necessary, to improve the provided solution and to work around practical and technical challenges that arose. The engineering design process was followed throughout the year; this was accomplished by brainstorming, researching, and designing solutions, and then improving the chosen solution. The main changes made from the original project plan were:

- During the preliminary design brainstorming and evaluation process, it became apparent that the project time and structural features of Mitchell Hall would make it impractical to shade the entire height of the glass curtain walls. This meant that the structural solutions considered would not be feasible to implement, and focusing on the lower half of the glass curtain walls would be the focus moving into the final design sections.
- Once the design solution of planting trees had been selected, it became apparent that the design layout would be more practical to implement along only the East wall of Mitchell Hall. Due to the existing site conditions, a planter box on the South wall would be very costly to implement. This constraint further narrowed the scope of the design.

If Shady Consulting could do this project again, the following changes would contribute to the success of the project:

- A more detailed preliminary site investigation would have made the brainstorming and design evaluation for this project more effective. Analyzing the structural limitations of Mitchell Hall and surrounding infrastructure in greater detail at the beginning of the project would have allowed for the development of more realistic structural solutions to be developed. For example, recognizing the inability of the curtain walls to support a structural overhang could have allowed for an overhang extending from the roof to be investigated in more detail.
- Obtaining relevant AutoCAD drawings of Mitchell Hall and surrounding infrastructure sooner would have allowed for each proposed design solution to be drafted. This would have been advantageous when providing the client with our initial design alternatives, to identify their preferences for the layout and aesthetic of their preferred solutions.

This project effectively created a link between the members of Shady Consulting and professionals in the industry and required the technical and intrapersonal skills developed at Queen’s to be integrated into a practical design project.

Appendix F: Solar Shading in the QBDS

The incorporation of solar shading within the Queen's Building Design Standards can be seen below.

01 00 00 Queen's University Specific General Requirements
Queen's University Building Design Standards

01 95 00 Solar Shading

.1 Solar shading shall be implemented where necessary to decrease energy consumption and related energy costs.

.2 The type of solar shading implemented should be determined on a case-by-case basis. Types of solar shading solutions to consider include, but are not limited to:

- Planting trees
- Structural solutions
- Glass coating
- Blinds

.3 A preliminary design schematic for each design option under consideration should be provided and a version of the final selected design should be provided and updated through to as-built construction. The design should be approved by a licensed professional engineer and shall be in accordance with the Queen's University Building Design Standard and Ontario Building Code.

.4 Where multiple design options are under consideration, costing shall be performed for each alternative to facilitate a clear comparison of construction cost, operational cost, and energy reduction savings for each option.

.5 Project manager should be present for inspection at all stages of design and implementation.

.6 The contractor shall provide all necessary co-ordination in order to achieve a successful project.

Last updated: Friday, March 24, 2023