Stable Designs

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Kingston, ON K7L 3N9

April 19, 2024

Nathan Splinter, Manager of Energy and Sustainability

Queen's University

355 King Street West

Kingston, ON K7L 3N6

Subject: Final Report of the KCVI Rehabilitation Project

Dear Nathan,

We hope this finds you well. Please accept this letter and accompanying report as the Final Report by Stable Designs for CIVL 460 – Civil Engineering Design & Practice, concerning the KCVI Rehabilitation Project. The report comprehensively details our final advancements within the four scope components, those being the windows, wall composition, adaptive space reuse, and roof design.

Within this report, Stable Designs has presented their investigation and process into determining options and solutions for the four scope components pertaining to the project. Evaluating the different options based on criteria you valued most, Stable Designs has formed a conceptual design. Energy efficiency, upfront cost, and structural analyses have been completed for this conceptual design.

Should you have any questions or require further clarification regarding the contents of this report or any aspect of the KCVI Rehabilitation Project, please do not hesitate to contact us. We are here to address any concerns and ensure that our actions align with your vision and expectations.

Sincerely,

Stable Designs,
Justin Boult, Katie Fitzpatrick, Abbey MacTaggart, Liam Reid

CIVL 460: Civil Engineering Design and Practice IV

Draft Final Report

Stable Designs

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Katie Fitzpatrick | 20157485
Abbey MacTaggart | 20165614
Liam Reid | 20145921

2024-04-19

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 Civil Engineering departmental web site (www.civil.queensu.ca/undergraduate) and confirm that this work is in accordance with the Policy.

Signature: Date: 2024-04-19

Signature: Date: 2024-04-19

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Signature: Date: 2024-04-19

Executive Summary

The Queen's Facilities team expressed the need for Stable Designs to provide an assessment of the historic Kingston Collegiate Vocational Institute's (KCVI) structural capacity and recommend overall improvements. KCVI, located in Kingston, Ontario, received a municipal heritage designation under Part IV of the Ontario Heritage Act (The Corporation of the City of Kingston 2023). Queen's University purchased the building in 2021 and is currently using it for its gym space and storage; however, the goal is to renovate the structure so it can serve as a versatile temporary swing space for staff and students.

Stable Designs will focus on the structural rehabilitation of KCVI as per the Queen's Facilities team's request. The primary goal is to modify the structure to support collaborative learning environments and enhance energy efficiency. The scope is divided into four essential components: windows, wall composition, adaptive space reuse, and roof design. Additionally, the roof has reached the end of its lifespan, so imminent replacement is required. Given the provided scope, Stable Designs took the opportunity to research a sustainable roof design to further promote energy efficiency for the building. Based on data gathered through site visits, structural assessments, and client input, various recommendations and proposed solutions were developed.

All project constraints and stakeholders were identified and accounted for prior to design option analyses to ensure that all possible solutions are feasible. The project constraints included limitations that impacted the general project thus influencing the design solutions. The constraints include parameters such as cost, safety, timeline and deliverables, other course commitments, building codes, and historical by-laws. The stakeholders were divided into three sections (primary, secondary, and tertiary), each indicating a given stakeholder's influence on the solution.

The various recommendations were developed using idea generation methods such as the Post-it Note method. TRIZ allowed Stable Designs to predict contradictions within this project and provide various relief options. Design options were evaluated, and if deemed unfeasible, the option was no longer being considered.

To determine the solution that best meets defined criteria for the windows, wall composition, and adaptive space reuse, a Weighted Evaluation Matrix (WEM) was analyzed. The criteria in the matrices were chosen and weighed based on client feedback and team collaboration to ensure all constraints, stakeholders, and the scope are satisfied. For the window scope component, implementing a secondary glazing onto the existing windows was the highest ranked solution. For the wall composition portion of the scope, spray foam insulation was ranked the highest out of all options scored in the WEM. For the adaptive space reuse section of the scope, the selected location for space reuse was STOR 015, CLR 001-002 and RES 001-005, which was KCVI's library space. It was determined that three classrooms could be implemented within this area. For the roof design section of the scope, various options and case studies were researched and information regarding them were provided.

Using the highest-ranking solutions from each of the WEM's for the windows and wall composition, a technical analysis was performed to provide more specific details regarding energy efficiency. The various solutions for the window scope component consisted of examining single, double, and triple pane secondary glazing. The wall composition analysis involved comparing five different options with various stud materials, dimensions, and spray foam thicknesses. The total heat loss per year and natural

gas usage was calculated for the window and wall compositions potential solutions to help provide insight on the energy efficiency of the options.

Additionally, a cost analysis was conducted to examine how enhancing the energy efficiency could impact the overall cost of ownership and to determine whether the higher upfront costs would be justified. The cost of ownership analysis showed that the best combinations of solutions for the different scope components would have a net positive return on investment after 15 years compared to a do-nothing base case. It was determined that double pane secondary glazing would be the most efficient option to implement to help restore the windows, which cost $656,734.40 upfront and have a lifespan of 25 years. In the terracotta-based wall composition of the building, it is recommended that 1.25" x 4" 25-gauge non-load-bearing metal studs be installed with a spray foam thickness of 101.6 mm. In the reinforced concrete-based wall composition portion, 1.25" x 6" 25-gauge non-load-bearing metal studs should be installed with a spray foam thickness of 152.4 mm. This solution costs $1,061,281.01 upfront.

Moreover, using the highest-ranking solution for the adaptive space reuse section, a structural and cost analysis was performed to provide more specific information on converting STOR 015, CLR 001-002, RES and 001-005 into integrative learning classrooms. The structural analysis consisted of analyzing the existing framing system to ensure it could support the 2.4 kPa live load associated with the classroom. It was determined that all the beams analyzed were able to support the loads and have been approved for the classroom space. Based on the cost analysis, it was estimated that the price of converting that space into the in integrative learning classrooms would cost around $45,074.04. This upfront cost was also included in the cost of ownership analysis.

The various options researched for the roof design consisted of a blue roof, a green roof, and a combination of both. The team explored ways to combine these options to utilize the roof space most effectively. Due to the lack of implementation within the Kingston area, it is difficult to determine which option or combination of options would be the best to implement for KCVI, therefore, recommending a solution for the roof design was outside of Stable Designs scope of work for this project.

Throughout the project it was important that various risks were evaluated throughout the design process. Different aspects of the project, including site visits, material selection, structural analyses, and construction, had their own risks to be considered. Mitigation measures including wearing protective gear, inspections, consulting experts, and proper planning took place to ensure overall project safety. The team additionally considered the risks associated to the construction process to suggest measures that mitigate these risks.

Overall, Stable Designs successfully completed the KCVI structural rehabilitation project. The team proposed energy-efficient solutions for improving the window and wall composition of the structure, an ideal location to implement integrative learning classrooms, and offered ideas regarding an innovative sustainable roof design. Stable Design's met various deadlines through time management strategies including a work breakdown structure and a Gantt chart. To ensure the clients were satisfied, the team attended biweekly meetings to get their opinion throughout the entire design process. These measures contributed to the complete project success. Stable Designs feels satisfied with the work they contributed to help rehabilitate KCVI and help Queen's University meet its sustainability goals.

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1.0 Introduction

Kingston Collegiate Vocational Institute (KCVI) was purchased by Queen's University (Queen's) in 2021 to be used as a versatile, temporary swing space. Queen's is currently using this building for gymnasium space and storage. This building dates to 1915, therefore, it is an historical building cherished by the Kingston community. Prior to Queen's faculty and students utilizing this building for regular operations, the structure needs to be assessed. Stable Designs examined the overall structural integrity and what should be preserved to respect the buildings' heritage.

The preliminary steps taken towards successfully completing this project involved thoroughly defining the scope, constraints, and stakeholders to complete this project to the clients' standards. Stable Designs reported directly to the Queen's Facilities team. Throughout the project process, the team was in discussion with the client and the team's teaching assistant (TA) to develop the proposed solutions for each scope component. The scope will outline specific objectives and deliverables, which guided the team towards successfully achieving the project goals. The constraints helped the team prepare and overcome the project's limitations and restrictions. Recognizing the stakeholders was crucial, as each has a different need that must be acknowledged for the project's success.

Additionally, a preliminary step included gathering background information, including research on the structure's history, and retrieving necessary engineering technical documents. Further research was gathered to provide deeper insight on fire safety, structural capacity, accessibility, and heritage structures.

This preliminary step then provided sufficient insight on developing different design options for the project. Design options were developed through an idea generation process that included the Post-it Note method and TRIZ method. To determine the most efficient option for each section of the scope, different Weighted Evaluation Matrices (WEMs) were developed using the client's insight and the team's knowledge on the topics. The results from the matrices were reviewed and the conceptual designs were selected.

These designs were furthered analyzed through technical and cost analyses. The technical analyses provided insight on the energy efficiency of the building envelope, structural calculations for the current capacity of the floor systems, and structural calculations for the current roof beam capacity. The cost analysis was used to provide the clients with an estimated price for the different options assessed.

To ensure proper time management throughout the process, the team referred to the initial Team Charter developed to provide structure and organization throughout the project. A plan was laid out on a responsibility assignment matrix (RAM) and a Gantt chart. These graphics outline specific deadlines, meetings, and responsibilities that ensured a smooth progression of the project.

2.0 Problem Definition

This section discusses the project scope, site visits, constraints, and stakeholders of the KCVI rehabilitation project.

2.1 Background Information

KCVI was constructed on 235 Frontenac Street, in Kingston, Ontario in 1915. After the building was destroyed by fires, modifications and additions were made in 1932 and the 1960s. The school accommodated approximately 1300 students and includes a gymnasium, office spaces, bathrooms, and utility facilities. The school was closed in 2020 and was listed as an endangered historical building according to the National Trust for Canada (National Trust for Canada 2023). In June 2021, Queen's University purchased the old school with the intentions of turning it into a swing space including lecture halls, classrooms, offices, and storage facilities. Figure 1 shows the topographic view of KCVI's relative location in Kingston and Figure 2 shows the front entrance of the building.

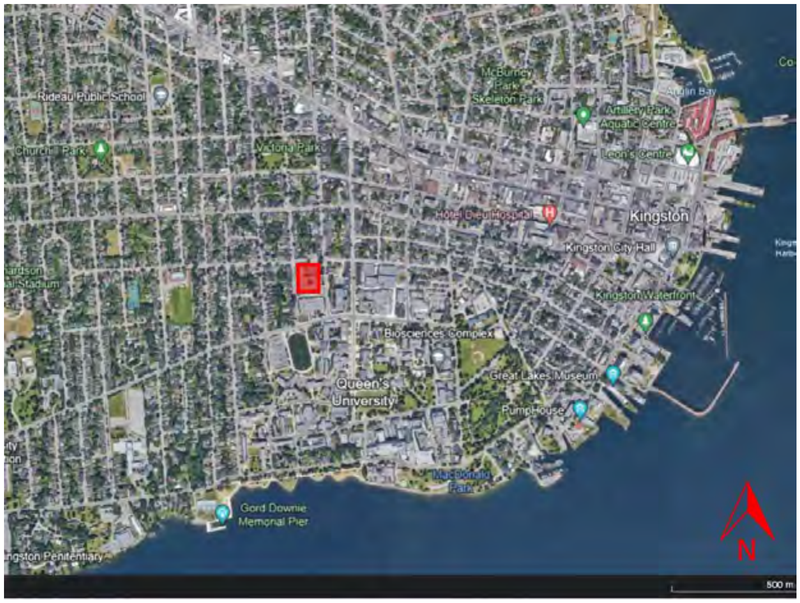

Figure 1: Areal View of Kingston, Ontario with KCVI Highlighted in Red, the Site of Analysis (Google Earth 2023)

Figure 2: Photo of the Front Entrance of KCVI (National Trust for Canada 2023)

It was necessary to perform an in-depth analysis of the existing conditions to generate solutions. Technical documents have been provided by the client, which includes:

- Floor plans of the existing building

- Structural/architectural drawings dated from 1929-1999
- Site survey
- Draft roof assessment
- Asbestos assessment report
- Asset condition assessment report

2.2 Project Scope

The primary objective is to retrofit the current building to accommodate collaborative learning environments along with an energy efficient building envelope. Queen's University intends to use KCVI as a functional swing space for multipurpose use with an emphasis on implementing high-tech, collaborative learning classrooms. Focusing on energy efficiency of the implemented solutions is essential to ensuring the building rehabilitation is sustainable and the overall cost of ownership is justifiable.

It was necessary to conduct a structural assessment to understand the current structural system of the building. The team's concerns were communicated to the client, and further analysis from a Professional Engineer who specializes in structural rehabilitation was recommended. As a result of these findings, Stable Designs could move forward with the primary objectives.

The project's scope has been broken down into four key components that will be analyzed. Options for each of these components will be evaluated and proposed solutions will be selected. In this report, the four scope components will be evaluated in the following order:

1. Windows
2. Wall Composition
3. Adaptive Space Reuse
4. Roof Design

The client has specifically requested to focus on the first three scope components, to ensure an energy efficient building envelope and to adapt the space for its intended use. The fourth scope component has been developed since the roof has reached the end of its lifespan, so imminent replacement is necessary. Figure 3 outlines the project scope in a visual format.

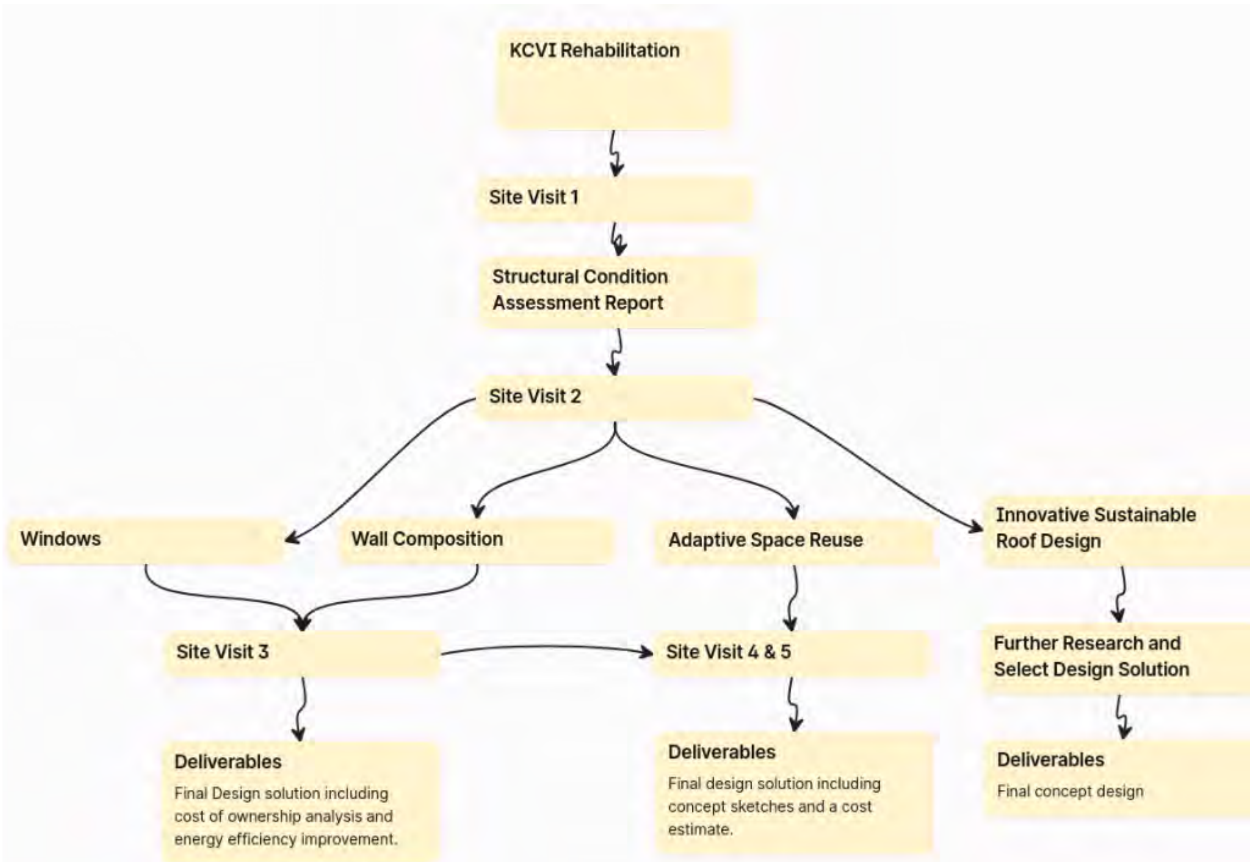

Figure 3: Scope Mind Map, Illustrating the Flow of the Project

The design criteria for each of the four scope components were initially analyzed and weighed by their relative importance based on Stable Designs' experience in design projects. This approach is rather biased, so during a meeting, the clients determined their own ranking and relative importance of the design criteria for the different scope components. The final criteria weightings were determined based on the client's suggestions.

The windows in the existing building are in poor condition and some panes are broken, which results in significant heat loss and energy efficiency issues. Since KCVI is classified as a historical building there are additional challenges involved with the retrofit and replacements. In this report, design options for the windows will be developed and a solution will be proposed based on the identified criteria and their relative importance. This report also includes a final cost estimate, a cost of ownership analysis, and an energy efficiency improvement rating.

The scope involved with the wall composition is identical to the building's windows. The current wall composition, which accounts for most of the building envelope, is old and much less efficient at preventing heat loss compared to newer wall compositions. In this report, Stable Designs will recommend an energy efficient wall composition based on the identified criteria found and their relative importance. A final cost estimate, a cost of ownership analysis, and an energy efficiency improvement rating have also been conducted for this scope component.

Adaptive space reuse involves identifying potential areas within the existing building that could be modified to accommodate the new collaborative learning classrooms that the Queen's Facility team wants to implement. It was requested to identify locations and propose designs for four collaborative learning classrooms with a capacity of 120 students, and a length to width ratio of 2:1 or 1:1. The Stable Designs team looked for the most viable potential options to meet these spacing requirements based on the design criteria. In this report, a few different locations and their potential designs were evaluated based on constraints and criteria. A proposed final design and its location within the existing building envelope has been identified. Calculations on the structural capacity for the classroom as well as concept sketches, and an in-depth cost analysis have also been included.

The final scope component is implementing a sustainable roof design. KCVI consists of many different levels of roofs from various building additions. For the purposes of this scope, only the roof that is three stories above the ground will be considered for design. This roof includes building additions built in 1929 and 1958. Upon identifying the imminent need for replacement of the roof it was determined that there is an opportunity to design an innovative and energy efficient solution. Therefore, a few potential options for the roof have been analyzed based on preliminary research and the design criteria. A final roof design is not included in this report. Instead, a preliminary assessment process has been developed based on important criteria, compatibility with the existing roof, and on global and Canadian case studies. It is evident that there is a lack of overall understanding on the long-term benefits and implications of these innovative roof options and that they are still being researched.

Based on the proposed design a cost of ownership analysis that incorporates the first three scope components will be included in this report. The cost of ownership, specifically requested by the clients, of the proposed final design is compared to a do-nothing approach.

2.3 Site Visits

The first phase involved a site visit which was a comprehensive examination of the condition of the structural elements within the building. Site visits are conducted in collaboration with the Queen's Facilities team. Recommendations for remediation have been determined on a case-by-case basis and the findings and recommendations can be found in Appendix A: Stable Design's Site Report 1. A second site visit was conducted to assess the building's envelope, the roof's structural system, and its supports. The findings of this site visit provided the constraints and design criteria for each scope component.

To finalize the designs of the first three scope components, a third site visit was required to identify locations of proposed intrusive sampling. During this site visit a representative of Queen's Health and Safety team took paint samples from each proposed location for intrusive sampling as well as the window caulking. The paint sample results were returned, and it showed that in one of the locations, the paint contained lead, which is shown in Appendix B: Intrusive Sampling Results. The locations were already identified to be free of asbestos as outlined in the drawing figures created by Pinchin, (Drawings 1-4). After the Queen's Health and Safety team determined that the locations were safe and approved intrusive sampling, the Physical Plant Services were engaged to open holes in these locations. Stable Designs conducted a fourth site visit to gather information from the intrusive sampling.

A fifth and final site visit was conducted after the optimal space was selected for the adaptive space reuse scope component. Stable Designs took detailed measurements and specific photographs of the space during this visit. The structural system of the first floor was also investigated to compare the existing support system to what was outlined in the available drawings.

2.4 Project Constraints

The constraints in this report will be broken down into multiple parts: constraints impacting the general project, and constraints that will affect the design solutions to each scope component.

The cost of the scope components will impact the selected solution. Although the client had not set a specific cost for the budget, the team understands that the steps for remediation must be feasible to be considered. The costs include the methods used to remediate or replace the existing windows, replace existing wall composition, and propose new spaces for classroom adaptation. The cost considered includes the material choice for each scope component, and the required labour to implement the proposed solution(s). The predicted costs will be based on the completed site inspections of the current building conditions, and background research conducted on industry practice.

Ensuring safety throughout the proposed site visits is imperative to the team's progress. Building access was granted to the team, however, the access comes with a set of rules and regulations set by Queen's University. A team member can only enter the building with at least one other person, whether that be a representative from the Queen's Facilities team, or a team member from Stable Designs. Roof access is only provided when a certified member of the Queen's Facilities team is present. Personal Protective Equipment (PPE) is only required when construction work is taking place.

Due to the building's age, careful consideration of asbestos was taken when performing site visits and wall composition investigations. As mentioned previously, a site visit was dedicated to sample paint and window caulking to test for lead and asbestos in locations that the team wanted to investigate further. The sampling for these hazardous materials was important and acted as a constraint that comes with the proposition of intrusive testing. The intrusive testing was imperative for the window, wall, and adaptive space reuse components of the project. This would provide information that would aid the rehabilitation design of the wall composition and help determine load bearing walls for potential classroom spaces.

Although the results from the asbestos sampling noted that the selected locations of sampling were asbestos free, there are located areas around the building that do contain asbestos, which is included in Appendix B: Intrusive Sampling Results. These areas were noted to be avoided during site visits, intrusive testing, and selecting locations for high-tech classrooms.

The proposed solutions must also be safe for all current and future stakeholders of the design. Ensuring safety will impact the design process through material choice and amount, as well as the design choices. The team will consult and follow codes and standards regarding remediation (structural) design and perform extensive modelling investigations to ensure the safety of the building occupants. The codes below were used:

- Ontario Building Code (OBC), 2021
- Handbook of Steel Construction (12th Edition), 2021
- National Building Code of Canada (NBCC), 2020
- Queens Facility Accessibility Design Standards, 2019
- Accessibility for Ontarians with Disabilities Act (AODA), 2005

Time constraints were considered throughout the entire design process. Throughout the duration of CIVL 460, there were multiple deliverables to submit to the teaching team as well as the client. The team also recognized that time would be spent in other courses to complete their Civil Engineering undergraduate degree. The team optimized the time spent on site by planning and setting clear expectations of the required tasks for each visit.

2.4.1 Heritage Building Constraints

As discussed previously, KCVI was built in 1915, therefore it is a historical building. Municipal and provincial laws protecting heritage buildings must be abided by when carrying out the methods of investigation of wall composition, material choice, and the required structural remediation.

According to the Ontario Property Owners Guide to Heritage Designation, when proposing new work to a designated heritage building, proper actions must be completed to gain City Approval. To apply for a Heritage Permit, the owner must meet with the City Heritage Planners to discuss the application and conservation project during the Heritage Roundtable. This takes place every Wednesday afternoon at the Heritage Resource Centre in City Hall (Community Services City of Kingston 2023).

The application is a process an owner must complete to gain approval from the Heritage Kingston community. An application is required where alterations are proposed that may affect the property's "reasons for designation"(Community Services City of Kingston 2023). Different reasons for designation include:

- The structure is representative of a particular architectural style of the building era.
- The structure was previously owned by a historical figure.
- The structure contributes significantly to the area's character or is a landmark.

Most designations apply to the exterior of the property. Work that does not apply to the heritage application includes interior work, and minor alterations. Therefore, proposed work for the high-tech classroom renovations, as well as the wall composition work will not require a permit (Community Services City of Kingston 2023).

Many types of proposed works that have required a permit have been approved in Kingston. Examples include:

- Minor repairs to existing features
- Replacing roofing where there is little or no change in material, colour, or design.
- Minor re-pointing masonry.
- Removing or altering signage within its current configuration and building coverage.
- Repairing or replacing windows.

Therefore, a permit will be required for proposed window and roof works (Community Services City of Kingston 2023).

The City of Kingston's "Official Plan" directs that the resources are to be conserved, managed, and marketed for their contribution to the City's unique character, history, and sense or place. This should be done in such a way as to balance heritage with environmental and accessibility concerns, considers cultural heritage resources are non-renewable, and once lost cannot be regained (Community Services City of Kingston 2023).

Since there are much more accessibility requirements in 2024 that did not exist when the building was initially built, there are many considerations into retrofitting the building interior to existing codes and standards that pertain to accessibility requirements. In the Standards and Guidelines for the Conservation of Historic Places in Canada, it is noted that solutions in design should consider accessibility for those of all ages, interests, and abilities ("The Standards & Guidelines for the Conservation in Canada" 2010). Work should be proposed so there is a balance between accessibility needs and minimal impact on the heritage value.

2.5 Stakeholders

There are many different stakeholders who will be influenced by the KCVI assessment and renovation project. This is a structure that is to be used by many and is valued by the community due to its significant heritage. It is important the stakeholders are recognized prior to beginning the assessment, as they all have different values and needs that must be met throughout the completion of the project. There are certain stakeholders whose needs should be considered over others. To recognize this, stakeholders can be sorted as primary, secondary, and tertiary stakeholders. The primary stakeholders have the most direct influence on the project solutions, the secondary stakeholders have some direct influence, and the tertiary stakeholders have minimal direct influence but is important to keep their needs in mind while defining project solutions.

2.4.1 Primary Stakeholders

A crucial primary stakeholder of this project is Queen's Facilities, the client of the KCVI project. As the project initiators, the clients have expressed a need for an assessment and the formulation of a renovation plan. To meet the client's goals, the team attended bi-weekly meetings, ensuring the work being completed was done to their standard and accurately represented the scope. Effective communication between the team and the client was crucial to ensure their goals were being met. The team followed the client's timeline to ensure no milestones were missed.

Queen's University is another primary stakeholder whose opinions were considered throughout the course of this project. KCVI will be used by the University as an academic building, therefore, the team ensured that all proposed renovations aligned with the standards and regulations all campus structures adhere to. Queen's will likely need to approve many proposed changes that will occur; therefore, their opinion was crucial to consider. Queen's University is also pushing to have a net-zero carbon emission campus by 2040, this was kept in mind when proposing renovating recommendations.

An additional primary stakeholder includes the staff, students, and visitors, the users of this building. Their needs include safety and accessibility, therefore, the team examined the problem areas that can cause potential safety hazards and ensured the building complies with the Accessibility in Ontario's Building Code (The Government of Ontario 2021). Additionally, students and staff would likely express some interest regarding the renovation and would be willing to provide input regarding their needs and wants concerning the renovation. This input could prevent future problems and help with the overall design plan.

2.4.2 Secondary Stakeholders

Another significant stakeholder includes the City of Kingston, the municipality the project is located in. The municipality is an important stakeholder as this is a structural heritage project and the municipality has specific codes that need to be followed before alterations to a heritage property takes place.

According to the Government of Ontario (Government of Ontario 2022), it is a municipality's responsibility to provide heritage designation to buildings in the region, for that reason, KCVI was designated under Part IV of the Ontario Heritage Act (The Corporation of the City of Kingston 2023) at the municipal level. Therefore, the municipality requires that a heritage permit needs to be obtained before any physical changes can take place. The team kept this in mind to ensure the recommendations to the client will be accepted by the municipality.

Furthermore, another secondary stakeholder includes the nearby Kingston community and neighbours surrounding the project. The surrounding community will be affected by the renovations of this plan, as these community members are in earshot of the construction that is to take place. It is important that the team recognized this to try to minimize the amount of loud construction methods recommended. These community members also highly value the buildings heritage aspect.

2.4.3 Tertiary Stakeholders

A tertiary stakeholder includes the contractors and construction staff, those who will be following the provided recommendations. If the workers operating on the project are provided with unclear instructions, there is an increased chance of errors. It is important the directions are detailed and comprehensible to ensure the construction process does not become prolonged for unnecessary reasons, which will help avoid any incurred costs for additional time.

3.0 Background Research

This section outlines the background research into the required documents for this project. It pertains to different aspects of the report that must be considered prior to idea generation and design selection. It discusses different materials consulted for fire safety, structural capacity, accessibility, and heritage structures.

3.1 Fire Safety

This section discusses the different documents consulted to ensure that fire safety protocols are met through Queen's University, the National Building Code of Canada, and the Ontario Building Code.

1. Section 2.17 Emergency Exits, Fire Evacuation, and Areas of Refuge / Rescue Assistance, from Queen's Facility Accessibility Design Standards (Queen's University Facilities Team 2019)
2. Section 3.2-3.4, Division B, Part 3: Fire Protection, Occupant Safety, and Accessibility, from National Building Code of Canada 2020 (NBCC)
3. Section 9.9.1.2 Fire Protection, from Ontario Building Code (OBC)

These sections outline the critical regulations for ensuring the safety and accessibility of the building. It includes the requirements for fire prevention, evacuation procedure, and accessibility standards to accommodate individuals with disabilities. The most relevant section specifically relates to the classroom materials that are most desirable for construction.

4. O. Reg. 213/07: Fire Code, from Fire Protection and Prevention Act, S.O 1997, c.4 (Government of Ontario 2014b)
5. Section 9.9.4.2 Fire Separation for Exits, from Ontario Building Code (OBC)

These sections ensure the windows provide sufficient fire access routes for firefighting operations, guarantees windows are used for a second means of escape, and can be opened from the inside without the use of a tool.

3.2 Structural Capacity

This section outlines the different codes consulted to ensure the structural capacity is safe to adapt different spaces throughout the building for reuse. The codes consulted were from the National Building Code of Canada, Ontario Building Code, and the Handbook of Steel Construction.

1. Division B, Part 4: Structural Design, from National Building Code of Canada 2020 (NBCC) (National Research Council of Canada 2020)

This section ensures that the school's structural elements meet the necessary standards for stability and durability, while safeguarding the well-being of its occupants. All proposed additional elements or renovations are to adapt the space to the client's needs for its intended use.

2. Section 4.1.5.3. Full and Partial Loading, from the Ontario Building Code (OBC)

This section states that the loads for a classroom with or without fixed seats is a uniform live load of 2.40 kPa.

3. Part 1: Design of Steel Structures, from Handbook of Steel Construction (12^{th} Edition), 2021

This section aids the design and analysis of steel structures. It contains many codes that must be followed for fully laterally supported beams, which is in use of the existing superstructure of the building.

3.3 Accessibility

This section discusses the different regulations set by the provincial government, Queen's University, and the National Building Code of Canada to ensure that the building can be used by all stakeholders.

1. Accessibility for Ontarians with Disabilities Act, 2005 (AODA) (Government of Ontario 2014a)
2. Section 2.0 and Section 7.7, Queens Facility Accessibility Design Standards (Queen's University Facilities Team 2023)

These documents ensure that all classrooms will be designed to comply with the standards that allows for accessibility on the premises on or before January 1, 2025. The team assumes that the Queen's Facility Accessibility Design Standards complies with the AODA. It accounts for items such as seating spacing requirements, floor spacing, and entry ways.

3. O. Reg. 368/13: Building Code, from the Building Code Act, 1992
4. Division B, Part 3.8: Accessibility, from National Building Code of Canada (National Research Council of Canada 2020)

These sections pertain to accessibility requirements for all public rooms, including regulations on entrances, seating requirements, turning spaces for wheelchairs, and ramps.

3.4 Heritage Structures

This section discusses the documents consulted to protect heritage structures in the provincial level.

1. Part 4 and Part 5, from the Ontario Heritage Act, RSO, 1990, c.O. 18 (Community Services City of Kingston 2023)

These sections outline the heritage regulations for Kingston, Ontario. For a property to be considered a historical designation, it needs to identify with at least one of the criterion types, that include design, historical, and/or contextual historical significance. It outlines the required steps for changing or remediating a heritage space through the City of Kingston. It has specific details on window replacement that emphasizes the importance of preserving these windows (Kingston City Council 2012).

4.0 Idea Generation

Idea generation is crucial because it serves as the foundation for innovation and problem-solving. It is the process of generating, developing, and refining new concepts, solutions, or approaches to address the challenges within this project. Effective idea generation fosters creativity, encourages diverse perspectives, and enables the discovery of novel solutions. This can lead to advancements, improvements, and breakthroughs across the four scope components of this project. Idea generation was done through two tools, the Post-it Note method, and TRIZ, a Russian acronym that roughly translates to the Theory of Inventive Problem Solving (MindTools Content 2023).

4.1 Post-it Note Method

The Post-it Note method is a simple yet powerful ideation technique that involves using sticky notes to capture and organize ideas during brainstorming sessions or discussions. Members write down individual thoughts or concepts on separate Post-it Notes, allowing for easy organization, rearrangement, and categorization on a board. This method encourages participation, stimulates creativity, and facilitates visual organization of ideas, making it an efficient tool for group collaboration and idea refinement.

Stable Designs used the Post-it Note method as a tool to get every idea, no matter how absurd it was, on the sticky note board. This is because sometimes the impossible ideas lead to innovative, viable solutions. Figure 4 below illustrates what Stable Designs produced during this ideation session on October 30th, 2023, for each of the four scope components.

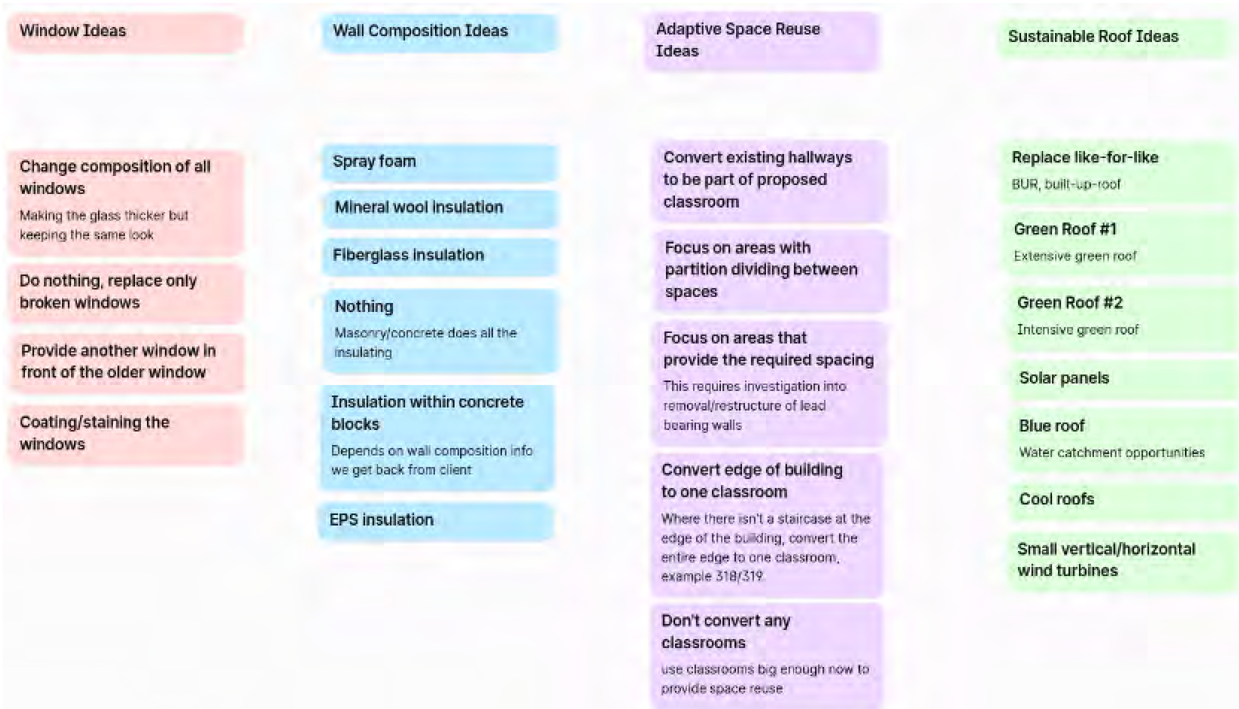

Figure 4: Post-it Note Idea Generation for Each of the Four Scope Components

For each of the scope components, a feasible design option is to do nothing. This was not considered because the client wanted to improve upon these four scope components. It was simply included as it will provide the basis for comparing the ideas, to see how much each idea can improve upon the applicable criteria. Not all options illustrated in Figure 4 were considered after refining the possible ideas. The reasoning for these are illustrated in Appendix C: Idea Generation Supporting Documents.

4.2 TRIZ

TRIZ, is a systematic approach to innovation and problem-solving developed by Genrich Altshuller. It provides a structured framework and a set of principles to help systematically analyze complex problems, identify contradictions, and generate inventive solutions. It offers a toolkit of methods and principles to guide the generation of creative and effective solutions (MindTools Content 2023).

A TRIZ analysis was conducted on elements of the project which showed value trade-offs in optimization. The evaluation was conducted on the windows, the wall composition, and the roof. The inverses of the contradictions were also analyzed to ensure that all possible inventive principles were captured in the process. Table 1 outlines the summary of the TRIZ analysis and which inventive principles each contradiction pertains to. The numbers in bold pertain to the inventive principles in the inverse contradictions that were not previously covered. The numbers that represent the inventive principle are shown in Appendix C: Idea Generation Supporting Documents. Note that not all inventive principles that the TRIZ matrix suggests are applicable to this project.

The first trade-off is the improvement of energy efficiency without sacrificing transparency of the windows. The TRIZ matrix suggests the following:

- Segmentation (Inventive Principle 1)

  - Divide the window into segments with varying energy efficiency features. For example, the lower part of the window could be double-glazed for better insulation, while the upper part remains transparent for daylight.
- Changing Optical Properties & Dynamicity (Inventive Principle 32 & 15 respectively)
  - Implement smart windows with adjustable tint levels. The windows can dynamically control transparency based on external conditions, optimizing natural light while minimizing energy loss.
  - Integrate dynamic systems that adjust to external conditions, such as automated shading devices for windows that respond to sunlight intensity.
- Partial Action (Inventive Principle 16)
  - Only change sun-facing windows.
- Composite Materials (Inventive Principle 40)
  - Explore the use of advanced composite materials for window construction that provide superior insulation properties without compromising transparency.

Creating energy efficient walls that do not take usable space away is another trade-off. The TRIZ matrix suggests the following:

- Multi-functionality (Inventive Principle 6)
  - Incorporate measures against temperature variations by utilizing materials that naturally counteract heat transfer, such as phase change materials that absorb and release heat as needed (Zeng et al. 2023).
  - Utilize vacuum insulated panels that have one of the highest R values on the market in its thin build, but it also consists of materials named getters that absorb gases, used to keep the panel free of air and moisture (Holmberg 2022).

Another trade-off is creating an energy efficient roof design that can evolve with the changing environmental needs and keep the weight of the roof to a minimum. As this project is in Kingston, Ontario, having a roof design that works well in both the summer and winter climates would be valuable. Additionally, adding objects such as green roofs to improve the energy efficiency of the roof, will ultimately increase the weight of the roof. The TRIZ matrix suggests the following for these trade-offs:

- Multi-functionality (Inventive Principle 6)
  - Introduce elements such as blue roofs or green roofs which can have many different purposes. For example, green roofs enhance insulation, but they also improve water quality by filtering pollutants for blue water catchment facilities (Connect LA 2024).

These are summarized below in Table 1.

Table 1: TRIZ Analysis

Description	Improving	Worsening	Inventive Principles
Improving energy efficiency of the windows without compromising transparency.	• Loss of energy	• Illumination intensity	1, 13, 40, 32, 15, **16, 6**
Improving wall energy efficiency without comprising usable space.	• Loss of energy	• Volume • Thickness	7, 6, 38, **28**
Improving roof energy efficiency that can adapt to changing environmental needs and keep the weight to a minimum.	• Loss of energy • Adaptability	• Weight	19, 15, 29, 16, 6, 18, 9, **28**

Not all the ideas generated from this TRIZ method were considered further when refining the possible solutions. The reasoning for these is illustrated in Appendix C: Idea Generation Supporting Documents.

5.0 Design Options

Various design options were developed in the idea generation phase for each part of the scope: windows, wall composition, adaptive space reuse, and roof design. These options were further researched to provide insight prior to comparing them in a WEM.

5.1 Windows

The initial component of the project scope focuses on enhancing the energy efficiency of the windows. One of the largest sources of energy loss in structures is through their windows according to a Construction21 article (Long 2021), and the current state of the windows in KCVI are contributing significantly to this issue. The windows are releasing a considerable amount of energy as there are broken windowpanes throughout the structure and the windows have not been updated in 30 years. The location of the broken windowpanes can be seen in Appendix D: Supporting Documents for Windows Scope Component.

To minimize the energy loss through the windows the broken panes need to be repaired. Additionally, the windows in place are double-glazed that have past their lifespan, so it can be assumed they have an R-value of 0.18 m^2K/W (1 $\frac{ft^2Fh}{BTU}$), which is a reasonably conservative assumption (Places 2011). It should be noted that R-values are typically in imperial units. To keep units consistently in metric form throughout this report, all R-values have been converted and will now be mentioned as RSI values for the remainder of the report. An example of a unit conversion calculation can be found in 7.1.1 Windows for reference. There are alternative methods that can be taken to prevent future energy loss. If the windows can maintain a high RSI value over a long period of time without having to be altered or replaced, the cost of ownership will decrease through energy conservation. This, in turn will be better for the environment.

5.1.1 Option 1: Change Composition of the Windows

One possible solution Stable Designs considered to improve KCVI's windows energy efficiency includes replacing all the windowpanes with thicker, more energy efficient glass, while keeping the same façade. Firstly, altering the windows to this extent would require approval from the City of Kingston, as the structural heritage would be reworked. The city recognizes that some repairs are necessary, however, the Policy for Period Windows (Kingston City Council 2012) mandates the retention of the window components as much as possible. Therefore, the accessibility of finding windows that could replace the current heritage windows would be very limited as they would have to match the sizing, colour, and material of the original. The replacement component needs to closely replicate the Period Window.

There are a variety of factors that go into changing the composition of the windows. These factors include disposal of windows to be replaced, the material of the new windows, and installation costs. The cost of replacing all the windows would be around $423.8/m^2 (CAD) for a high quality standard double pane window. This value was found using RSMeans (Gordian 2024) as shown in Appendix D: Supporting Documents for Windows Scope Component. Implementing a standard double pane window would increase the RSI value from an assumed value of around 0.18 m^{2}K/W to a range from 0.53 m^{2}K/W to 0.67 m^{2}K/W (Windows 2021). The estimated heat loss for this option can be found in

Appendix D: Supporting Documents for Windows Scope Component. According to Everest (2020), these windows typically have a lifespan ranging from 25-30 years, however, the lifespan could decrease to 10 years if the window constantly faces undesirable weather conditions, which is a common occurrence during Kingston winters.

5.1.2 Option 2: Fixed Secondary Glazing

Another possible solution included fixed secondary glazing. This involves installing an independent window that is fitted on the inside of the existing window. This is a good option to consider as secondary glazing is not an intrusive procedure and is very common within heritage buildings. It reduces heat loss and improves the building's energy efficiency by providing an additional layer of insulation.

Fixed secondary glazing is an inexpensive solution with an approximate price of $142.4/m^2 (CAD), according to RSMeans data (Gordian 2024). Additionally, secondary glazing would provide an extra layer to prevent heat loss through the window. Depending on the number of glazes installed in the secondary glazing it can add an additional 0.19 m^{2}K/W to 0.57 m^{2}K/W to the existing RSI value according to recent research (All Weather Windows Ltd 2024). The estimated heat loss for this option can be found in Section 7.1.1 Windows.

Secondary glazing is readily accessible and easy to implement as it does not need to meet specific heritage or pane sizing requirements. To install secondary glazing, the overall windowsill must match the sizing of the windows currently in place. The total lifespan of secondary glazing is around 20 to 25 years (Henry 2020). These frames do not face the elements, so there is a very small chance the lifespan would be less than that.

5.1.3 Option 3: Insulating Film

An additional solution considered includes applying a temperature control film onto the existing windows. This would require the same glass panes, or very similar panes to be installed into the broken pane locations prior to application. As mentioned, the windows at KCVI are currently fixed double-glazed window. The most recent replacement of the windows occurred in 1994, not including the windows added in the recent additions. Although the windows are 30 years old, the building received its heritage designation after this replacement, meaning the windows are now protected by the Period Window Standard since they are now apart of a heritage structure.

Over the past 30 years it can be assumed that the windows have lost a significant amount of their energy efficiency due to "weathering, wear and tear, and deterioration in the seal or frame" (MaxHome 2023). Applying an insulated film to the windows could increase the RSI value by up to 50% (3M 2023). For this project, it was assumed that insulting film would give the windows an RSI value of 0.44 m^2K/W. The total heat loss for this option can be found in Appendix D: Supporting Documents for Windows Scope Component.

The estimated price for materials and installing the insulating film for the windows would cost around \$822.7/m^2 (CAD) according to data found in RSMeans (Gordian 2024), outlined in Appendix D: Supporting Documents for Windows Scope Component.

. The factors that were considered include the material itself and labour costs for applying the film to the windows. Most insulating films have a life expectancy ranging from 3 to 10 years (Energy Products Distribution 2023), therefore, replacement and maintenance costs would occur more often than the other options. In addition to replacing the film, the windows itself would have a lifespan of around 20 to 25 years (Smith 2021).

5.1.4 Criteria and Evaluation

To ensure the most effective solution was chosen and the client's needs were met, all potential options to prevent energy loss were compared in a WEM. The criteria in the matrix have been weighted through collaboration amongst the team and the client to ensure all constraints, stakeholders, and the scope were satisfied. Table 2 below demonstrates the assigned weighting with a short description of why that weight was provided.

Table 2: Reasons for Including Criteria and Justification of its Relative Weighting for the Windows Component

Criteria	Score (/100)	Justification
Energy Efficiency	25	The main part of the scope with respect to window alterations includes finding an energy efficient solution. Overall having an energy efficient window solution will save the owner money in the long run, will be better for the environment, and meet Queens's sustainability goals.
Aesthetic	20	The windows having a good aesthetic will satisfy the client's needs of wanting the façade to look good and help meet the heritage building requirements.
Lifespan	20	It is important the solution has a long lifespan to prevent additional costs within a short time frame.
Upfront Cost	7.5	There is no specific budget for this project. It is important to save money where possible, however, spending what is necessary on proper windows can save the client from spending unnecessarily in later years on maintenance, replacement, or energy loss. It is important to maintain Queens's aesthetic and meet heritage building guidelines regardless of the cost.
Cost of Ownership	7.5	The cost of ownership is an important factor to consider within the overall structural renovations of KCVI. It encompasses the initial purchase price and the operation expenses over time. In the grand scheme of the scope, the windows will only have minimal effects on the cost of ownership.
Constructability	7.5	There is no dedicated time frame for this project. It is understood that construction will need to take place, however, the timeframe at which it is done is not a pressing matter.
Accessibility	7.5	It is important to ensure the required material is available for construction, however, altering the windows is not a time sensitive issue. Construction on the windows can wait until the material is acquired.

In addition to the criteria and its individual weighting, each proposed window solution received a score of 1-10 based on each criterion. A score within each column in Table 3 was allocated based on the criteria being on the low, medium, or high range of that specific criteria.

For example, a score of 1 will be allocated for energy efficiency if the windows have an RSI value of 0.16 m^2K/W or below, a score of 2 if the RSI value is between 0.16 m^2K/W and 0.3 m^2K/W, and a score of 3 if the RSI value is closer to 0.3 m^2K/W. The energy efficiency values were based on data found in a recent report (Au 2021). The lifespan was estimated using information found in the Showplace article (Alexandria et al. 2021). Additionally, using RSMeans data (Gordian 2024), the upfront cost was approximated.

Table 3: Windows Scoring Rubric for Each Criteria

Constraint	Score 1-3	Score 4-6	Score 7-10
Energy Efficiency	Windows allow significant heat or cool air to escape. Has an RSI value ranging from 0.16 m^2K/W to 0.3 m^2K/W	Windows allow some heat or cool air to escape. Has an RSI value ranging from 0.301 m^2K/W to 0.53 m^2K/W	Windows allow little to no heat or cool air to escape. Has an RSI value of 0.531 m^2K/W or higher.
Aesthetic	Windows are not visually appealing and do not match existing heritage windows.	Windows are somewhat visually appealing and remotely match existing heritage windows.	Windows are visually appealing and match existing heritage windows.
Lifespan	Windows must be replaced within 15 years.	Windows must be replaced withing 15 to 30 years.	Windows can be replaced after 30 years.
Upfront Cost	The proposed window solution costs over $450/m^2$ (CAD).	Proposed window solution costs $275-450/m^2$ (CAD).	Proposed window solution costs under $275/m^2$ (CAD).
Cost of Ownership	Increases the cost of ownership over time.	Has minimal effect on the cost of ownership.	Decreases the cost of ownership over time.
Constructability	Construction requires significant invasion/replacement of the existing windows. Time of construction is more than 6 months.	Construction requires some invasion of the existing windows. Time of construction is between 1 and 6 months.	Construction requires little to no invasion of the existing windows. Time of construction is less than 1 month.
Accessibility	Materials are difficult to access and there is limited availability. Time frame of obtaining materials is over 6 months.	Materials are accessible with slightly limited availability. Time frame of obtaining materials is between 1 and 6 months.	Materials are very accessible. Time frame of obtaining materials is less than 1 month.

Using the criterion weight and scores for each potential solution outlined, the WEM was completed as shown below in Table 4 to determine the most effective method for window repair and energy efficiency.

Table 4: Weighted Evaluation Matrix for the Windows Component

Criteria	Weightings	Option #1		Option #2		Option #3	
		Score	Total	Score	Total	Score	Total
Efficiency	25.0	8	200.0	9	225.0	5	125.0
Aesthetic	20.0	6	120.0	4	80.0	5	100.0
Lifespan	20.0	7	140.0	6	120.0	6	120.0
Upfront Cost	7.5	4	30.0	9	67.5	2	15.0
Cost of Ownership	7.5	7	52.5	9	67.5	5	37.5
Constructability	7.5	2	15.0	7	52.5	9	67.5
Accessibility	7.5	3	22.5	8	60.0	5	37.5
Total		580.0		672.5		502.5	

After weighing all the options in the WEM, the second option, which is fixed secondary glazing, was selected for fixing the windows and enhancing its energy efficiency. This selection was presented to the client to ensure they agreed with the decision.

5.2 Wall Composition

The second component of the project scope is the wall composition. From the intrusive testing results seen on site January 24th, 2024, there are two different wall compositions within KCVI, illustrated below.

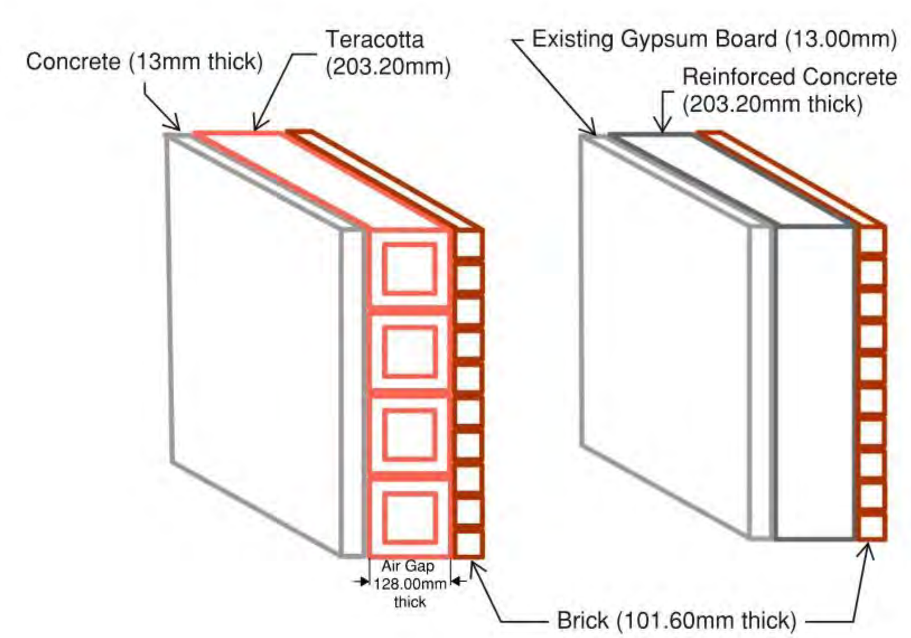

Figure 5: Two Typical Existing Wall Composition Cross-Sections. Terracotta-Based Wall Composition on the Left, Reinforced Concrete-Based Wall Composition on the Right.

The terracotta block-based wall composition accounts for about 60% of KCVI, with the reinforced concrete-based wall composition making up the remainder. The exact thicknesses of the terracotta block and reinforced concrete are unknown, however using the information available from visual inspection and commonly used sizes, it is estimated that both structural elements are eight inches thick (Kibbel 2019). For the inside finish of the terracotta-based wall composition, there is a 13 mm thick layer of finished concrete, while the inside finish of the reinforced concrete-based wall composition is a 13 mm thick layer of gypsum board. There is a brick façade on the outside of the building for both wall compositions. There is no current insulation in either wall composition within KCVI, a highly energy inefficient system.

Three options of the insulating layer of the wall composition were considered and weighed. To properly score these three different options, heat loss and cost estimation calculations were required. These are included within Appendix E: Supporting Documentation for Wall Composition Scope Component.

5.2.1 Option 1: Spray Foam Insulation

There are two types of spray foam insulation, open cell, and closed cell. Closed cell spray foam was considered as it is denser, allowing for better insulating properties and longevity (King Consulting Group 2018). Although closed cell spray foam costs more than open cell, energy efficiency and lifespan were two criterions particularly important to the client, with cost being less important, as seen in Table 5 below. Closed cell spray foam insulation could be an excellent option for the wall composition of the KCVI rehabilitation project for several reasons. Firstly, its superior insulating properties offer high thermal resistance, effectively sealing gaps and minimizing heat transfer, having an RSI value of 1.06 m^2K/W (LearnMetrics 2020). This significantly enhances the building's energy efficiency in a relatively small thickness, reducing heating and cooling costs over time. Additionally, spray foam insulation acts as an effective air barrier, preventing drafts and moisture infiltration, thereby mitigating the risk of mold and moisture-related issues within the walls. Its ability to conform and expand into small spaces ensures a seamless and tight fit, maximizing insulation performance and noise reduction. Moreover, considering the client’s want for a long lifespan, spray foam's durability and resistance to deterioration, featuring a lifespan of 80-100 years (John 2022) make it a reliable choice (Appendix F: Meeting Minutes). This contributes to the sustainability and longevity of the structure while providing occupants with a comfortable indoor environment. However, these advantages come at a significant cost. Using RSMeans (Gordian 2024), spraying 152.4 mm thick closed cell spray foam costs \$115.07/m^2 (CAD) to implement. All information stated throughout this paragraph was confirmed by King Consulting Group (2018).

5.2.2 Option 2: Expanded Polystyrene

Expanded polystyrene (EPS) insulation was another option considered for the wall composition of the KCVI rehabilitation project. Firstly, EPS offers excellent thermal insulation properties, featuring an RSI value of 0.74 m^2K/W (LearnMetrics 2020), enhancing the building's energy efficiency by minimizing heat transfer through the walls. This capability aids in maintaining a comfortable indoor temperature while reducing heating and cooling costs. Additionally, EPS is lightweight, contributing to easier handling and installation, which can potentially streamline construction processes, thus saving time and labour expenses. Using RSMeans (Gordian 2024), a piece of EPS insulation that is 76.2 mm thick has an overall RSI value of 2.02 m^2K/W, costs \$26.80/m^2 (CAD) to implement. Moreover, its moisture resistance and durability make it an ideal choice for withstanding various environmental conditions. This ensures long-term performance over a span of 40-60 years (Schleier et al. 2022), and reduces the need for frequent maintenance. Lastly, EPS insulation is environmentally friendly, as it is recyclable and has a low impact on the environment during production, aligning with sustainable construction practices for the KCVI rehabilitation project. All information stated throughout this paragraph was confirmed by Buy Insulation Online (2023).

5.2.3 Option 3: Fiberglass Insulation

Fiberglass insulation was another option considered for the wall composition in this project due to several reasons. Firstly, fiberglass insulation offers good thermal performance, featuring an RSI value of 0.65 m^2K/W, minimizing heat transfer through the walls. Additionally, its ease of installation aligns well with the project's requirements, facilitating a smoother construction process. Fiberglass insulation materials are typically cost-effective, providing a good value for the project budget without compromising on quality. Using RSMeans (Gordian 2024), a 304.8 mm thick piece of fiberglass insulation that is 279.4 mm wide that has an overall RSI value of 6.70 m^2K/W costs \$38.43/m^2 (CAD) to implement. However, fiberglass insulation can start deteriorating after 15-20 years (REenergizeCO 2023) as it holds moisture and can breed mold, but can last 80-100 years (John 2022) if not damaged. This means fiberglass insulation requires more maintenance over its lifespan compared to the other two options. Moreover, fiberglass insulation is readily available in various sizes and RSI values, allowing for flexibility in meeting specific insulation needs for different areas within the building. Lastly, fiberglass insulation is known for its fire-resistant properties, enhancing the safety standards of the structure. All information stated throughout this paragraph was confirmed by Shine (2022) and Orentas (2022).

5.2.4 Criteria & Evaluation

To ensure the most effective solution is chosen and the client's needs are met, all potential options to prevent energy loss are compared in a WEM. The criteria and their respective weights in the matrix have been determined through collaboration amongst the team and the client to determine the most important aspects of insulation with respect to this project. This was done on October 26, 2023, as shown in the meeting minutes included within Appendix F: Meeting Minutes. This approach ensures the team's bias does not affect the outcome of the evaluation process. Table 5 illustrates and justifies the assigned weighting to each of the criteria.

Table 5: Reasons for Including Criteria and Justification of its Relative Weighting for the Wall Composition Component

Criteria	**Score (/100)**	**Justification**
Energy Efficiency	35.0	The main part of the scope with respect to wall composition alterations includes finding an energy efficient solution. Overall having an energy efficient wall composition solution will save the client money in the long run, will be better for the environment, and meets Queen's sustainability goals. This is their main priority.
Lifespan	25.0	Client expressed interest in this criterion as changing the wall composition is not a change that can happen often. This is a great time to do it now and they want it to last.
Upfront Cost	15.0	There is no specific budget for this project. However, on a scale this large, price will be a large factor. Being more cost-effective in certain aspects that have the same properties will save the client immense amounts, which they expressed interest in.
Cost of Ownership	10.0	This is related to energy efficiency and lifespan; however, this criterion is not the most important to the client. It refers to how much the option would cost over its lifetime.

Criteria	Score (/100)	Justification
Constructability	10.0	This refers to how easy the option is to construct and how long it takes to implement. The client stated that there is no deadline, however they do not want it to be dragging on for a long time.
Accessibility	5.0	This refers to how accessible the materials are and how accessible people who can construct it are. In terms of the wall composition, this is not a huge concern for the client.

In addition to the criteria and its individual weighting, each proposed wall composition solution will receive a score of 1-10 based on how well it performs in each criterion. The scoring rubric, Table 6, is shown below for guidance with regards to scoring the solutions for each criterion. A score within each column in Table 6 was allocated based on the criteria being on the low, medium, or high range of that specific criteria. For example, in Table 6, a score of 1 will be allocated for energy efficiency if the walls have an RSI value closer to 0 m²K/W, a score of 2 if the RSI value is between 1 m²K/W and 3 m²K/W and a score of 3 if the RSI value is around 3.5 m²K/W. The energy efficiency values were based on data found in a recent report (EcoStar Insulation 2020).

Table 6: Wall Composition Scoring Rubric for Each Criteria

Constraint	Score 1-3	Score 4-6	Score 7-10
Energy Efficiency	Proposed wall insulation has an RSI value per inch of less than 0.62 m²K/W.	Proposed wall insulation has an RSI value per inch between 0.62 m²K/W and 0.97 m²K/W.	Proposed wall insulation has an RSI value per inch greater than 0.971 m²K/W.
Lifespan	Proposed wall insulation has an expected lifespan less than 50 years.	Proposed wall insulation has an expected lifespan between 50 and 80 years.	Proposed wall insulation has an expected lifespan greater than 80 years.
Upfront Cost	Proposed wall insulation costs more than $97/ m² to implement.	Proposed wall insulation costs between $54-97/ m² to implement.	Proposed wall insulation costs less than $54/m² to implement.
Cost of Ownership	Increases the cost of ownership overtime.	Has minimal effect on the cost of ownership.	Decreases the cost of ownership overtime.
Constructability	Construction requires significant invasion/replacement of the wall composition. Time of construction is more than 1 year.	Construction requires some invasion of the existing windows. Time of construction is between 6-12 months.	Construction requires little to no invasion of the existing windows. Time of construction is less than 6 months.
Accessibility of materials/ people who can construct it	Materials are difficult to access and there is limited availability. Time frame of obtaining	Materials are accessible with slightly limited availability. Time frame of obtaining materials is	Materials are very accessible. Time frame of obtaining materials is less than 1 month.

	materials is over 6 months.	between 1 and 6 months.	

Using the criteria weighting, scoring rubric, and the information explained of the three different insulation options, the WEM, Table 7, was then used to determine the most effective solution.

Table 7: Weighted Evaluation Matrix for the Wall Composition Component

Criteria	Weight	Option #1		Option #2		Option #3	
		Score	Total	Score	Total	Score	Total
Energy Efficiency	35.0	9	315.0	5	175.0	3	105.0
Lifespan	25.0	9	225.0	4	100.0	6	150.0
Upfront Cost	15.0	2	30.0	4	60.0	8	120.0
Cost of Ownership	10.0	9	90.0	8	80.0	5	50.0
Constructability	10.0	6	60.0	9	90.0	9	90.0
Accessibility	5.0	7	35.0	10	50.0	10	50.0
Total		**755.0**		**555.0**		**565.0**	

After weighing all the options in the WEM, the first option of using spray foam insulation scored the best and will therefore be used to enhance the energy efficiency within the wall envelope. Further analysis of this design selection is outlined in 6.0 Conceptual Design, 7.0 Technical Analysis, and 8.0 Cost Analysis.

5.3 Adaptive Space Reuse

The third component of the project scope pertains to proposing solutions for adaptive space reuse. The client has specifically requested that four new active learning classrooms are to be proposed by the team through converting the existing classrooms of KCVI. These classrooms are known as high-tech team-based classrooms. The goal for these classrooms is to promote collaboration and use technology such as TV monitors for student-driven learning (Queen's University 2023a).

All proposed classrooms must abide by regulations outlined in the Ontario Building Code, National Building Code of Canada, the National Fire Code of Canada, and the Accessibility for Ontarians with Disabilities Act. As discussed in Section 3.0 Background , these regulations are required by law, therefore a solution that does not abide by these guidelines will not be considered.

The constraints that will aid the design selection location includes cost, spacing requirements for people and equipment, constructability and time of construction, future potential modifications, accessibility, and aesthetics. The criterion for adaptive space reuse was developed based on team member project experience, and from the discussions with the client in Meeting #3, as seen in Appendix F: Meeting Minutes.

Cost of ownership pertains to the overall cost of renovation and maintenance of the proposed solution. Although there is not a hard budget for the rehabilitation of KCVI, typically, renovations of this stature can cost \$1500-\$3000/m^2 (CAD) (Jacobs 2022). This will be scored based on the current general condition of these rooms and evaluate what sort of work is required to achieve the high-tech classroom.

Spacing requirements will be assessed based on the proposed area of the high-tech classroom. The client had provided floor plans for existing high-tech classrooms to the team to base the desirable spacing requirements off. The following points are a description of the existing high-tech classrooms currently on Queen’s campus.

- Jeffrey Hall 155-156
    - 264.77m^2 (longest length is 17.55m, longest width is 15.51m)
    - 19 desks, 8 chairs per desk (seats 152 students)
    - 0.53 (1) students per square meter.
- Ellis Hall 321
    - 255.22m^2 (longest length is 11.51m, longest width is 22.35m)
    - 17 desks, 8 chairs per desk (seats 136 students)
    - 0.57 (1) students per square meter.

A floor plan of each existing classroom can be found in Appendix G: Supporting Documents for Adaptive Space Reuse Scope Component.

The constructability and time of construction must also be considered when selecting the locations to be reused. The team must consider what methods will be required to create these spacings, which may include the removal of load bearing walls, temporary shoring, and/or implement utility work. Utility work includes but is not limited to power cord needs (laptop, television, and cellphone), light panels, and conduits for future modifications and technology advances.

These items take time which may impact the construction schedule. For the current projects on Queen’s campus such as the Leonard Dining Hall renovation and the John Deutsch Hall renovation, it is predicted that the renovations of these rooms can take up to seven months to over a year (Queen’s University 2023b).

The proposed design should also be accessible for all students, staff, and faculty. Along with the AODA guidelines, the proposed design should take all opportunities to ensure that all students can participate in the interactive learning environment. Also, the proposed solution should be able to be modified for future renovations as needed. With a high-tech classification, the selected locations should allow for easy adaptability to technology advances. The area should have plenty of natural light and provide the look and feel of the existing high-tech classrooms at Queen’s.

During a site visit, the team visited multiple spaces that could be converted into these high-tech classrooms. The following images are markups of the converted floorplan of the potential spaces that can be reused. Full markups on the floorplan can be found in Appendix G: Supporting Documents for Adaptive Space Reuse Scope Component.

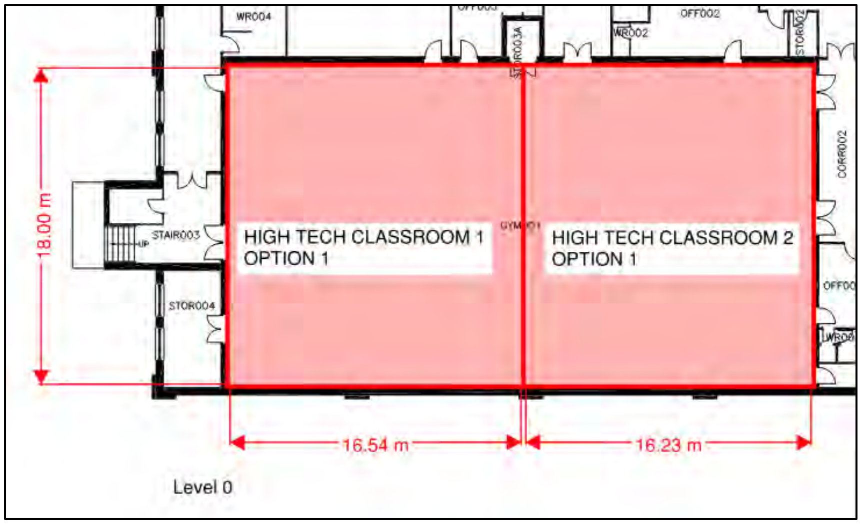

Figure 6: Option #1, Including Classroom 1 & 2 on Level 0

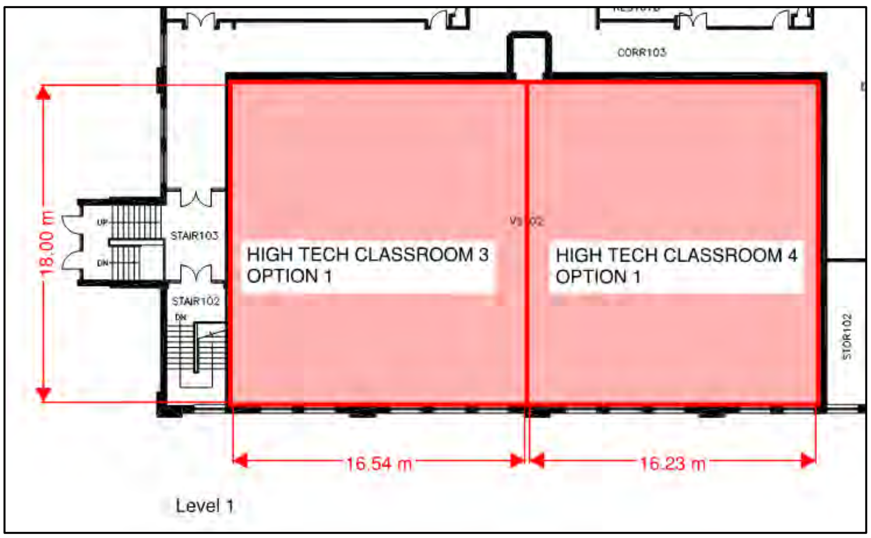

Figure 7: Option #1, Including Classroom 3 & 4 on Level 1

The first option requires the conversion of the existing gym on the northwest side of the building (GYM 001) into two high-tech classrooms per level (basement and first floor). Each class has a floor area of 292 m^2. Using an averaged value of the students per square meter from the Ellis and Jeffrey Hall high-tech classrooms, each classroom will be able to seat 160 students.

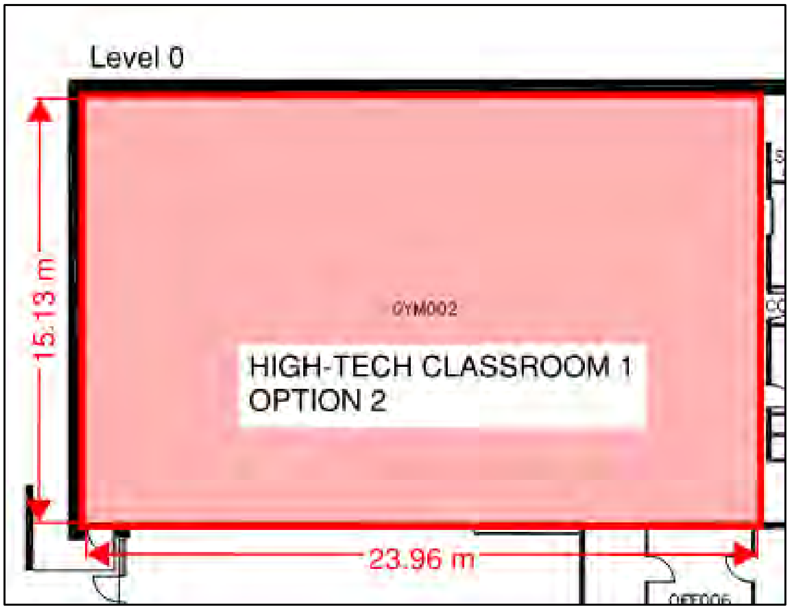

Figure 8: Option #2, Including Classroom 1 on Level 0

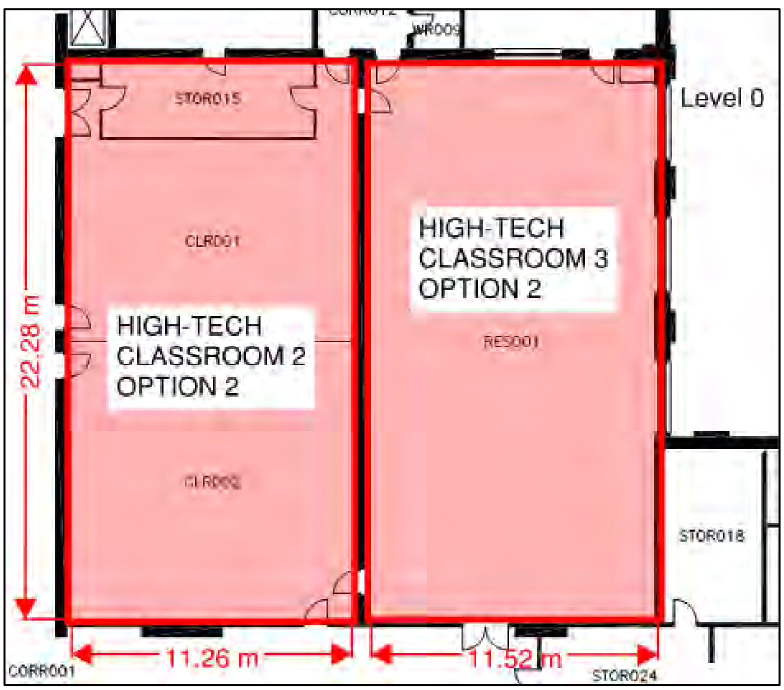

Figure 9: Option #2, Including Classroom 2 & 3 on Level 0

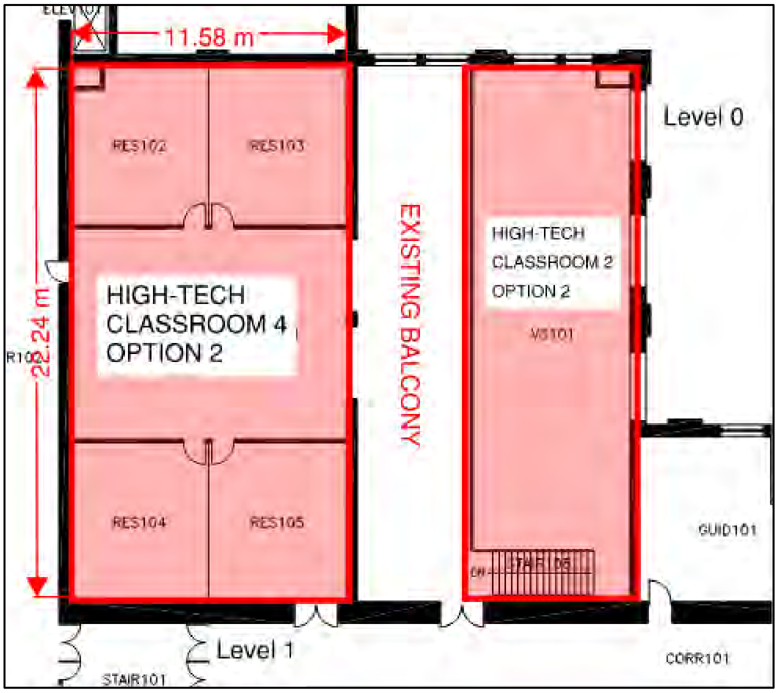

Figure 10: Option #2, Including Classroom 4 on Level 1

The proposed spaces for Option 2 are located on the basement and first level. The first classroom is proposed to be in the northeast gym, and the remaining three classrooms are to be in the existing library space, located on the central west side of the building. The gym has a floor area of 381 m^2. Each proposed classroom on the library space has a floor area of 265 m^2. Using an averaged value of the students per square meter from the Ellis and Jeffrey Hall high tech classrooms, each classroom will be able to seat a range of 146-210 students. Calculations for the estimated classroom capacities can be seen in Appendix G: Supporting Documents for Adaptive Space Reuse Scope Component.

5.3.1 Criteria and Evaluation

To select a proposed location for adaptive space reuse, each criterion will be provided a weight out of 100 points based on importance to the client and based on past team experience in the engineering design process.

Table 8: Reasons for Including Criteria and Justification of its Relative Weighting for the Adaptive Space Reuse Component

Criteria	**Score (/100)**	**Justification**
Cost	30.0	While it is important to save money where possible, being more cost-effective when reviewing design options will save the client from spending unnecessarily. Cost of ownership is not considered for this criterion because there will be no values considered that will save the client future potential costs.
Spacing Requirements for People and Equipment	20.0	This category should meet the minimum spacing requirements specifically from the client.

Accessibility	20.0	Accessibility is a feature that is highly important in the Queen's Building Guidelines. All proposed solutions must follow AODA guidelines, but the team will work to propose solutions that will enhance and improve accessibility.
Aesthetic/Natural Light	20.0	The client wants an inviting space that resembles the Queen's aesthetic, however this is not as important as the overall cost of the project.
Constructability / Time of Construction	5.0	There is no hard deadline when construction must begin, however the proposed space should not take an unfeasible amount of time for renovation and should use construction methods that are familiar to general contractors.
Allows for Easy Modification in the Future	5.0	While this criterion is ideal, it will not govern the design choices. This is a favorable feature; the team will focus on capturing the existing Queen's aesthetic first.

Along with the weighting, each proposed location will receive a score of 1-10 based on each criterion. A score rubric has been provided below to justify each score for each criterion. A score within each column in Table 9 was allocated based on the criteria being on the low, medium, or high range of that specific criteria. For example, in Table 9, a score of 1 will be allocated for cost if the retrofit costs greater than $\$2000/m^2$, a score of 2 if it costs between $\$2000/m^2$ and $\$1700/m^2$and a score of 3 if it costs between $\$1500/m^2$and $\$1700/m^2$.

Table 9: Adaptive Space Reuse Scoring Rubric for Each Criteria

Constraint	Score 1-3	Score 3-6	Score 7-10
Cost	Proposed renovation and transition to high-technology classroom costs over $\$1500/m^2$ due to the poor conditions of the existing rooms, and the number of spaces required for re-use.	Proposed renovation and transition to high-technology classroom costs $\$500$-$\$1500/m^2$ due to the moderate conditions of the existing rooms, and the number of spaces required for re-use.	The proposed renovation and transition to high-technology classroom costs less than $\$500/m^2$ due to the good conditions of the existing rooms, and limited number of spaces required to converge.
Spacing Requirements for People and Equipment	The spacing requirements allow for minimum capacity (120 students/classroom). Length to width ratio is unreasonable.	The spacing requirements allow for standard capacity (120-152 students/classroom). Length to width ratio is somewhat reasonable.	The spacing requirements allow for over maximum requested capacity (152+/classroom). Length to width ratio optimizes teaching possibilities for future students.
Accessibility	Opportunities to make the classroom even	There are some opportunities to make	There are more opportunities to make

Constraint	Score 1-3	Score 3-6	Score 7-10
	more accessible are not possible.	the classroom more accessible, such as its proximity to elevators, washrooms, and large spaces between desks.	the classroom more accessible, such as its proximity to elevators, washrooms, and large spaces between desks and a wide door entrance.
Aesthetics and Natural Light Use	The proposed space has limited windows that do not allow for much natural light to illuminate the classroom, and the overall look and feel of the classroom is poor.	The proposed space has some windows that allow for some natural light to illuminate the classroom, and the overall look and feel of the classroom is good.	The proposed space has many windows for natural light to illuminate the classroom, and the overall look and feel of the classroom is good.
Constructability / Time of Construction	Ease of construction is limited due to location of asbestos, temporary shoring is required on existing walls, limited existing utilities, considers removal of load bearing walls. Multiple floor and wall systems may be required. Time for renovation is estimated to be more than one year.	Ease of construction is moderate due to potential use of temporary shoring and the limited use of existing utilities. A singular floor or wall system is required. Time of renovation is expected to be 11-12 months.	Construction methods for renovations are limited due to the lack of wall construction required, and some existing utilities are available and active. Time of renovation is expected to be 7-8 months.
Allows for Easy Modification in the Future	The chosen space has limiting factors such as an irregular classroom shape, limited nearby classrooms, or is protected by Heritage by-laws such that changes will be difficult to implement in the future.	The chosen space has limiting factors such as an irregular classroom shape, and limited nearby classrooms, such that changes will be difficult to implement in the future.	The chosen space has minimal factors that influence future potential changes to the classroom to be changed.

With the criterion weight and scores for each solution option outlined, the WEM can be completed to choose which space should be selected for adaptive space reuse.

Table 10: Weighted Evaluation Matrix for the Adaptive Space Reuse Component

Criteria	Weightings	Option #1		Option #2	
		Score	Total	Score	Total
Cost	30.0	2	60.0	6	180.0
Spacing Requirements for People and Equipment	20.0	10	200.0	10	200.0
Accessibility	20.0	8	160.0	7	140.0
Aesthetic/natural light	20.0	5	100.0	9	180.0
Constructability / Time of Construction	5.0	2	10.0	7	35.0
Allows for Easy Modification in the Future	5.0	5	25.0	8	40.0
Total		555.0		775.0	

Therefore, the second option will be selected for the high-tech classroom conversion. Further analysis into the design selection will be outlined in 6.0 Conceptual Design, 7.0 Technical Analysis, and 8.0 Cost Analysis.

5.4 Roof Design

The fourth and final scope component is designing a new sustainable roof. The current roof being analyzed is a Built-up Roof (BUR) which has exceeded its lifespan. This particular BUR consists of a 4-ply membrane, an EPS insulation board, and a gravel surface (Gray 2021). The BUR sits on top of an 18-gauge corrugated steel deck with a series of wide flanged beams supporting the roof deck (Appendix H: Supporting Documents for Roof Design Scope Component). A technical analysis of how much load can be sustained by the roof can be found in Section All beams in this analysis have been approved for the classroom space. This will eliminate the requirement of steel retrofitting, or any other methods of remediation, therefore significantly reducing costs and time of construction. Stable Designs recommends the client to acquire a professional structural engineer to review this analysis prior to proceeding with the selection of the existing library space.
7.3 Roof Structural Supports. Since the current BUR has exceeded its 25-year lifespan for each of the building additions under investigation, replacement is imminent and necessary.

With the primary objective of promoting energy efficiency in the building there are several energy efficient modifications that can be made to the roof when replacing it. A wide range of solutions were discussed but after a preliminary evaluation during the idea generation process, the following options are the design concepts proposed to incorporate with the new roof design.

5.4.1 Option 1: Extensive Green Roof

A green roof is essentially a roof that can support life and vegetation. A green roof is also known as vegetated roofs, eco roofs or living roofs. The composition of a proper green roof consists of a rooftop waterproof and root protection membrane, a drainage layer, an irrigation system, a water retention fleece, a growing medium or soil, and the vegetation itself (Green Roofs 2013). A cross sectional depiction can be found in Appendix H: Supporting Documents for Roof Design Scope Component. Often, a lightweight soil will be used to reduce the overall dead load on the roof.

There are two different types of green roofs. The proposed design option is an extensive green roof instead of an intensive for reasons stated in Appendix C: Idea Generation Supporting Documents. An extensive green roof has a thin layer of soil and little to no irrigation after establishment whereas an intensive roof consists of large vegetation with deeper soils and wide-spread irrigation systems. An extensive green roof is self-sustaining, requiring no pesticides, herbicides, or fertilizers to grow. This type of green roof can withstand varying harsh climates, extreme temperature fluctuations and requires little maintenance (Green Roofs 2013).

One advantage to implementing an extensive green roof is that storm sewer runoff is reduced by retaining the water in the soil or nurturing the plants. A green roof also removes pollutants by absorbing carbon dioxide and filtering out pollutants within precipitation. The temperature of the water runoff leaving a green roof will also be much cooler than it would be coming of the existing BUR. A green roof also provides sound insulation, and it protects the roof against UV radiation. Green roofs are known for being an effective heat insulator. This can be used for water-based exchange systems and industrial cooling or for reducing energy required for air conditioning. Since green roofs keep relative surrounding air temperatures cooler in warm weather, they will increase the efficiency of near-by solar panels (Green Roofs 2013). Winter green roofs can ultimately reduce the energy used for heating by more than 10% during the winter seasons (Missios et al. 2005).

There are some considerations that need to be evaluated prior to designing and implementing a green roof. It is important that a proper leak detection system is in place since leaks will be difficult to detect from on top of the roof. Also, ensuring that there is an effective maintenance plan to constantly maintain the green roof to its full potential and ensure it maintains its long-term appeal. Some additional limitations of the green roof that must be considered includes root penetration, fire safety, and overall weight (Green Roofs 2013). A study was conducted in 2016 to understand the implications and costs associated with implementing a green roof over the entire life span. Figure 24 located in Appendix H: Supporting Documents for Roof Design Scope Component outlines these estimated costs. Note that this cost analysis does not account for any increases in structural capacity and costs will likely vary depending on location and current state of the building.

In 2016, a study was conducted that compared green roof performance in three different locations in Canada: London, ON, Calgary, AB, and Halifax, NS. Table 11 outlines the rainfall events and the green roof storm water retention rates (Hammond 2017).

Table 11: Summary of Rainfall Events in Three Canadian Cities (Hammond 2017) (O'Carroll 2016)

London, ON		
Event Size	**Events**	**Retention (%)**
Small (<3mm)	51	94
Medium (3-15mm)	81	77
Large (>15mm)	28	43
All Events	**160**	**76**
Calgary, AB		
Small (<3mm)	38	95
Medium (3-15mm)	39	92
Large (>15mm)	9	59
All Events	**86**	**90**
Halifax, NS		
Small (<3mm)	32	90
Medium (3-15mm)	36	52
Large (>15mm)	30	36
All Events	**98**	**60**

It is evident that the rainfall intensity and retention rates vary significantly for each city in Canada. This is not only a result of weather patterns varying by location but also that water retention depends on the health of the plants and the saturation of the growing medium (Hammond 2017). Therefore, a comprehensive understanding of the climate in Kingston, ON and material properties used in construction is required to effectively design a green roof.

5.4.2 Option 2: Blue Roof Water Catchment Facilities

A blue roof solution would involve designing a water catchment system on the roof along with the associated water catchment infrastructure. A blue roof works by collecting rainwater where it is slightly sloped to a few central points on the roof. From there, water will be directed from the rooftop down interior or exterior drainpipes. A blue roof can be outfitted with a smart drain valve that regulates the amount of water stored on the roof and the amount of water that is drained through the building (Taylor 2023).

There are a few options that can be done with the water, which will need to be evaluated if a blue roof is selected as the optimal roof design concept. The water could be used for the heating or cooling systems within the building. This would work by routing pipes to the heating or cooling units and supplying them with the water that is essential to operating their systems. The water also could be directed into an exterior, underground storage tank where the grey water could be filtered and stored. This stored water could then be used as non-potable water for the building when it is required (Taylor 2023).

There are several additional advantages to implementing a blue roof other than it being able to use rainwater for other purposes. Rainwater ponded on a flat roof can cool the interior of a building and reduce the need for air conditioning through a process of evaporate cooling. With a regulated drainage system, a roof catchment facility can also regulate or eliminate storm runoff into the city storm water system (Taylor 2023) (Szmudrowska 2020). Implementing a blue roof would be easy to retrofit based on the current roof drainage system, since the current roof simulates a blue roof catchment area. However, implementing the drainage system within the building would be a more difficult and involved task. In Appendix H: Supporting Documents for Roof Design Scope Component, a general example of a blue roof water catchment design is shown.

When considering the design for a blue roof it is important to consider that it will have to be regularly inspected and maintained. Mechanical systems and other rooftop architectural features cannot be impacted by the ponded water. A blue roof with basic water containment, pipes, sensors, and valves costs about \$21.00/m^2 (CAD) depending on the amount of rehabilitation involved prior to the blue roof installation (Szmudrowska 2020).

One of the primary advantages of implementing a blue roof is its ability to harvest water and reuse it for non-potable applications within the building. A study was conducted by Hammond where the harvesting potential of different building types was evaluated for three different Canadian cities. Figure 11 illustrates how rainwater harvested can contribute to non-potable uses like toilet demand in London, ON (Hammond 2017). Due to the relatively close proximity to Kingston, ON, the case study in London was the only one included by Hammond.

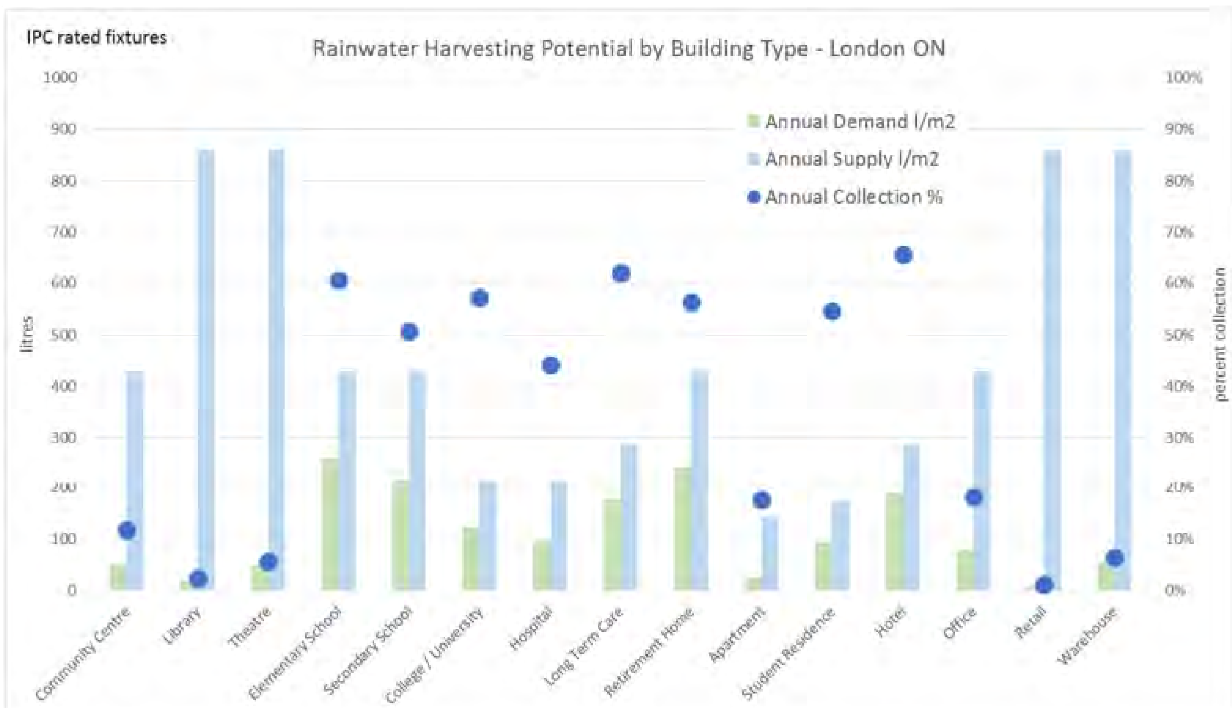

Figure 11: Average Annual Toilet Demand and Rainwater Supply by Building Type (Hammond 2017)

It is important to note that there are several limitations in the current evaluation methods. Some of these uncertainties include use of aggregated monthly precipitation data, variations in building occupancy patterns, future climate variability, and limited economic data for rainwater harvesting systems (Hammond 2017).

5.4.3 Combination of a Blue Roof and Green Roof

Since green roofs and blue roofs are used to solve essentially the same problems, it may be beneficial to combine the two options. Implementing a hybrid roof would not only combine the benefits of each sustainable roof type but it would also create new challenges. One additional challenge to consider is a significant amount of weight would be added to structural support system. With a hybrid system it would also be necessary to ensure that the proper high-quality membranes and liners are used to separate and protect the systems. Additional monitoring technology would then be required to ensure the system is working properly and efficiently, especially now that the blue roof is no longer easily accessible for serviceability and maintenance. Finding qualified contractors to build this system properly would be difficult and expensive.

Since the technology is relatively new, there is limited understanding of the long-term implications. Therefore, it is necessary to analyze case studies of a green roof and blue roof hybrid. The South Korea University of Science and Technology conducted a study at Chungwoon middle school where they implemented a green-blue roof. In this study a 285 m^2 green-blue roof assembly was placed on top of the common roof and was compared to an adjacent common control roof section of similar size (Shafique et al. 2016). Photos and diagrams of the green-blue roof can be found in Appendix H: Supporting Documents for Roof Design Scope Component. From July 24^{th}-28^{th} of 2014, a storm occurred with an average rainfall intensity of 90mm/hr (Shafique et al. 2016). The runoff control and the surface temperature of the green-blue roof was measured and compared to the control roof. Found in Appendix H: Supporting Documents for Roof Design Scope Component, Figure 29 displays the variation of water flows and Figure 30 displays the variation of surface temperature. The study concluded that overall runoff outflow is consistently much smaller than the control roofs along with a significantly reduced peak outflow. These results clearly show that the green-blue roof was effectively able to store rainfall and regulate its outflow, which would ultimately reduce stress on storm water infrastructure. It was also concluded that the green-blue roof had reduced its surface temperature by roughly 5˚C compared to the control roof. This indicates that a green-blue roof was able to change the microclimate of the roof, which increases the building's energy efficiency by reducing cooling costs (Shafique et al. 2016).

5.4.4 Criteria and Evaluation

Upon further research it was determined that there are many unknown factors involved in implementing both green roofs and blue roof facilities. Due to time constraints and lack of quantifiable research, Stable Designs has elected to not evaluate these options through a WEM. A full detailed design of an innovative roof will not be provided. Instead, Stable Desings will assess the design options based on the client and building requirements as well as their relative compatibility with the current roof. It is recommended that another consultant focuses specifically on an innovative roof design.

The quantitative criteria that must be considered when selecting the best option or a combination of options is outlined in Table 12. This process was conducted in association with the Queen's Facilities team. Some of the criteria is important to consider including cost of ownership and energy efficiency improvements, however, is difficult to assess based on a lack of long-term, quantifiable data.

Table 12: Qualitative Criteria to Consider When Implementing an Innovative Roof Design

Criteria	**Description**
Upfront Cost	Based on the size of the roof and the scale of the undertaking to replace the entire roof, there will be a significant upfront cost associated with doing any option. Therefore, ensuring this cost isn't completely unattainable is important.
Cost of ownership	The cost of ownership essentially justifies the implementation of the roof design. In conjunction with energy efficiency improvements, if the added efficiency will save money in the long term, the implementation of the design is justifiable.
Energy efficiency improvement	The primary objective of this project is to improve the energy efficiency of this building. Therefore, when deciding on a roof design it is one of the most important criteria to consider.
Weight	It is important that the proposed roof concept weight is kept to a minimum. The current roof support system can support an additional 2.08 kPa of load, any more load and additional structural supports will be required. This value was calculated in the technical analysis Section 5.3: Roof Structural Supports. If the proposed design is significantly heavier than other, it will lead to an extensive and costly design process.
Life span	Since a roof replacement is such a large undertaking, it is important that the proposed roof design concept has a long-lasting life span. This directly correlates to the cost of ownership since the longer the life span is of the roof concept, the less money will have to be spent on replacement.
Sustainable initiatives government grants or subsidies	There are several different grants or subsidies that the design could be eligible for. This would be great for saving upfront costs and justifying cost of ownership along with providing Queen's with a marketable accolade. However, this is a bonus of the roof design and isn't necessary.
Stress on storm water system	The existing storm water system is old and a combined sanitary and sewer system. Any significant flow into the system will create significant consequences. Depending on the roof design concept, the stress on the storm water system could vary. Currently, there are large ground infiltration areas on site resulting in little stress on the storm water system. Therefore, it is important that there is not a significant increase in storm water output but if the change is minor then this criterion is not as significant as others.
Constructability	There is no hard deadline when construction must begin, however the proposed space should not take an unfeasible amount of time for renovation and should use construction methods that are familiar to general contractors. It is important that constructability is considered to ensure that the building can be operation in a feasible amount of time.
Accessibility of materials or people who can construct	When proposing the roof design, the availability of the materials and people who have experience constructing the design will make the job go smoother, be more effective and cost less. Although it is

Criteria	Description
	important to ensure there are people and materials readily available to construct the proposed roof concept, if a job of this scale is feasible, it will be necessary to hire specialists and get the best materials regardless.
Serviceability of roof	Maintenance workers will be the main stakeholders involved directly with the everyday function of the roof design. The roof needs to be serviceable for maintenance purposes however since maintenance will be relatively infrequent, it is not as important as some of the other criteria.
Aesthetics	Since the scope of the building in focus is primarily 3 stories above ground, there are very few people that will be able to see the roof. Student and faculty access will also likely be limited. Therefore, there is little need for pleasing aesthetics however, it is something to consider for Queen's marketing and advertising for example.

Since some of the important design criteria is difficult to assess based on current research, a design option will not be selected but instead a quantifiable process has been developed that will help inform the best decision. Referencing the qualitative criteria in Table 12, a process of determining what option is the most viable can be conducted using a flow chart as seen in Figure 12. Determining the optimal solution using this approach is more logical than a WEM due to lack of understanding and quantitative data of the long-term implications of these innovative roof design options.

To begin the evaluation using Figure 12, start with the overarching problem in green and then evaluate the criteria under question in the orange diamonds. Once a decision has been made follow the resultant criteria in the blue rectangles and continue the process. Note that some criteria are cumulative, and the greater sum of best solutions will lead to the best design decision. The ovals in yellow are ultimately the final design decision. It is possible to have both a green roof and blue roof system based on the cumulative criteria being divided equally. Therefore, a further detailed analysis is required that includes accurate cost of ownership and energy efficiency evaluations of both options to determine the best possible solution.

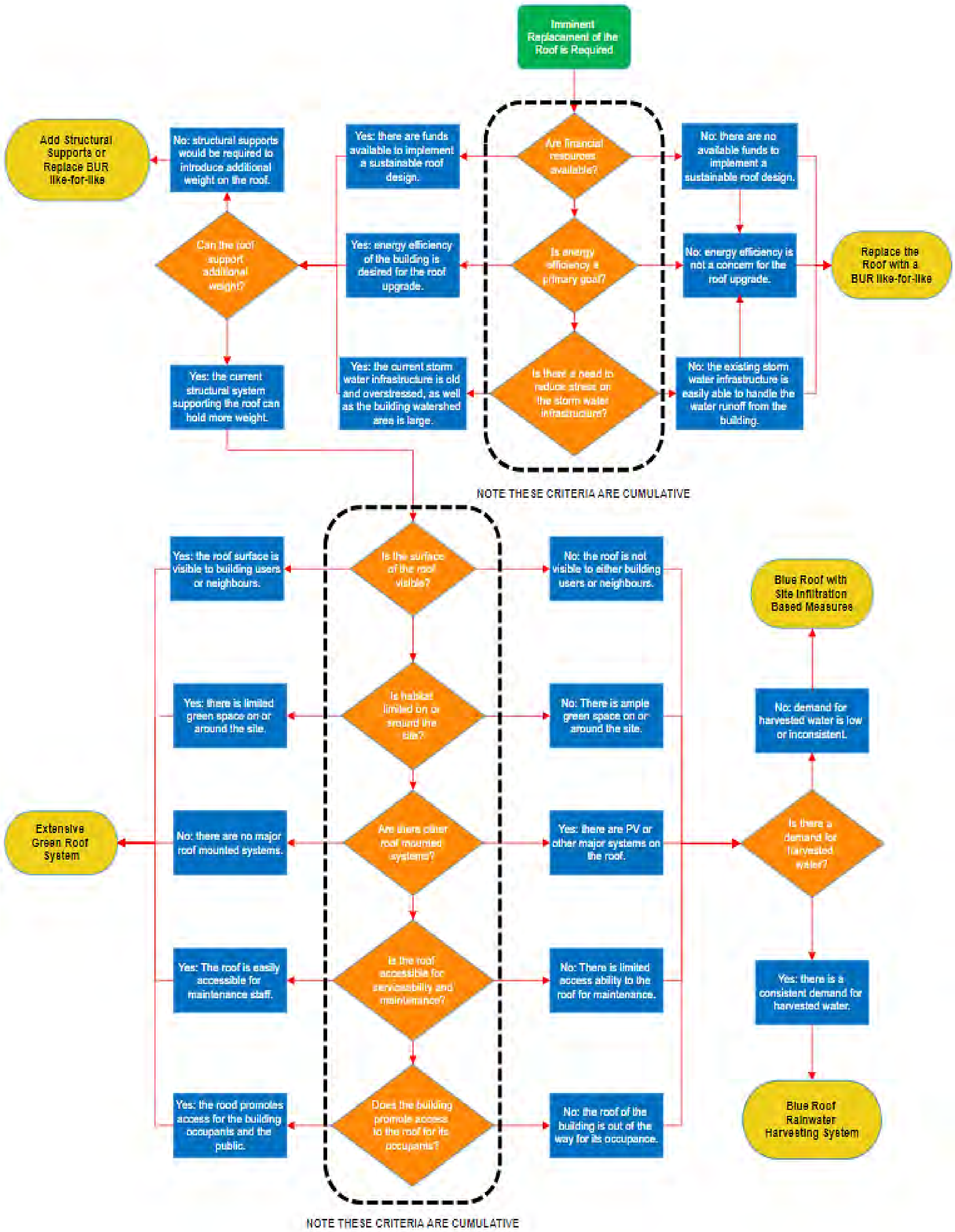

Figure 12: Roof Design Option Evaluation Flow Chart

6.0 Conceptual Design

This section further discusses the selected design for each scope component.

6.1 Windows

The method recommended to repair the windows and increase its energy efficiency is through secondary glazing. There are multiple different window types throughout the structure, all of which are considered heritage windows; therefore, many different frames are required to integrate the secondary glazing into the structure.

Secondary glazing typically has minimal initial cost. The price will consist of framing for the various windowsills, the number of panes being installed, and labour. The aesthetic of the secondary glazing does not have to match any heritage guidelines as they are not part of the building's façade. Therefore, the client has freedom when choosing the appearance and material of the glazing.

Prior to implementing the secondary glazing into the structure, it is essential to confirm that it meets the Fire Safety regulations. The regulation that the secondary glazing needs to satisfy includes the O. Reg. 213/07: Fire Code 2.5.1.2 and 9.8.3.4. These regulations prevent the glazing from obstructing any fire access routes for firefighting operations and ensure windows used for a second means of escape can be opened from the inside without the use of a tool (Government of Ontario 2014a).

Additionally, the number of panes can vary for secondary glazing. The team evaluated the use of a single pane, double pane, and triple pane secondary glazing implementation for KCVI. The more panes used will reduce the energy consumption which minimizes the carbon emission and has a beneficial environmental impact. However, the more panes installed will increase the initial cost. To determine the most effective option, the initial cost, cost of ownership, and energy efficiency is compared in Section 8.1 Windows.

After this thorough analysis and further discussion with the clients, it was determined that double pane secondary glazing would be the best suited option to implement throughout KCVI. As previously mentioned, there are multiple windowsill shapes located throughout the building. This is important to recognize and ensure that there is secondary glazing framing for each window shape. The team recommends using an aluminum window frame to keep the panes in place as it is high strength, low maintenance, and has excellent thermal efficiency (Giles 2024).

6.2 Wall Composition

The selected insulation type for the wall composition is closed cell spray foam. Closed cell spray foam was chosen due to its superior RSI value per 25.4 mm of thickness compared to the other options. This allows the thickness of the wall to be up to 38% smaller than other options to achieve the same RSI value. This feature relates to the energy efficiency, which was the most important criteria of the wall insulation. Closed cell spray foam insulation also acts as an effective air barrier as it can conform and expand into small spaces, ensuring a seamless and tight fit. This ability prevents drafts and moisture infiltration, thereby mitigating the risk of mold and moisture-related issues within the walls. This is important from a maintenance and longevity perspective for a couple of reasons. For example, a water pipe bursts, or the fire sprinklers go off, if fiberglass insulation were used, all of it would need to be replaced. However, with closed cell spray foam this is not the case as it does not hold moisture. Additionally, the other layers within the wall composition behind the spray foam would not get ruined or have water in between, mitigating the risk of mold. Spray foam's ability to conform and expand into small spaces is also beneficial for the use of the space. As KCVI will be rehabilitated back into a learning space, having a tight fit maximizes noise reduction, allowing for a better learning environment.

As the client did not express a timeline, which is reflected in the time of construction criterion weighting, the longer construction time for spray foam compared to the other two options is not an issue. However, there are more risks with the construction process of spray foam compared to the other two insulation options which is explained in Section 9.0 Risk Assessment.

For the proposed wall composition, five different options were considered using spray foam. These are summarized below in Table 13.

Table 13: Structural Sizing and Material Options for Wall Size to Hold Spray Foam

Option	Stud Material & Dimension	Spray Foam Thickness (mm)
1	Wooden 2" x 4" studs	88.90
2	Wooden 2" x 6" studs	139.70
3	Metal 1.25" x 3.625" studs	92.08
4	Metal 1.25" x 4" studs	101.60
5	Metal 1.25" x 6" studs	152.40

Through energy efficiency calculations, upfront cost, and cost of ownership analyses, outlined in detail in Appendix E: Supporting Documentation for Wall Composition Scope Component, the preferred solution was Option 4 in the terracotta section of the building, and Option 5 in the reinforced concrete section of the building. The proposed wall compositions are illustrated below.

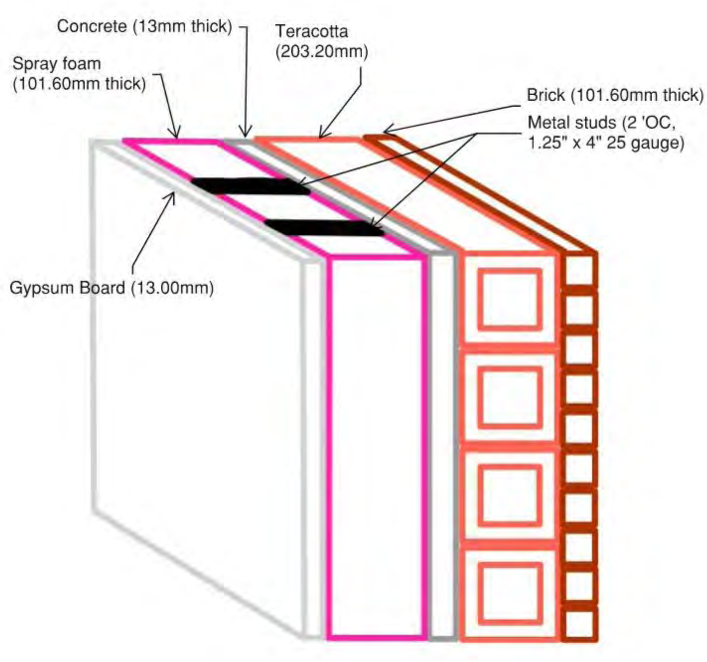

Figure 13: Typical Cross-Section of the Proposed Solution for the Terracotta-Based Wall Composition.

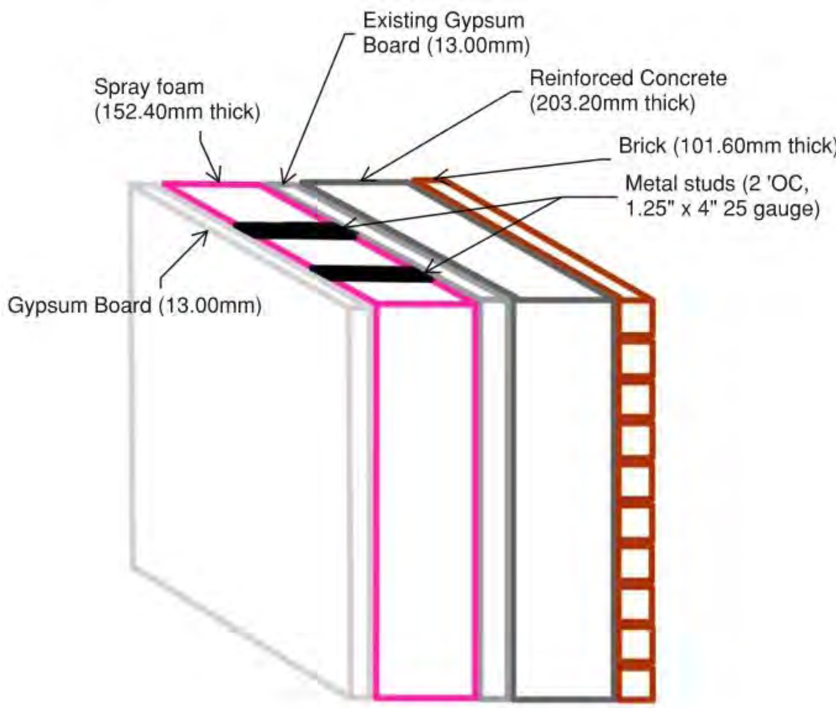

Figure 14: Typical Cross-Section of the Proposed Solution for the Reinforced Concrete-Based Wall Composition.

In the terracotta-based wall composition, 1.25” x 4” 25-gauge non-load-bearing metal studs will be used with a spray foam thickness of 101.6 mm. In the reinforced concrete-based wall composition, 1.25” x 6” 25-gauge non-load-bearing metal studs will be used with a spray foam thickness of 152.4 mm. Note that these non-load bearing metal studs are available from DASS metal products (DASS Metal 2024). These metal studs are non-load bearing as their primary objective is to house the insulation against the current wall composition.

6.3 Adaptive Space Reuse

The selected space is in two large areas across the building footprint: the northeast corner, and the central-west side of the building, on the basement and first level floor. Upon further discussion with the client, found in Meeting #5 in Appendix F: Meeting Minutes, the gym space acting as the first proposed classroom (Gym 002) will be discarded from the technical analysis and cost analysis.

Although the gym was initially considered, the costs that comes with converting a gym space to a high-tech classroom is large, considering the amount of utility work that will need to be added. Also, the lack of natural light and high ceilings will cause auditory and visual concerns. Stable Designs will continue with a three-classroom proposal in the existing library space.

The three proposed classrooms are 22.6 m long and 11.6 m wide. Therefore, the classroom floor area is 265 m^2. This classroom size meets the maximum length to width ratio requirements and will guarantee the space capacity for 120 students. Any other configuration (for example, keeping the actual layout CLR 001-002) will risk not being able to hold 120 students, and will not provide a cohesive space that promotes collaboration. Pictures of the selected location are in Appendix G: Supporting Documents for Adaptive Space Reuse Scope Component.

Stable Designs suspects that the costs will be minimal because the removal of load bearing walls and/or the construction of new complete floor and walls are not required, therefore temporary shoring is not needed. Most of the costs will go towards removing the partition on the northern sections of the space. The team expects the renovation time to be 7-8 months based on the current timelines provided in active renovations around Queen's Campus (Queen's Gazette 2022)

The spacing requirements for each classroom allow for a maximum of 146 people. The length to width ratio optimizes teaching possibilities for future students as each room is a rectangular shape with little-to-no intrusions in the floor plan. The spacing also opens opportunities for accessibility as there is a lot of open space to work with and is near building exits and elevators.

The proposed space has natural light from the south side windows, but the northern spaces are not exposed to much sunlight. The team will consider the use of windows along the southern wall (of the northern classrooms) to obtain more sunlight into the space. In Appendix G: Supporting Documents for Adaptive Space Reuse Scope Component, concept sketches have also been provided to provide a visual, innovative concept of the proposed space.

6.4 Innovative Roof Design Assessment

Innovation is a cornerstone of the team's design philosophy, with the incorporation of new design processes, approaches, and technologies. With the replacement of the roof comes an opportunity for innovation which may include renewable energy sources, efficient energy practices, sustainable building materials, and smart building technologies.

The intent behind conducting such detailed research on this topic began with a desire for energy efficiency and the pressing need for a roof replacement. As the research developed it became apparent that there are new systems and technologies that could drastically change the performance of a building. To improve the energy efficiency of an existing building, often the envelope and heating/cooling systems are upgraded. To reduce stress on the storm water infrastructure it is common for the infrastructure itself to be upgraded. Therefore, addressing both issues from a different perspective, along with several other added benefits is an attractive alternative for many building owners. The combination of creating a new way to solve these problems along with long-term quantifiable research being sparce is a testament to Stable Designs' innovative design philosophy. Installing a blue roof on KCVI would be the first one in Kingston and even more significantly, it would be on a historical building. Blue roofs are often only implemented in new buildings. Therefore, this research has been conducted to not only be utilized for KCVI but also to act as a stepping stone for how Queen's University implements roof upgrades in the future.

There are a few notable case studies conducted on green roofs, blue roofs, and a combination of both. These studies outline the effectiveness of rainwater harvesting systems for both roof types and provides detailed information on what to consider when deciding on what type of roof system is best suited to a specific building. It was also found that there are significant effects on reducing roof surface temperature and reducing rainwater runoff into storm water systems (Shafique et al. 2016). Although the research contains limitations, it is recommended that these case studies are utilized as the groundwork for a full detailed roof design for the KCVI building.

It is recommended that another consultant focuses specifically on the roof design and conducts in-depth research to justify the viability of implementing a design solution. Ensuring that the new roof has improved insulation is essential to enhance energy efficiency in the overall building envelope. A minimum RSI value of 9.69 m^2K/W is recommended for the roof insulation of the building (EcoStar Insulation 2020). A full detailed design should consider the local climate and ensures that the roof upgrade effectively ties in with the existing structural system, architectural features, and the surrounding environment. A cost of ownership must be completed to justify the capital costs required for the upgrade.

7.0 Technical Analysis

This section is a preliminary technical analysis of the four scope components. This section includes window and wall composition energy efficiency calculations, structural floor system analysis for adaptive space reuse, and roof capacity calculations.

7.1 Energy Efficiency Calculations

A large portion of the project scope is to determine the energy efficiency of the building envelope, including the windows and wall composition. An energy efficiency analysis was performed on each of the potential window and wall composition options to determine each options energy efficiency. This analysis was conducted by determining the total heat loss in units of kilowatts-hours, resulting from each option over the year using the following equation (Mousdell 2023).

$$Heat\ Loss = (Area)(Uvalue)(Temperature\ Difference)(Days\ in\ Month)(Hours\ per\ Day)$$

Assuming the temperature inside KCVI is 21°C (294.15 K) all year around, the temperature difference between inside and outside the structure can be determined using the average temperature in Kingston per month (NOAA 2023), as shown in Table 14 below.

Table 14: Temperature Data for All 12 Months in Kingston, Ontario

Month	**Average Temperature (°C)**	**Average Temperature (K)**	**Temperature Difference (K)**
January	-7.00	266.15	28.00
February	-6.00	267.15	27.00
March	-0.50	272.65	21.50
April	6.50	279.65	14.50
May	13.50	286.65	7.50
June	18.50	291.65	3.00
July	21.50	294.65	0.50
August	20.50	293.65	0.50
September	16.00	289.15	5.00
October	9.50	282.65	11.50
November	4.50	277.65	16.50
December	-3.00	270.15	24.00

7.1.1 Windows

It is important to have good energy efficient windows in large structures such as KCVI, as the windows take up a large area along the exterior walls. In KCVI the windows have a total area of approximately 1180.54 m^2 along the exterior of the structure. This area calculation can be found in Appendix D: Supporting Documents for Windows Scope Component.To determine whether windows are energy efficient, the insulation factor can be determined by inversing the energy efficiency value of the windows, as shown below.

$$Uvalue = \frac{1}{Rvalue}$$

Typical windows have a U-Value that ranges from 1.1 to 6.7 (US Department of Energy 2010). A lower insulation factor means the windows are more energy efficient and has sufficient insulation.

The addition of fixed secondary glazing involves implementing an additional window on the interior of the structure. The implemented secondary glazing's RSI value differs based on the thickness and the material of the glazing. The RSI value depends on the current windows energy efficiency, assuming KCVI's current windows have an RSI value of 0.18 m^2K/W, the total heat loss for a thin, medium thickness, and thick secondary glaze can be approximated using measurements from a Chameleon article (Povshednyy 2023). Using these values, the insulation factor can be determined in Table 15.

Table 15: Relative R and U Values for Different Window Glazing Thicknesses

Number of Panes	Total R-Value ($\frac{ft^2*°F*h}{BTU}$)	Total RSI Value (m^2K/W)	U-Value (W/m^2K)
Single Pane	2.08	0.37	2.73
Double Pane	3.08	0.54	1.84
Triple Pane	4.23	0.74	1.34

The U-value, along with the total area of windows, and the average temperature difference for each month, the heat loss due to the windows for KCVI can be determined. A sample calculation for a single pane secondary glaze for the month of January can be seen below (eFunda, Inc 2024).

$$Rvalue\ conversion = 2.08\frac{ft^2 * °F * h}{BTU} * \frac{1}{5.67446\ \frac{m^2 * K}{W}} = 0.37\frac{m^2 * K}{W}$$

$$Uvalue = \frac{1}{0.37\ \frac{m^2K}{W}} = 2.73\ \frac{W}{m^2K}$$

$$Heat\ Loss = (1180.54m^2)\left(\frac{0.48W}{m^2K}\right)(28\ K)(31\ days)(24\frac{hours}{day})$$

$$Heat\ Loss = \ 11824\ kWh$$

Using this equation for the different number of panes corresponding U-value and changing the temperature difference for each month, the total heat loss per month was determined. These values can be summed to provide the total heat loss due to the windows in KCVI per year, as shown in Table 16.

Table 16: Relative Heat Loss for Each Month Based on Number of Secondary Glazing Panes

Month	Heat Loss (kWh)		
	Single Pane Secondary Glaze	Double Pane Secondary Glaze	Triple Pane Secondary Glaze
January	67092	45309	32991
February	58435	39463	28734
March	51517	34791	25332
April	33623	22707	16534
May	17971	12136	8837
June	6957	4698	3421
July	1198	809	589
August	1198	809	589
September	11594	7830	5701
October	27556	18609	13550
November	38261	25839	18814
December	57508	38836	28278
Annual Sum (kWh)	**372911**	**251836**	**183370**

According to Table 16, the range of projected annual heat loss based on a few assumptions is 183,370 kWh to 372,911 kWh depending on the number of panes. It is important to compare the upfront cost with the cost of ownership as the more panes will cost more initially, however, over time it will have a better energy efficiency. This will save Queen's money in the future and could be more beneficial in the long term. It was determined that double pane secondary glazing would be the most efficient option after comparing the energy efficiency with the cost of ownership, as shown in 8.1 Windows.

7.1.2 Wall Composition

The area of the walls were required to determine the amount of allowable heat loss of the proposed solution. This was done through the AutoCAD drawings the client provided, determining the perimeter of the walls from each of the four floors. The basement and first floor have the exact same building footprint, as well as the second and third floor. Using the respective heights of the four floors, and subtracting the area of the doors and windows, the total area of exterior walls is 5383.29 m^2. Note that all the detailed calculations, assumptions made, and information used for this section are shown and explained in Appendix E: Supporting Documentation for Wall Composition Scope Component.

Using the diagrams illustrated in Figure 13 and Figure 14, the combined U value of the new proposed wall compositions are summarized below in Table 17. Note that the metal studs were excluded from the combined U value calculation.

Table 17: Evaluating Thermal Properties of the Proposed Wall Composition Materials (My Engineering Tools 2023) (Rahmani et al. 2022) (Purios 2017)

Structural Wall Component	Wall Element	Thickness (mm)	Thermal Conductivity (W/mK)	RSI value (m^2K/W)	Combined RSI Value (m^2K/W)	Combined U Value (W/m^2K)
Terracotta	Brick	101.60	0.72	0.14	9.52	0.11
	Terracotta	203.20	0.82	0.25		
	Air	128.00	0.02	5.12		
	Concrete	13.00	0.50	0.03		
	Spray Foam	101.60	0.02	3.91		
	Gypsum Board	13.00	0.17	0.076		
Reinforced Concrete	Brick	101.60	0.72	0.14	7.63	0.13
	Reinforced Concrete	203.20	0.50	0.41		
	Existing Gypsum Board	13.00	0.17	0.08		
	Spray Foam	152.40	0.02	6.93		
	Gypsum Board	13.00	0.17	0.08		

The insulation building code of 2021 states that in Kingston, the overall RSI value for exterior walls are recommended to be at least 7.05 m^2K/W (EcoStar Insulation 2020). From Table 17, the proposed solution is over this recommended limit, meeting the insulation building code. Note that the terracotta-based wall composition accounts for 3379.2 m^2 and the reinforced concrete-based wall composition accounts for 2004.09 m^2 of the total exterior wall area. With their respective U-values, the heating usage can be calculated and can be compared to the existing conditions to compare how well this solution improves energy efficiency. Note that KCVI is heated through its own boiler system using natural gas, it is not connected to the Queen's steam system. KCVI does not have any existing cooling system.

Queen's Facilities provided Stable Designs with some past metering data of the building to understand current annual heating usage, shown in Appendix E: Supporting Documentation for Wall Composition Scope Component. This information was used to calibrate the different sources of heat loss throughout the entire building, and how many cubic metres of natural gas are used annually. Table 18 below summarizes the five main areas of heat loss within KCVI using the proposed solution for both the walls and windows. It also assumes an overall RSI value of 9.69 m^2K/W for the roof. Note that thermal conductance is calculated as follows.

$$Thermal\ Conductance = (U\ value\ of\ Item) * (Area\ of\ Item)$$

Table 18: Thermal Conductance of Different Surface Areas in the Building

Heat Loss Type	Thermal Conductance (W/K)
Exterior Wall Surface Area Loss	617.70
Exterior Window Surface Area Loss	2174.98
Exterior Door Surface Area Loss	49.19

Heat Loss Type	Thermal Conductance (W/K)
Roof Surface Area Loss	574.83
Air Infiltration	4450.38

Using the KCVI's heat loss envelope, the proposed wall composition heating usage is summarized below in Table 19. Note that July does not have any natural gas usage because the average temperature is above the design room temperature, and KCVI does not have a cooling system.

Table 19: Average Natural Gas Usage by Month

Month	ΔT (K)	Heat Loss (kWh)	Natural Gas (m^3)
January	28.00	109806.00	27940.00
February	27.00	98040.00	24947.00
March	21.50	84315.00	21454.00
April	14.50	55029.00	14002.00
May	7.50	29412.00	7484.00
June	3.00	11385.00	2897.00
July	0.50	0.00	0.00
August	0.50	1961.00	499.00
September	5.00	18976.00	4828.00
October	11.50	45099.00	11476.00
November	16.50	62620.00	15934.00
December	24.00	94119.00	23949.00
		Total Sum (m^3)	**155,410.00**

Refer to Appendix E: Supporting Documentation for Wall Composition Scope Component for detailed explanations of all assumptions and calculations. It is imperative to acknowledge that a calibration factor of 1.5 is necessary to adjust natural gas consumption, derived from metering data provided by Queen's Facilities. The total heating bill indicated in the metering information includes various fees like service charges, delivery fees, taxes, etc., in addition to the natural gas cost. The precise proportion of these additional fees within the monthly natural gas bill is unknown.

Upon calibrating heat loss sources throughout the building based on existing conditions to match the annual heating cost provided by Queen's Facilities, a ratio of 1.5 was established. This adjustment accounts for the inclusive nature of the calculated annual usages and removes additional fees for a fair comparison. This clarification is elaborated in Appendix E: Supporting Documentation for Wall Composition Scope Component. Therefore, the proposed solution suggests an annual natural gas usage of 103,607 m^3, significantly reducing consumption compared to the current usage at KCVI, which exceeds 260,000 cubic meters, achieving a reduction of over 2.5 times.

7.2 First Floor Structural Analysis

The technical analysis for the adaptive space reuse will involve preliminary analysis of the floor's structural system and will determine its feasibility for a high-tech classroom. The team will assume the floor beams are fully laterally supported. The approach for the structural analysis for this scope component was discussed with the team's professor, Dr. Neil Hoult, who specializes in structural and infrastructure engineering, and currently teaches at Queen's University.

To analyze a fully laterally supported beam, local bucking, shear strength, deflection, and flexural strength of the beams will be checked. The analysis is based on the architectural drawings from Colin Denver– Architect, July 19, 1929, based in Kingston, Ontario, which is in Appendix G: Supporting Documents for Adaptive Space Reuse Scope Component.

The location of each beam relative to each other, the beam metric name, and length is noted in Figure 15.

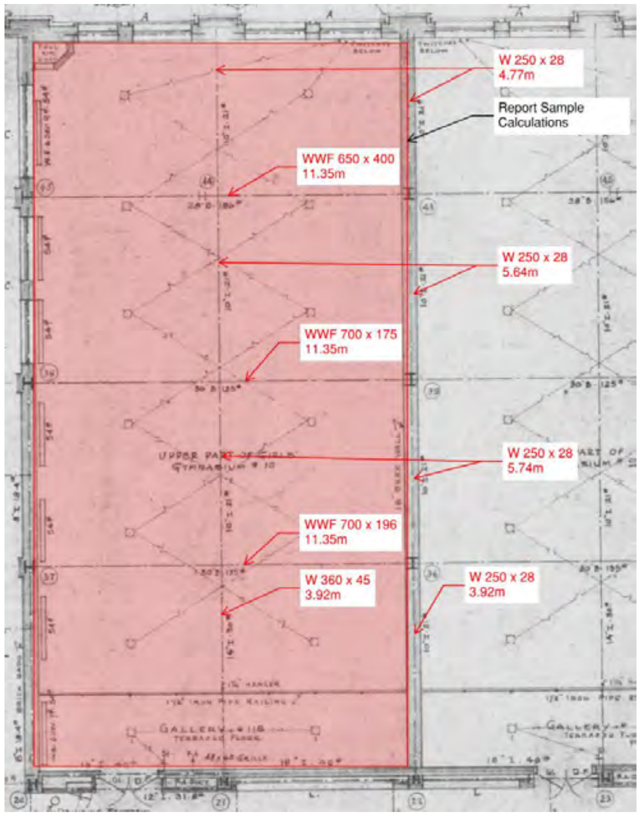

Figure 15: A figure showing the area of focus for analysis and highlights the beams under analysis.

The floor system consists of eight W-section beams (w), and three built-up sections (WWF). The beams that span 11.35 metres (WWF), experience a point load from the overlying steel beams located in the middle of the floor system.

To analyze each beam, a load combination investigation must be performed. The calculated dead load includes the dead load of the concrete deck. According to the drawing specifications, the thickness of the concrete slab is 2 inches, or 0.05 metres. The weight of the concrete can be calculated using the density of concrete, which is assumed to be 24 kN/m^3.

$$\sigma_c = \gamma_c \times t_c = 24 \times 0.05 = 1.20$$

Clause 4.1.5.3, Division B of the National Building Code of Canada (NBCC) 2020 states that the live load for classrooms with or without fixed seats are 2.4 kPa. For the purposes of this report, a sample calculation will be created for a beam size of W250x28, that is 4.77 meters long. According to the OBC, W210 steel was used in buildings from 1905-1932.

Table 20: Load Combination Calculations for Adaptive Space Reuse

LC	Combination	Calculations	Factored Load – σ (kPa)
1	1.40DL	1.40x(1.20)	1.68
2	1.25DL + 1.50LL +1.00SL	1.25x(1.20) + 1.50x(2.40)	5.10

Therefore, the selected factored stress will be 5.10 kPa. To calculate the uniform load from that stress distribution, one must solve for the tributary area of each beam. The tributary area for each beam is highlighted in the figures below.

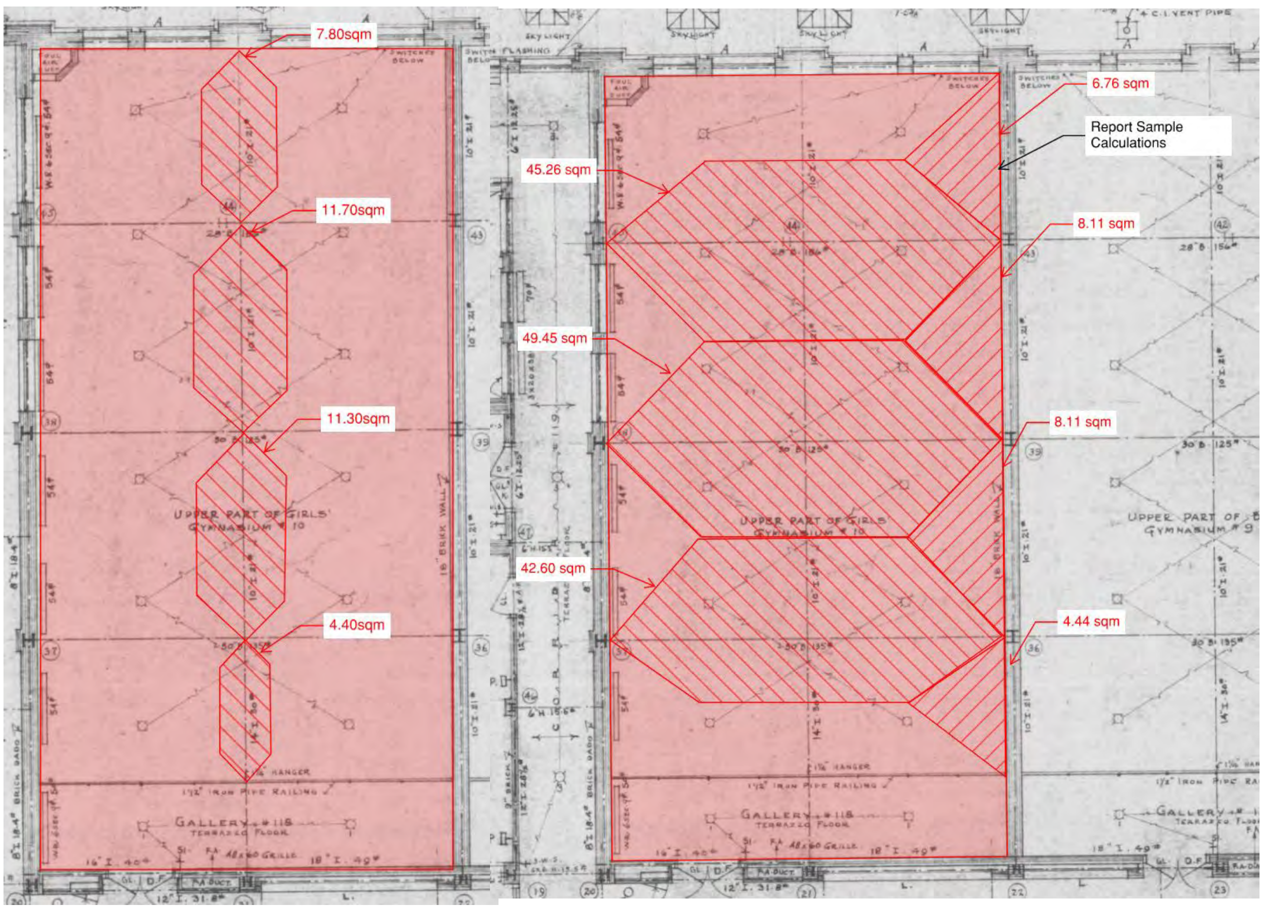

Figure 16: A figure showing the different tributary areas for each beam analyzed.

Using the tributary area for the beam used in this sample calculation, the uniform load is calculated.

$$w = \frac{\sigma \times TA}{L} = \frac{5.10 \times 6.76}{4.77} = 7.27\ kN/m$$

Assuming a simply supported beam, the maximum shear (V_f) and moment (M_f) observed on the beam are:

$$V_f = \frac{w \times L}{2} = \frac{7.27 \times 4.77}{2} = 17.34\ kN$$

$$M_f = \frac{w \times L^2}{8} = \frac{7.27 \times (4.77)^2}{8} = 20.65\ kNm$$

With the maximum factored shear and moment values, local buckling, shear strength, deflection, and flexural resistance can be calculated. These standards are outlined in the Code.

For local buckling:

$$\frac{b}{2t} \leq \frac{170}{\sqrt{350}}$$

Where b is the width of the flange (mm), and t is the thickness of the flange (mm).

$$\frac{102}{2 \times 10} \leq \frac{170}{\sqrt{350}}$$

$$5.10 \leq 9.09$$

For shear strength:

$$V_R = \varphi A_w F_s$$

Where φ is 0.9, a reduction factor outlined in the Code. A_w is the area of the web in the beams' cross section. F_s is the material property's strength based on the web geometric sizes.

$$V_R = \varphi \times (d \times w) \times 0.66 \times F_y$$

$$V_R = 0.9 \times (259 \times 6.4) \times 0.66 \times 210$$

$$V_R = 206.77\ kN$$

For flexural strength:

$$M_R = \varphi z F_y$$

Where φ is 0.9, a reduction factor outlined in the Steel Construction Handbook is the section modulus, and F_y is the material strength of steel.

$$M_R = 0.9 \times 354 \times 10^3 \times 210$$

$$M_R = 66.91\ kNm$$

For deflection:

$$\Delta \leq \frac{L}{360} = \frac{4770}{360} = 13.25mm$$

$$\Delta = \frac{5wL^4}{384EI} = \frac{5 \times 7.27 \times 4770^4}{384 \times 200000 \times 2.998 \times 10^7} = 7.52\ mm$$

Where EI is the stiffness parameters of the cross section.

Therefore, the beam meets all requirements according to the steel code with respect to the components checked. A summary table of all calculation results are below:

Table 21: A table summarizing the calculated loads, demanding shear force, and moment capacity for each beam under technical analysis.

Beam Number	Name (Metric)	Length (m)	Uniform Load (kN/m)	Point Load (kN)	Factored Shear Force (kN)	Factored Bending Moment (kNm)
1	W 250 x 28	4.77	8.36	N/A	19.93	23.77
2	W 250 x 28	5.74	10.43	N/A	29.94	42.96
3	W 250 x 28	5.64	10.25	N/A	28.90	40.76
4	W 360x45	3.92	5.70	N/A	11.16	10.94
5	W 250 x 28	4.77	7.27	N/A	17.34	20.65
6	W 250 x 28	5.74	7.24	N/A	20.78	29.82
7	W 250 x 28	5.64	7.37	N/A	20.78	29.30
8	W 250 x 28	3.91	5.82	N/A	11.38	11.12
9	WWF 660 x 232	11.35	9.11	1.46	53.17	146.72
10	WWF 700 x 175	11.35	9.48	1.76	55.56	152.67
11	WWF 700 x 196	11.35	8.89	1.73	52.17	143.13

Table 22: A table summarizing the local buckling, shear strength, moment capacity, and maximum deflection for each beam under technical analysis.

Beam Number	Local Buckling	Shear Strength (kN)	Resisting Moment Capacity (kNm)	Maximum Deflection (mm)	Meets Approval?
1	5.10	206.77	66.91	8.66	Yes
2	5.10	206.77	66.91	13.00	Yes
3	5.10	206.77	66.91	12.55	Yes
4	8.72	302.97	147.23	1.20	Yes
5	5.10	206.77	66.91	7.52	Yes
6	5.10	206.77	66.91	15.94	Yes
7	5.10	206.77	66.91	9.02	Yes
8	5.10	206.77	66.91	4.94	Yes
9	8.33	1621.62	2627.10	0.16	Yes
10	6.00	960.50	1183.14	0.36	Yes
11	9.09	960.50	1358.91	4.94	Yes

All beams in this analysis have been approved for the classroom space. This will eliminate the requirement of steel retrofitting, or any other methods of remediation, therefore significantly reducing costs and time of construction. Stable Designs recommends the client to acquire a professional structural engineer to review this analysis prior to proceeding with the selection of the existing library space.

7.3 Roof Structural Supports

When assessing design options and conceptualizing a final roof design, it is necessary to know how much weight the roof can support. In this preliminary analysis, the 1958 KCVI roof framing plan, in

Appendix H: Supporting Documents for Roof Design Scope Component, were used as an approximation for the entire roof under investigation. Further information will be required during site visit 4 to determine the size and spacing of the beams in the South-West wing of the building. The governing beam size is W610x113 which was converted from the imperial size of W24x76 denoted on the drawings. To determine how much additional load can be placed on the roof an existing load breakdown had to be created first.

Based on the 1958 KCVI roof framing plan it was determined that the steel deck on top of the roof is 18-gauge corrugated steel. To calculate the current dead loads, the following weights of materials were added together and converted to kilopascals (kPa). The self weight of 1.11kN/m for the W610x113 beam was also added to the dead load. The tributary length from which the governing beam is supporting was found to be 2.44m from the drawings.

- Corrugated Steel Deck = 14.16 kg/m^3 (Gray 2021)
- 4 – Ply Built Up Membrane, Graveled Surface = 30.76 kg/m^3 (Gray 2021)
- 3" Polystyrene (EPS) Insulation Board = 0.51 kg/m^3 (per inch of thickness) (Gray 2021)

The Dead Load on top of the beam is:

$$Dead\ Load\ of\ Supporting\ Materials = \frac{(14.16 + 30.76 + 3 \times 0.51) \times 9.81}{1000} = 0.46\ kPa$$

The unfactored dead load acting on the governing beam is:

$$Dead\ Load\ (DL) = (0.46kN/m^2 \times 2.44m) + 1.11kN/m = 2.23\ kN/m$$

From Clause 4.1.5.3, Division B of the NBCC 2020 the live load for a roof is 1 kPa. The unfactored live load applied on the governing beam is:

$$Live\ Load\ (LL) = 1 \times 2.44 = 2.44\frac{kN}{m}$$

To determine the applied snow load, an online tool called Jabacus was used (Jabacus 2023). This tool possesses a locational database and provides accurate loading information based on an inputted location along with additional parameter. The following parameters were input including assumptions with an associated justification:

- Location: Kingston, Ontario
- Importance Factor: Normal, a school is under normal importance according to Clause 4.1.6.2 NBCC 2020
- Cw = 1
- Ca = 1
- Slope Factor - Cs = 1, the roof is flat
- Longer Dimension – l = 40.3m, taken from the 1958 KCVI roof framing plan
- Shorter Dimension – w = 18.8m, taken from the 1958 KCVI roof framing plan

The online tool produced an ultimate limit state (ULS) snow load of 2.08 kPa and a serviceability limit state (SLS) of 1.87 kPa. For maximum applied moments and shear the ULS value will be used and for deflection limits the SLS value will be used. The unfactored snow loads applied on the governing beam for both ULS and SLS is as follows:

$$SLS\ Snow\ Load\ (SL) = 1.87 \times 2.44 = 4.56 \frac{kN}{m}$$

$$ULS\ Snow\ Load\ (SL) = 2.08 \times 2.44 = 5.08 \frac{kN}{m}$$

To determine the applied factored load, each of the ULS loads needs to be factored in the Clause 4.1.3.2 NBCC 2020 load combinations. The load combination with the highest resulting factored load governs. Table 23 is a summary of the load combination calculations.

Table 23: Load Combination Calculations for the Roof Beam Design

LC	Combination	Calculations	Factored Load – w (kN/m)
1	1.40DL	1.40x(2.23)	3.12
2	1.25DL + 1.50LL +1.00SL	1.25x(2.23) + 1.50x(2.44) + 1.00x(5.08)	11.53
3	1.25DL + 1.50SL +1.00LL	1.25x(2.23) + 1.50x(5.08) + 1.00x(2.44)	12.85

Therefore, the factored applied load w = 12.85 kN/m. The beam is assumed to be simply supported over a span of 18.8m and is laterally restrained so the maximum factored shear strength (V_f) under a distributed load (w) is as follows:

$$V_f = \frac{wL}{2} = \frac{(12.85) \times (18.8)}{2} = 120.8\ kN$$

The maximum factored moment based on the same assumptions is:

$$M_f = \frac{wL^2}{8} = \frac{(12.85) \times (18.8)^2}{8} = 567.7\ kNm$$

Under serviceability limit states, the deflection must be calculated using only applied live loads and no factored loads. Since the snow load is technically considered a live load, and the SLS snow load is greater than the designed live load specified in NBCC 2020, the SLS snow load was used for to calculate the deflection. A length of 18.8m was assumed to be unbraced to be conservative and a moment of inertia of 8.75 x 108 was used for a W610x113 beam.

The deflection on the governing beam was found to be:

$$\Delta = \frac{5wL^4}{384EI} = \frac{5 \times (4.56) \times (18800)^4}{384 \times (200000) \times (8.75 \times 10^8)} = 42.4mm$$

To ensure that the beam does not fail under local buckling, the following limit was taken from NBCC 2020 and evaluated:

$$\frac{b}{2t} \leq \frac{170}{\sqrt{350}}$$

Where b is the width of the flange (mm), and t is the thickness of the flange (mm).

$$\frac{228}{2 \times 17.3} \leq \frac{170}{\sqrt{350}}$$

$$6.59 \leq 9.09$$

Therefore, the governing beam W610x113 satisfies the local buckling limit.

To analyse how much additional load the roof can support, the resistance of the governing roof beam must be calculated. The calculations performed in section 5.2 Adaptive Space reuse are identical to the calculations performed to determine the moment capacity and shear capacity of the beam. The same calculations were performed for a W610x113 beam, and the results are summarized in Table 24. Note that according to Clause 9.4.3.1 NBCC 2020, the roof beam deflection limit is to be taken as L/240. In Table 24 the utilization ratio was calculated which can takes the applied moment, shear or deflection and divides by the limit or the capacity. If the utilization ratio is larger than 1 then the existing beam cannot support the current applied loads.

Table 24: Calculated Results of Deflection, Maximum Factored Shear and Moment for the Roof Beam

	Applied	**Capacity or limit**	**Utilization Ratio**
Shear	V_f = 120.80 kN	V_R = 1500.00 kN	0.08
Moment	M_f = 567.70 kNm	M_R = 1036.00 kNm	0.55
Deflection	42.40 mm	78.30 mm	0.54

Since the utilization ratio of the moment is the largest, moment governs in this case. Therefore, to determine the allowable dead load that can be applied, a reverse calculation needs to be performed by first setting the max factored moment equal to the governing beams maximum moment capacity.

$$M_R = M_f = \frac{wL^2}{8}$$

The equation can then be rearranged and solved for w:

$$w = \frac{8 \times M_R}{L^2} = \frac{8 \times (1036)}{(18.8)^2} = 23.5\ kN/m$$

To get an unfactored dead load, the factored distributed load above is inputted into each of the load combinations along with the predetermined live load and ULS snow load. The load combinations are then rearranged and solved for three maximum allowable dead loads. Table 25 summarized these calculations.

Table 25: Back-Calculating Load Combinations to Determine the Additional Dead Load that the Roof Beams can Support.

LC	**Combination**	**Calculations**	**Dead Load – (kN/m)**
1	w = 1.4DL	23.5 = 1.4x(DL)	16.79
2	w = 1.25DL + 1.5LL +1.0SL	23.5 = 1.25x(DL) + 1.5x(2.44) + 1.0x(5.08)	11.81
3	w = 1.25DL + 1.5SL +1.0LL	23.5 = 1.25x(DL) + 1.5x(5.08) + 1.0x(2.44)	10.75

The smallest dead load was taken from Table 25. Finally, to determine the maximum allowable additional dead load that can be added to this roof, the maximum allowable dead load taken from Table 25 must be divided by the Tributary length and then the existing dead load must be subtracted.

$$Maximum\ Additional\ Dead\ Load = \left(\frac{10.75}{2.44}\right) - 2.23 = 2.08\ kPa$$

Therefore, an additional Dead Load of 2.08 kPa can be safely added to the roof without adding any additional structural supports.

In the final report a full building structural analysis will take place to ensure that the additional loading on the roof can be supported by the entire structural envelop. A further analysis will also be conducted to quantify the energy efficiency improvements of the implemented roof design.

8.0 Cost Analysis

This section shows a preliminary cost estimate for all window options, wall composition replacement, and the work done to create the new learning spaces. RSMeans data (Gordian 2024) was used to predict the costs, which includes labour.

8.1 Windows

To install secondary glazing to a windowsill, there are many considerations that need to be examined during a cost analysis. These factors include site preparation, the materials, and installation costs. Using RSMeans data (Gordian 2024), the estimated upfront cost for single pane fixed secondary glazing is shown below in Table 26.

Table 26: Cost Analysis of a Single Pane Fixed Secondary Glazing

Item	**RSMeans reference number and description**	**Cost ($CAD)**
Site preparation	090190940400: Surface preparation, interior, windows, per side, excludes trim	22.78 /m^2
Materials	85113203000: Windows, aluminum, commercial grade, stock units, single-hung, standard glazed	277.30 / m^2
Installation costs	085113206200: Windows, aluminum, incl. frame and glazing, for installation	8% of material costs = 22.18/ m^2
	Total Cost of all Items ($CAD)	380,445.50

The estimated upfront cost for double pane fixed secondary glazing is shown below in Table 27.

Table 27: Cost Analysis of a Double Pane Fixed Secondary Glazing

Item	**RSMeans reference number and description**	**Cost ($CAD)**
Site preparation	090190940400: Surface preparation, interior, windows, per side, excludes trim	22.78/m^2
Materials	85213400400: Windows, wood, bay, end panels operable, double-hung, double insulated	494/ m^2
Installation costs	085113206200: Windows, aluminum, incl. frame and glazing, for installation	8% of material costs = 39.52/ m^2
	Total Cost of all Items ($CAD)	656,734.40

The estimated upfront cost for triple pane fixed secondary glazing is shown below in Table 28.

Table 28: Cost Analysis of a Triple Pane Fixed Secondary Glazing

Item	RSMeans reference number and description	Cost ($CAD)
Site preparation	090190940400: Surface preparation, interior, windows, per side, excludes trim	22.78/m^2
Materials	85213200300: Windows, aluminum, commercial grade, stock units, single-hung, standard glazed	772.83/m^2
Installation costs	085113206200: Windows, wood, bow, metal-clad, end panels operable, double insulated 3 panel	8% of material costs = 61.83/ m^2
	Total Cost of all Items ($CAD)	1,012,234.00

Note that the provided totals are only an estimation as the values will vary depending on local labour prices, type of materials, and windowsill size and shape. These costs do not include the price of replacing the existing windowpanes.

The clients expressed a preference for a reduced total cost of ownership as opposed to a lower initial price. To help determine the optimal option, the team estimated and compared the cost of ownership associated with varying pane amounts against the current windows cost of ownership. These calculations used each options' individual RSI value to find the net gross value for natural gas usage and carbon tax. Additionally, the payback period was calculated by dividing the initial cost by the determined total savings per year, which was determined by finding the difference between the total cost of operations for double pane and the cost of operations for the existing windows. For example, the initial estimated cost of double pane secondary glazing was $656,734.40 and the savings per year was $41484.43, therefore, double pane secondary glazed windows would have a payback period of 16 years. These calculations can be found in Appendix D: Supporting Documents for Windows Scope Component.

It was approximated that the fixed secondary glaze has a lifespan of around 20 years. The triple pane windows have a payback period of 21 years; therefore, this is not a feasible option as the payback period is higher than the lifespan, meaning there would be no savings with this option. The single pane windows have the lowest payback period of around 12 years. Although the single pane windows have the lowest cost of ownership, the double pane secondary glazing is recommended. This is because energy efficiency is a top priority to the clients in comparison to the initial cost.

8.2 Wall Composition

An upfront cost estimate was conducted on the proposed wall compositions. Note that the detailed calculations and assumptions made in this section are explained in Appendix E: Supporting Documentation for Wall Composition Scope Component. Table 29 below summarizes the cost for items unique to the terracotta-based wall composition, including the spray foam and metal studs. Note that terracotta makes up 3379.2 m^2 of exterior wall area.

Table 29: Cost to Implement the Proposed Wall Composition Solution for Terracotta Walls

RSMeans Reference Number and Description	Total Cost Per Unit ($CAD/Unit)	Total Cost ($CAD)
072129100340: Insulation, polyurethane foam, 2#/CF density, 4” thick, R26, sprayed	79.87 /m^2	269,896.70
092216133130: Metal stud partition, non-load bearing, galvanized, 12’ high, 4” wide, 25 gauge, 24” OC, includes top & bottom track	20.56 /m^2	217,958.21
	Total Cost of all Items ($CAD)	**487,854.91**

Table 30 summarizes the cost for items unique to the reinforced concrete-based wall composition, including the spray foam and metal studs. Note that reinforced concrete makes up 2004.09 m^2 of exterior wall area.

Table 30: Cost to Implement the Proposed Wall Composition Solution for Reinforced Concrete Walls

RSMeans Reference Number and Description	Total Cost Per Unit ($CAD/Unit)	Total Cost ($CAD)
072129100360: Insulation, polyurethane foam, 2#/CF density, 6” thick, R39, sprayed	120.02 /m^2	240,526.08
092216133150: Metal stud partition, non-load bearing, galvanized, 12’ high, 6” wide, 25 gauge, 24” OC, includes top & bottom track	21.85 /m^2	137,374.01
	Total Cost of all Items ($CAD)	**377,900.09**

Table 31 summarizes the cost for items used in both proposed wall compositions to finish the wall surfaces.

Table 31: Total Cost to Implement the Wall Efficiency Upgrade on All Walls

RSMeans Reference Number and Description	Total Cost Per Unit ($CAD/Unit)	Total Cost ($CAD)
099123720290: Paints & coatings, walls & ceilings, interior, concrete, drywall or plaster, latex paint, primer or sealer coat, sand finish, cut-in brushwork	0.47 /L.F.	10,764.97
099123720380: Paints & coatings, walls & ceilings, interior, concrete, drywall or plaster, latex paint, primer or sealer, sand finish, spray	3.01 /m^2	16,224.67
099123720590: Paints & coatings, walls & ceilings, interior, concrete, drywall or plaster, latex paint, 2 coats, smooth finish, cut-in by brushwork	0.78 /L.F.	17,865.28
099123720880: Paints & coatings, walls & ceilings, interior, concrete, drywall or plaster, latex paint, 2 coats, smooth finish, spray	1.94 /m^2	10,443.58

RSMeans Reference Number and Description	Total Cost Per Unit ($CAD/Unit)	Total Cost ($CAD)
092910300550: Gypsum wallboard, on walls, water resistant, taped & finished, ½" thick	26.05 /m^2	140,227.51
	Total Cost of all Items ($CAD)	**195,526.01**

Summing the total costs of all items illustrated in the previous three tables, the total upfront cost to implement the proposed wall composition is $1,061,281.01. Note that this is only an estimation, not a quote. This estimation does not include the cost for demolition to remove and relocate any existing equipment that is currently on the exterior walls.

Using the information previously presented in section 7.1.2 Wall Composition, Table 32 was created showing how much money would be spent on heating if the proposed solution were implemented.

Table 32: Annual Cost of Natural Gas and Carbon Tax if the Proposed Solution were Implemented.

Month	ΔT	Heat Loss (kW)	Heat Loss (kWh)	Natural Gas Usage (m^3)	Cost of Natural Gas ($CAD)	Cost of Carbon Tax ($CAD)
J	28	95.67	109806	27940	7823.31	3461.82
F	27	92.25	98040	24947	6985.07	3090.89
M	21.5	73.46	84315	21454	6007.19	2658.18
A	14.5	49.54	55029	14002	3920.67	1734.90
M	7.5	25.63	29412	7484	2095.53	927.27
J	3	10.25	11385	2897	811.17	358.94
J	0.5	0.00	0.00	0.00	0.00	0.00
A	0.5	1.71	1961	499	139.70	61.82
S	5	17.08	18976	4828	1351.95	598.24
O	11.5	39.29	45099	11476	3213.15	1421.82
N	16.5	56.38	62620	15934	4461.45	1974.19
D	24	82.00	94119	23949	6705.70	2967.27
Annual Sum		543.25	610763	155410.31	43514.89	19255.34
Annual Cost of Natural Gas & Carbon Tax ($CAD)					**62770.22**	

For comparison, if the carbon tax were 12.39 cents per cubic metre of natural gas, the annual heating cost for KCVI is about $160,200. The proposed solution saves nearly $100,000 in annual heating costs.

As mentioned previously, the clients expressed a preference for a reduced total cost of ownership as opposed to a lower initial price. To help determine the optimal option, a cost of ownership analysis was done for each option considered, shown in detail within Appendix I: Cost of Ownership Analysis. A simple payback period analysis, explained previously, was also conducted to provide a preliminary sense of viability of the wall composition options. The proposed solution for the wall composition has a payback period under 11 years, showing its viability as spray foam has a lifespan of up to 100 years (John 2022).

8.3 Adaptive Space Reuse

The required actions for the chosen space for the high-tech classrooms are to demolish the existing walls of the northern spaces. The basement and first level have three main partition walls to demolish. Some doors and windows require removal, as well as the carpet along the floors. STOR015 in the basement level have wooden cabinets attached to the interior walls which require removal. Finally, the shear wall construction is needed for the first floor to create one cohesive space.

The cost table below predicts the upfront costs of converting the proposed spaces into three different classrooms.

Table 33: Cost Analysis of the Proposed Design Adapted Space Design

Action Item	RSMeans reference number and description	Cost ($CAD)	Unit Requirement for Adaptive Space Reuse	Total Cost ($CAD)
Demolition of existing partition	015616101000: Selective demolition, rubbish handling, dust partition, 4'x8' panels	11.90/m	49.63m	590.97
Demolition of existing masonry block	040505100340: Selection demolition, masonry, concrete block walls, unreinforced, 10" thick	9.46/m	23.2m	219.47
Disposal of existing windows	024210200810: Deconstruction of building doors and windows.	70.96 per windowsill	22 windowsills	1561.12
Removal of carpeted area	028713330465: Demolition in mold contaminated area, partitions, carpet & pad	43.40/m^2	412.22m^2	17890.59
Destruction of existing wooden cabinets	024210200610: Deconstruction of millwork and trim, cabinets, wood, up to two storeys	90.06/m	9.20m	828.55
Wall construction on first floor	015423700460: Scaffolding, steel tubular, regular, labor only to erect and dismantle, building interior, wall face, 6'-4" x 5' frames	5092.00/m^3	4.71m^3	23983.34
			Total	**45,074.04**

Appendix G: Supporting Documents for Adaptive Space Reuse Scope Component provides a floor plan mark-up that contains the dimensions used to calculate the areas in the table. Therefore, the total cost is just over $45,000 to change the spacing arrangements to fit the spatial needs of a high-tech classroom.

Along with these costs, the high-tech classrooms will require the use of electronic devices such as laptops, computer desktops, television screens, and classroom furniture such as a podium, tables, and chairs. This report will not consider the cost estimation of these elements because this work will be required regardless of selection of the library space.

The technical analysis of this scope component has reviewed the structural capacity of the existing first floor, and the results show that no structural remediation is required for the loads of a high-tech classroom. However, the team recommends a professional structural engineer to review the existing files and confirm the analysis results from Stable Designs. If a retrofit is required, then additional costs that come with the installation and inspection of the selected retrofit method should be considered.

8.4 Cost of Ownership of Entire Proposed Solution

Using the information presented in the three previous sections for the windows, walls, and adaptive space reuse, a cost of ownership analysis was conducted for the proposed solution. Note that the cost of ownership analysis was completed using a template Queen's Facilities provided Stable Designs. Table 34 below summarizes the cost of ownership of the proposed solution compared to a do-nothing scenario to see if the proposed solution is viable. The complete cost of ownership analysis is shown in Appendix I: Cost of Ownership Analysis.

Table 34: Cost of Ownership Summary of Proposed Solution Compared to a Do-Nothing Approach.

Options:	Base	Proposed Solution
Capital changes relative to Base case		
Total Construction ($)	**0.00**	**1,061,281.00**
Operating Costs		
Annual Natural Gas [m3]	264,252.00	103,607.00
Annual Natural Gas Cost [$]	111,005.00	43,515.00
Annual Carbon [Tonnes]	748.00	293.00
Annual Carbon Cost [$]	49,342.00	19,255.00
ANNUAL TOTAL FUEL COST [$]	**160,347.20**	**62,770.22**
Savings vs Base		**97,489.87**
Periodic Cost - Window Replacement [$]	**380,446.00**	**656,734.00**
Adaptive Space Reuse Upfront Cost [$]	**0.00**	**45,074.00**
GHG Performance		
GHG Natural Gas (tonnes/yr)	748.00	293.00
Reductions % from Base		**61%**
Financials (3% discount rate)		
Net Present Value (10 yr NPV) @ 3% Disc [$]	**- 1,870,932.00**	**- 476,440.00**
Net Present Value (15 yr NPV) @ 3% Disc [$]	**- 3,156,107.00**	**537,289.00**
Net Present Value (50 yr NPV) @ 3% Disc [$]	**- 9,525,178.00**	**1,081,491.00**
Net Present Value (105 yr NPV) @ 3% Disc [$]	**- 33,263,617.0**	**4,567,679.00**
GHG Performance		
15-year emissions (tonnes)	11,214.00	4,396.02
50-year emissions (tonnes)	37,380.00	14,653.39
105-year emissions (tonnes)	78,499.00	30,772.12
Total 50-year emissions reduction (tonnes)		22,727.00
Total 105-year emissions reduction (tonnes)		47,727.00

The base case is a do-nothing approach; however, windows will need to be replaced as part of any option due to their lifespan. The base case assumes windows are replaced like for like, which are double glazed windows. It is important to note that the base case uses a double glazed window lifespan of 15 years (Lebreton 2023), while the proposed solution uses a double pane secondary glazed window lifespan of 25 years (Henry 2020). From Table 34, the proposed solution greatly improves the energy efficiency of KCVI. The proposed solution saves over $97,000 annually on heating costs, reduces the greenhouse gas emissions by 61%, and has a positive net present value (NPV) after approximately 15 years of being implemented, all relative to the base case. This validates that the proposed solution is viable and should be implemented for KCVI.

9.0 Risk Assessment

It is important to understand and evaluate the risks involved, their likelihood and their importance through this design process. It is also important to know how to properly mitigate the associated risks to ensure safety, efficiency, cost optimization, and effectiveness. Some risks are associated with the design process which involves going to site. Other risks are associated with the final design and its implementation. The following paragraphs outline all the risks involved and their associated mitigation measures.

When visiting the site of KCVI, there is relatively low risk since the building is still in use. However, there are some broken glass or pipe spills throughout the building, so boots are worn to prevent penetrations and slipping. Other than that, no additional PPE is required for site since there are no risks that would require a hardhat, safety glasses or gloves. The importance is significant since it directly relates to human health and safety, however the risk is low due to the likelihood of an injury occurring.

Since intrusive sampling is required for the first three scope components, it was determined that there is potential for asbestos and lead which are carcinogenic and poisonous respectively if inhaled or swallowed. This is a significant risk and the likelihood of asbestos or lead exposure is significant in this building due to the age of the building and the common use of these materials during the time of construction. The importance of this risk is high because it directly relates to human health and safety. Before Stable Designs was engaged, the Queen's Health and Safety team conducted an assessment and prepared an asbestos report. This report can be found in Appendix B: Intrusive Sampling Results.

Stable Designs made sure to avoid the areas that have identified potential asbestos contamination for intrusive sampling. To mitigate the risk of lead paint, prior to conducting intrusive sampling, the Queen's Health and Safety team joined Stable Designs on site to take paint samples at each proposed location. If the samples are determined to not contain lead, then intrusive sampling can be conducted. If the samples do contain lead, the Queen's Physical Plant Services had to take additional precautionary measures when conducting the intrusive sampling or a new location for intrusive sampling was selected. These additional measures involve proper tarping and disposal of debris, respiratory protection, and skin protection suits.

The risk pertaining to fixed secondary glazing includes but is not limited to measurement and quantity error for all windows that require remediation. As discussed previously, an accurate measurement of the windows' thickness is required to increase the efficiency of the building envelope. There also must be very accurate measurements of the existing windows, as a sizing error can also impact the design and create additional costs and time delays. The likelihood of this risk occurring is somewhat significant since human error and poor measurement techniques are common. It is relatively important to mitigate this risk to avoid purchasing windows that do not fit, ultimately costing the owners a significant amount of money. Another risk includes not abiding by all heritage protocols established by the City of Kingston. The likelihood of this risk occurring is low as long as proper consideration is taken into how the heritage protocols will affect the work being done. This risk is of minor importance since the building inspector will simply not approve the design if it does not follow heritage protocols.

For the wall composition solution, spray foam can be toxic if inhaled or if it comes into contact with the eyes or skin prior to the foam being fully cured. This is a significant risk, and the likelihood of this occurring is significant since the proposed design is to spray foam insulate all the exterior walls. The importance of this risk is high because it directly relates to human health and safety. To safely install spray foam, professionals should be engaged and should wear PPE including protective clothing, gloves, eye and face protection and respiratory protection. Adequate time will be given for the spray foam to fully cure, ensuring that the substance no longer poses a safety threat (Palya 2019). It takes approximately 8 to 24 hours for the spray foam to fully cure depending on the site conditions. The spray foam product label, instructions and professionals should be consulted prior to use (Palya 2019).

The efficiency of materials and their lifespan must also be considered when implementing the solutions of the window and wall composition. Management schedules for maintenance on these items must be upkept during their life expectancy, and replaced when their lifespan has ended. This is a significant risk when it comes to structural materials. If structural members were to deteriorate there would be significant consequences and potential cause for safety concern. The likelihood of this occurring is relatively low especially if proper inspection is conducted. It is an important risk to consider since proper upkeep of materials will help ensure the building's stability, prolong its lifespan, and reduce maintenance costs.

As discussed in the Section 7.2 First Floor Structural Analysis, all beams were found to be structurally adequate. Regardless, there are still considerable risks when retrofitting structural aspects of heritage buildings. These risks have high importance since if the structural floor members were to fail it could pose a threat to human health and safety. The likelihood of this occurring is low since the classroom above will likely not exceed the anticipated live loads than the current existing space imposes on the floor.

The risk of remediation includes error in structural analysis, and the material choice of the technique used. The likelihood of these errors occurring is relatively low since the current commercially available rehabilitation techniques are common in practice, conservative, relatively cheap, and easy to install. To mitigate the risks associated with remediation, Stable Desings consulted Dr. Neil Hoult. To reduce the risk further, Stable Designs recommends that a Professional Engineer also performs an analysis on this space to either approve or deny this proposal.

There are general risks regarding the implementation of all proposed solutions. The time and cost of construction is a risk that must be discussed among general contractors and the client. Items such as detailed scheduling, project management, and contingencies are necessary to consider avoiding significant costs and construction delays. The likelihood of scheduling and cost issues is high because there is a large variety of issues and setbacks that can happen during any construction project. This is a relatively important risk to consider since time and money are the main drivers of success and completion of these projects. Prior to construction and remediation processes, the construction team and client must understand the risks involved. These include oversized loads, and scheduling the transportation of materials that will not cause work delays.

There are many different types of risks that can occur throughout the construction process. These risks include working at heights, abundance of dust, noise and vibrations caused from the work, and environmental damage because of construction. These risks are all significant and extremely important since they can pose a threat to both people on the construction crew and environmental health and safety. The likelihood of potential issues during common construction practices is relatively high, however can be drastically reduced with the proper planning and mitigation measures. These items can be accounted for upon discussion with the general contracting team and the client to take proactive measures to reduce these risks where possible.

10.0 Future Work & Recommendations

A structural assessment was completed by Stable Designs to understand the current structural system of the building and to determine if there are any high importance deficiencies. All concerns were communicated to the client. However, Stable Designs recommends that further analysis from a Professional Engineer who specializes in structural rehabilitation is necessary.

Stable Designs also recommends getting the technical analysis calculations conducted in 7.2 First Floor Structural Analysis for the adaptive space reuse reviewed by a professional structural engineer prior to proceeding with the selection of the existing library space. This is also recommended for the technical analysis calculations conducted in 7.3 Roof Structural Supports for the roof design. A full load path analysis should also be conducted to ensure each structural element can support the additional load.

Furthermore, it is advised to engage a consultant dedicated to assessing the roof design. This consultant should conduct thorough research to validate the feasibility of adopting an innovative approach, such as a blue roof. The detailed design must integrate seamlessly with the local climate, existing structural elements, architectural aesthetics, and environmental context. Emphasis should be placed on enhancing energy efficiency and establishing a comprehensive cost analysis to justify the investment in upgrading the roof. Additionally, future work should prioritize exploring sustainable materials and construction methods to align with long-term environmental objectives.

Regarding the heat loss calculations performed for the windows and wall composition, it is recommended that a professional review these calculations as it is directly involved with the cost of ownership analysis. This review will ensure that the design has been validated and is viable to be implemented.

The costs provided in Section 8.0 Cost Analysis for the windows, walls, and adaptive space reuse are estimates intended to give an overview of potential expenses. They should not be interpreted as formal quotes. Stable Designs advises contacting a contractor to obtain precise quotes for the proposed work. Moreover, some elements of the cost analysis are omitted due to uncertainty regarding the extent of required tasks. For instance, the proposed wall composition solution entails the removal or relocation of existing features like radiators, electrical outlets, and cabinetry at KCVI. Once the client finalizes space use plans for each area, it is recommended to seek a contractor's detailed quote for obstruction demolition. Similarly, for the adaptive space reuse solution involving removing or relocating utilities in the current library, consulting a contractor for detailed pricing is advisable.

11.0 Group Dynamics

Over the course of the seven-month term working on this KCVI rehabilitation project, Stable Designs worked very well with each other. With three of the four members having completed 16-month internships with engineering firms, and all four members having very different backgrounds, the collective experience proved to be invaluable to the completion of the project.

To ensure all the deliverables were met in a timely manner, Stable Designs had weekly internal meetings, weekly meetings with the TA, and bi-weekly meetings with the client. The weekly internal meetings primarily served to update members on their respective progress from the previous week and address any encountered issues. Additionally, these meetings facilitated essential project phases, particularly those requiring collaborative input, where the collective expertise of the team was essential for progress, such as idea generation. Reviewing feedback from the Work Plan and Progress Report deliverables was also done in these meetings, ensuring everyone is up to date and on the same page on how to improve and proceed with the project. The weekly meetings with the TA were used to ask questions or get clarification on something that the team was uncertain about. The bi-weekly meetings with the client served as updates on team progress, ensuring transparency, as well as a chance to get some input and feedback from the client.

A Gantt chart and RAM were created to promote equal work for all team members, and clearly set goals and expectations for an achievable period. These are included within Appendix J: Team Member Hour Logs and Gantt Chart. Stable Designs did an excellent job adhering to the calendar and Gantt chart over the course of this project, and each contributed to over 160 hours. At no point was Stable Designs rushing their work to meet deadlines of deliverables. There was always plenty of time to review and edit the work produced, as a team, ensuring it was of high-quality.

During the progression of the project, if there was an internal disagreement with how things should be handled, members did a great job to be respectful of one another and come to a solution that everyone agreed on. Stable Designs created an open environment where everyone could feel comfortable to share and bring up any problems they had.

Stable Design's strong camaraderie, mutual goals and encouragement propelled the team to consistently strive for excellence and support one another's growth. Members worked closely together, pushing boundaries, and embracing challenges as opportunities for improvement. The collaborative efforts not only boosted productivity but also fostered a positive environment where everyone felt empowered to contribute their best. Stable Design’s is proud of what was achieved with respect to this project, and enjoyed the time spent together bringing this project to completion.

12.0 Conclusion

Stable Designs has been recruited by Queen’s University Facilities team to perform a structural analysis for the KCVI Rehabilitation Project. KCVI is a historical building, built in 1915, and requires modifications for future use as a gymnasium, academic, and storage space for students, faculty members, and staff.

The scope of this project was based on structural assessments and client feedback. This assessment was conducted through two site visits, where the team examined the condition of structural elements within the building, the building envelope, and the roof’s structural system and supports. The scope was then divided into four components: windows, wall composition, adaptive space reuse, and roof design. Stable

Designs focused on finding energy efficient solutions for the windows and wall composition. Additionally, the team reviewed the floor plan to recommend potential spaces that could be used for collaborative learning classrooms. Finally, different sustainable roof designs were researched.

The constraints of this project include parameters such as cost, safety, timeline and deliverables, other course commitments, and historical by-laws. The stakeholders were divided into primary, secondary, and tertiary categories. Overall, the stakeholders considered are the client, Queen's University, the City of Kingston, occupants of the building such as staff, students and visitors, neighbours, and contractors working on the project during construction.

A full design and cost analysis was performed to provide a recommended solution for the windows, wall composition, and adaptive space reuse. The team determined the most effective measure to improve the windows' energy efficiency is to install double pane secondary glazed windows throughout the entire structure. This solution has an upfront cost of $656,734.40. As per improving the energy efficiency of the wall composition, the team recommends two different spray foam options depending on the section of KCVI. In the terracotta-based wall composition of the building, the team advises 1.25" x 4" 25 gauge non-load-bearing metal studs be installed with a spray foam thickness of 101.6 mm. Additionally, in the reinforced concrete-based wall composition portion, 1.25" x 6" 25 gauge non-load-bearing metal studs should be used with a spray foam thickness of 152.4 mm. This solution has an upfront cost of $1,061,281.02.

Stable Designs recommends that three integrative learning classrooms be implemented in the space where KCVI's library was previously located. The three proposed classrooms are 22.6 m long and 11.6 m wide, adhering to Queen's University's integrated learning classroom standards. The upfront cost to partially convert the library space is $45,074.25. Different options were researched and presented for the sustainable roof design, however due to the scope of the project, presenting a fully analysis solution was not required by the clients. The cost of ownership analysis of the windows, walls, and adaptive space reuse yielded a positive NPV after 15 years compared to the do-nothing base case.

In conclusion, Stable Designs has successfully completed the KCVI Assessment and Rehabilitation Project to the client's specifications. Through effective background research, collaboration, and diligent assessment, the team identified ways to improve the energy efficiency of the building, provided a sufficient location to implement three integrative learning classrooms, and produced adequate research on implementing a sustainable roof acting as a base step for further investigation. Stable Designs was delighted to contribute meaningfully to transforming KCVI to the client's standards and hope these recommendations help Queen's meet their goal of creating a more sustainable campus while providing more space to gain an education.

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Appendix A: Stable Design's Site Report 1

KCVI Building
235 Frontenac St, Kingston ON K7L3S7

Kingston Collegiate and Vocational Institute (KCVI) Site Visit

To:	**Nathan Splinter** splinter@queensu.ca	Client Ref. No.:	...
		Report No.:	**001**
		Total Pages:	
		Date of Visit:	**10-05-2023**
Weather:	**Sunny, 20°C**	Time Frame:	**2:00pm-4:00pm**
Review By:			
Subject:	**Site Visit**		
CC:			

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Scope

Stable Designs visited the KCVI building to identify what structural components need attention to be rehabilitated to ensure the building is safe and up to standards moving forward. Stable Designs went to site to review the current conditions in a non-invasive manner. This report shows the findings from this visit.

Observations

The KCVI Building is a high school that was built in 1915. It consists of 3 above-ground floors, a basement, with roof access. The purpose of Stable Design's visit was to identify structural elements on various floors that require remediation measures.

In this report Stable Designs provides a preliminary analysis of the inspected floors of the current conditions and provides an undergraduate level of recommendations to move forward with the project's scope.

The general floor plan for each floor, basement, and roof, can be found in the Appendix A. Throughout the site inspection, there was a focus on the historical elements of the high school (west side of building), where the team was able to observe various deficiencies in the building. The locations of the main rooms inspected are also appended.

Brief inspections took place throughout the building, however due to time constraints, the third floor was not investigated during the site visit. Due to access constraints, not all rooms on each floor have been inspected. Based on the non-invasive manner of the condition assessment, the underlying structure of the building was unable to be assessed due to finishings covering the structure.

Five deficiencies with a medium-low level of importance were identified in the basement. Four deficiencies with a medium-low level of importance were identified on the first and third floor. A high level of importance level deficiency was identified in the roof.

It is important to note that all recommendations made by Stable Designs should be confirmed by a Professional Engineer in structural engineering. The team members of Stable Designs consist of current fourth year Civil Engineering students in their undergraduate degree.

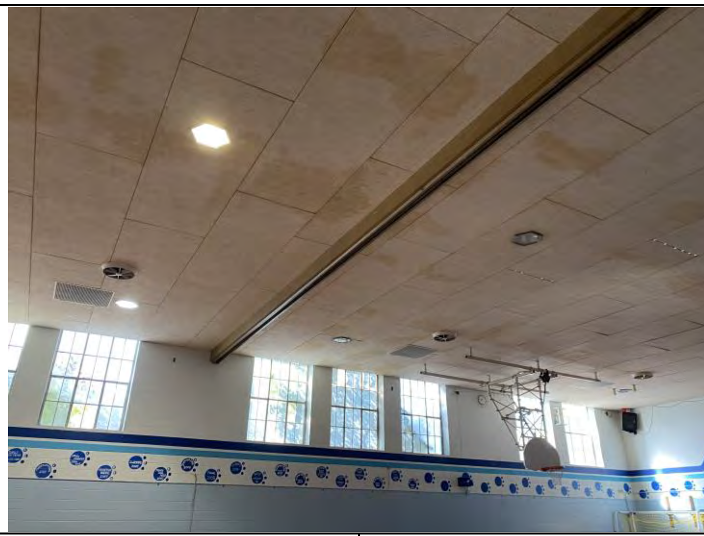
Floor 0 – Deficiency #1	
	
Description:	Large crack along Mechanical Room pit wall. The maximum thickness of this crack is 40mm, and extends over 3000mm in length.
Recommendation:	Repointing.
Level of Importance:	Medium

Floor 0 – Deficiency #2	
	
Description:	Thick crack/hole along Mechanical Room pit wall. The maximum thickness of this crack is 120mm wide, and 340mm long.
Recommendation:	Repointing/shotcrete.
Level of Importance:	Medium

<table>
<tr><th colspan="2">Floor 0 – Deficiency #3</th></tr>
<tr><td colspan="2"> </td></tr>
<tr><td>Description:</td><td>Exposed rebar along the Mechanical Room floor. The maximum thickness of the exposed rebar and floor cracking is 50mm, and the length extends approximately 780mm</td></tr>
<tr><td>Recommendation:</td><td>Spalling and repointing.</td></tr>
<tr><td>Level of Importance:</td><td>Low</td></tr>
</table>

Floor 0 – Deficiency #4


Description:	Exposed rebar along the Mechanical Room floor. The maximum thickness of the exposed rebar and floor cracking is 40mm, and the length extends approximately 680mm.
Recommendation:	Spalling and repointing.
Level of Importance:	Low

Floor 0 – Deficiency #5	
	
Description:	Broken windows along the West side of the Gymnasium windows.
Recommendation:	Repair windows according to historical building and building envelope guidelines. Additional research required on optimal window replacement.
Level of Importance:	Low

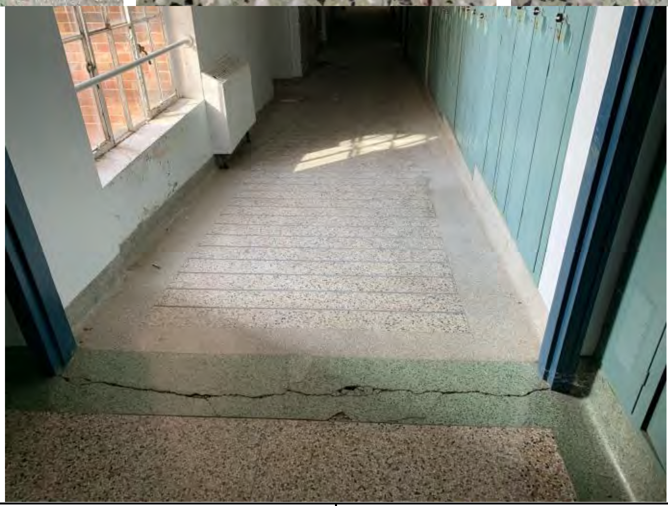
Floor 1 – Deficiency #1	
	
Description:	Large man-made hole in wall, exposing concrete block interior. Minor efflorescence on floor below wall.
Recommendation:	No further action is required.
Level of Importance:	Low

Floor 1 – Deficiency #2	
	
Description:	Horizontal and vertical cracking along mortar.
Recommendation:	Repointing.
Level of Importance:	Medium

Floor 1 – Deficiency #3	
	
Description:	Horizontal and vertical cracking along mortar. Sections of cracking appeared to extend through the wall.
Recommendation:	Repointing.
Level of Importance:	Medium

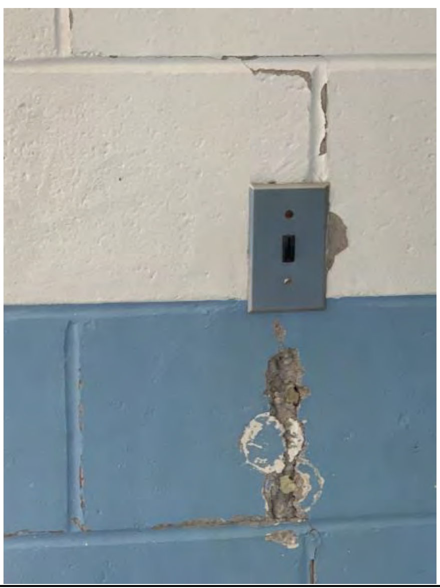
Floor 1 – Deficiency #4	
	
Description:	Hairline cracking and spalling along concrete flooring.
Recommendation:	Replace flooring. Further inspection required to assess the structural integrity.
Level of Importance:	Medium

Floor 3 – Deficiency #1	
	
Description:	In the classroom labelled as 317 on the drawings, on the exterior wall, there was a concrete hole that could indicate potential spalling. Note that this section of the building was made of concrete from what we could see.
Recommendation:	Shotcrete.
Level of Importance:	Low

Floor 3 – Deficiency #2	
   	
Description:	At the end of this ramp to the point that connects with the floor that is level (the joint), there was a significant crack in the concrete floor. 50 mm at its largest.
Recommendation:	Fix flooring, assess structural integrity.
Level of Importance:	Medium

Floor 3 – Deficiency #3






Description:	Note that the floor plan for this area was not correct. On the north exterior wall of this northeast stairwell, there was a large crack running through the masonry blocks. Note that there were multiple areas of these sorts of cracks within this area that have all been included as Deficiency #3. 5 mm at its largest.
Recommendation:	Repointing
Level of Importance:	Low

Floor 3 – Deficiency #4	
	
Description:	When entering the northeast stairwell, walking through the doors, there was a crack within the floor. 10 mm at its largest.
Recommendation:	Fix flooring, assess structural integrity.
Level of Importance:	Low

Roof – Deficiency #1	
	
Description:	The roof consists of several different additions with varying heights and sizes. All roof assembly systems are conventional built-up roof assembly (BUR). Built up parapets and metal flashing surround the perimeter of each roof. Internal roof drains are the typical drainage system for each roof. All the roofs on different additions have reached the end or are nearing the end of their theoretical life cycle of 22-25 years. See Appendix C for more information regarding a roof condition assessment.
Recommendation:	Replace roof and incorporate additional energy efficient improvements as indicated in the coming report.
Level of Importance:	Urgent

Overall Recommendations

Since the roofs of all the additions and the original building are near or have reached their theoretical end of lifecycle it is recommended that urgent action be taken. If action is not taken, water leaks could become increasingly prominent and structural issues could arise. At the very least, the roof should be replaced with a new BUR roof assembly. Stable Designs will conduct further analysis of potential roof upgrades that could incorporate energy efficiency and innovative solutions to improve the overall functionality of KCVI.

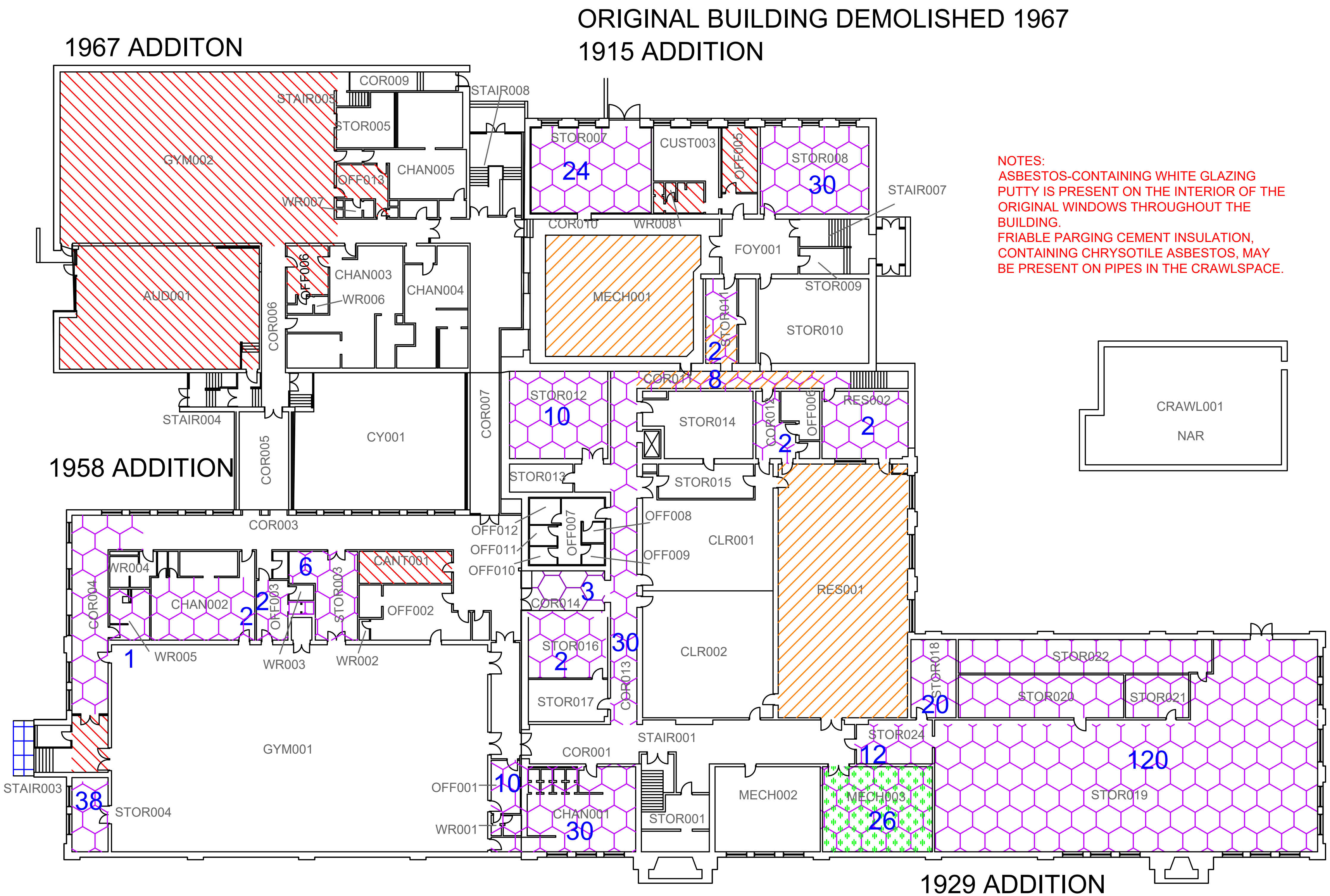
The recommendations outlined in this report do not constitute professional advice. These areas of structural deficiencies are problems Stable Desings has identified in a preliminary site condition assessment. Further site assessments may be required to gain a further understanding of KCVI. It is recommended that Professional Engineers conduct a structural assessment to ensure the overall stability, safety, and urgency of repairs along with their professional remediation recommendations.

Appendix B: Intrusive Sampling Results

NOT ALL KNOWN OR SUSPECTED ASBESTOS-CONTAINING BUILDING MATERIALS MAY BE DEPICTED ON THE DRAWING. REFER TO THE ASBESTOS ASSESSMENT REPORT FOR A COMPLETE LIST OF KNOWN AND SUSPECTED ASBESTOS-CONTAINING BUILDING MATERIALS.

LEGEND IS COLOUR DEPENDENT. NON-COLOUR COPIES MAY ALTER INTERPRETATION.

BASE PLAN PROVIDED BY CLIENT.



NOTES:
ASBESTOS-CONTAINING WHITE GLAZING PUTTY IS PRESENT ON THE INTERIOR OF THE ORIGINAL WINDOWS THROUGHOUT THE BUILDING.
FRIABLE PARGING CEMENT INSULATION, CONTAINING CHRYSOTILE ASBESTOS, MAY BE PRESENT ON PIPES IN THE CRAWLSPACE.

PINCHIN

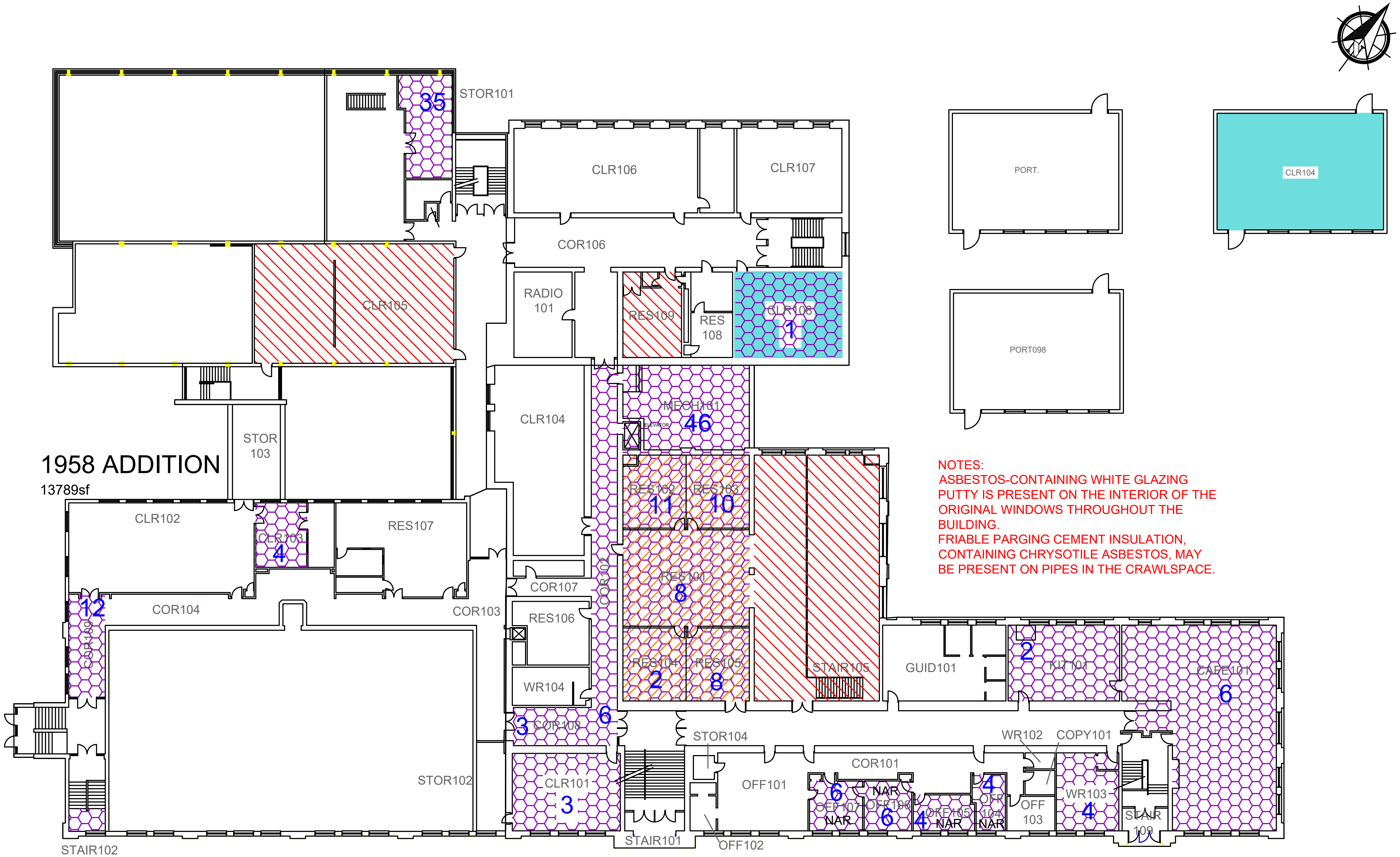
LEGEND:

NAR NO ACCESS TO ROOM/AREA

ASBESTOS-CONTAINING MATERIALS:

- VINYL FLOOR TILES AND MASTIC
- VINYL FLOOR TILES
- THERMAL INSULATION
- # QUANTITY OF FITTINGS WITH ASBESTOS-CONTAINING INSULATION
- CEILING TEXTURE COAT
- CEILING TILE (MASTIC CONTAINS ASBESTOS DUE TO CONTAMINATION)
- TRANSITE
- SPRAYED FIREPROOFING
- DUCT INSULATION

CLIENT: LIMESTONE DISTRICT SCHOOL BOARD	
LOCATION: KCVI 235 FRONTENAC STREET KINGSTON, ONTARIO	
TITLE: 2020 ASBESTOS REASSESSMENT BASEMENT	
DATE: 08/29/2020	PROJECT # : 201262.163
DRAWN BY: KV	DRAWING: 1 OF 4
CHECKED BY: SY	
SCALE: NTS	



NOTES:
ASBESTOS-CONTAINING WHITE GLAZING PUTTY IS PRESENT ON THE INTERIOR OF THE ORIGINAL WINDOWS THROUGHOUT THE BUILDING.
FRIABLE PARGING CEMENT INSULATION, CONTAINING CHRYSOTILE ASBESTOS, MAY BE PRESENT ON PIPES IN THE CRAWLSPACE.

NOT ALL KNOWN OR SUSPECTED ASBESTOS-CONTAINING BUILDING MATERIALS MAY BE DEPICTED ON THE DRAWING. REFER TO THE ASBESTOS ASSESSMENT REPORT FOR A COMPLETE LIST OF KNOWN AND SUSPECTED ASBESTOS-CONTAINING BUILDING MATERIALS.

LEGEND IS COLOUR DEPENDENT. NON-COLOUR COPIES MAY ALTER INTERPRETATION.

BASE PLAN PROVIDED BY CLIENT.

PINCHIN

LEGEND:

NAR NO ACCESS TO ROOM/AREA

ASBESTOS-CONTAINING MATERIALS:

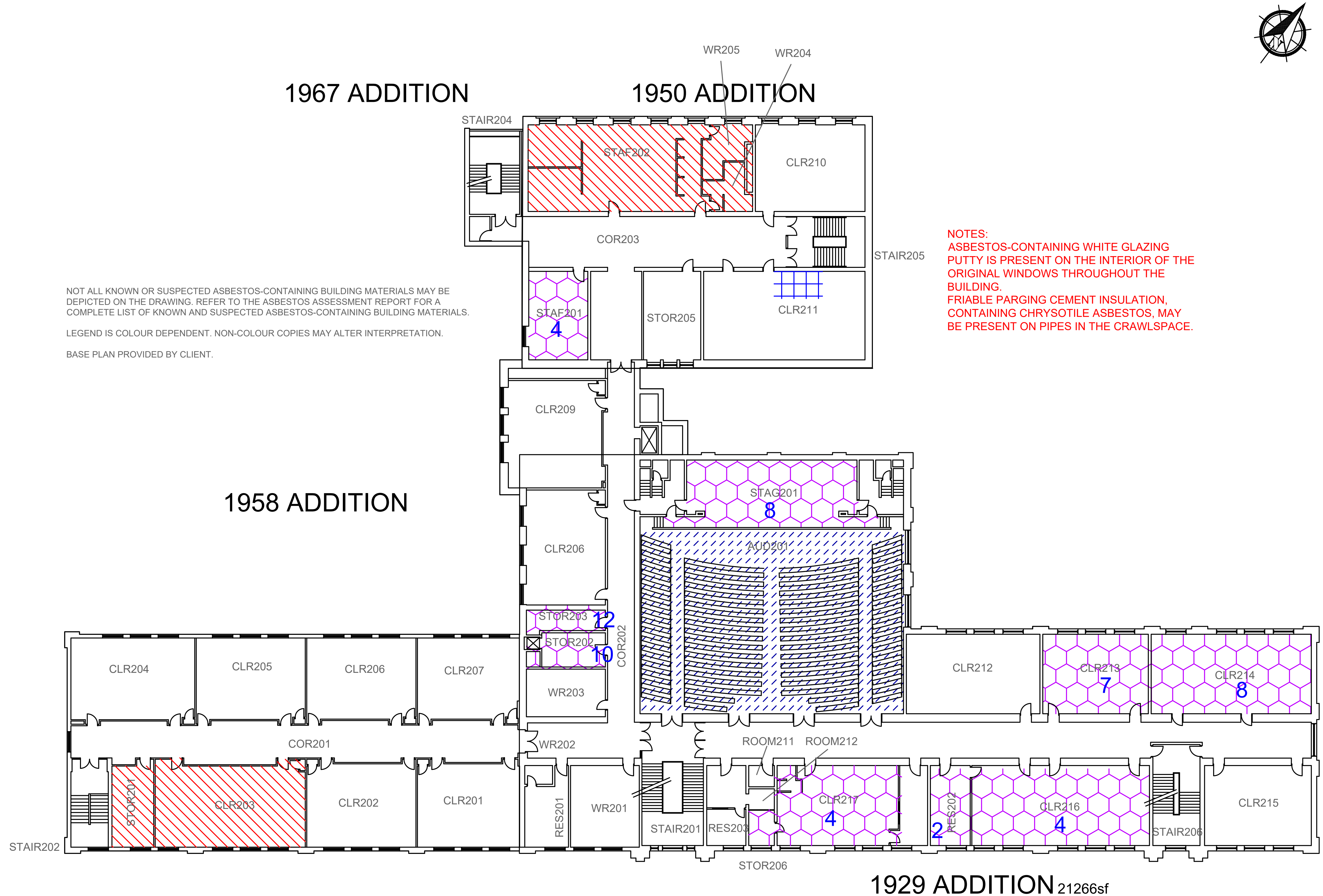
- VINYL FLOOR TILES AND MASTIC
- VINYL FLOOR TILES
- THERMAL INSULATION
- # QUANTITY OF FITTINGS WITH ASBESTOS-CONTAINING INSULATION
- CEILING TEXTURE COAT
- CEILING TILE (MASTIC CONTAINS ASBESTOS DUE TO CONTAMINATION)
- TRANSITE
- SPRAYED FIREPROOFING
- DUCT INSULATION

CLIENT:
LIMESTONE DISTRICT SCHOOL BOARD

LOCATION:
KCVI
235 FRONTENAC STREET
KINGSTON, ONTARIO

TITLE:
2020 ASBESTOS REASSESSMENT
FIRST FLOOR

DATE: 08/29/2020	PROJECT # : 201262.163
DRAWN BY: KV	DRAWING: 2 OF 4
CHECKED BY: SY	
SCALE: NTS	



NOT ALL KNOWN OR SUSPECTED ASBESTOS-CONTAINING BUILDING MATERIALS MAY BE DEPICTED ON THE DRAWING. REFER TO THE ASBESTOS ASSESSMENT REPORT FOR A COMPLETE LIST OF KNOWN AND SUSPECTED ASBESTOS-CONTAINING BUILDING MATERIALS.

LEGEND IS COLOUR DEPENDENT. NON-COLOUR COPIES MAY ALTER INTERPRETATION.

BASE PLAN PROVIDED BY CLIENT.

NOTES:
ASBESTOS-CONTAINING WHITE GLAZING PUTTY IS PRESENT ON THE INTERIOR OF THE ORIGINAL WINDOWS THROUGHOUT THE BUILDING.
FRIABLE PARGING CEMENT INSULATION, CONTAINING CHRYSOTILE ASBESTOS, MAY BE PRESENT ON PIPES IN THE CRAWLSPACE.

PINCHIN

LEGEND:

NAR NO ACCESS TO ROOM/AREA

ASBESTOS-CONTAINING MATERIALS:

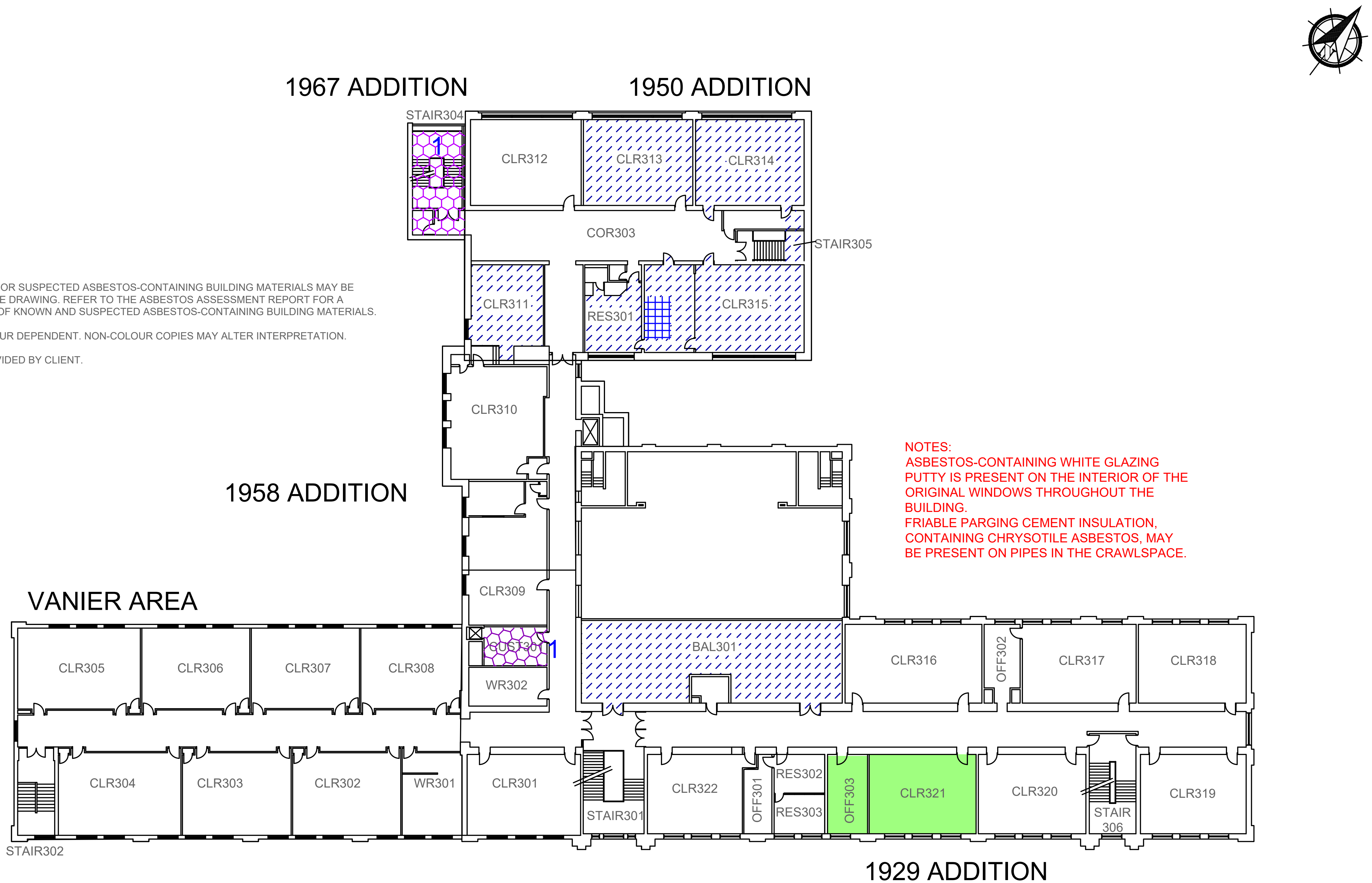
- VINYL FLOOR TILES AND MASTIC
- VINYL FLOOR TILES
- THERMAL INSULATION
- # QUANTITY OF FITTINGS WITH ASBESTOS-CONTAINING INSULATION
- CEILING TEXTURE COAT
- CEILING TILE (MASTIC CONTAINS ASBESTOS DUE TO CONTAMINATION)
- TRANSITE
- SPRAYED FIREPROOFING
- DUCT INSULATION

CLIENT: LIMESTONE DISTRICT SCHOOL BOARD

LOCATION: KCVI, 235 FRONTENAC STREET, KINGSTON, ONTARIO

TITLE: 2020 ASBESTOS REASSESSMENT SECOND FLOOR

DATE: 08/29/2020	PROJECT #: 201262.163
DRAWN BY: KV	DRAWING: 3 OF 4
CHECKED BY: SY	
SCALE: NTS	



NOT ALL KNOWN OR SUSPECTED ASBESTOS-CONTAINING BUILDING MATERIALS MAY BE DEPICTED ON THE DRAWING. REFER TO THE ASBESTOS ASSESSMENT REPORT FOR A COMPLETE LIST OF KNOWN AND SUSPECTED ASBESTOS-CONTAINING BUILDING MATERIALS.

LEGEND IS COLOUR DEPENDENT. NON-COLOUR COPIES MAY ALTER INTERPRETATION.

BASE PLAN PROVIDED BY CLIENT.

NOTES:
ASBESTOS-CONTAINING WHITE GLAZING PUTTY IS PRESENT ON THE INTERIOR OF THE ORIGINAL WINDOWS THROUGHOUT THE BUILDING.
FRIABLE PARGING CEMENT INSULATION, CONTAINING CHRYSOTILE ASBESTOS, MAY BE PRESENT ON PIPES IN THE CRAWLSPACE.

PINCHIN

LEGEND:

NAR NO ACCESS TO ROOM/AREA

ASBESTOS-CONTAINING MATERIALS:

- VINYL FLOOR TILES AND MASTIC
- VINYL FLOOR TILES
- THERMAL INSULATION
- # QUANTITY OF FITTINGS WITH ASBESTOS-CONTAINING INSULATION
- CEILING TEXTURE COAT
- CEILING TILE (MASTIC CONTAINS ASBESTOS DUE TO CONTAMINATION)
- TRANSITE
- SPRAYED FIREPROOFING
- DUCT INSULATION

CLIENT:
LIMESTONE DISTRICT SCHOOL BOARD

LOCATION:
KCVI
235 FRONTENAC STREET
KINGSTON, ONTARIO

TITLE:
2020 ASBESTOS REASSESSMENT
THIRD FLOOR

DATE: 08/29/2020	PROJECT # : 201262.163
DRAWN BY: KV	DRAWING: 4 OF 4
CHECKED BY: SY	
SCALE: NTS	

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Certificate of Analysis

Queen's University-Department of Environmental H&S

355 King Street West, 1st Floor
Kingston, ON K7L 2X3
Attn: Tyler MacDonald

Client PO:
Project: KCUI
Custody:

Report Date: 23-Nov-2023
Order Date: 16-Nov-2023

Order #: 2346368

This Certificate of Analysis contains analytical data applicable to the following samples as submitted:

Paracel ID	Client ID
2346368-01	A1 - Room 205 - White paint
2346368-02	B1 - Room 205 - Light green paint
2346368-03	C1 - Room 209 - White paint
2346368-04	D1 - 3rd floorhallway - white paint
2346368-05	E1 - 304 - White paint
2346368-06	F1 - 312 - Turquoise paint

Approved By: Mark Foto

Mark Foto, M.Sc.
Lab Supervisor

Analysis Summary Table

Analysis	Method Reference/Description	Extraction Date	Analysis Date
Metals, ICP-MS	EPA 6020 - Digestion - ICP-MS	22-Nov-23	23-Nov-23

Qualifier Notes:

Sample Qualifiers :

1 : Complete separation of paint from substrate not possible for this sample and a small amount of substrate has been included in the paint digestion.

Sample Data Revisions

None

Work Order Revisions/Comments:

None

Other Report Notes:

n/a: not applicable
ND: Not Detected
MDL: Method Detection Limit
Source Result: Data used as source for matrix and duplicate samples
%REC: Percent recovery.
RPD: Relative percent difference.

PARACEL LABORATORIES LTD.

Order #: 2346368

Certificate of Analysis

Client: **Queen's University-Department of Environmental H&S**

Client PO:

Report Date: 23-Nov-2023

Order Date: 16-Nov-2023

Project Description: KCUI

Sample Results

Lead

Matrix: Paint

Paracel ID	Client ID	Sample Date	Units	MDL	Result
2346368-01	A1 - Room 205 - White paint	15-Nov-23	% by Wt.	0.0005	0.0577 [1]
2346368-02	B1 - Room 205 - Light green paint	15-Nov-23	% by Wt.	0.0005	0.0584
2346368-03	C1 - Room 209 - White paint	15-Nov-23	% by Wt.	0.0005	0.0772
2346368-04	D1 - 3rd floorhallway - white paint	15-Nov-23	% by Wt.	0.0005	0.316
2346368-05	E1 - 304 - White paint	15-Nov-23	% by Wt.	0.0005	0.246
2346368-06	F1 - 312 - Turquoise paint	15-Nov-23	% by Wt.	0.0005	0.169

Laboratory Internal QA/QC

Analyte	Result	Reporting Limit	Units	Source Result	%REC	%REC Limit	RPD	RPD Limit	Notes
Matrix Blank									
Lead	**ND**	**0.0005**	**% by Wt.**						
Matrix Duplicate									
Lead	**0.295**	**0.0005**	**% by Wt.**	**0.316**			**6.83**	**50**	
Matrix Spike									
Lead	190	5.00	% by Wt.	127	127	70-130			

Paracel ID: 2346368

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Page ___ of ___

Client Name: Queen's Environmental Health & Safety
Contact Name: Tyler MacDonald
Address: 355 King Street W., 1st Floor, West Wing, Kingston, Ontario, K7L 3N6
Telephone: 613-533-2999

Project Reference: KCUT
Quote #:
PO #:
Email Address: Tyler.MacDonald@Queensu.Ca

TAT: [x] Regular [ ] 3 Day [ ] 2 Day [ ] 1 Day
Date Required:

Criteria: [ ] O. Reg. 153/04 (As Amended) Table ___ [ ] RSC Filing [ ] O. Reg. 558/00 [ ] PWQO [ ] CCME [ ] SUB (Storm) [ ] SUB (Sanitary) Municipality: ______ [ ] Other: ______

Matrix Type: S (Soil/Sed.) GW (Ground Water) SW (Surface Water) SS (Storm/Sanitary Sewer) P (Paint) A (Air) O (Other)

Paracel Order Number: 2346368

	Sample ID/Location Name	Matrix	Air Volume	# of Containers	Sample Taken Date	Sample Taken Time	PHCs F1-F4+BTEX	VOCs	PAHs	Metals by ICP	Hg	CrVI	B (HWS)	Pb (lead)					
1	A1-Room 205-White paint	P	/	1	11/15/23	11:30am	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[x]	[ ]	[ ]	[ ]	[ ]	[ ]
2	B1-Room 205-Light green paint	P	/	1	↓	↓	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[x]	[ ]	[ ]	[ ]	[ ]	[ ]
3	C1-Room 209-White paint	P	/	1	↓	↓	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[x]	[ ]	[ ]	[ ]	[ ]	[ ]
4	D1-3rd floor hallway-White paint	P	/	1	↓	↓	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[x]	[ ]	[ ]	[ ]	[ ]	[ ]
5	E1-304-White paint	P	/	1	↓	↓	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[x]	[ ]	[ ]	[ ]	[ ]	[ ]
6	F1-312-Turquoise paint	P	/	1	↓	↓	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[x]	[ ]	[ ]	[ ]	[ ]	[ ]
7							[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
8							[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
9							[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]
10							[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]	[ ]

Comments:

Method of Delivery: UPS

Relinquished By (Sign): [signature]	Received by Driver/Depot:	Received at Lab: [signature]	Verified By: SD
Relinquished By (Print): Tyler MacDonald	Date/Time:	Date/Time: Nov. 16 2023 1100	Date/Time: Nov 16, 2023 2:19 pm
Date/Time: Nov 15, 2023 ~ 12:30	Temperature: ___ °C	Temperature: ___ °C	pH Verified [ ] By:

Appendix C: Idea Generation Supporting Documents

Justifications of Post-it Note Method Ideated Solutions Not Being Evaluated

Table 35: Justifications for Options Not Being Evaluated Based on the Post-It Note Method

Scope Component	Ideated Solution	Reasoning for not Evaluating Further
Wall Composition	Insulation within Concrete Blocks	Decided to not be evaluated further due to the difficulty to construct in an existing building. Additionally, this ideated solution only works in part of the building. KCVI is comprised of two different wall compositions, one where the structural element is reinforced concrete, and the other one with terracotta blocks. Since reinforced concrete is used in about 40% of the building, it does not make sense to use an idea that is difficult to construct and only works in 60% of the building. Also, the terracotta blocks have a continuous opening horizontally seen from visual inspection on site, instead of the conventional vertical opening if masonry blocks were used. This would make it much more difficult to insert insulation within the blocks for the exterior walls. Note that at the time of creating Figure 4, it was ideated that the blocks seen on site were masonry blocks, however from the intrusive testing results seen on site January 24th, 2024, it was determined that these were terra cotta blocks.
Wall Composition	Mineral Wool	Mineral wool and fiberglass are very similar with their properties. According to Rmax, fiberglass is more readily available than mineral wool and costs half as much per square foot. Mineral wool has an R-value of R15 for 3.5 inches of thickness while fiberglass has an R-value of R13 at the same thickness (Rmax 2023). However, this slightly better thermal performance does not outweigh the significant cost difference.
Sustainable Roof	Intensive Green Roof	An intensive green roof can be thought of as gardens on a roof. It has a deep layer of soil, typically around 2 feet deep, practically allowing an unlimited amount of possibilities with respect to the plants that can be used. This type of roof can have a dry weight of over 100 pounds per square foot, or 4.8 kPa (Archtoolbox 2021). The current roof design could not handle this added dead load, strengthening of the roof would be needed. This roof type also requires routine maintenance and has a high upfront cost. Due to the climate in Kingston, Ontario, it also does not make sense to have this type of roof, a warmer climate all year round where vegetation could truly thrive is more desirable (Yegon 2021).
Sustainable Roof	Cool Roof	A cool roof is designed to reflect more sunlight than a conventional roof by utilizing a high albedo. Although this is a fairly inexpensive option, to see a worthwhile difference in energy savings, a warmer climate year-round is needed (Trautmann 2023). Additionally, other ideas generated have better impacts on energy efficiency improvements and the building as a whole.

Scope Component	Ideated Solution	Reasoning for not Evaluating Further
Sustainable Roof	Small Vertical/ Horizontal Wind Turbines	The small vertical or horizontal wind turbines were initially included since the KCVI building is located right off Lake Ontario, meaning there is a lot of wind, allowing the wind turbines to be effective. However, due to the estimated size required to truly see a benefit in energy savings, they have been decided to not be assessed (Kh 2019) (Hartman 2023). Additionally, due to the potential to harm surrounding wildlife, these turbines were not evaluated further as this would create a negative reputation for Queen's.
Sustainable Roof	Solar Panels	Solar panels were not considered for the proposed design since Queen's Facilities team stated in Meeting #5 dated (2024-02-08) that they are seriously considering implementing Geothermal technology as an energy source, which ultimately eliminated the prospect of solar panels being a practical upgrade for the roof. Therefore, although solar panels are potentially a viable and impactful option for the roof, they will not be considered in the proposed design for the clients.

Justifications of TRIZ Analysis Ideated Solutions Not Being Evaluated

Table 36: Justifications for Options Not Being Evaluated Based on the TRIZ Analysis Method

Scope Component	Ideated Solution	Reasoning for not Evaluating Further
Windows	Segmentation: Divide the window into segments with varying energy efficiency features. For example, the lower part of the window could be double-glazed for better insulation, while the upper part remains transparent for daylight.	Although this option could save money, it risks creating a discontinuous aesthetic of the window, something that was important to the client. Additionally, the added complexity to the design and installation process could introduce more risks and potential points of failure.
Windows	Changing Optical Properties & Dynamicity: Implement smart windows with adjustable tint levels. The windows can dynamically control transparency based on external conditions, optimizing natural light while minimizing energy loss.	Although this option is innovative and presents a dynamic solution to create an energy efficient window, the technology has not been developed enough to implement it in a building of this size. There are still a lot of reliability issues with these smart windows, creating a high maintenance cost, added onto the already high upfront cost (DeMarco 2023). Additionally, this option may be difficult to implement while meeting the Heritage guidelines.
Windows	Changing Optical Properties & Dynamicity: Integrate dynamic systems that adjust to external	This option does not solve the root cause, that being that the windows are highly inefficient. However, this option could be used in tandem

Scope Component	Ideated Solution	Reasoning for not Evaluating Further
	conditions, such as automated shading devices for windows that respond to sunlight intensity.	with the proposed solution for the window improvement. There are some smart blinds available at Ikea, as well as smart instruments that automatically open curtains on Amazon (Hill 2024). However, doing the cost-benefit analysis of how much these blinds improve the energy efficiency could not be completed due to issues with reliable thermal resistance values of these materials and systems.
Windows	Partial Action: Only change sun-facing windows.	Although this option would save money, it is not a holistic approach to improving the building envelope. It is an incomplete solution and would not solve the underlying problem completely. Additionally, it risks creating a discontinuous aesthetic, and does not have long-term sustainability.
Wall Composition	Multi-functionality: Incorporate measures against temperature variations by utilizing materials that naturally counteract heat transfer, such as phase change materials that absorb and release heat as needed (Zeng et al. 2023).	The main issue with this ideated solution is that other proposed options offer better thermal resistances. The maintenance and durability of this option is not yet proven with it being a relatively new idea. Although this option offers interesting advantages, such as releasing heat when needed, there is still some performance uncertainty (Zeng et al. 2023), going with a more proven and predictable solution makes sense at this time.
Wall Composition	Multi-functionality: Utilize vacuum insulated panels that have one of the highest R-values on the market in its thin build, but it also consists of materials named getters that absorb gases, used to keep the panel free of air and moisture (Holmberg 2022).	Although this option has an R-value of R30 per 25.6 mm of thickness, there is an extreme upfront cost (Action1Insulation 2021), around 4 times higher than closed cell spray foam (Eco Spray Insulation 2023). This option would save a lot of space within KCVI due to the energy efficiency of the vacuum insulated panels, however their lifespan is around 25 years (Holmberg 2022), while closed cell spray foam ranges from 80-100 years (John 2022). These vacuum insulated panels are also very fragile (Action1Insulation 2021), creating more risks during the installation process. The high upfront cost, short lifespan and fragileness, far outweigh the space saved and energy efficiency benefits, based on criteria that was important to the client.

Improving Feature \ Worsening	1 Weight of moving object	2 Weight of stationary object	3 Length of moving object	4 Length of stationary object	5 Area of moving object	6 Area of stationary object	7 Volume of moving object	8 Volume of stationary object	9 Speed	10 Force (Intensity)	11 Stress or pressure	12 Shape	13 Stability of the object's composition	14 Strength	15 Duration of action of moving object	16 Duration of action of stationary object	17 Temperature	18 Illumination intensity	19 Use of energy by moving object	20 Use of energy by stationary object
1 Weight of moving object	+		15, 8, 29, 34		29, 17, 38, 34		29, 2, 40, 28		2, 8, 15, 38	8, 10, 18, 37	10, 36, 37, 40	10, 14, 35, 40	1, 35, 19, 39	28, 27, 18, 40	5, 34, 31, 35		6, 29, 4, 38	19, 1, 32	35, 12, 34, 31	
2 Weight of stationary object		+		10, 1, 29, 35		35, 30, 13, 2		5, 35, 14, 2		8, 10, 19, 35	13, 29, 10, 18	13, 10, 29, 14	26, 39, 1, 40	28, 2, 10, 27		2, 27, 19, 6	28, 19, 32, 22	19, 32, 35		18, 19, 28, 1
3 Length of moving object	8, 15, 29, 34		+		15, 17, 4		7, 17, 4, 35		13, 4, 8	17, 10, 4	1, 8, 35	1, 8, 10, 29	1, 8, 15, 34	8, 35, 29, 34	19		10, 15, 19	32	8, 35, 24	
4 Length of stationary object		35, 28, 40, 29		+		17, 7, 10, 40		35, 8, 2, 14		28, 10	1, 14, 35	13, 14, 15, 7	39, 37, 35	15, 14, 28, 26		1, 10, 35	3, 35, 38, 18	3, 25		
5 Area of moving object	2, 17, 29, 4		14, 15, 18, 4		+		7, 14, 17, 4		29, 30, 4, 34	19, 30, 35, 2	10, 15, 36, 28	5, 34, 29, 4	11, 2, 13, 39	3, 15, 40, 14	6, 3		2, 15, 16	15, 32, 19, 13	19, 32	
6 Area of stationary object		30, 2, 14, 18		26, 7, 9, 39		+				1, 18, 35, 36	10, 15, 36, 37		2, 38	40		2, 10, 19, 30	35, 39, 38			
7 Volume of moving object	2, 26, 29, 40		1, 7, 4, 35		1, 7, 4, 17		+		29, 4, 38, 34	15, 35, 36, 37	6, 35, 36, 37	1, 15, 29, 4	28, 10, 1, 39	9, 14, 15, 7	6, 35, 4		34, 39, 10, 18	2, 13, 10	35	
8 Volume of stationary object		35, 10, 19, 14	19, 14	35, 8, 2, 14				+		2, 18, 37	24, 35	7, 2, 35	34, 28, 35, 40	9, 14, 17, 15		35, 34, 38	35, 6, 4			
9 Speed	2, 28, 13, 38		13, 14, 8		29, 30, 34		7, 29, 34		+	13, 28, 15, 19	6, 18, 38, 40	35, 15, 18, 34	28, 33, 1, 18	8, 3, 26, 14	3, 19, 35, 5		28, 30, 36, 2	10, 13, 19	8, 15, 35, 38	
10 Force (Intensity)	8, 1, 37, 18	18, 13, 1, 28	17, 19, 9, 36	28, 10	19, 10, 15	1, 18, 36, 37	15, 9, 12, 37	2, 36, 18, 37	13, 28, 15, 12	+	18, 21, 11	10, 35, 40, 34	35, 10, 21	35, 10, 14, 27	19, 2		35, 10, 21		19, 17, 10	1, 16, 36, 37
11 Stress or pressure	10, 36, 37, 40	13, 29, 10, 18	35, 10, 36	35, 1, 14, 16	10, 15, 36, 28	10, 15, 36, 37	6, 35, 10	35, 24	6, 35, 36	36, 35, 21	+	35, 4, 15, 10	35, 33, 2, 40	9, 18, 3, 40	19, 3, 27		35, 39, 19, 2		14, 24, 10, 37	
12 Shape	8, 10, 29, 40	15, 10, 26, 3	29, 34, 5, 4	13, 14, 10, 7	5, 34, 4, 10		14, 4, 15, 22	7, 2, 35	35, 15, 34, 18	35, 10, 37, 40	34, 15, 10, 14	+	33, 1, 18, 4	30, 14, 10, 40	14, 26, 9, 25		22, 14, 19, 32	13, 15, 32	2, 6, 34, 14	
13 Stability of the object's composition	21, 35, 2, 39	26, 39, 1, 40	13, 15, 1, 28	37	2, 11, 13	39	28, 10, 19, 39	34, 28, 35, 40	33, 15, 28, 18	10, 35, 21, 16	2, 35, 40	22, 1, 18, 4	+	17, 9, 15	13, 27, 10, 35	39, 3, 35, 23	35, 1, 32	32, 3, 27, 16	13, 19	27, 4, 29, 18
14 Strength	1, 8, 40, 15	40, 26, 27, 1	1, 15, 8, 35	15, 14, 28, 26	3, 34, 40, 29	9, 40, 28	10, 15, 14, 7	9, 14, 17, 15	8, 13, 26, 14	10, 18, 3, 14	10, 3, 18, 40	10, 30, 35, 40	13, 17, 35	+	27, 3, 26		30, 10, 40	35, 19	19, 35, 10	35
15 Duration of action of moving object	19, 5, 34, 31		2, 19, 9		3, 17, 19		10, 2, 19, 30		3, 35, 5	19, 2, 16	19, 3, 27	14, 26, 28, 25	13, 3, 35	27, 3, 10	+		19, 35, 39	2, 19, 4, 35	28, 6, 35, 18	
16 Duration of action by stationary object		6, 27, 19, 16		1, 40, 35				35, 34, 38					39, 3, 35, 23			+	19, 18, 36, 40			
17 Temperature	36, 22, 6, 38	22, 35, 32	15, 19, 9	15, 19, 9	3, 35, 39, 18	35, 38	34, 39, 40, 18	35, 6, 4	2, 28, 36, 30	35, 10, 3, 21	35, 39, 19, 2	14, 22, 19, 32	1, 35, 32	10, 30, 22, 40	19, 13, 39	19, 18, 36, 40	+	32, 30, 21, 16	19, 15, 3, 17	
18 Illumination intensity	19, 1, 32	2, 35, 32	19, 32, 16		19, 32, 26		2, 13, 10		10, 13, 19	26, 19, 6		32, 30	32, 3, 27	35, 19	2, 19, 6		32, 35, 19	+	32, 1, 19	32, 35, 1, 15
19 Use of energy by moving object	12, 18, 28, 31		12, 28		15, 19, 25		35, 13, 18		8, 35, 35	16, 26, 21, 2	23, 14, 25	12, 2, 29	19, 13, 17, 24	5, 19, 9, 35	28, 35, 6, 18	-	19, 24, 3, 14	2, 15, 19	+	-
20 Use of energy by stationary object		19, 9, 6, 27								36, 37			27, 4, 29, 18	35				19, 2, 35, 32	-	+
21 Power	8, 36, 38, 31	19, 26, 17, 27	1, 10, 35, 37		19, 38	17, 32, 13, 38	35, 6, 38	30, 6, 25	15, 35, 2	26, 2, 36, 35	22, 10, 35	29, 14, 2, 40	35, 32, 15, 31	26, 10, 28	19, 35, 10, 38	16	2, 14, 17, 25	16, 6, 19	16, 6, 19, 37	
22 Loss of Energy	15, 6, 19, 28	19, 6, 18, 9	7, 2, 6, 13	6, 38, 7	15, 26, 17, 30	17, 7, 30, 18	7, 18, 23	7	16, 35, 38	36, 38			14, 2, 39, 6	26			19, 38, 7	1, 13, 32, 15		
23 Loss of substance	35, 6, 23, 40	35, 6, 22, 32	14, 29, 10, 39	10, 28, 24	35, 2, 10, 31	10, 18, 39, 31	1, 29, 30, 36	3, 39, 18, 31	10, 13, 28, 38	14, 15, 18, 40	3, 36, 37, 10	29, 35, 3, 5	2, 14, 30, 40	35, 28, 31, 40	28, 27, 3, 18	27, 16, 18, 38	21, 36, 39, 31	1, 6, 13	35, 18, 24, 5	28, 27, 12, 31
24 Loss of Information	10, 24, 35	10, 35, 5	1, 26	26	30, 26	30, 16		2, 22	26, 32						10	10		19		
25 Loss of Time	10, 20, 37, 35	10, 20, 26, 5	15, 2, 29	30, 24, 14, 5	26, 4, 5, 16	10, 35, 17, 4	2, 5, 34, 10	35, 16, 32, 18		10, 37, 36, 5	37, 36, 4	4, 10, 34, 17	35, 3, 22, 5	29, 3, 28, 18	20, 10, 28, 18	28, 20, 10, 16	35, 29, 21, 18	1, 19, 26, 17	35, 38, 19, 18	1
26 Quantity of substance/the matter	35, 6, 18, 31	27, 26, 18, 35	29, 14, 35, 18		15, 14, 29	2, 18, 40, 4	15, 20, 29		35, 29, 34, 28	35, 14, 3	10, 36, 14, 3	35, 14	15, 2, 17, 40	14, 35, 34, 10	3, 35, 10, 40	3, 35, 31	3, 17, 39		34, 29, 16, 18	3, 35, 31
27 Reliability	3, 8, 10, 40	3, 10, 8, 28	15, 9, 14, 4	15, 29, 28, 11	17, 10, 14, 16	32, 35, 40, 4	3, 10, 14, 24	2, 35, 24	21, 35, 11, 28	8, 28, 10, 3	10, 24, 35, 19	35, 1, 16, 11		11, 28	2, 35, 3, 25	34, 27, 6, 40	3, 35, 10	11, 32, 13	21, 11, 27, 19	36, 23
28 Measurement accuracy	32, 35, 26, 28	28, 35, 25, 26	28, 26, 5, 16	32, 28, 3, 16	26, 28, 32, 3	26, 28, 32, 3	32, 13, 6		28, 13, 32, 24	32, 2	6, 28, 32	6, 28, 32	32, 35, 13	28, 6, 32	28, 6, 32	10, 26, 24	6, 19, 28, 24	6, 1, 32	3, 6, 32	
29 Manufacturing precision	28, 32, 13, 18	28, 35, 27, 9	10, 28, 29, 37	2, 32, 10	28, 33, 29, 32	2, 29, 18, 36	32, 23, 2	25, 10, 35	10, 28, 32	28, 19, 34, 36	3, 35	32, 30, 40	30, 18	3, 27	3, 27, 40		19, 26	3, 32	32, 2	
30 Object-affected harmful factors	22, 21, 27, 39	2, 22, 13, 24	17, 1, 39, 4	1, 18	22, 1, 33, 28	27, 2, 39, 35	22, 23, 37, 35	34, 39, 19, 27	21, 22, 35, 28	13, 35, 39, 18	22, 2, 37	22, 1, 3, 35	35, 24, 30, 18	18, 35, 37, 1	22, 15, 33, 28	17, 1, 40, 33	22, 33, 35, 2	1, 19, 32, 13	1, 24, 6, 27	10, 2, 22, 37
31 Object-generated harmful factors	19, 22, 15, 39	35, 22, 1, 39	17, 15, 16, 22		17, 2, 18, 39	22, 1, 40	17, 2, 40	30, 18, 35, 4	35, 28, 3, 23	35, 28, 1, 40	2, 33, 27, 18	35, 1	35, 40, 27, 39	15, 35, 22, 2	15, 22, 33, 31	21, 39, 16, 22	22, 35, 2, 24	19, 24, 39, 32	2, 35, 6	19, 22, 18
32 Ease of manufacture	28, 29, 15, 16	1, 27, 36, 13	1, 29, 13, 17	15, 17, 27	13, 1, 26, 12	16, 40	13, 29, 1, 40	35	35, 13, 8, 1	35, 12	35, 19, 1, 37	1, 28, 13, 27	11, 13, 1	1, 3, 10, 32	27, 1, 4	35, 16	27, 26, 18	28, 24, 27, 1	28, 26, 27, 1	1, 4
33 Ease of operation	25, 2, 13, 15	6, 13, 1, 25	1, 17, 13, 12		1, 17, 13, 16	18, 16, 15, 39	1, 16, 35, 15	4, 18, 39, 31	18, 13, 34	28, 13, 35	2, 32, 12	15, 34, 29, 28	32, 35, 30	32, 40, 3, 28	29, 3, 8, 25	1, 16, 25	26, 27, 13	13, 17, 1, 24	1, 13, 24	
34 Ease of repair	2, 27, 35, 11	2, 27, 35, 11	1, 28, 10, 25	3, 18, 31	15, 13, 32	16, 25	25, 2, 35, 11	1	34, 9	1, 11, 10	13	1, 13, 2, 4	2, 35	11, 1, 2, 9	11, 29, 28, 27	1	4, 10	15, 1, 13	15, 1, 28, 16	
35 Adaptability or versatility	1, 6, 15, 8	19, 15, 29, 16	35, 1, 29, 2	1, 35, 16	35, 30, 29, 7	15, 16	15, 35, 29		35, 10, 14	15, 17, 20	35, 16	15, 37, 1, 8	35, 30, 14	35, 3, 32, 6	13, 1, 35	2, 16	27, 2, 3, 35	6, 22, 26, 1	19, 35, 29, 13	
36 Device complexity	26, 30, 34, 36	2, 26, 35, 39	1, 19, 26, 24	26	14, 1, 13, 16	6, 36	34, 26, 6	1, 16	34, 10, 28	26, 16	19, 1, 35	29, 13, 28, 15	2, 22, 17, 19	2, 13, 28	10, 4, 28, 15		2, 17, 13	24, 17, 13	27, 2, 29, 28	
37 Difficulty of detecting and measuring	27, 26, 28, 13	6, 13, 28, 1	16, 17, 26, 24	26	2, 13, 18, 17	2, 39, 30, 16	29, 1, 4, 16	2, 18, 26, 31	3, 4, 16, 35	30, 28, 40, 19	35, 36, 37, 32	27, 13, 1, 39	11, 22, 39, 30	27, 3, 15, 28	19, 29, 39, 25	25, 34, 6, 35	3, 27, 35, 16	2, 24, 26	35, 38	19, 35, 16
38 Extent of automation	28, 26, 18, 35	28, 26, 35, 10	14, 13, 17, 28	23	17, 14, 13		35, 13, 16		28, 10	2, 35	13, 35	15, 32, 1, 13	18, 1	25, 13	6, 9		26, 2, 19	8, 32, 19	2, 32, 13	
39 Productivity	35, 26, 24, 37	28, 27, 15, 3	18, 4, 28, 38	30, 7, 14, 26	10, 26, 34, 31	10, 35, 17, 7	2, 6, 34, 10	35, 37, 10, 2		28, 15, 10, 36	10, 37, 14	14, 10, 34, 40	35, 3, 22, 39	29, 28, 10, 18	35, 10, 2, 18	20, 10, 16, 38	35, 21, 28, 10	26, 17, 19, 1	35, 10, 38, 19	1

Improving Feature \ Worsening	21 Power	22 Loss of Energy	23 Loss of Substance	24 Loss of Information	25 Loss of Time	26 Quantity of substance	27 Reliability	28 Measurement accuracy	29 Manufacturing precision	30 Object-affected harmful factors	31 Object-generated harmful factors	32 Ease of manufacture	33 Ease of operation	34 Ease of repair	35 Adaptability or versatility	36 Device complexity	37 Difficulty of detecting and measuring	38 Extent of automation	39 Productivity
1 Weight of moving object	12, 36, 18, 31	6, 2, 34, 19	5, 35, 3, 31	10, 24, 35	10, 35, 20, 28	3, 26, 18, 31	1, 3, 11, 27	28, 27, 35, 26	28, 35, 26, 18	22, 21, 18, 27	22, 35, 31, 39	27, 28, 1, 36	35, 3, 2, 24	2, 27, 28, 11	29, 5, 15, 8	26, 30, 36, 34	28, 29, 26, 32	26, 35, 18, 19	35, 3, 24, 37
2 Weight of stationary object	15, 19, 18, 22	18, 19, 28, 15	5, 8, 13, 30	10, 15, 35	10, 20, 35, 26	19, 6, 18, 26	10, 28, 8, 3	18, 26, 28	10, 1, 35, 17	2, 19, 22, 37	35, 22, 1, 39	28, 1, 9	6, 13, 1, 32	2, 27, 28, 11	19, 15, 29	1, 10, 26, 39	25, 28, 17, 15	2, 26, 35	1, 28, 15, 35
3 Length of moving object	1, 35	7, 2, 35, 39	4, 29, 23, 10	1, 24	15, 2, 29	29, 35	10, 14, 29, 40	28, 32, 4	10, 28, 29, 37	1, 15, 17, 24	17, 15	1, 29, 17	15, 29, 35, 4	1, 28, 10	14, 15, 1, 16	1, 19, 26, 24	35, 1, 26, 24	17, 24, 26, 16	14, 4, 28, 29
4 Length of stationary object	12, 8	6, 28	10, 28, 24, 35	24, 26,	30, 29, 14		15, 29, 28	32, 28, 3	2, 32, 10	1, 18		15, 17, 27	2, 25	3	1, 35	1, 26	26		30, 14, 7, 26
5 Area of moving object	19, 10, 32, 18	15, 17, 30, 26	10, 35, 2, 39	30, 26	26, 4	29, 30, 6, 13	29, 9	26, 28, 32, 3	2, 32	22, 33, 28, 1	17, 2, 18, 39	13, 1, 26, 24	15, 17, 13, 16	15, 13, 10, 1	15, 30	14, 1, 13	2, 36, 26, 18	14, 30, 28, 23	10, 26, 34, 2
6 Area of stationary object	17, 32	17, 7, 30	10, 14, 18, 39	30, 16	10, 35, 4, 18	2, 18, 40, 4	32, 35, 40, 4	26, 28, 32, 3	2, 29, 18, 36	27, 2, 39, 35	22, 1, 40	40, 16	16, 4	16	15, 16	1, 18, 36	2, 35, 30, 18	23	10, 15, 17, 7
7 Volume of moving object	35, 6, 13, 18	7, 15, 13, 16	36, 39, 34, 10	2, 22	2, 6, 34, 10	29, 30, 7	14, 1, 40, 11	25, 26, 28	25, 28, 2, 16	22, 21, 27, 35	17, 2, 40, 1	29, 1, 40	15, 13, 30, 12	10	15, 29	26, 1	29, 26, 4	35, 34, 16, 24	10, 6, 2, 34
8 Volume of stationary object	30, 6		10, 39, 35, 34		35, 16, 32, 18	35, 3	2, 35, 16		35, 10, 25	34, 39, 19, 27	30, 18, 35, 4	35		1		1, 31	2, 17, 26		35, 37, 10, 2
9 Speed	19, 35, 38, 2	14, 20, 19, 35	10, 13, 28, 38	13, 26		10, 19, 29, 38	11, 35, 27, 28	28, 32, 1, 24	10, 28, 32, 25	1, 28, 35, 23	2, 24, 35, 21	35, 13, 8, 1	32, 28, 13, 12	34, 2, 28, 27	15, 10, 26	10, 28, 4, 34	3, 34, 27, 16	10, 18	
10 Force (Intensity)	19, 35, 18, 37	14, 15	8, 35, 40, 5		10, 37, 36	14, 29, 18, 36	3, 35, 13, 21	35, 10, 23, 24	28, 29, 37, 36	1, 35, 40, 18	13, 3, 36, 24	15, 37, 18, 1	1, 28, 3, 25	15, 1, 11	15, 17, 18, 20	26, 35, 10, 18	36, 37, 10, 19	2, 35	3, 28, 35, 37
11 Stress or pressure	10, 35, 14	2, 36, 25	10, 36, 3, 37		37, 36, 4	10, 14, 36	10, 13, 19, 35	6, 28, 25	3, 35	22, 2, 37	2, 33, 27, 18	1, 35, 16	11	2	35	19, 1, 35	2, 36, 37	35, 24	10, 14, 35, 37
12 Shape	4, 6, 2	14	35, 29, 3, 5		14, 10, 34, 17	36, 22	10, 40, 16	28, 32, 1	32, 30, 40	22, 1, 2, 35	35, 1	1, 32, 17, 28	32, 15, 26	2, 13, 1	1, 15, 29	16, 29, 1, 28	15, 13, 39	15, 1, 32	17, 26, 34, 10
13 Stability of the object's composition	32, 35, 27, 31	14, 2, 39, 6	2, 14, 30, 40		35, 27	15, 32, 35		13	18	35, 24, 30, 18	35, 40, 27, 39	35, 19	32, 35, 30	2, 35, 10, 16	35, 30, 34, 2	2, 35, 22, 26	35, 22, 39, 23	1, 8, 35	23, 35, 40, 3
14 Strength	10, 26, 35, 28	35	35, 28, 31, 40		29, 3, 28, 10	29, 10, 27	11, 3	3, 27, 16	3, 27	18, 35, 37, 1	15, 35, 22, 2	11, 3, 10, 32	32, 40, 25, 2	27, 11, 3	15, 3, 32	2, 13, 25, 28	27, 3, 15, 40	15	29, 35, 10, 14
15 Duration of action of moving object	19, 10, 35, 38		28, 27, 3, 18	10	20, 10, 28, 18	3, 35, 10, 40	11, 2, 13	3	3, 27, 16, 40	22, 15, 33, 28	21, 39, 16, 22	27, 1, 4	12, 27	29, 10, 27	1, 35, 13	10, 4, 29, 15	19, 29, 39, 35	6, 10	35, 17, 14, 19
16 Duration of action by stationary object	16		27, 16, 18, 38	10	28, 20, 10, 16	3, 35, 31	34, 27, 6, 40	10, 26, 24		17, 1, 40, 33	22	35, 10	1	1	2		25, 34, 6, 35	1	20, 10, 16, 38
17 Temperature	2, 14, 17, 25	21, 17, 35, 38	21, 36, 29, 31		35, 28, 21, 18	3, 17, 30, 39	19, 35, 3, 10	32, 19, 24	24	22, 33, 35, 2	22, 35, 2, 24	26, 27	26, 27	4, 10, 16	2, 18, 27	2, 17, 16	3, 27, 35, 31	26, 2, 19, 16	15, 28, 35
18 Illumination intensity	32	13, 16, 1, 6	13, 1	1, 6	19, 1, 26, 17	1, 19		11, 15, 32	3, 32	15, 19	35, 19, 32, 39	19, 35, 28, 26	28, 26, 19	15, 17, 13, 16	15, 1, 19	6, 32, 13	32, 15	2, 26, 10	2, 25, 16
19 Use of energy by moving object	6, 19, 37, 18	12, 22, 15, 24	35, 24, 18, 5		35, 38, 19, 18	34, 23, 16, 18	19, 21, 11, 27	3, 1, 32		1, 35, 6, 27	2, 35, 6	28, 26, 30	19, 35	1, 15, 17, 28	15, 17, 13, 16	2, 29, 27, 28	35, 38	32, 2	12, 28, 35
20 Use of energy by stationary object			28, 27, 18, 31			3, 35, 31	10, 36, 23			10, 2, 22, 37	19, 22, 18	1, 4					19, 35, 16, 25		1, 6
21 Power	+	10, 35, 38	28, 27, 18, 38	10, 19	35, 20, 10, 6	4, 34, 19	19, 24, 26, 31	32, 15, 2	32, 2	19, 22, 31, 2	2, 35, 18	26, 10, 34	26, 35, 10	35, 2, 10, 34	19, 17, 34	20, 19, 30, 34	19, 35, 16	28, 2, 17	28, 35, 34
22 Loss of Energy	3, 38	+	35, 27, 2, 37	19, 10	10, 18, 32, 7	7, 18, 25	11, 10, 35	32		21, 22, 35, 2	21, 35, 2, 22		35, 32, 1	2, 19		7, 23	35, 3, 15, 23	2	28, 10, 29, 35
23 Loss of substance	28, 27, 18, 38	35, 27, 2, 31	+		15, 18, 35, 10	6, 3, 10, 24	10, 29, 39, 35	16, 34, 31, 28	35, 10, 24, 31	33, 22, 30, 40	10, 1, 34, 29	15, 34, 33	32, 28, 2, 24	2, 35, 34, 27	15, 10, 2	35, 10, 28, 24	35, 18, 10, 13	35, 10, 18	28, 35, 10, 23
24 Loss of Information	10, 19	19, 10		+	24, 26, 28, 32	24, 28, 35	10, 28, 23			22, 10, 1	10, 21, 22	32	27, 22				35, 33	35	13, 23, 15
25 Loss of Time	35, 20, 10, 6	10, 5, 18, 32	35, 18, 10, 39	24, 26, 28, 32	+	35, 38, 18, 16	10, 30, 4	24, 34, 28, 32	24, 26, 28, 18	35, 18, 34	35, 22, 18, 39	35, 28, 34, 4	4, 28, 10, 34	32, 1, 10	35, 28	6, 29	18, 28, 32, 10	24, 28, 35, 30	
26 Quantity of substance/the matter	35	7, 18, 25	6, 3, 10, 24	24, 28, 35	35, 38, 18, 16	+	18, 3, 28, 40	13, 2, 28	33, 30	35, 33, 29, 31	3, 35, 40, 39	29, 1, 35, 27	35, 29, 25, 10	2, 32, 10, 25	15, 3, 29	3, 13, 27, 10	3, 27, 29, 18	8, 35	13, 29, 3, 27
27 Reliability	21, 11, 26, 31	10, 11, 35	10, 35, 29, 39	10, 28	10, 30, 4	21, 28, 40, 3	+	32, 3, 11, 23	11, 32, 1	27, 35, 2, 40	35, 2, 40, 26		27, 17, 40	1, 11	13, 35, 8, 24	13, 35, 1	27, 40, 28	11, 13, 27	1, 35, 29, 38
28 Measurement accuracy	3, 6, 32	26, 32, 27	10, 16, 31, 28		24, 34, 28, 32	2, 6, 32	5, 11, 1, 23	+		28, 24, 22, 26	3, 33, 39, 10	6, 35, 25, 18	1, 13, 17, 34	1, 32, 13, 11	13, 35, 2	27, 35, 10, 34	26, 24, 32, 28	28, 2, 10, 34	10, 34, 28, 32
29 Manufacturing precision	32, 2	13, 32, 2	35, 31, 10, 24		32, 26, 28, 18	32, 30	11, 32, 1		+	26, 28, 10, 36	4, 17, 34, 26		1, 32, 35, 23	25, 10		26, 2, 18		26, 28, 18, 23	10, 18, 32, 39
30 Object-affected harmful factors	19, 22, 31, 2	21, 22, 35, 2	33, 22, 19, 40	22, 10, 2	35, 18, 34	35, 33, 29, 31	27, 24, 2, 40	28, 33, 23, 26	26, 28, 10, 18	+		24, 35, 2	2, 25, 28, 39	35, 10, 2	35, 11, 22, 31	22, 19, 29, 40	22, 19, 29, 40	33, 3, 34	22, 35, 13, 24
31 Object-generated harmful factors	2, 35, 18	21, 35, 2, 22	10, 1, 34	10, 21, 29	1, 22	3, 24, 39, 1	24, 2, 40, 39	3, 33, 26	4, 17, 34, 26		+					19, 1, 31	2, 21, 27, 1	2	22, 35, 18, 39
32 Ease of manufacture	27, 1, 12, 24	19, 35	15, 34, 33	32, 24, 18, 16	35, 28, 34, 4	35, 23, 1, 24		1, 35, 12, 18		24, 2		+	2, 5, 13, 16	35, 1, 11, 9	2, 13, 15	27, 26, 1	6, 28, 11, 1	8, 28, 1	35, 1, 10, 28
33 Ease of operation	35, 34, 2, 10	2, 19, 13	28, 32, 2, 24	4, 10, 27, 22	4, 28, 10, 34	12, 35	17, 27, 8, 40	25, 13, 2, 34	1, 32, 35, 23	2, 25, 28, 39		2, 5, 12	+	12, 26, 1, 32	15, 34, 1, 16	32, 26, 12, 17		1, 34, 12, 3	15, 1, 28
34 Ease of repair	15, 10, 32, 2	15, 1, 32, 19	2, 35, 34, 27		32, 1, 10, 25	2, 28, 10, 25	11, 10, 1, 16	10, 2, 13	25, 10	35, 10, 2, 16		1, 35, 11, 10	1, 12, 26, 15	+	7, 1, 4, 16	35, 1, 13, 11		34, 35, 7, 13	1, 32, 10
35 Adaptability or versatility	19, 1, 29	18, 15, 1	15, 10, 2, 13		35, 28	3, 35, 15	35, 13, 8, 24	35, 5, 1, 10		35, 11, 32, 31		1, 13, 31	15, 34, 1, 16	1, 16, 7, 4	+	15, 29, 37, 28	1	27, 34, 35	35, 28, 6, 37
36 Device complexity	20, 19, 30, 34	10, 35, 13, 2	35, 10, 28, 29		6, 29	13, 3, 27, 10	13, 35, 1	2, 26, 10, 34	26, 24, 32	22, 19, 29, 40	19, 1	27, 26, 1, 13	27, 9, 26, 24	1, 13	29, 15, 28, 37	+	15, 10, 37, 28	15, 1, 24	12, 17, 28
37 Difficulty of detecting and measuring	18, 1, 16, 10	35, 3, 15, 19	1, 18, 10, 24	35, 33, 27, 22	18, 28, 32, 9	3, 27, 29, 18	27, 40, 28, 8	26, 24, 32, 28		22, 19, 29, 28	2, 21	5, 28, 11, 29	2, 5	12, 26	1, 15	15, 10, 37, 28	+	34, 21	35, 18
38 Extent of automation	28, 2, 27	23, 28	35, 10, 18, 5	35, 33	24, 28, 35, 30	35, 13	11, 27, 32	28, 26, 10, 34	28, 26, 18, 23	2, 33	2	1, 26, 13	1, 12, 34, 3	1, 35, 13	27, 4, 1, 35	15, 24, 10	34, 27, 25	+	5, 12, 35, 26
39 Productivity	35, 20, 10	28, 10, 29, 35	28, 10, 35, 23	13, 15, 23		35, 38	1, 35, 10, 38	1, 10, 34, 28	18, 10, 32, 1	22, 35, 13, 24	35, 22, 18, 39	35, 28, 2, 24	1, 28, 7, 10	1, 32, 10, 25	1, 35, 28, 37	12, 17, 28, 24	35, 18, 27, 2	5, 12, 35, 26	+

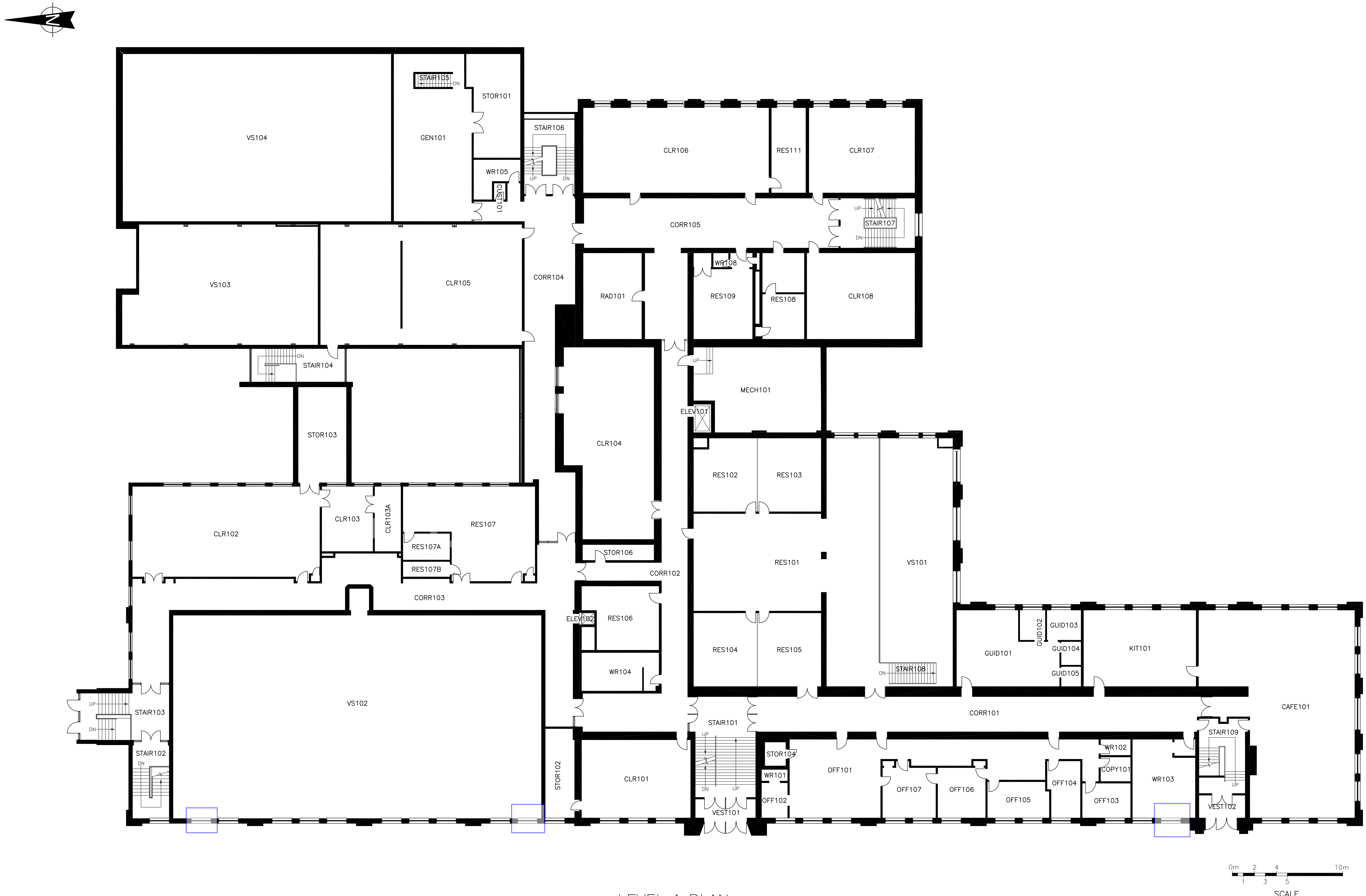
Inventive Principles

1. Segmentation
2. Extraction, Separation, Removal, Segregation
3. Local Quality
4. Asymmetry
5. Combining, Integration, Merging
6. Universality, Multi-functionality
7. Nesting
8. Counterweight, Levitation
9. Preliminary anti-action, Prior counteraction
10. Prior action
11. Cushion in advance, compensate before
12. Equipotentiality, remove stress
13. Inversion, The other way around
14. Spheroidality, Curvilinearity
15. Dynamicity, Optimization
16. Partial or excessive action
17. Moving to a new dimension
18. Mechanical vibration/oscillation
19. Periodic action
20. Continuity of a useful action
21. Rushing through
22. Convert harm into benefit, "Blessing in disguise"
23. Feedback
24. Mediator, intermediary
25. Self-service, self-organization
26. Copying
27. Cheap, disposable objects
28. Replacement of a mechanical system with 'fields'
29. Pneumatics or hydraulics:
30. Flexible membranes or thin film
31. Use of porous materials
32. Changing color or optical properties
33. Homogeneity
34. Rejection and regeneration, Discarding and recovering
35. Transformation of the physical and chemical states of an object, parameter change, changing properties
36. Phase transformation
37. Thermal expansion
38. Use strong oxidizers, enriched atmospheres, accelerated oxidation
39. Inert environment or atmosphere
40. Composite materials

Appendix D: Supporting Documents for Windows Scope Component

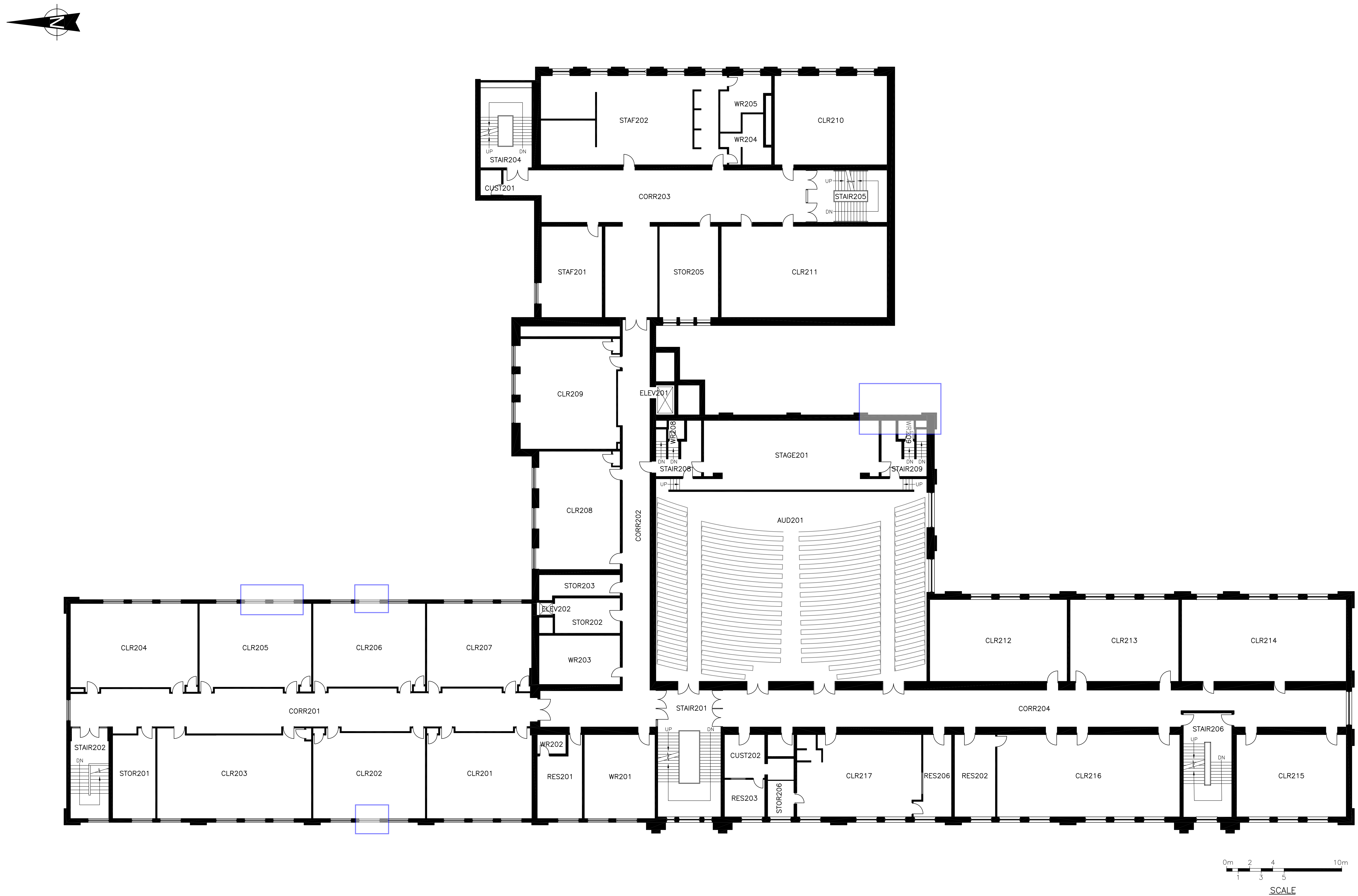
LEVEL 0 PLAN

5			DR'N BY: P.D.	Queen's University FACILITIES
4			DATE: MARCH 2022	
3			APP'D BY:	235 FRONTENAC ST.
2			SCALE: AS SHOWN	BLDG. No. 303 · BLOCK · LEVEL 0 · C.A.D.D. REF. 303-00
1			FILE NO. 303	PROJECT No. / FILE No. 303 · DRAWING No. A001 · REV. 0
0	DATE	REVISION	DWG. 1 OF 5	



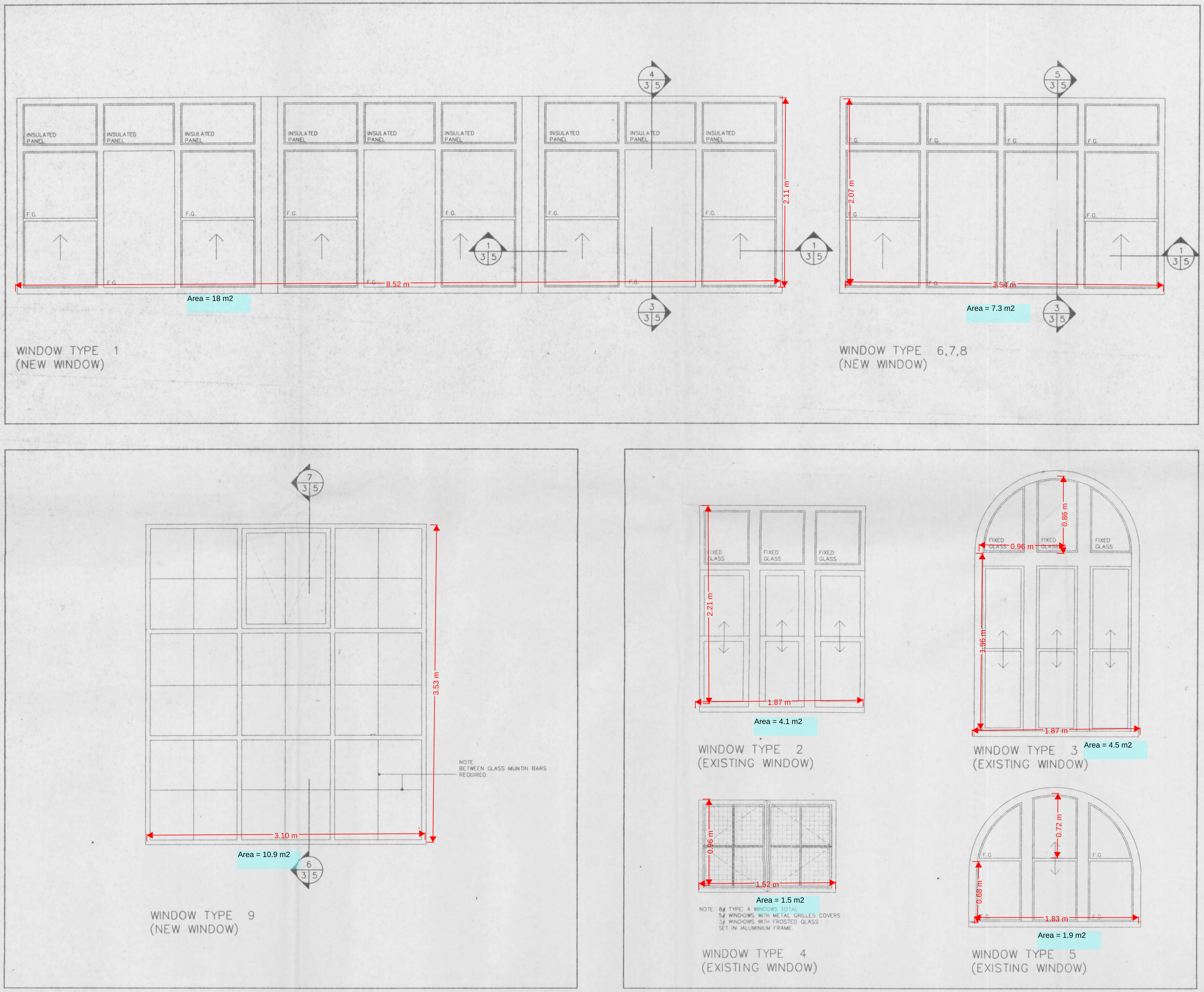
LEVEL 1 PLAN

5			DR'N BY: P.D.	Queen's University FACILITIES
4			DATE: MARCH 2022	
3			APP'D BY:	235 FRONTENAC ST.
2			SCALE: AS SHOWN	BLDG. No. 303 / BLOCK / LEVEL 1 / C.A.D.D. REF. 303-01
1			FILE NO. 303	PROJECT No. / FILE No. 303 / DRAWING No. A002 / REV. 0
0	DATE	REVISION	DWG. 2 OF 5	



LEVEL 2 PLAN

5			DR'N BY: P.D.	Queen's University FACILITIES
4			DATE: MARCH 2022	
3			APP'D BY:	235 FRONTENAC ST.
2			SCALE: AS SHOWN	BLDG. No. 303 · BLOCK · LEVEL 2 · C.A.D.D. REF. 303-02
1			FILE NO. 303	PROJECT No. / FILE No. 303 · DRAWING No. A003 · REV. 0
0	DATE	REVISION	DWG. 3 OF 5	



metric — All dimensions unless otherwise noted are in millimetres

NOTE:
1.0 ALL WINDOW OPENING SIZES TO BE CONFIRMED ON SITE BY WINDOW MANUFACTURER.

2.0 EXISTING WINDOWS 2,3,4,5 – EXISTING PAINT FINISH REPAIR NAIL HOLES,CRACKS, AND OTHER DEFECTS. IF ANY SURFACE CANNOT BE REPAIRED IN A PROPER MANNER NOTIFY THE CONSULTANT IMMEDIATELY

3.0 NEW WINDOWS 1,6,7,8&9 TO BE INSTALLED IN EXISTING WINDOW OPENINGS AFTER REMOVING EXISTING WINDOWS (SEE ELEVATIONS)

4.0 PATCH AND REPAIR INTERIOR FINISHES TO MATCH EXISTING.

5.0 CAULK, SEAL AND INSULATE PERIMETER OF NEW WINDOW FRAMES.

A – DETAIL NUMBER
B – DRAWING NUMBER WHERE DETAIL REQUIRED
C – DRAWING NUMBER WHERE DETAIL FOUND

No.	Date	Description
2	96.07.25	ISSUED FOR BIDDING
1	94.05.10	FOR CLIENTS APPROVAL

Revisions

ONTARIO ASSOCIATION OF ARCHITECTS — ROBERT L. CROTHERS LICENCE 3950

Consultants

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Project
Kingston Collegiate & Vocational Institute
Window Replacement

Drawing Title
New & Exist. Window Elevations

Scale: 1:20 | Drawn by:
Date: 96.06.25. | Checked by:
Project Number: 800120 | Drawing Number: A–3 | Rev 2

CAD FILENAME: 800120G3 LAST UPDATE: 19960724.0931 LAST PLOTTED: 19960724.0931 FILE DRAWER: 00

A1

Heritage Window 1 =
2.43 x 2.45 = 5.95

Heritage Window 2 =
4.46

HW3 = 2.98

HW4 = 5.58

HW5 = 1.12

East side:
Type 1 x 3 = 54
Type 2 x 9 = 36.9
Type 3 x 9 = 40.5
Type 4 x (8 + 22 + 5) = 52.5
Type 6 x 3 = 21.9
HW2 x (26+29) = 245.3
HW3 x 3 = 8.94

South side:
Type 5 x 2 = 3.8
Type 6 x 1 = 7.3
Type 9 x 3 = 32.7
HW2 x (2+4) = 26.76
HW1 x 3 = 17.85

West side:
Type 1 x 1 = 18
Type 6 x 1 = 7.3
HW2 x 90 = 401.4
HW4 x 12 = 66.96
HW5 x 10 = 11.2

North side:
Type 4 x 3 = 4.5
Type 9 x (2+4) = 65.4
2/3 Type 9 x 3 = 21.8
1/3 Type 9 x 4 = 14.53

Gym section on east side (not east wall)
type 4 x 14 = 21

Total Area = 1180.54

Window RSI Value Calculations

Changing the composition of the windows would involve replacing the existing windowpanes with a double-glazed pane. It can be assumed that these windows would have an RSI value of approximately 0.599 m^2K/W ($3.4 \frac{ft^2*°F*h}{BTU}$), as mentioned in section 5.1 Windows. Converting this value into metric form is shown below and is required before inverting this value to provide the insulation factor.

$$Rvalue\ consersion = 3.4 \frac{ft^2 * °F * h}{BTU} * \frac{1}{5.67446\ \frac{m^2 * K}{W}} = 0.599 \frac{m^2 * K}{W}$$

$$Uvalue = \frac{1}{0.599\ \frac{m^2 K}{W}} = 1.67 \frac{W}{m^2 K}$$

Insulating film is an additional layer that can be added to the glass panes of the historical windows to provide more insulation, further improving its energy efficiency. With the addition of insulating film, it can be assumed that the windows would have an RSI value of approximately 0.44 m^2K/W ($2.5 \frac{ft^2*°F*h}{BTU}$) through the addition of insulating film. The RSI value used is a conservative estimate as it depends on the current windows energy efficiency, so based on that value the U-value calculated will differ. Using this value, the insulation factor can be determined.

$$Rvalue\ consersion = 2.5 \frac{ft^2 * °F * h}{BTU} * \frac{1}{5.67446\ \frac{m^2 * K}{W}} = 0.44 \frac{m^2 * K}{W}$$

$$Uvalue = \frac{1}{0.44\ \frac{m^2 K}{W}} = 2.27 \frac{W}{m^2 K}$$

Using the U-value, along with the total area of windows, and the average temperature difference for each month, the heat loss due to the windows for KCVI can be determined for changing the composition of the windows and insulating film, as shown in Table 37.

Table 37: Relative Heat Loss for Each Month Based for Option 1 and 3

Month	**Heat Loss (kWh)**	
	Option #1	**Option #3**
January	41045	55821
February	35749	48618
March	31516	42862
April	20570	27975
May	10994	14952
June	4256	5788
July	733	997
August	733	997
September	7093	9646
October	16858	22926
November	23407	31833
December	35181	47846
Annual Sum (kWh)	**228134**	**310262**

Cost Estimation

Below provides insight on the total cost estimation for option 1, changing the composition of the windows.

Table 38: Cost Analysis of Option 1: Change Composition of the Windows

Item	**RSMeans reference number and description**	**Cost ($CAD)**
Disposal of existing windowpanes	024210200810: Deconstruction of building doors and windows.	70.96/windowsill
New windowpanes	085213200300: Windows, wood, bow, metal-clad, end panels operable, casement, double insulated glass.	1700.24/windowsill
Installation costs	085113206200: Windows, aluminum, incl. frame and glazing, for installation	8% of material costs = 136.00/ windowsill
	Total per square foot (average square foot per sill = 4.6 m^2)	423.70/m^2
	Total Cost (Total window area = 1180.54 m^2)	500270.00

Below provides insight on the total cost estimation for option 1, changing the composition of the windows.

Table 39: Cost Analysis of Option 3: Insulating Film

Item	RSMeans reference number and description	Cost ($CAD)
Material	088130102500: Insulating glass, heat reflective, film inside, clear, 1" thick unit	761.80/m^2
Labour costs	085113206200: Windows, aluminum, incl. frame and glazing, for installation	8% of material costs = 60.90/m^2
	Total/m^2	822.70
	Total Cost (Total window area = 1180.54 m^2)	971230.00

Payback Period Calculations

Stable Designs used past metering information that Queen's Facilities provided, which demonstrated how much money they spend on natural gas heating per month. This information was then used to calibrate the calculations Stable Designs performed to ensure an accurate representation of the KCVI heat loss. This information can be found in Table 40.

Table 40: Existing Natural Gas Usage for the Past Two Years (Queen's Facilities 2024)

Month	Electricity (kWh)	Electricity ($)	Natural Gas (m3)	Carbon Tax ($)	Natural Gas Total Cost ($)
Feb-22	39,851.16	$ 1,568.28	60,493	$ 4,827.34	$ 11,231.51
Mar-22	43,397.66	$ 1,813.39	28,456	$ 2,270.78	$ 5,397.87
Apr-22	40,140.04	$ 804.68	35,130	$ 3,468.19	$ 7,310.96
May-22	42,685.64	$ 1,399.85	6,928	$ 688.64	$ 1,541.43
Jun-22	43,439.22	$ 1,821.81	500	$ 49.70	$ 200.08
Jul-22	46,643.36	$ 3,245.50	453	$ 45.03	$ 210.39
Aug-22	49,569.94	$ 4,036.06	156	$ 15.50	$ 105.13
Sep-22	42,353.00	$ 2,258.51	-	$ -	$ 77.95
Oct-22	69,147.16	$ 2,582.80	11,128	$ 1,106.12	$ 36,193.24
Nov-22	54,118.02	$ 2,565.97	49,090	$ 4,879.55	$ 22,224.00
Dec-22	66,009.08	$ 2,955.24	50,264	$ 4,996.25	$ 22,768.33
Jan-23	64,866.92	$ 1,610.37	44,066	$ 4,380.16	$ 19,988.78
Feb-23	56,074.04	$ 1,520.03	49,002	$ 4,870.80	$ 22,208.75
Mar-23	52,792.36	$ 1,194.30	32,721	$ 3,746.44	$ 15,476.70
Apr-23	40,760.10	$ 761.27	13,699	$ 1,717.86	$ 6,734.75
May-23	39,952.44	$ 966.34	12	$ 1.51	$ 85.33
Jun-23	35,787.28	$ 1,378.21	-	$ -	$ 82.86
Jul-23	38,848.12	$ 1,387.77	-	$ -	$ 79.12
Aug-23	38,185.98	$ 1,427.18	-	$ -	$ 82.86
Sep-23	36,321.92	$ 1,178.17	-	$ -	$ 80.23
Oct-23	50,045.14	$ 1,489.58	24,968	$ 3,130.98	$ 11,801.83
Nov-23	55,288.40	$ 1,785.06	49,520	$ 6,209.81	$ 22,436.17

The first step to determine the heat loss for KCVI involved determining the thermal conductance for the five main areas of heat loss.

1. Surface area heat loss through walls

a. Using the U values calculated in Section 7.1.2 Wall Composition, the overall thermal conductance of the exterior walls was calculated as follows:

$$TC_{Walls} = (U_{terracotta} * A_{wall\ terracotta}) + (U_{concrete} * A_{wall\ concrete})$$
$$TC_{Walls} = \left(0.18064 \frac{W}{m^2 * K} * 3379.2\ m^2\right) + \left(1.60261 \frac{W}{m^2 * K} * 2004.09\ m^2\right)$$
$$TC_{Walls} = 3822.2 \frac{W}{K}$$

2. Surface area heat loss through windows
   a. The current windows were assumed to have an imperial R value of 1 (Places 2011). Converting this R value to a metric RSI value and then calculating the thermal conductance of the windows is shown below (eFunda, Inc 2024):

$$R\ value\ conversion = 1 \frac{ft^2 * °F * h}{BTU} * \frac{1}{5.67446\ \frac{m^2 * K}{W}} = 0.176228 \frac{m^2 * K}{W}$$
$$U_{Windows} = \frac{1}{0.176228\ \frac{m^2 * K}{W}} = 5.67446\ \frac{W}{m^2 * K}$$
$$TC_{Windows} = (U_{Windows} * A_{Windows})$$
$$TC_{Windows} = 5.67446 \frac{W}{m^2 * K} * 1180.54\ m^2$$
$$TC_{Windows} = 6698.93 \frac{W}{K}$$

3. Surface area heat loss through exterior doors
   a. Assuming the existing exterior doors have an RSI value of 0.88 m^2K/W (Energy.gov n.d.), the thermal conductance is as follows:

$$TC_{Doors} = (U_{Doors} * A_{Doors})$$
$$TC_{Doors} = \left(\frac{1}{\frac{5\ \frac{ft^2 * °F * h}{BTU}}{5.67446 \frac{m^2 * K}{W}}}\right) * 43.34\ m^2$$
$$TC_{Doors} = 1.135 \frac{W}{m^2 * K} * 43.34\ m^2$$
$$TC_{Doors} = 49.1862 \frac{W}{K}$$

4. Surface area heat loss through roof
   a. It was assumed that the roof has a uniform overall RSI value, and was assumed to be 5.29 m^2K/W, as it was found to be appropriate for 1993 and 1998, which was the last time it was replaced (Shannon Household 2023). Using the AutoCAD drawings provided

by the client, the roof has an area of 5571.52 m^2. The thermal conductance of the roof is as follows:

$$TC_{Roof} = (U_{Roof} * A_{Roof})$$
$$TC_{Roof} = \left(\frac{1}{\frac{30 \frac{ft^2 * °F * h}{BTU}}{5.67446 \frac{m^2 * K}{W}}} \right) * 5571.52\, m^2$$
$$TC_{Roof} = 0.18915 \frac{W}{m^2 * K} * 5571.52\, m^2$$
$$TC_{Roof} = 1053.846 \frac{W}{K}$$

5. Air infiltration heat loss
    a. Air infiltration heat loss was calculated as follows (Lay 2012):

$$TC_{Air} = Volume_{KCVI} * Air\ Changes\ Per\ Hour * 0.018$$
$$TC_{Air} = 61810.8852\, m^3 * 4 * 0.018$$
$$TC_{Air} = 4450.38$$

Table 41: Summary of Thermal Conductance for Base Case Values for the Five Main Areas of Heat Loss summarizes the thermal conductance for the five main areas of heat loss in KCVI. These values are used in

Table 42: KCVI Base Case Natural Gas Cost. to provide the natural gas usage KCVI is currently experiencing. This cost was used to compare the various secondary glazing options to help determine the payback period (PBP). There are five main areas a building loses heat, summarized below with their respective calculations of thermal conductance.

Table 41: Summary of Thermal Conductance for Base Case Values for the Five Main Areas of Heat Loss

Heat Loss Type	Thermal Conductance (W/K)
Exterior Wall Surface Area Loss	3822.20
Exterior Window Surface Area Loss	6698.93
Exterior Door Surface Area Loss	49.19
Roof Surface Area Loss	1053.85
Air Infiltration	4450.38

Below is the summary of annual heating costs with for the base case.

Table 42: KCVI Base Case Natural Gas Cost.

Month	ΔT	Heat Loss (kW)	Heat Loss (kWh)	Natural Gas Usage (m^3)	Cost of Natural Gas ($CAD)	Cost of Carbon Tax ($CAD)
J	28.0	325.48	280783.81	55055.65	15415.58	6821.39
F	27.0	313.85	246956.85	48422.91	13558.42	5999.60
M	21.5	249.92	215601.85	42274.87	11836.96	5237.86
A	14.5	168.55	140715.39	27591.25	7725.55	3418.56
M	7.5	87.18	75209.95	14747.05	4129.17	1827.16
J	3.0	34.87	29113.53	5708.53	1598.39	707.29
J	0.5	5.81	5014.00	983.14	275.28	121.81
A	0.5	5.81	5014.00	983.14	275.28	121.81
S	5.0	58.12	48522.55	9514.22	2663.98	1178.81
O	11.5	133.68	115321.92	22612.14	6331.40	2801.64
N	16.5	191.80	160124.41	31396.94	8791.14	3890.08
D	24.0	278.98	240671.83	47190.56	13213.36	5846.91
				Annual Sum	85814.51	37972.92
					Annual Cost of Natural Gas & Carbon Tax ($CAD)	123787.43

To find sample calculations regarding the results of Table 42 and similar tables in this section, refer to Appendix E: Supporting Documentation for Wall Composition Scope Component.

To determine the PBP for single pane secondary glazing, its thermal conductivity needs to be determined which is shown below.

$$R\ value\ conversion = 2.08\frac{ft^2 * °F * h}{BTU} * \frac{1}{5.67446\ \frac{m^2 * K}{W}} = 0.37\frac{m^2 * K}{W}$$

$$U_{Windows} = \frac{1}{0.37\ \frac{m^2 * K}{W}} = 2.702\ \frac{W}{m^2 * K}$$

$$TC_{Windows} = (U_{Windows} * A_{Windows})$$

$$TC_{Windows} = 2.702\frac{W}{m^2 * K} * 1180.54\ m^2$$

$$TC_{Windows} = 3220.64\frac{W}{K}$$

Table 43: Summary of Thermal Conductance with Single Pane Secondary Glazing for the Five Main Areas of Heat Loss

Heat Loss Type	Thermal Conductance (W/K)
Exterior Wall Surface Area Loss	3822.20
Exterior Window Surface Area Loss	3220.64
Exterior Door Surface Area Loss	49.19
Roof Surface Area Loss	1053.85
Air Infiltration	4450.38

Below is the summary of annual heating costs with single pane secondary glazing.

Table 44: KCVI Natural Gas Cost and PBP for Single Pane Secondary Glazing

Month	ΔT	Heat Loss (kW)	Heat Loss (kWh)	Natural Gas Usage (m^3)	Cost of Natural Gas ($CAD)	Cost of Carbon Tax ($CAD)
J	28.0	228.08	208324.09	40847.86	11437.40	5061.05
F	27.0	219.94	183846.77	36048.39	10093.55	4466.40
M	21.5	175.14	159963.14	31365.32	8782.29	3886.16
A	14.5	118.12	104402.05	20470.99	5731.88	2536.36
M	7.5	61.09	55801.10	10941.39	3063.59	1355.64
J	3.0	24.44	21600.42	4235.38	1185.91	524.76
J	0.5	0.00	0.00	0.00	0.00	0.00
A	0.5	4.07	3720.07	729.43	204.24	90.38
S	5.0	40.73	36000.71	7058.96	1976.51	874.61
O	11.5	93.68	85561.68	16776.80	4697.50	2078.65
N	16.5	134.41	118802.33	23294.58	6522.48	2886.20
D	24.0	195.50	178563.51	35012.45	9803.49	4338.04
				Annual Sum	63498.83	28098.23
					Annual Cost of Natural Gas & Carbon Tax ($CAD)	91597.07
					Savings ($CAD)/yr	32190.37

The savings per year was determined by finding the difference between the total amount spent on natural gas and the total from the base case. Then the PBP was determined by dividing the initial cost by savings per year. A sample calculation is shown below using the initial cost of installing single pane secondary glazing which is $380445.54, as shown in 8.1 Windows.

$$Savings_{/yr} = Total_{Basecase} - Total_{New}$$

$$Savings_{/yr} = 123787.43 - 91597.07 = 32190.37$$

$$PBP = \frac{Inital\ Cost}{Savings_{/yr}}$$

$$PBP = \frac{380445.54}{32190.37} = 11.8 \cong 12$$

Therefore, the PBP for single pane secondary glazing would be around 12 years.

To determine the PBP for double pane secondary glazing its thermal conductivity needs to be determined which is shown below.

$$R\ value\ conversion = 3.08 \frac{ft^2 * °F * h}{BTU} * \frac{1}{5.67446 \frac{m^2 * K}{W}} = 0.54 \frac{m^2 * K}{W}$$

$$U_{Windows} = \frac{1}{0.54 \frac{m^2 * K}{W}} = 1.851 \frac{W}{m^2 * K}$$

$$TC_{Windows} = (U_{Windows} * A_{Windows})$$

$$TC_{Windows} = 1.851 \frac{W}{m^2 * K} * 1180.54\, m^2$$

$$TC_{Windows} = 2174.98 \frac{W}{K}$$

Table 45: Summary of Thermal Conductance with Double Pane Secondary Glazing for the Five Main Areas of Heat Loss

Heat Loss Type	Thermal Conductance (W/K)
Exterior Wall Surface Area Loss	3822.20
Exterior Window Surface Area Loss	2174.98
Exterior Door Surface Area Loss	49.19
Roof Surface Area Loss	1053.85
Air Infiltration	4450.38

Below is the summary of annual heating costs with double pane secondary glazing.

Table 46: KCVI Natural Gas Cost and PBP for Double Pane Secondary Glazing

Month	ΔT	Heat Loss (kW)	Heat Loss (kWh)	Natural Gas Usage (m^3)	Cost of Natural Gas ($CAD)	Cost of Carbon Tax ($CAD)
J	28.0	198.81	186540.87	36576.64	10241.46	4531.85
F	27.0	191.71	164874.28	32328.29	9051.92	4005.48
M	21.5	152.65	143236.74	28085.63	7863.98	3479.81
A	14.5	102.95	93485.34	18330.46	5132.53	2271.14
M	7.5	53.25	49966.30	9797.31	2743.25	1213.89
J	3.0	21.30	19341.79	3792.51	1061.90	469.89
J	0.5	0.00	0.00	0.00	0.00	0.00
A	0.5	3.55	3331.09	653.15	182.88	80.93
S	5.0	35.50	32236.32	6320.85	1769.84	783.15
O	11.5	81.65	76615.00	15022.55	4206.31	1861.29
N	16.5	117.15	106379.87	20858.80	5840.46	2584.41
D	24.0	170.40	159892.17	31351.41	8778.39	3884.44
				Annual Sum	56872.93	25166.27
					Annual Cost of Natural Gas & Carbon Tax ($CAD)	82039.20
					Savings ($CAD)/yr	41748.24

The initial cost for of installing double pane secondary glazing is $656734.40.

$$Savings_{/yr} = Total_{Basecase} - Total_{New}$$

$$Savings_{/yr} = 123787.43 - 82039.20 = 41748.24$$

$$PBP = \frac{Inital\ Cost}{Savings_{/yr}}$$

$$PBP = \frac{656734.40}{41748.24} = 15.73 \cong 16$$

Therefore, the PBP for double pane secondary glazing is around 16 years.

To determine the PBP for triple pane secondary glazing its thermal conductivity needs to be determined which is shown below.

$$R\ value\ conversion = 4.23 \frac{ft^2 * °F * h}{BTU} * \frac{1}{5.67446 \frac{m^2 * K}{W}} = 0.75 \frac{m^2 * K}{W}$$

$$U_{Windows} = \frac{1}{0.75 \frac{m^2 * K}{W}} = 1.333 \frac{W}{m^2 * K}$$

$$TC_{Windows} = (U_{Windows} * A_{Windows})$$

$$TC_{Windows} = 1.333 \frac{W}{m^2 * K} * 1180.54\, m^2$$

$$TC_{Windows} = 1583.67 \frac{W}{K}$$

Table 47: Summary of Thermal Conductance with Triple Pane Secondary Glazing for the Five Main Areas of Heat Loss

Heat Loss Type	Thermal Conductance (W/K)
Exterior Wall Surface Area Loss	3822.20
Exterior Window Surface Area Loss	1583.67
Exterior Door Surface Area Loss	49.19
Roof Surface Area Loss	1053.85
Air Infiltration	4450.38

Below is the summary of annual heating costs with triple pane secondary glazing.

Table 48: KCVI Natural Gas Cost and PBP for Triple Pane Secondary Glazing

Month	ΔT	Heat Loss (kW)	Heat Loss (kWh)	Natural Gas Usage (m³)	Cost of Natural Gas ($CAD)	Cost of Carbon Tax ($CAD)
J	28.0	182.25	174222.79	34161.33	9565.17	4232.59
F	27.0	175.74	154145.63	30224.63	8462.90	3744.83
M	21.5	139.94	133778.21	26231.02	7344.69	3250.02
A	14.5	94.38	87312.11	17120.02	4793.61	2121.17
M	7.5	48.82	46666.82	9150.36	2562.10	1133.73
J	3.0	19.53	18064.57	3542.07	991.78	438.86
J	0.5	0.00	0.00	0.00	0.00	0.00
A	0.5	3.25	3111.12	610.02	170.81	75.58
S	5.0	32.54	30107.62	5903.46	1652.97	731.44
O	11.5	74.85	71555.79	14030.55	3928.55	1738.38
N	16.5	107.40	99355.16	19481.40	5454.79	2413.75
D	24.0	156.21	149333.82	29281.14	8198.72	3627.93
				Annual Sum	53126.08	23508.29
					Annual Cost of Natural Gas & Carbon Tax ($CAD)	76634.37
					Savings ($CAD)/yr	47153.06

The initial cost for of installing double pane secondary glazing is $1012234.49.

$$Savings_{/yr} = Total_{Basecase} - Total_{New}$$

$$Savings_{/yr} = 123787.43 - 76634.37 = 47153.06$$

$$PBP = \frac{Inital\ Cost}{Savings_{/yr}}$$

$$PBP = \frac{1012234.49}{47153.06} = 21.48 \cong 22$$

Therefore, the PBP for triple pane secondary glazing is around 22 years, which is over the window lifespan so would not be recommended.

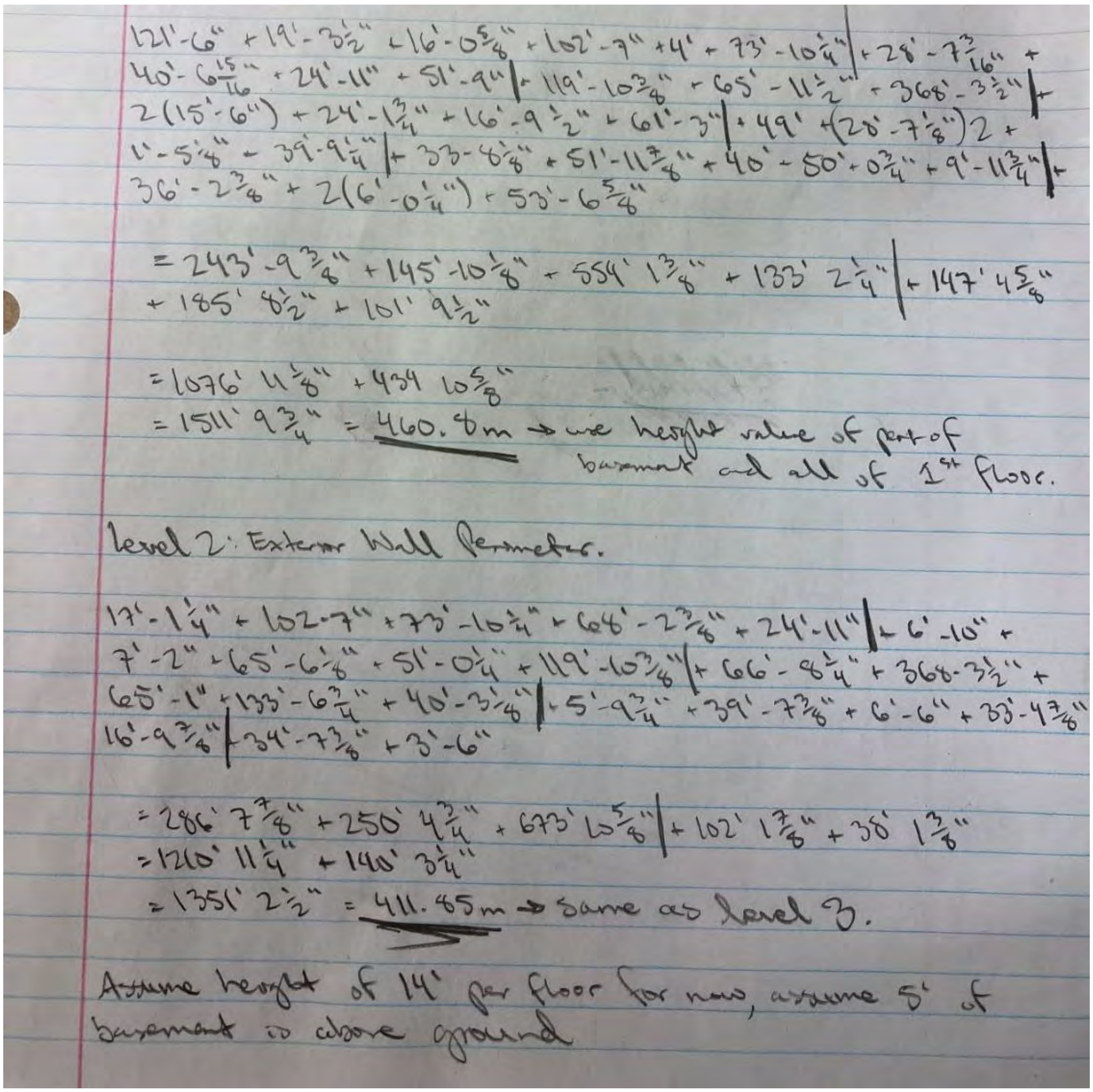
Appendix E: Supporting Documentation for Wall Composition Scope Component

Wall Composition Calculations

The following will explain the process and calculations performed with respect to the wall composition to derive the proposed solution.

Wall Area Calculations

The exterior wall perimeter of the basement and first floor came to 460.8 m per floor. The exterior wall perimeter of the second and third floor came to 411.85 m per floor. There were 24 doors on the exterior that were located on the drawings. Using standard exterior door sizing (FirstinArchitecture 2020), the area of the doors came to 45.34 m^2. This is shown in Figure 17 and Figure 18.



121'-6" + 19'-3½" + 16'-0⅝" + 102'-7" + 4' + 73'-10¼" + 28'-7 3/16" +
40'-6 15/16" + 24'-11" + 51'-9" + 119'-10⅜" + 65'-11½" + 368'-3½" +
2(15'-6") + 24'-1¾" + 16'-9½" + 61'-3" + 49' + (28'-7⅛")2 +
1'-5¼" + 39'-9¼" + 33'-8⅛" + 51'-11⅞" + 40' - 50'-0¾" + 9'-11¾" +
36'-2⅜" + 2(6'-0¼") + 53'-6⅝"

= 243'-9⅜" + 145'-10⅛" + 554' 1⅜" + 133' 2¼" + 147' 4⅝"
+ 185' 8½" + 101' 9½"

= 1076' 11⅛" + 434 10⅝"
= 1511' 9¾" = 460.8m → use height value of part of basement and all of 1st floor.

Level 2: Exterior Wall Perimeter.

17'-1¼" + 102-7" + 73'-10¼" + 68'-2⅞" + 24'-11" + 6'-10" +
7'-2" + 65'-6⅛" + 51'-0¼" + 119'-10⅜" + 66'-8¼" + 368-3½" +
65'-1" + 133'-6¾" + 40'-3⅛" + 5'-9¾" + 39'-7⅜" + 6'-6" + 33'-4⅞"
16'-9⅞" + 34'-7⅜" + 3'-6"

= 286' 7⅞" + 250' 4¾" + 673' 10⅝" + 102' 1⅞" + 38' 1⅜"
= 1210' 11¼" + 140' 3¼"
= 1351' 2½" = 411.85m → same as level 3.

Assume height of 14' per floor for now, assume 5' of basement is above ground

Figure 17: Perimeter Calculations for the Walls

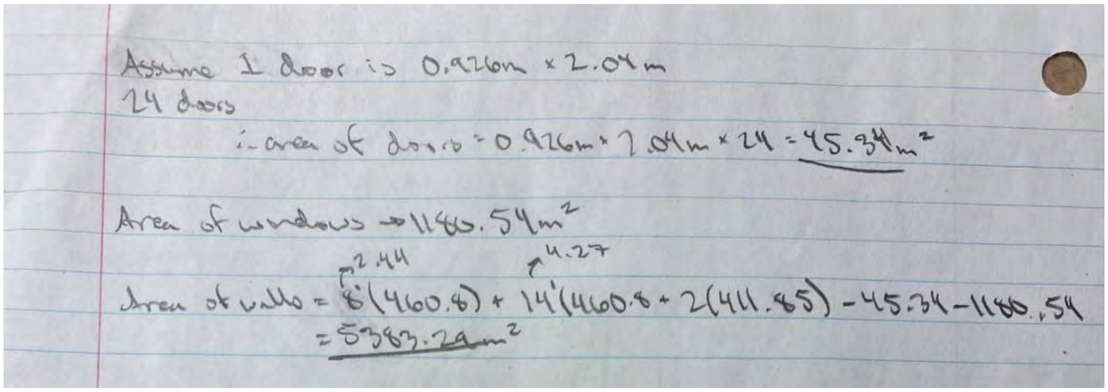

Assume 1 door is 0.926m × 2.04m
24 doors
∴ area of doors = 0.926m × 2.04m × 24 = 45.34m²
Area of windows → 1180.54m²
2.44 4.27
Area of walls = 8'(460.8) + 14'(460.8 + 2(411.85)) − 45.34 − 1180.54
= 5383.29m²

Figure 18: Area Calculations for the Walls

A height of 14 feet was used for floors 1, 2, and 3, and an average height of eight feet was used for the basement which was found in other files the client provided. This calculation is shown below.

$$A_{wall\ total} = A_{walls} - A_{windows} - A_{doors}$$
$$A_{wall\ total} = 2.44\ m(460.8\ m) + 4.27\ m(460.8\ m + 411.85\ m) - 43.34\ m^2 - 1180.54\ m^2$$
$$A_{wall\ total} = 5383.29\ m^2$$

Using the AutoCAD drawings, as well as notes from the site visits, it was determined that the terracotta-based wall composition accounts for 3379.2 m^2 and the reinforced concrete-based wall composition accounts for 2004.09 m^2 of the total exterior wall area.

Existing Wall Composition RSI Value

Using the intrusive testing visual results, the existing wall composition is illustrated in Figure 5. The combined U value of the entire wall composition is calculated as follows (Brennan 2020).

$$U_{wall} = \frac{1}{R_1 + R_2 + \cdots + R_i}$$

Table 49 below summarizes the calculation in determining the existing RSI value of the two wall compositions within KCVI. The thermal conductivities of the respective wall elements were compiled from the following citations (My Engineering Tools 2023) (Rahmani et al. 2022) (Purios 2017).

Table 49: Thermal Properties of Existing Wall Materials

Structural Wall Component	Wall Element	Thickness (mm)	Thermal Conductivity (W/mK)	RSI value (m^2K/W)	Combined RSI Value (m^2K/W)	Combined U Value (W/m^2K)
Terracotta	Brick	101.60	0.72	0.14	5.53	0.18
	Terracotta	203.20	0.82	0.245		
	Air	128.00	0.03	5.12		
	Concrete	13.00	0.50	0.03		
Reinforced Concrete	Brick	101.60	0.72	0.14	0.62	1.60
	Reinforced Concrete	203.20	0.50	0.41		
	Existing Gypsum Board	13.00	0.17	0.08		

From these calculations, the existing walls do not meet the minimum requirements set out in the Insulation Building Code 2021 (EcoStar Insulation 2020).

Existing Natural Gas Usage

The existing wall composition U values were used to calculate the existing heat loss within KCVI. Queen's Facilities provided Stable Designs with past metering information, which shows how much money is spent on natural gas heating per month. This information is shown below.

Table 50: Existing Natural Gas Usage for the Past Two Years (Queen's Facilities 2024)

Month	Electricity (kWh)	Electricity ($)	Natural Gas (m3)	Carbon Tax ($)	Natural Gas Total Cost ($)
Feb-22	39,851.16	$ 1,568.28	60,493	$ 4,827.34	$ 11,231.51
Mar-22	43,397.66	$ 1,813.39	28,456	$ 2,270.78	$ 5,397.87
Apr-22	40,140.04	$ 804.68	35,130	$ 3,468.19	$ 7,310.96
May-22	42,685.64	$ 1,399.85	6,928	$ 688.64	$ 1,541.43
Jun-22	43,439.22	$ 1,821.81	500	$ 49.70	$ 200.08
Jul-22	46,643.36	$ 3,245.50	453	$ 45.03	$ 210.39
Aug-22	49,569.94	$ 4,036.06	156	$ 15.50	$ 105.13
Sep-22	42,353.00	$ 2,258.51	-	$ -	$ 77.95
Oct-22	69,147.16	$ 2,582.80	11,128	$ 1,106.12	$ 36,193.24
Nov-22	54,118.02	$ 2,565.97	49,090	$ 4,879.55	$ 22,224.00
Dec-22	66,009.08	$ 2,955.24	50,264	$ 4,996.25	$ 22,768.33
Jan-23	64,866.92	$ 1,610.37	44,066	$ 4,380.16	$ 19,988.78
Feb-23	56,074.04	$ 1,520.03	49,002	$ 4,870.80	$ 22,208.75
Mar-23	52,792.36	$ 1,194.30	32,721	$ 3,746.44	$ 15,476.70
Apr-23	40,760.10	$ 761.27	13,699	$ 1,717.86	$ 6,734.75
May-23	39,952.44	$ 966.34	12	$ 1.51	$ 85.33
Jun-23	35,787.28	$ 1,378.21	-	$ -	$ 82.86
Jul-23	38,848.12	$ 1,387.77	-	$ -	$ 79.12
Aug-23	38,185.98	$ 1,427.18	-	$ -	$ 82.86
Sep-23	36,321.92	$ 1,178.17	-	$ -	$ 80.23
Oct-23	50,045.14	$ 1,489.58	24,968	$ 3,130.98	$ 11,801.83
Nov-23	55,288.40	$ 1,785.06	49,520	$ 6,209.81	$ 22,436.17

This information was then used to calibrate the calculations Stable Designs performed to ensure an accurate representation of the KCVI heat loss, explained more later. To do this properly, all heat loss areas must be calculated. There are five main areas a building loses heat, summarized below with their respective calculations of thermal conductance.

6. Surface area heat loss through walls
   a. Using the U values calculated in Table 50, the overall thermal conductance of the exterior walls was calculated as follows:

$$TC_{Walls} = (U_{terracotta} * A_{wall\ terracotta}) + (U_{concrete} * A_{wall\ concrete})$$
$$TC_{Walls} = \left(0.18064 \frac{W}{m^2 * K} * 3379.2\ m^2\right) + \left(1.60261 \frac{W}{m^2 * K} * 2004.09\ m^2\right)$$
$$TC_{Walls} = 3822.2 \frac{W}{K}$$

7. Surface area heat loss through windows
   a. The current windows were assumed to have an imperial R value of 1 (Places 2011). Converting this R value to a metric RSI value and then calculating the thermal conductance of the windows is shown below (eFunda, Inc 2024):

$$R\ value\ conversion = 1 \frac{ft^2 * °F * h}{BTU} * \frac{1}{5.67446\ \frac{m^2 * K}{W}} = 0.176228 \frac{m^2 * K}{W}$$
$$U_{Windows} = \frac{1}{0.176228\ \frac{m^2 * K}{W}} = 5.67446\ \frac{W}{m^2 * K}$$
$$TC_{Windows} = (U_{Windows} * A_{Windows})$$
$$TC_{Windows} = 5.67446 \frac{W}{m^2 * K} * 1180.54\ m^2$$
$$TC_{Windows} = 6698.93 \frac{W}{K}$$

8. Surface area heat loss through exterior doors
   a. Assuming the existing exterior doors have an RSI value of 0.88 m^2K/W, the thermal conductance is as follows (Energy.gov n.d.):

$$TC_{Doors} = (U_{Doors} * A_{Doors})$$
$$TC_{Doors} = \left(\frac{1}{\frac{5\ \frac{ft^2 * °F * h}{BTU}}{5.67446 \frac{m^2 * K}{W}}}\right) * 43.34\ m^2$$
$$TC_{Doors} = 1.135 \frac{W}{m^2 * K} * 43.34\ m^2$$
$$TC_{Doors} = 49.1862 \frac{W}{K}$$

9. Surface area heat loss through roof
    a. The oldest part of the roof was last replaced in 1993, with the majority of the roof being replaced in 1998, found in Appendix H: Supporting Documents for Roof Design Scope Component. It was assumed that the roof has a uniform overall RSI value, and was assumed to be 5.29 m^2K/W, as it was found to be appropriate for the time (Shannon Household 2023). Using the AutoCAD drawings provided by the client, the roof has an area of 5571.52 m^2. The thermal conductance of the roof is as follows:

$$TC_{Roof} = (U_{Roof} * A_{Roof})$$

$$TC_{Roof} = \left(\frac{1}{\frac{30 \frac{ft^2 * {}^\circ F * h}{BTU}}{5.67446 \frac{m^2 * K}{W}}} \right) * 5571.52\ m^2$$

$$TC_{Roof} = 0.18915 \frac{W}{m^2 * K} * 5571.52\ m^2$$

$$TC_{Roof} = 1053.846 \frac{W}{K}$$

10. Air infiltration heat loss
    a. Air infiltration heat loss was calculated as follows (Lay 2012):

$$TC_{Air} = Volume_{KCVI} * Air\ Changes\ Per\ Hour * 0.018$$
$$TC_{Air} = 61810.8852\ m^3 * 4 * 0.018$$
$$TC_{Air} = 4450.38$$

The air changes per hour is unknown specifically for KCVI, however it is assumed to be four as per Engineering Toolbox (EngineeringToolBox 2005). This is simply the first part of air infiltration heat loss, remember this number for later. Note that this number is not the thermal conductance of air infiltration, it is the equivalent of thermal conductance for air filtration, meaning that the same steps need to be applied to the other four areas of heat loss and air infiltration to arrive at the usage of natural gas in cubic metres.

The total surface area thermal conductance calculated from above is 11624.16 W/K. Note that this does not include the air infiltration. The existing natural gas usage was then calculated as follows.

Table 51: Calibrated Natural Gas Usage and Cost Based on Existing Conditions Using a Carbon Tax of 10¢ / m^3 of Natural Gas

Month	ΔT	Heat Loss (kW)	Heat Loss (kWh)	Natural Gas Usage (m^3)	Cost of Natural Gas ($CAD)	Cost of Carbon Tax ($CAD)
J	28.0	325.48	280783.8	71446.27	20004.95	7144.63
F	27.0	313.85	246956.9	62838.90	17594.89	6283.89
M	21.5	249.92	215601.9	54860.53	15360.95	5486.05
A	14.5	168.55	140715.4	35805.44	10025.52	3580.54

Month	ΔT	Heat Loss (kW)	Heat Loss (kWh)	Natural Gas Usage (m^3)	Cost of Natural Gas ($CAD)	Cost of Carbon Tax ($CAD)
M	7.5	87.18	75209.95	19137.39	5358.47	1913.74
J	3.0	34.87	29113.53	7408.02	2074.25	740.80
J	0.5	0.00	0.00	0.00	0.00	0.00
A	0.5	5.81	5013.997	1275.83	357.23	127.58
S	5.0	58.12	48522.55	12346.70	3457.08	1234.67
O	11.5	133.68	115321.9	29344.00	8216.32	2934.40
N	16.5	191.80	160124.4	40744.13	11408.36	4074.41
D	24.0	278.98	240671.8	61239.66	17147.10	6123.97
Annual Sum		1848.24	1558036.16	396446.86	111005.12	39644.70
Annual Cost of Natural Gas & Carbon Tax ($CAD)					**150649.81**	

The annual cost of natural gas and carbon tax from the metering information the client provided was $150,879.53, taken from Dec-22 to Nov-23. This shows how the model Stable Designs created accurately represents the existing conditions. Sample calculations deriving the table above are shown below.

Calculating heat loss (kW), month of January shown:

$$HL_{Jan} = SATC_{tot} * \Delta T_{Jan}$$
$$HL_{Jan} = 11624.16 \frac{W}{K} * 28\ K$$
$$HL_{Jan} = 325.48\ kW$$

Calculating heat loss (kWh), month of January shown:

$$HL(kWh)_{Jan} = HL_{Jan} * 31\ days * 24\ hrs + TC_{Air} * \Delta T_{Jan} * 31\ days * 10\ hrs$$
$$HL(kWh)_{Jan} = 325.48k\ kW * 31\ days * 24 \frac{hrs}{day} + 4450.38 \frac{W}{K} * 28\ K * 31\ days * 10 \frac{hrs}{day}$$
$$HL(kWh)_{Jan} = 280784\ kWh$$

Note that this calculation assumes that the air infiltration is only happening 10 hours per day. This is because the Centers for Disease Control and Prevention recommend running this system 2 hours before and after the school is occupied, bringing the total running hours to 10 a day (CDC 2020). This is to keep good ventilation to reduce the risk of air borne diseases. Then, calculating the natural gas usage, month of January shown:

$$NG_{Jan} = \frac{HL(kWh)_{Jan}}{Conversion\ Factor} = \frac{280784\ kWh}{3.93 \frac{kWh}{m^3}} = 71446.27\ m^3$$

Note that the conversion factor used was to calibrate the annual cost of heating to the metering information provided by the client. The cost provided in the metering information is the total bill, which includes fees such as service fees, delivery fees, taxes, and more, all on top of the cost for the natural gas. Depending on how efficient the boiler system is at KCVI, the conversion factor can vary between 8 to 12 kWh per 1 cubic metre of natural gas (Bolt 2023). The factor is 3.93 here since it includes all the other fees, not just the cost of natural gas. Note however if a conversion factor of 8 were to be used in the model Stable Designs has developed, the natural gas usage in cubic metres would be underestimated by approximately 25%. This discrepancy would likely be due to using the wrong value for air changes per day for air infiltration, or missing areas of heat loss within KCVI. It is important to note that there were approximately 20 broken windows within KCVI as of October 2023, which could also be responsible for this discrepancy. Regardless, with the information available, the model is reasonably accurate, providing a good idea and basis for the calculations done for proposed solutions. The given annual natural gas usage from Dec-22 to Nov-22 of 264252 cubic metres. The ratio between the calculated annual usage to the given annual usage is 1.5. Moving forward, to better compare the annual natural gas usage, the ratio of 1.5 was used to reduce the calculated annual natural gas usages for the options considered. This is reasonable since the calculated annual usages include all the fees associated with the total bill, this factor is removing those additional fees, providing a better comparison. An example of this will be seen further within the calculations. With the cubic metres of natural gas now calculated, the cost of natural gas can now be calculated, with the month of January shown:

$$Cost\ of\ NG_{Jan} = Cost\ per\ m^3\ of\ NG * NG_{Jan}$$
$$Cost\ of\ NG_{Jan} = \frac{\$0.28}{m^3} * 71446.27\ m^3$$
$$Cost\ of\ NG_{Jan} = \$20004.96$$

Note that the cost per cubic metre of natural gas came from information the client provided in shared files. The carbon tax can now also be calculated. Note that with the metering information the client provided, the carbon tax is ten cents per cubic metre of natural gas. This has however been increased to 12.39 cents per cubic metre of natural gas according to Enbridge Gas, and will continue to increase each year (Enbridge Gas 2024). Note that this increasing carbon tax rate is considered within the cost of ownership analysis. The month of January is shown below:

$$CT_{Jan} = NG_{Jan} * \frac{\$0.1239}{m^3} = 71446.27\ m^3 * \frac{\$0.10}{m^3} = \$7144.63$$

These sample calculations for the month of January describe how Table 52 was derived to calibrate the model. This method was then replicated for all different options considered during the project, with varying heat loss values, and a carbon tax of 12.39 cents per cubic metre of natural gas. The existing conditions with a carbon tax of 12.39 cents per cubic metre of natural gas are shown below.

Table 52: Calibrated Natural Gas Usage and Cost Based on Existing Conditions Using a Carbon Tax of 12.39¢ / m^3 of Natural Gas

Month	ΔT	Heat Loss (kW)	Heat Loss (kWh)	Natural Gas Usage (m^3)	Cost of Natural Gas ($CAD)	Cost of Carbon Tax ($CAD)
J	28.0	325.48	280783.8	71446.27	20004.95	8852.19
F	27.0	313.85	246956.9	62838.90	17594.89	7785.74
M	21.5	249.92	215601.9	54860.53	15360.95	6797.22
A	14.5	168.55	140715.4	35805.44	10025.52	4436.30

Month	ΔT	Heat Loss (kW)	Heat Loss (kWh)	Natural Gas Usage (m^3)	Cost of Natural Gas ($CAD)	Cost of Carbon Tax ($CAD)
M	7.5	87.18	75209.95	19137.39	5358.47	2371.12
J	3.0	34.87	29113.53	7408.02	2074.25	917.85
J	0.5	0.00	0.00	0.00	0.00	0.00
A	0.5	5.81	5013.997	1275.83	357.23	158.07
S	5.0	58.12	48522.55	12346.70	3457.08	1529.76
O	11.5	133.68	115321.9	29344.00	8216.32	3635.72
N	16.5	191.80	160124.4	40744.13	11408.36	5048.20
D	24.0	278.98	240671.8	61239.66	17147.10	7587.59
Annual Sum		1848.24	1558036.16	396446.86	111005.12	49119.80
Annual Cost of Natural Gas & Carbon Tax ($CAD)					**160124.89**	

Cost Estimation of Preliminary Options

A cost estimate has been done on the three insulation options to quantitatively compare the three options in the WEM. Note that the thickness of each insulation type corresponds to a stud depth shown in Table 66. EPS does not have a thickness that corresponds to the stud depth, meaning a combination of EPS boards may have been used. Additionally, fiberglass insulation does not come in a 4" thickness (101.6 mm), meaning the entry shown for 88.9 mm will be used for the 3.625" and 4" stud depth. Table 53 below summarizes the total cost for the three insulation options. Note that the exterior wall area is 5383.29 m^2.

Table 53: Cost Analysis for All 3 Wall Insulation Options

Insulation Type	Thickness (mm)	RSMeans Reference Number and Description	Total Cost Per Square Foot ($CAD/$ft^2$)	Total Cost Per Square Meter ($CAD/$m^2$)	Total Cost ($CAD)
Spray Foam	88.90	072129100335: Insulation, polyurethane foam, 2#/CF density, 3.5" thick, R23, sprayed	6.49	69.86	376,077.00
	101.60	072129100340: Insulation, polyurethane foam, 2#/CF density, 4" thick, R26, sprayed	7.42	79.87	429,963.00
	152.40	072129100360: Insulation, polyurethane foam, 2#/CF density, 6" thick, R39, sprayed	11.15	120.02	646,102.00
EPS	76.20	072113102140: Wall insulation, rigid, expanded polystyrene, 3" thick, R11.49	2.27	24.43	131,536.00
	101.60	072113102140: Wall insulation, rigid,	3.51	37.78	203,388.00

Insulation Type	Thickness (mm)	RSMeans Reference Number and Description	Total Cost Per Square Foot ($CAD/ft²)	Total Cost Per Square Meter ($CAD/m²)	Total Cost ($CAD)
		expanded polystyrene, 3” thick, R11.49 **And** 072113102100: Wall insulation, rigid, expanded polystyrene, 1” thick, R3.85			
	152.4	072113102140: Wall insulation, rigid, expanded polystyrene, 3” thick, R11.49 **(Two of these)**	4.54	48.87	263,071.00
Fiberglass	88.9	072116200836: Blanket insulation, for walls or ceilings, unfaced fiberglass, 3.5” thick, R15, 23” wide	1.87	20.13	108,357.00
	152.4	072116200880: Blanket insulation, for walls or ceilings, unfaced fiberglass, 6” thick, R19, 23” wide	1.95	20.99	112,993.00

From Table 53, spray foam is nearly six times more expensive than fiberglass insulation at a thickness of 152.4 mm, however spray foam has an RSI value twice that of fiberglass. Ultimately, due to longevity, cost of ownership (shown later within this Appendix) and other reasons shown in the WEM, spray foam is the preferred solution. Table 54 summarizes the different U values that will be used later to calculate the heat loss within the two different sections of KCVI (Greenspec 2024).

Table 54: Summary of Overall U Values for the Two Different Sections of KCVI With the Three Different Insulation Options

Insulation Type	Thickness (mm)	Thermal Conductivity (W/mK)	RSI value (m^2K/W)	Terracotta Based Overall U value (W/m^2K)	Reinforced Concrete Overall U Value (W/m^2K)
Spray Foam	0.092	0.022	3.541	0.109	0.236
	0.102	0.022	3.908	0.105	0.217
	0.152	0.022	6.927	0.080	0.131
Fiberglass Insulation	0.089	0.04	2.223	0.129	0.351
	0.152	0.04	3.810	0.107	0.225
EPS	0.076	0.035	2.177	0.130	0.357
	0.102	0.035	2.903	0.118	0.283
	0.152	0.035	4.354	0.101	0.201

Calculations of the Conceptual Design Options

The five proposed options for the conceptual design were then compared back to the existing conditions using a carbon tax rate of 12.39 cents per cubic metre, determining how well the proposed options improved upon the existing conditions. These are summarized below for the five options considered in the conceptual design of the wall composition. Table 55 below summarizes the five options considered. Note that the U values for the respective wall compositions were derived from using the existing wall composition information and adding on the respective u value created from the spray foam for each option, as well as a 13 mm thick gypsum board layer with a thermal conductivity of 0.17 W/mK.

Table 55: Summary of U Values for Five Stud Options and Materials for the Proposed Wall Composition

Option	Stud Material & Dimension	Spray Foam Thickness (mm)	Combined U Value Terracotta (W/m^2K)	Combined U Value Reinforced Concrete (W/m^2K)
1	Wooden 2” x 4” studs	88.90	0.110	0.241
2	Wooden 2” x 6” studs	139.70	0.091	0.165
3	Metal 1.25” x 3.625” studs	92.08	0.109	0.236
4	Metal 1.25” x 4” studs	101.60	0.105	0.217
5	Metal 1.25” x 6” studs	152.40	0.080	0.131

Note that the heat loss from air infiltration and exterior door surface area loss remain constant for all five options as these are not changing in the proposed design. However, the exterior wall surface area loss changes for each of the five options, while the window and roof surface area loss changes to the proposed solution for that respective area. This means that the windows will have an RSI value of 0.71 m^2K/W, while the roof will have an overall RSI value of 9.69 m^2K/W.

Option 1

Below is a summary of the thermal conductance values respective to Option 1 for the five main areas of heat loss.

Table 56: Option #1, Summary of Thermal Conductance for Five Main Areas

Heat Loss Type	Thermal Conductance (W/K)
Exterior Wall Surface Area Loss	856.35
Exterior Window Surface Area Loss	2174.98
Exterior Door Surface Area Loss	49.19
Roof Surface Area Loss	574.83
Air Infiltration	4450.38

Below is the summary of annual heating costs for Option 1.

Table 57: Option #1, Summary of Annual Heating Costs

Month	ΔT	Heat Loss (kW)	Heat Loss (kWh)	Natural Gas Usage (m^3)	Cost of Natural Gas ($CAD)	Cost of Carbon Tax ($CAD)
J	28.0	102.35	114777.37	29205.44	8177.52	3618.55
F	27.0	98.69	102370.59	26048.50	7293.58	3227.41

Month	ΔT	Heat Loss (kW)	Heat Loss (kWh)	Natural Gas Usage (m^3)	Cost of Natural Gas ($CAD)	Cost of Carbon Tax ($CAD)
M	21.5	78.59	88132.62	22425.60	6279.17	2778.53
A	14.5	53.00	57520.92	14636.37	4098.18	1813.45
M	7.5	27.42	30743.94	7822.89	2190.41	969.26
J	3.0	10.97	11900.88	3028.21	847.90	375.20
J	0.5	0.00	0.00	0.00	0.00	0.00
A	0.5	1.83	2049.60	521.53	146.03	64.62
S	5.0	18.28	19834.80	5047.02	1413.17	625.33
O	11.5	42.04	47140.71	11995.09	3358.63	1486.19
N	16.5	60.31	65454.84	16655.17	4663.45	2063.58
D	24/0	87.73	98380.60	25033.23	7009.31	3101.62
Annual Sum		581.20	638306.86	162419.05	45477.33	20123.72
Annual Cost of Natural Gas & Carbon Tax ($CAD)					**65601.05**	

As mentioned previously, reducing the annual natural gas usage by 1.5 to better compare the proposed option to the existing conditions, yields an annual natural gas usage of 108279.37 cubic metres for Option 1. This is a reduction of nearly 2.5 times, while saving over $94500 annually on heating costs.

Option 2

Below is a summary of the thermal conductance values respective to Option 2 for the five main areas of heat loss.

Table 58: Option #2, Summary of Thermal Conductance for Five Main Areas

Heat Loss Type	Thermal Conductance (W/K)
Exterior Wall Surface Area Loss	637.58
Exterior Window Surface Area Loss	2174.98
Exterior Door Surface Area Loss	49.19
Roof Surface Area Loss	574.83
Air Infiltration	4450.38

Below is the summary of annual heating costs for Option 2.

Table 59: Option #2, Summary of Annual Heating Costs

Month	ΔT	Heat Loss (kW)	Heat Loss (kWh)	Natural Gas Usage (m^3)	Cost of Natural Gas ($CAD)	Cost of Carbon Tax ($CAD)
J	28.0	96.22	110219.91	28045.78	7852.82	3474.87
F	27.0	92.79	98401.19	25038.47	7010.77	3102.27
M	21.5	73.89	84633.14	21535.15	6029.84	2668.21
A	14.5	49.83	55236.94	14055.20	3935.46	1741.44
M	7.5	25.77	29523.19	7512.26	2103.43	930.77
J	3.0	10.31	11428.33	2907.97	814.23	360.30

Month	ΔT	Heat Loss (kW)	Heat Loss (kWh)	Natural Gas Usage (m^3)	Cost of Natural Gas ($CAD)	Cost of Carbon Tax ($CAD)
J	0.5	0.00	0.00	0.00	0.00	0.00
A	0.5	1.72	1968.21	500.82	140.23	62.05
S	5.0	17.18	19047.22	4846.62	1357.05	600.50
O	11.5	39.52	45268.89	11518.80	3225.26	1427.18
N	16.5	56.70	62855.82	15993.85	4478.28	1981.64
D	24.0	82.48	94474.21	24039.24	6730.99	2978.46
Annual Sum		546.41	613057.05	155994.16	43678.37	19327.67
Annual Cost of Natural Gas & Carbon Tax ($CAD)					**63006.04**	

Reducing the annual natural gas usage by 1.5 yields an annual natural gas usage of 103996.11 cubic metres for Option 2. This is a reduction of over 2.5 times, while saving over $97100 annually on heating costs.

Option 3

Below is a summary of the thermal conductance values respective to Option 3 for the five main areas of heat loss.

Table 60: Option #3, Summary of Thermal Conductance for Five Main Areas

Heat Loss Type	Thermal Conductance (W/K)
Exterior Wall Surface Area Loss	841.63
Exterior Window Surface Area Loss	2174.98
Exterior Door Surface Area Loss	49.19
Roof Surface Area Loss	574.83
Air Infiltration	4450.38

Below is the summary of annual heating costs for Option 3.

Table 61: Option #3, Summary of Annual Heating Costs

Month	ΔT	Heat Loss (kW)	Heat Loss (kWh)	Natural Gas Usage (m^3)	Cost of Natural Gas ($CAD)	Cost of Carbon Tax ($CAD)
J	28.0	101.94	114470.61	29127.38	8155.67	3608.88
F	27.0	98.30	102103.41	25980.51	7274.54	3218.99
M	21.5	78.27	87897.07	22365.67	6262.39	2771.11
A	14.5	52.79	57367.18	14597.25	4087.23	1808.60
M	7.5	27.30	30661.77	7801.98	2184.55	966.66
J	3.0	10.92	11869.07	3020.12	845.63	374.19
J	0.5	0.00	0.00	0.00	0.00	0.00
A	0.5	1.82	2044.12	520.13	145.64	64.44
S	5.0	18.20	19781.79	5033.53	1409.39	623.65
O	11.5	41.87	47014.71	11963.03	3349.65	1482.22

N	16.5	60.07	65279.90	16610.66	4650.98	2058.06
D	24.0	87.37	98117.66	24966.33	6990.57	3093.33
Annual Sum		578.86	636607.29	161986.59	45356.25	20070.14
Annual Cost of Natural Gas & Carbon Tax ($CAD)					**65426.38**	

Reducing the annual natural gas usage by 1.5 yields an annual natural gas usage of 107972.3 cubic metres for Option 3. This is a reduction of nearly 2.5 times, while saving $94700 annually on heating costs.

Option 4

Below is a summary of the thermal conductance values respective to Option 4 for the five main areas of heat loss.

Table 62: Option #4, Summary of Thermal Conductance for Five Main Areas

Heat Loss Type	Thermal Conductance (W/K)
Exterior Wall Surface Area Loss	800.47
Exterior Window Surface Area Loss	2174.98
Exterior Door Surface Area Loss	49.19
Roof Surface Area Loss	574.83
Air Infiltration	4450.38

Below is the summary of annual heating costs for Option 4.

Table 63: Option #4, Summary of Annual Heating Costs

Month	ΔT	Heat Loss (kW)	Heat Loss (kWh)	Natural Gas Usage (m^3)	Cost of Natural Gas ($CAD)	Cost of Carbon Tax ($CAD)
J	28.0	100.78	113613.18	28909.21	8094.58	3581.85
F	27.0	97.19	101356.62	25790.49	7221.34	3195.44
M	21.5	77.39	87238.69	22198.14	6215.48	2750.35
A	14.5	52.19	56937.48	14487.91	4056.61	1795.05
M	7.5	27.00	30432.10	7743.54	2168.19	959.42
J	3.0	10.80	11780.17	2997.50	839.30	371.39
J	0.5	0.00	0.00	0.00	0.00	0.00
A	0.5	1.80	2028.81	516.24	144.55	63.96
S	5.0	18.00	19633.61	4995.83	1398.83	618.98
O	11.5	41.39	46662.55	11873.42	3324.56	1471.12
N	16.5	59.39	64790.92	16486.24	4616.15	2042.65
D	24.0	86.39	97382.72	24779.32	6938.21	3070.16
Annual Sum		572.31	631856.86	160777.83	45017.79	19920.37
Annual Cost of Natural Gas & Carbon Tax ($CAD)					**64938.16**	

Reducing the annual natural gas usage by 1.5 yields an annual natural gas usage of 107166.6 cubic metres for Option 4. This is a reduction of nearly 2.5 times, while saving $95200 annually on heating costs.

Option 5

Below is a summary of the thermal conductance values respective to Option 5 for the five main areas of heat loss.

Table 64: Option #5, Summary of Thermal Conductance for Five Main Areas

Heat Loss Type	Thermal Conductance (W/K)
Exterior Wall Surface Area Loss	532.22
Exterior Window Surface Area Loss	2174.98
Exterior Door Surface Area Loss	49.19
Roof Surface Area Loss	574.83
Air Infiltration	4450.38

Below is the summary of annual heating costs for Option 5.

Table 65: Option #5, Summary of Annual Heating Costs

Month	ΔT	Heat Loss (kW)	Heat Loss (kWh)	Natural Gas Usage (m^3)	Cost of Natural Gas ($CAD)	Cost of Carbon Tax ($CAD)
J	28.0	93.27	108025.05	27487.29	7696.44	3405.68
F	27.0	89.94	96489.54	24552.05	6874.57	3042.00
M	21.5	71.62	82947.81	21106.31	5909.77	2615.07
A	14.5	48.30	54136.98	13775.31	3857.09	1706.76
M	7.5	24.98	28935.28	7362.67	2061.55	912.23
J	3.0	9.99	11200.75	2850.06	798.02	353.12
J	0.5	0.00	0.00	0.00	0.00	0.00
A	0.5	1.67	1929.02	490.84	137.44	60.82
S	5.0	16.66	18667.92	4750.11	1330.03	588.54
O	11.5	38.31	44367.43	11289.42	3161.04	1398.76
N	16.5	54.96	61604.15	15675.36	4389.10	1942.18
D	24.0	79.95	92592.90	23560.54	6596.95	2919.15
Annual Sum		529.66	600896.85	152899.96	42811.99	18944.31
Annual Cost of Natural Gas & Carbon Tax ($CAD)					**61756.30**	

Reducing the annual natural gas usage by 1.5 yields an annual natural gas usage of 101915.60 cubic metres for Option 5. This is a reduction of over 2.5 times, while saving $98400 annually on heating costs.

Cost Estimation & Justification of Conceptual Design Options

Using RSMeans, it was determined that wooden 2” x 6” studs cost $42.65 / linear foot (RSMeans#: 061110261300) in the 2024 year for Kingston, while metal 2” x 6” 18-gauge metal studs cost $43.58 / linear foot (RSMeans#: 054113306210). Since the metal studs are non-structural, 25-gauge metal studs can be used, resulting in a lower cost since they weigh less than 18-gauge. However, RSMeans does not have an entry for 25-gauge metal studs. Regardless, because metal studs will likely cost less than wooden studs at the same width value, while also offering better longevity and better fire resistance than wooden studs, it only makes sense to use metal studs for the wall composition to house the insulation.

Now the question becomes which of the three metal stud options should be used, and in which part of the building. This can be answered partly through the table below.

Table 66: RSI Values for Three Sizes of Metal Studs for Different Existing Wall Materials

Option	Stud Size	Terracotta		Reinforced Concrete	
		U value (W/m²K)	RSI value (m²K/W)	U value (W/m²K)	RSI value (m²K/W)
3	2" x 3.625"	0.1092	9.16	0.2357	4.24
4	2" x 4"	0.1050	9.52	0.2170	4.61
5	2" x 6"	0.0797	12.54	0.1311	7.63

From these overall RSI values and following the insulation building code of 2021, it makes sense to use Option 3 in the terracotta-based wall composition, and Option 5 in the reinforced concrete-based wall composition. Only Option 5 can be used for the reinforced concrete-based wall composition to follow the minimum RSI value in exterior walls from the insulation building code. However, for the terracotta-based wall composition, Option 4 provides a marginally better RSI value, the additional cost to have this option compared to Option 3 does not makes sense, especially when Option 4 only saves $500 annually in heating costs. The cost estimation for Option 3 and Option 4 are summarized below respectively for the terracotta-based wall composition.

Option 3:

Table 67: Option #3, Cost Estimation for Terracotta Wall Composition

RSMeans Reference Number and Description	Total Cost Per Unit ($CAD/Unit)	Total Cost ($CAD)
072129100335: Insulation, polyurethane foam, 2#/CF density, 3.5" thick, R23, sprayed	69.86 /m²	236,063.41
092216133210: Metal stud partition, non-load bearing, galvanized, 12' high, 3-5/8" wide, 20 gauge, 24" OC, includes top & bottom track	25.83 /m²	273,825.90
	Total Cost of all Items ($CAD)	**509,889.31**

Option 4:

Table 68: Option #4, Cost Estimation for Terracotta Wall Composition

RSMeans Reference Number and Description	Total Cost Per Unit ($CAD/Unit)	Total Cost ($CAD)
072129100340: Insulation, polyurethane foam, 2#/CF density, 4" thick, R26, sprayed	79.87 /m²	269,896.70

RSMeans Reference Number and Description	Total Cost Per Unit ($CAD/Unit)	Total Cost ($CAD)
092216133130: Metal stud partition, non-load bearing, galvanized, 12’ high, 4” wide, 25 gauge, 24” OC, includes top & bottom track	20.56 /m^2	217,958.21
	Total Cost of all Items ($CAD)	**487,854.91**

The fact that Option 4 costs less than Option 3 upfront makes it an easy decision to choose Option 4, as it also reduces heating costs. Option 5 was not considered for the terracotta-based wall composition as the absurd overall RSI value does not make a significant difference in annual savings, especially when it costs a significant amount more to install upfront.

Appendix F: Meeting Minutes

MEETING MINUTES

MEETING #2: WORK PLAN OVERVIEW

Date:	September 28, 2023
Time:	1:30 PM
Meeting called to order by:	Stable Designs: Justin Boult, Katie Fitzpatrick, Liam Reid, Abbey MacTaggart

IN ATTENDANCE

Stable Designs, Nathan Splinter, Meghan Corbett

SCOPE DISCUSSION

Scope drafted for Work Plan was read and discussed with the client. The following notes were made:

- Focus on historic elements to the KCVI building during structural rehabilitation idea generation.
- Background information containing floor plans and CAD drawings are readily available, may have to request for other documents.
- Focus on wall composition and high-performance building envelope for design solution/recommendations.
- Cost estimating tools from Queen's facilities may be provided.
- Documents can be provided via SharePoint.

SITE VISIT

- Keys are required to be signed out and returned to the office for site access.
- Separate keys are required for roof access, client will confirm if team can go on roof with supervision.
- Email Meghan and Nathan (client) for site access.
- 2-3 people required for a site visit. Individual site visits are not permitted.
- Important for team to note locations that they would like to elaborate on.
- Team will provide site review reports after site visit is conducted and append reviews in next report.

AWARENESS

- Client requests two presentations for two different submissions

1. Progress Report
2. Final Report

- 10-minute presentation, 10 slides

NEXT MEETING

Next meeting will be a site visit on October 5th, meeting at the KCVI West Entrance.

Next meeting for discussion will be after reading week (October 9-14) and the date will be discussed at a later date.

MEETING MINUTES

MEETING #2: FIELD REVIEW OVERVIEW AND DISCUSSION

Date:	October 26, 2023
Time:	1:30 PM
Meeting called to order by:	Stable Designs: Justin Boult, Katie Fitzpatrick, Liam Reid, Abbey MacTaggart

IN ATTENDANCE

Stable Designs, Nathan Splinter, Meghan Corbett, Viet Tran

PROJECT DISCUSSION

- A representative, Tony, will need to contact the team for discussion questions around adaptive space reuse based on site visit results. This discussion will revolve around space reuse, wall capacities, and cost-effective solutions.
- The assessment done on KCVI roof has been completed and KCVI has the most critical roof conditions out of the assessed buildings a part of Queen's University.
- The Heritage team wants to retain as much façade and window material as possible.

SCOPE DISCUSSION

Scope drafted for Work Plan was read and discussed with the client. The following notes were made:

- The team will assess the structural capacity of the roof, including an analysis of dead and live loads, dimensions of the roof will be required.
- The team will assess wall composition, next steps for site visit will be outlined in the next section.
- The scope has been narrowed down to three main items, including:
  1. Adaptive space reuse.
  2. Creating a high-performance building envelope.
  3. Assessing and recommending sustainable design options, such as solar energy, green roof, and geothermal energy efficiency.
- Embodied carbon was also discussed for building material recommendations.
- Required documents discussed in this meeting are below:
  - Roof analysis/design calculations
  - Roof draft assessment completed by obtained consultant.

SITE VISIT

Additional site visits will be required to complete the proposed scope.

- Wall Composition investigation: The team will visit the site next week and mark where the team would like wall composition sampling to take place. Review of reports regarding asbestos, and structural assessment will be required.
- Crack Assessment: The team will visit the site and review cracking on interior/exterior walls. A focus will be placed on exterior walls, and the heritage portion and newer additions will be considered. It would be optimal to visit the site after rainy weather.

MEETING MINUTES

MEETING #3: PROJECT UPDATE DISCUSSION

Date:	November 9, 2023
Time:	1:30 PM
Meeting called to order by:	Stable Designs: Justin Boult, Katie Fitzpatrick, Liam Reid, Abbey MacTaggart

IN ATTENDANCE

Stable Designs, Nathan Splinter, Meghan Corbett

PROJECT DISCUSSION

- The team must set up a separate meeting with Tony to discuss adaptive space reuse items. The team will prepare a floor plan mark-up to present to stakeholders. The focus will
- The team sent sampling locations to the client on November 1, 2023. The client will forward this to an asbestos sampling team. Approximate timing for sampling to be completed is one month after request date.
- The client had rated constraints made from Stable Designs for each aspect of the scope. The ratings ranged from 1 to 3, where 1 is the most important and 3 is the least important.

SCOPE DISCUSSION

- The client has requested a cost analysis of the adaptive space reuse, envelope performance, and high effective wall structures. This includes a net present value analysis including maintenance and operation fees.
- The team will contact the client to schedule a 5–10-minute presentation to the Queen’s Facilities Group.

NEXT MEETING

Next meeting will be on November 23, 2023.

MEETING MINUTES

MEETING #4: PROJECT UPDATE DISCUSSION

Date:	December 7, 2023
Time:	1:30 PM
Meeting called to order by:	Stable Designs: Justin Boult, Katie Fitzpatrick, Liam Reid, Abbey MacTaggart

IN ATTENDANCE

Stable Designs, Nathan Splinter, Tony Gkotsis, Meghan Corbett

PROJECT DISCUSSION - WINDOWS

- The windows are metal framed, and the City of Kingston Window Policy claims that, at a minimum, the existing pattern will need to be kept.
- Window Policies may require that the windows must not be able to be opened.

PROJECT DISCUSSION – ADAPTIVE SPACE RE-USE

- Intentions were declared, where the building will be used as a teaching facility, and help shape what the future of Queen's facilities will look like,
- Each option considered in the Progress report for adaptive space re-use was presented to the client and Tony, a few notes were made:
    - The elevator located in the central area of the building will not be in service (Floor 0-1).
    - The gym's serviceability will not need to be considered for these proposals, therefore consideration of the use of existing gym space should be considered.
    - Areas of the 1960's addition should not be considered in the adaptive space re-use space proposals.
- Moving forward, the team should observe the existing classroom shapes of each floor and see where it would be cost effective to create a classroom of 120-seat floor plan.

PROJECT DISCUSSION – ROOF INNOVATION

- There are guidelines stating that the pre-development storm water retention values must equal the post-development storm water retention values. However, it is common that there is 20% less in post-development more recently.

MOVING FORWARD

- January 17th at 10am, a short, high-level presentation will be delivered to the Queen's facilities team introducing the problem.
- Next meeting will take place in early 2024.

MEETING MINUTES

MEETING #5: PROJECT UPDATE DISCUSSION

Date:	February 8, 2024
Time:	10:30 AM
Meeting called to order by:	Stable Designs: Justin Boult, Katie Fitzpatrick, Liam Reid, Abbey MacTaggart

IN ATTENDANCE

Stable Designs, Nathan Splinter, Tony Gkotsis, Meghan Corbett

PROJECT DISCUSSION – BUILDING ENVELOPE

- Building envelope calculations were presented in the meeting that outlines cost-analysis and efficiency with the walls.
- The investigative testing of the walls was also presented.
- Energy savings and costs for wall composition rehabilitation will be valued in the final report.
- KCVI uses natural gas for heating and should be calculated as such. It is not connected to the current system at Queen's. No cooling is used currently.

PROJECT DISCUSSION – ADAPTIVE SPACE RE-USE

- Existing library space will be investigated in the final report. Other options included the existing Gym 001 and Gym 002.
- Existing balcony of the library space will not be used as part of the classrooms but can be converted to bookable rooms and/or sitting area.
- The team will need to indicate location of load bearing walls, upon further discussion with Professors and analysis of the provided files in the OneDrive.
- Can propose what would be a feasible study in the future for different adaptive space re-use options. The team will move forward with performing a technical analysis for 3 classrooms (existing library space).
- The team will re-observe the use of the northern classrooms on the second and third level for a final recommendation.

PROECT DISCUSSION – ROOF INNOVATION

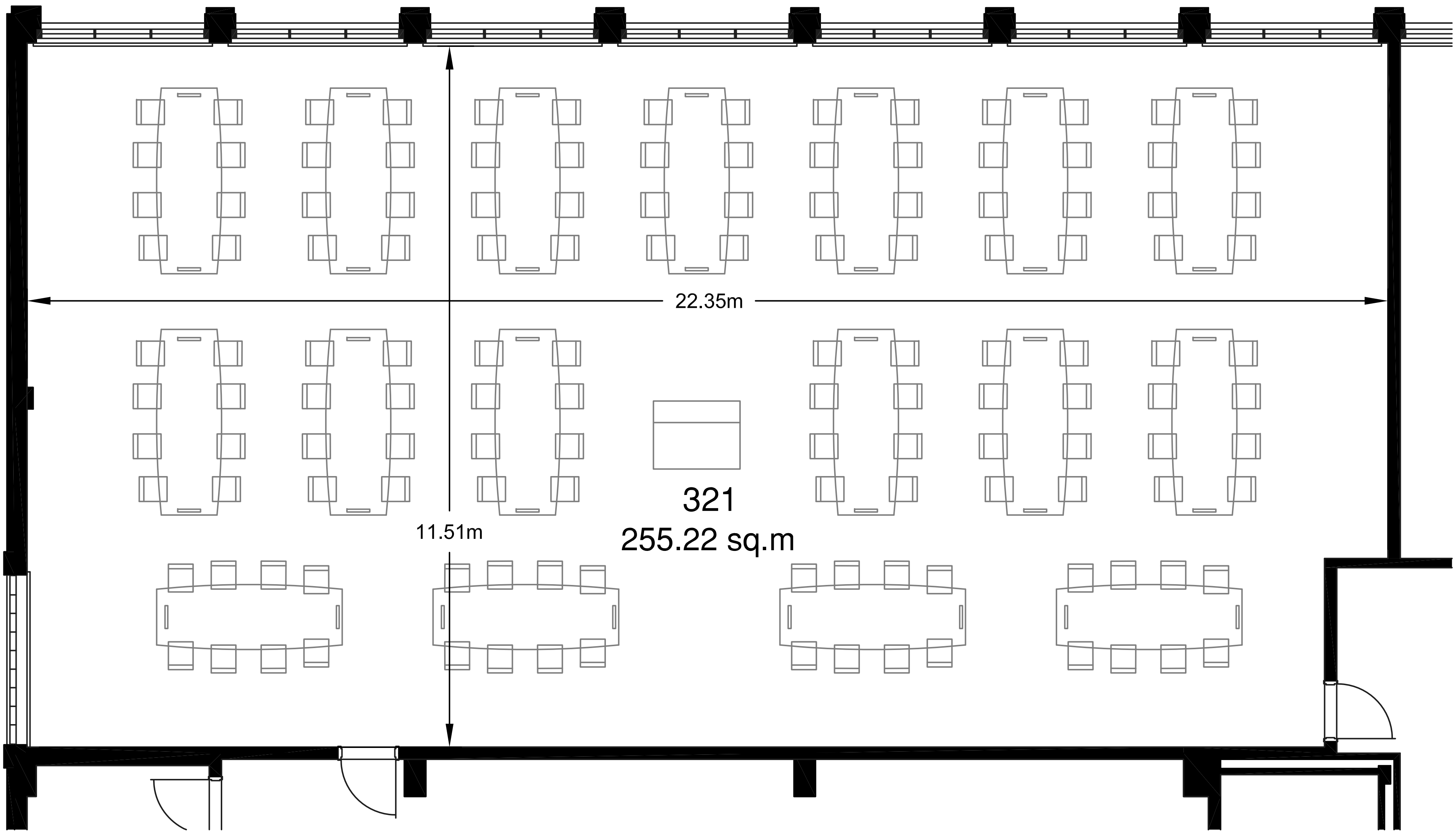
- For base-case roof replacement, an increase of insultation will be required.
- The team will need to consider what typical construction methods for the roof would be used at the time of construction, the number of times it has been re-roofed, and assume what would have been replaced.
- A final design will not be presented, but case studies will be shown in the final report, along with a final recommendation, and next steps for a future potential capstone project for CIVI 460 students.

MOVING FORWARD

- The team will request that next week's meeting be postponed later due to reading week taking place on February 19-23, 2024.
- The team will present a final presentation in late March.
- A final draft report will be created and submitted in late March.

Appendix G: Supporting Documents for Adaptive Space Reuse Scope Component


15.51m
17.55m
155
264.77 sq.m
155A
4.51


22.35m
11.51m
321
255.22 sq.m

LEVEL 0 PLAN

5			DR'N BY: P.D.	Queen's University FACILITIES
4			DATE: MARCH 2022	
3			APP'D BY:	235 FRONTENAC ST.
2			SCALE: AS SHOWN	BLDG. No. 303 / BLOCK / LEVEL 0 / C.A.D.D. REF. 303-00
1			FILE NO. 303	PROJECT No. / FILE No. 303 / DRAWING No. A001 / REV. 0
0	DATE	REVISION	DWG. 1 OF 5	

Level 1

LEVEL 1 PLAN

0m 2 4 10m
1 3 5
SCALE

5			DR'N BY: P.D.
4			DATE: MARCH 2022
3			APP'D BY:
2			SCALE: AS SHOWN
1			FILE NO. 303
0	DATE	REVISION	DWG. 2 OF 5

Queen's University
FACILITIES

235 FRONTENAC ST.

BLDG. No.	BLOCK	LEVEL	C.A.D.D. REF.
303		1	303-01

PROJECT No. / FILE No.	DRAWING No.	REV.
303	A002	0

LEVEL 0 PLAN

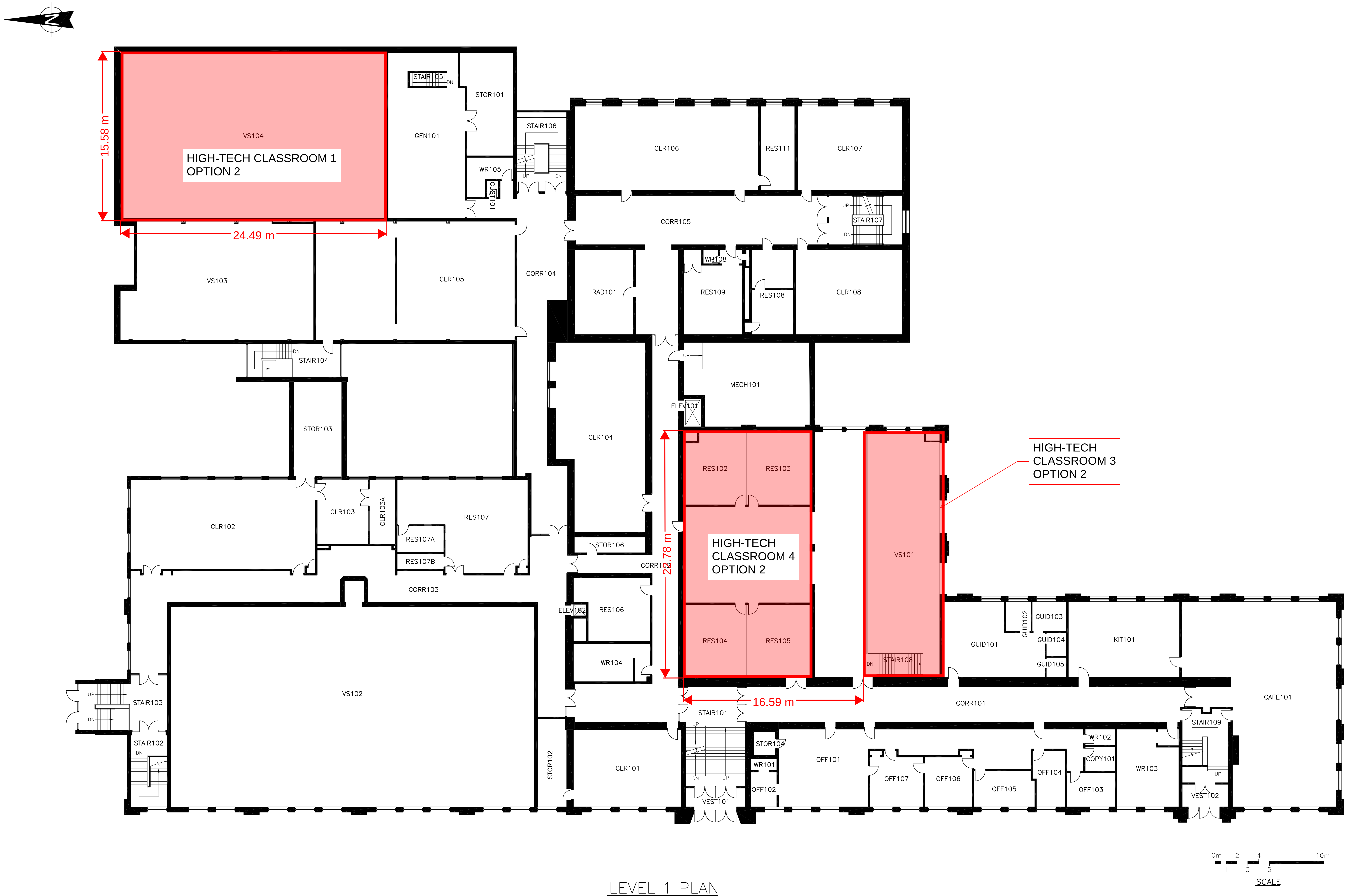
5			DR'N BY: P.D.
4			DATE: MARCH 2022
3			APP'D BY:
2			SCALE: AS SHOWN
1			FILE NO. 303
0	DATE	REVISION	DWG. 1 OF 5

Queen's University
FACILITIES

235 FRONTENAC ST.

BLDG. No.	BLOCK	LEVEL	C.A.D.D. REF.
303		0	303-00

PROJECT No. / FILE No.	DRAWING No.	REV.
303	A001	0



LEVEL 1 PLAN

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4			DATE: MARCH 2022	
3			APP'D BY:	235 FRONTENAC ST.
2			SCALE: AS SHOWN	BLDG. No. 303 — BLOCK — LEVEL 1 — C.A.D.D. REF. 303-01
1			FILE NO. 303	PROJECT No. / FILE No. 303 — DRAWING No. A002 — REV. 0
0	DATE	REVISION	DWG. 2 OF 5	

Table 69: Average Length-to-Width Ratio of Existing High-Tech Classrooms

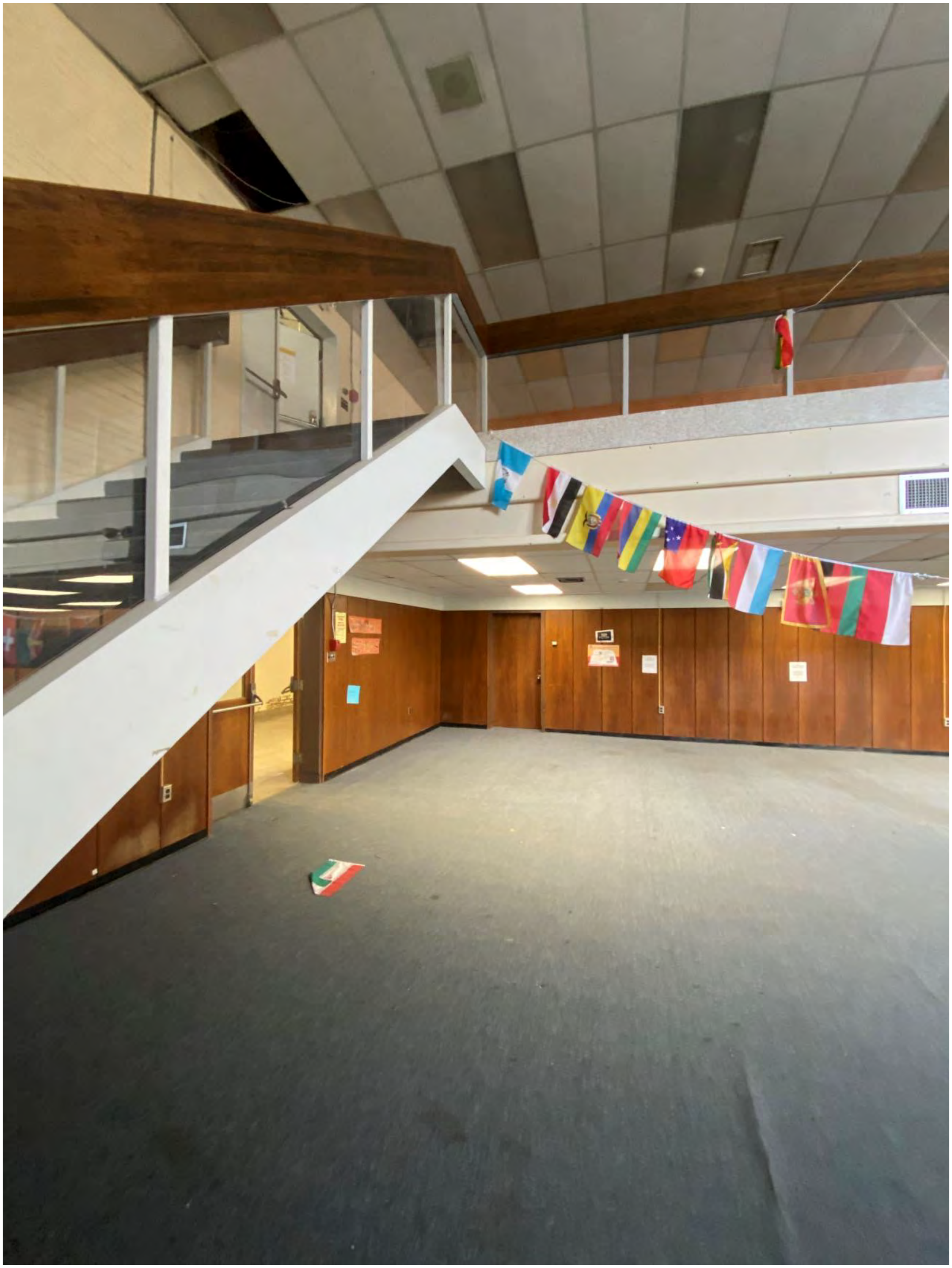
Building of High-Tech Classroom	Maximum Length (m)	Maximum Width (m)	Total Area (m^2)	Number of Students	Students/
Ellis Hall	11.51	22.35	257.25	136	0.53
Jeffery Hall	17.55	15.51	272.20	155	0.57
				AVERAGE:	0.55

Table 70: Option #1, Sizing Requirement Check for Determining Best Locations of Four High-Tech Classrooms

Class Number	Length (m)	Width (m)	Area (m^2)	Maximum Number of Students	Meets Minimum Requirements?
1	18	16.23	292.14	161	Yes
2	18	16.23	292.14	161	Yes
3	18	16.23	292.14	161	Yes
4	18	16.23	292.14	161	Yes
		TOTAL	1168.5		

Table 71: Option #2, Sizing Requirement Check for Determining Best Locations of Four High-Tech Classrooms

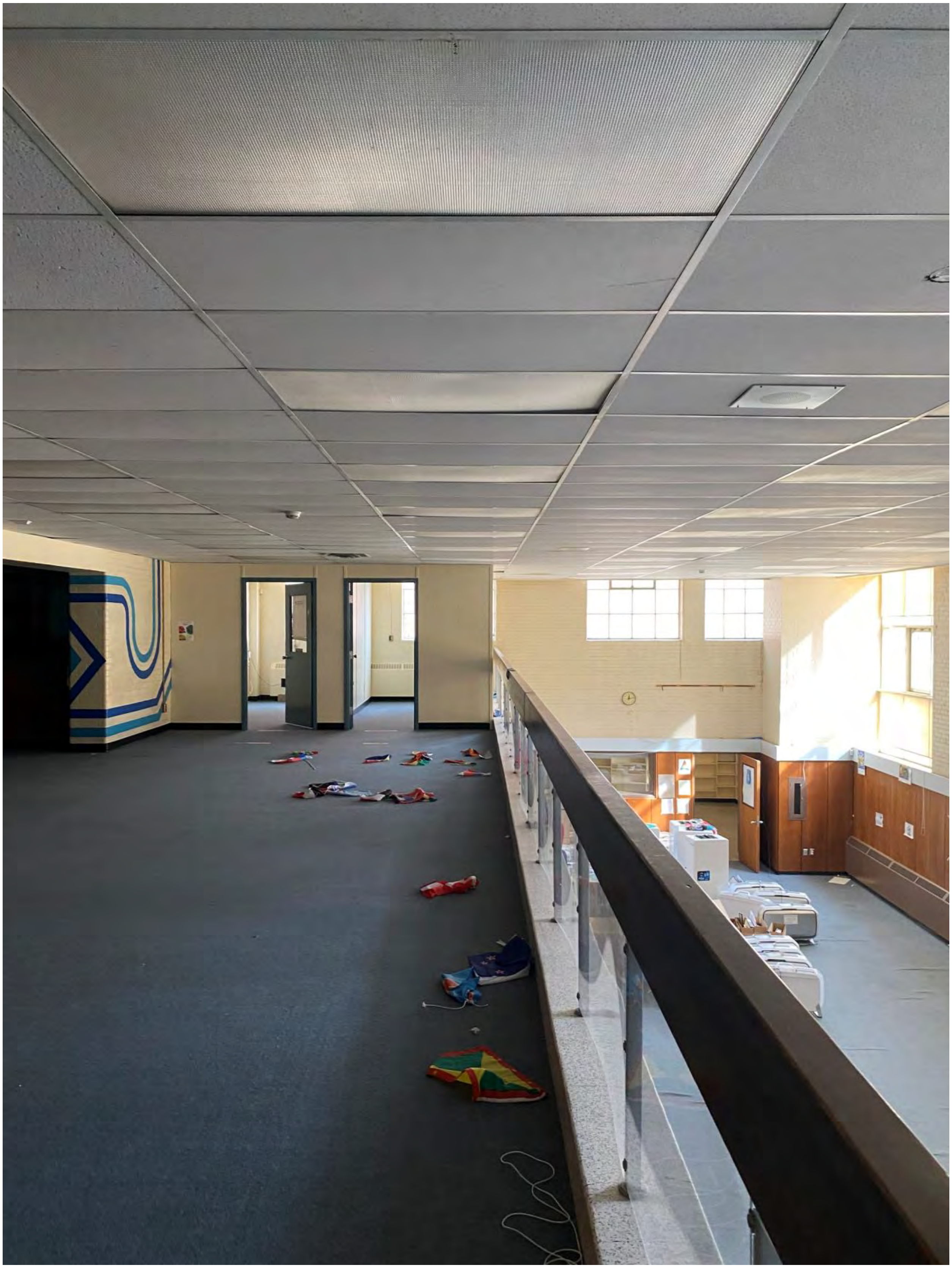
Class Number	Length (m)	Width (m)	Area (m^2)	Maximum Number of Students	Meets Minimum Requirements?
1	15.58	24.49	381.55	210	Yes
2	22.78	11.67	265.84	146	Yes
3	22.78	12.02	273.82	151	Yes
4	22.78	16.59	377.92	208	Yes
		TOTAL	1299.1		



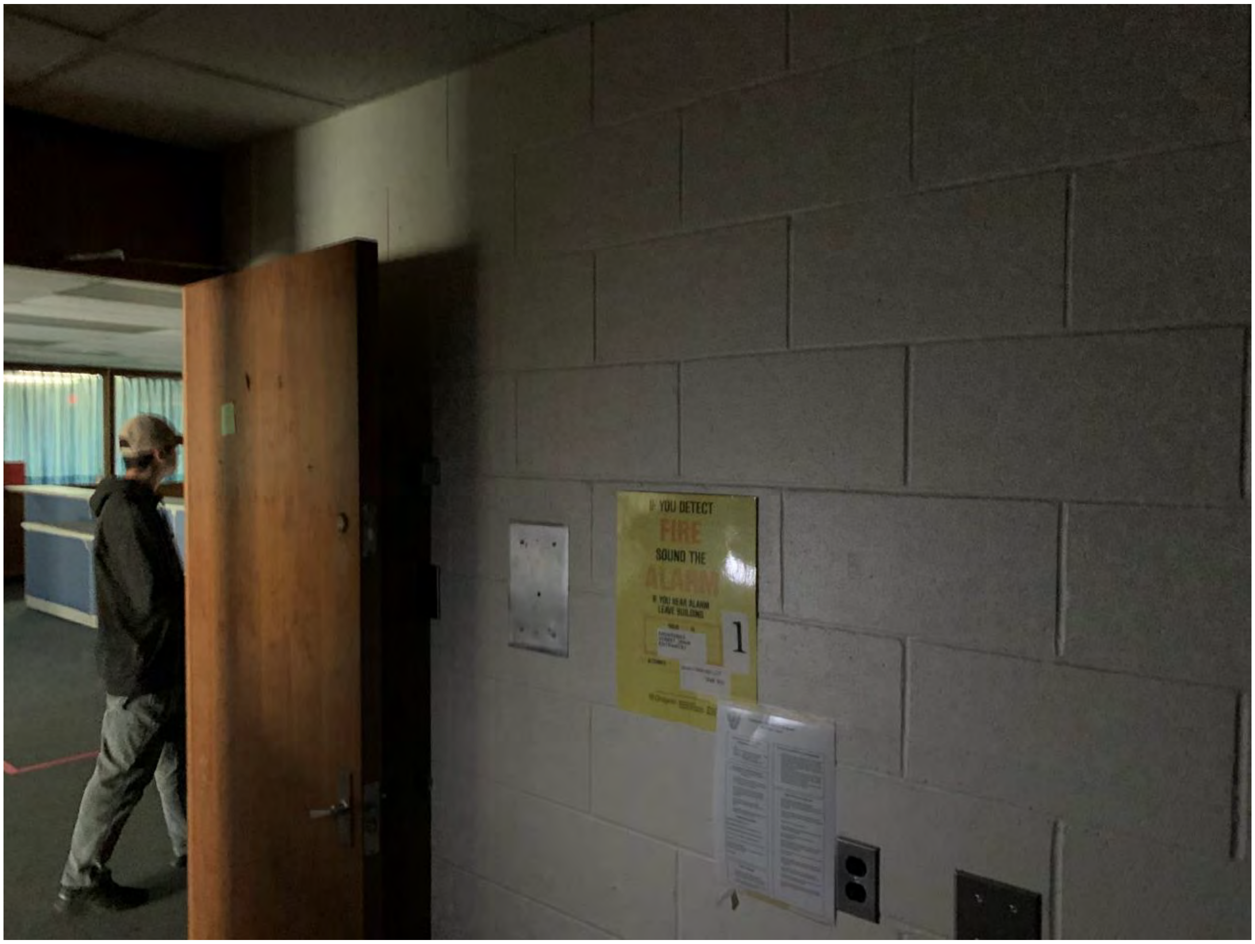

WELCOME BACK!
THE BOOKS MISSED YOU


READ
THE SMARTER YOU GROW


austin



Volunteer Hours Form


YOU DETECT
FIRE
SOUND THE
ALARM
IF YOU HEAR ALARM
LEAVE BUILDING
1


WAIT HERE
WAIT HERE

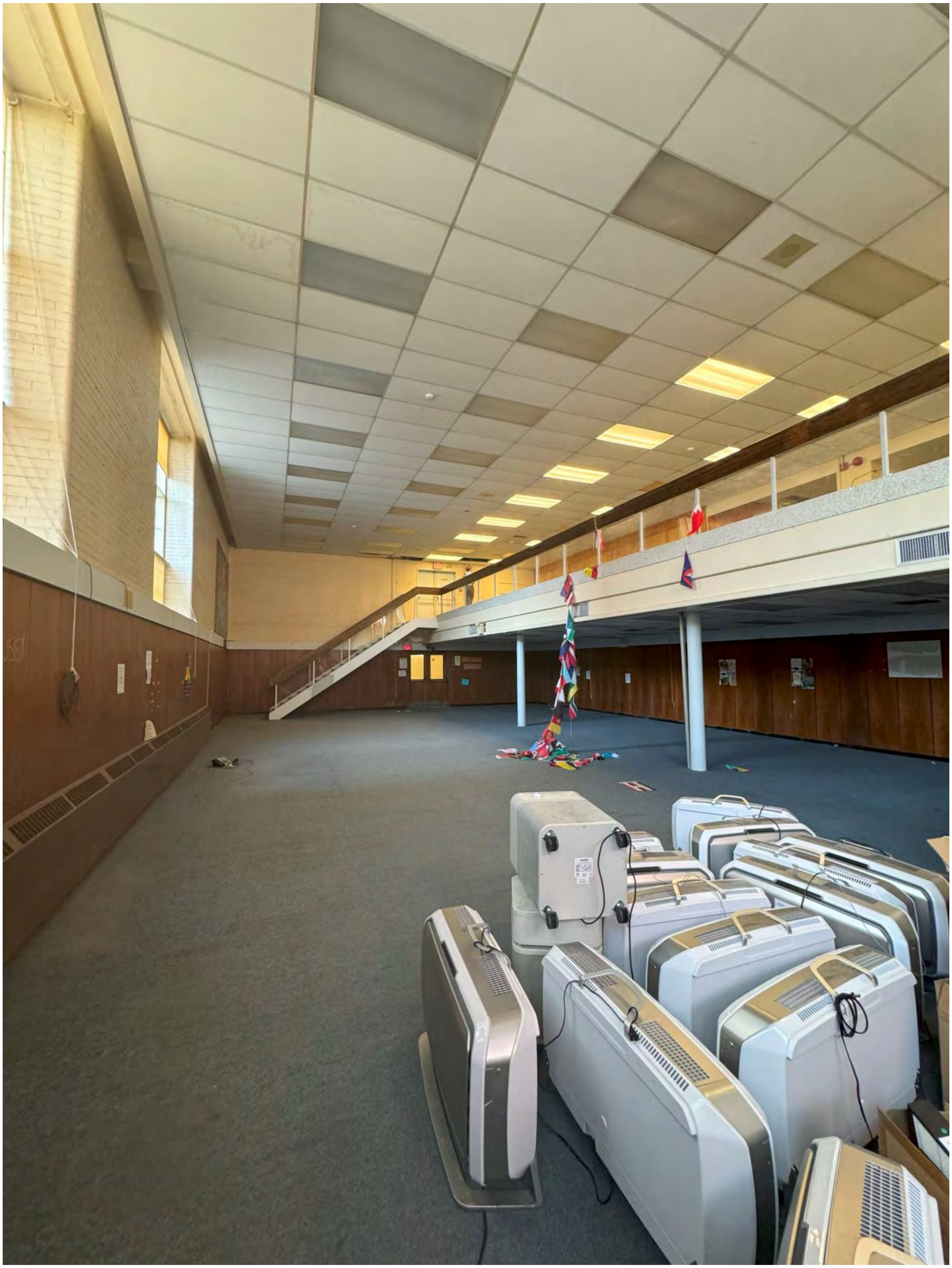

APPRENTICESHIP


D


D
Please sanitize
your hands
before touching the
fridge or microwave


Grad!
Dual Credit!
SUMMER SCHOOL


Grad!
Dual Credit!
SUMMER SCHOOL




austin
AERA MAX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AERA MAX

NO CELL PHONE
ZONE
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AF1000

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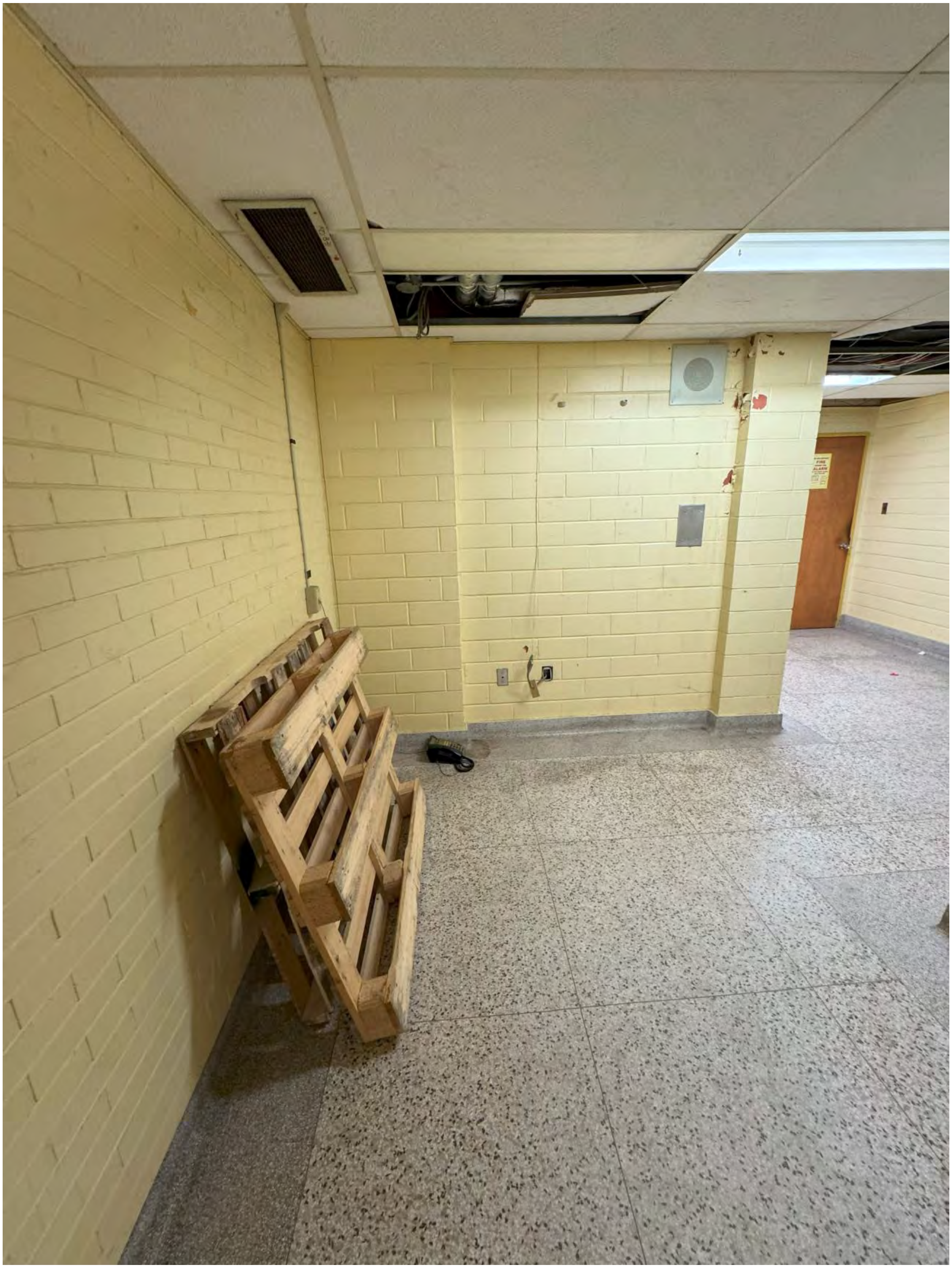
To Print

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120-277

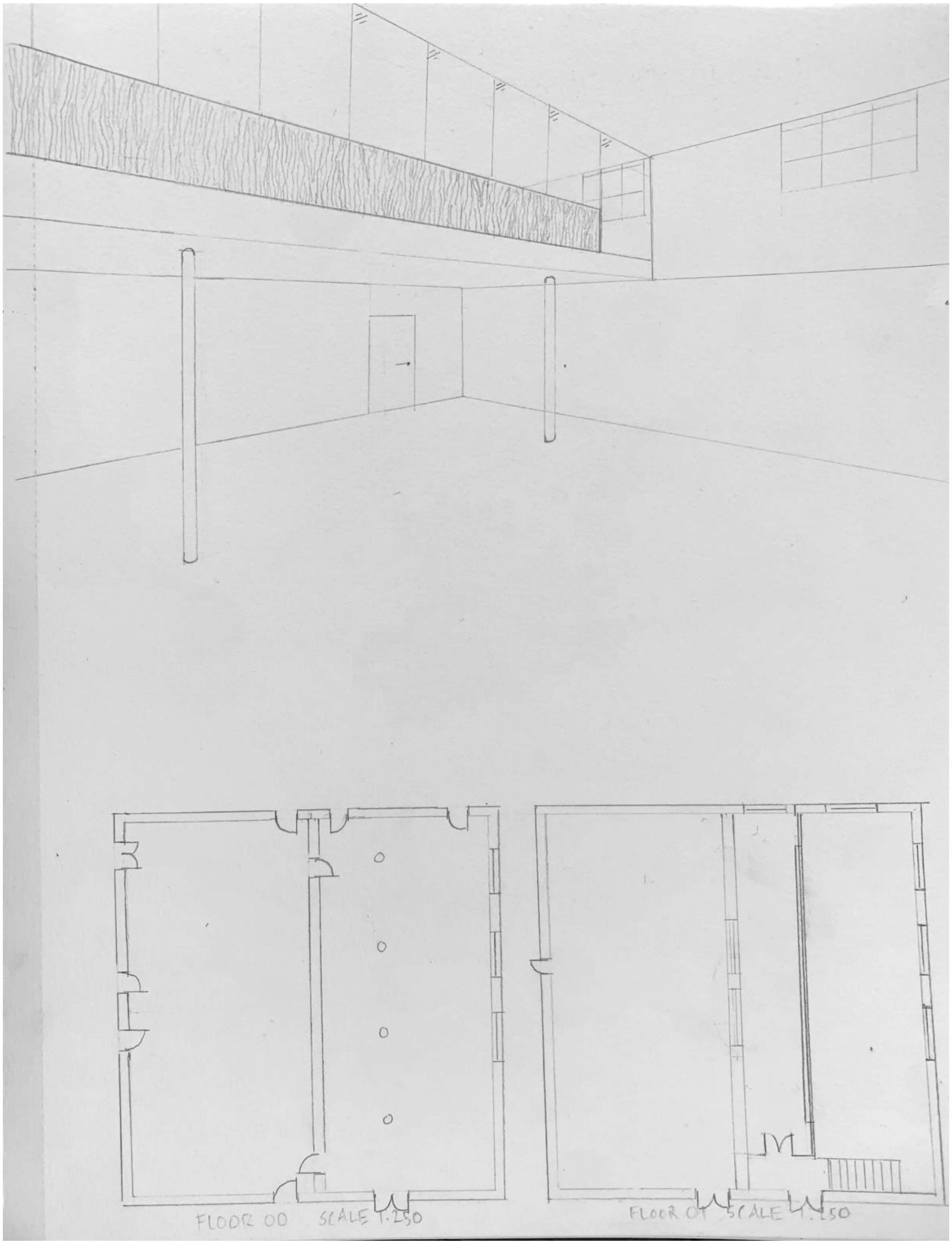


Figure 19: A Concept Sketch of the Library Space After Renovations Including a Glass Partition Wall System Along the Existing Balcony

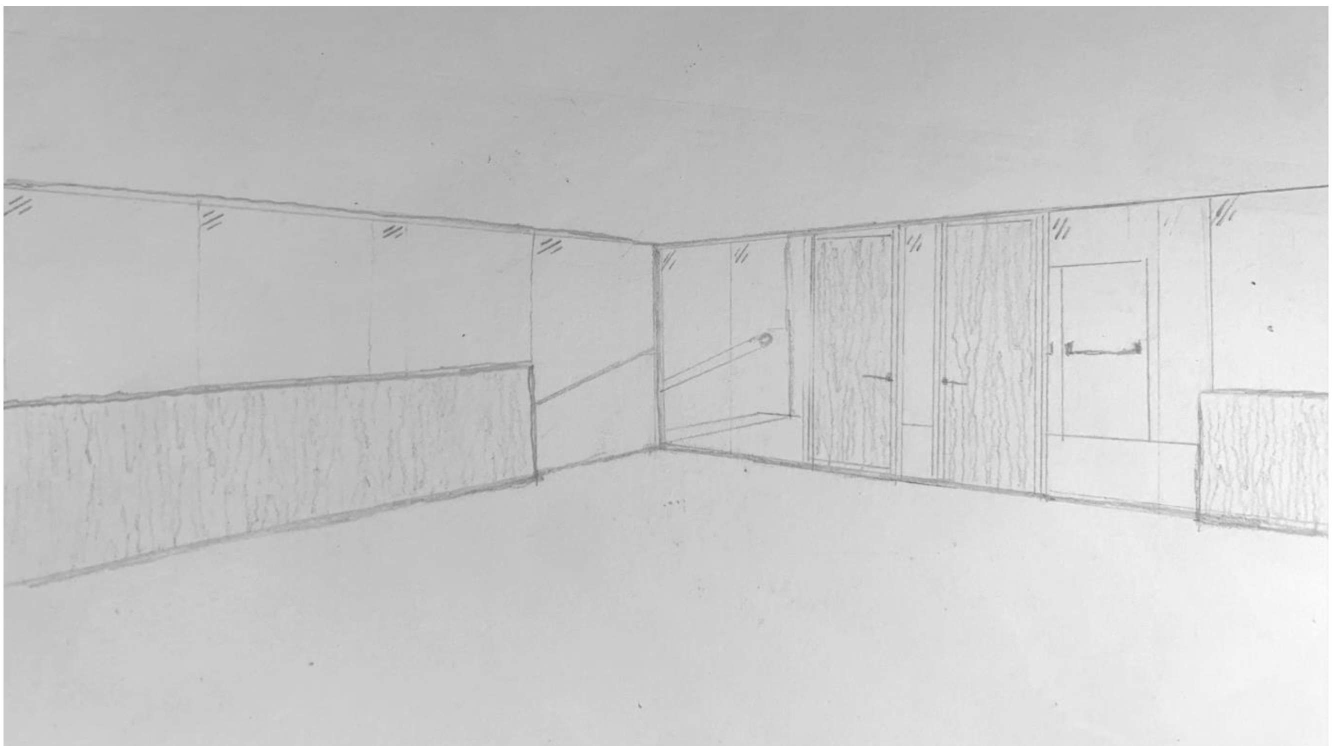


Figure 20: A Concept Sketch of the Existing Space on the First Level (RES 101) After Renovations Looking Toward the Balcony

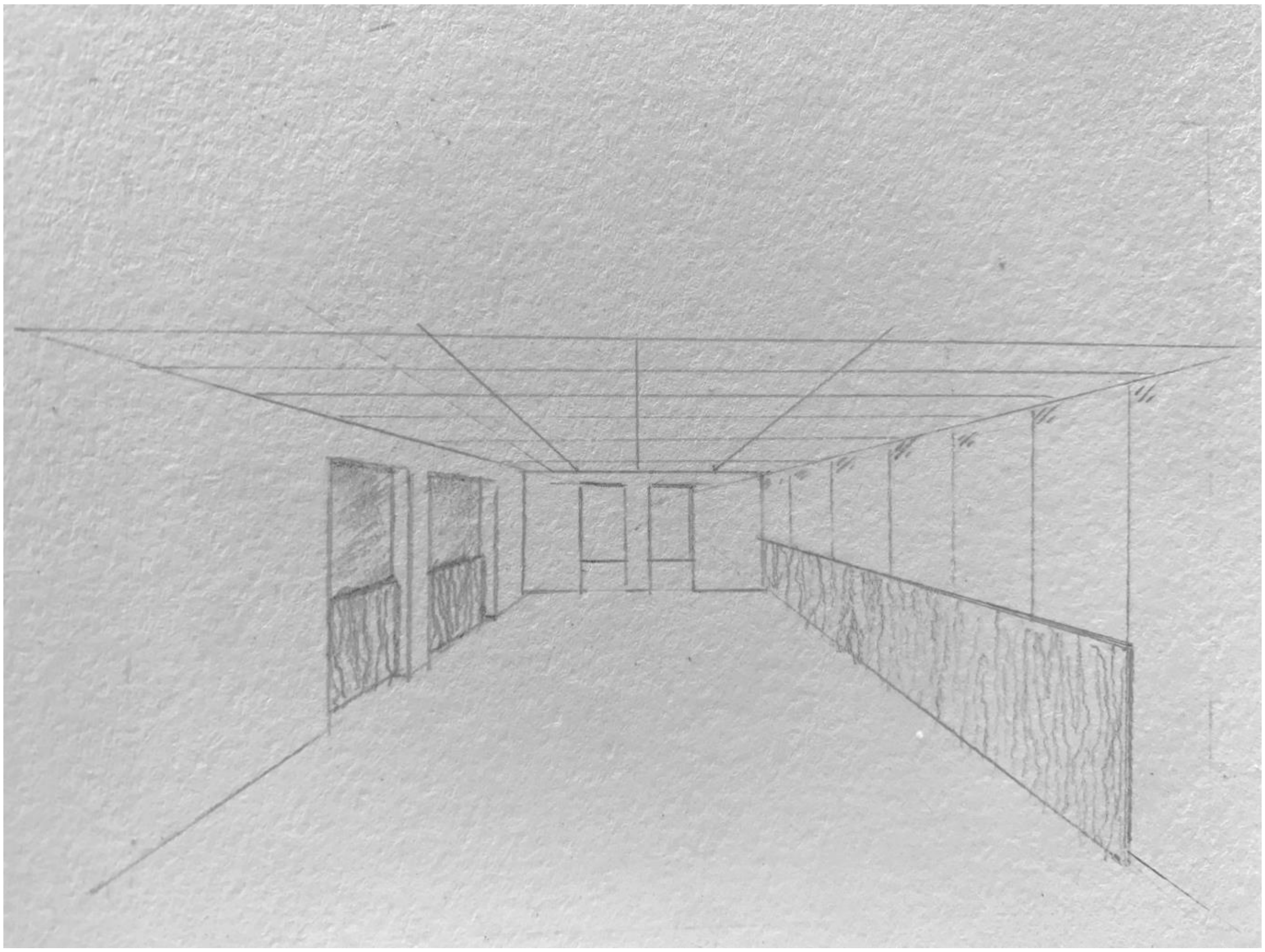


Figure 21: A Concept Sketch of the Existing Balcony on the First-Floor Level Facing East

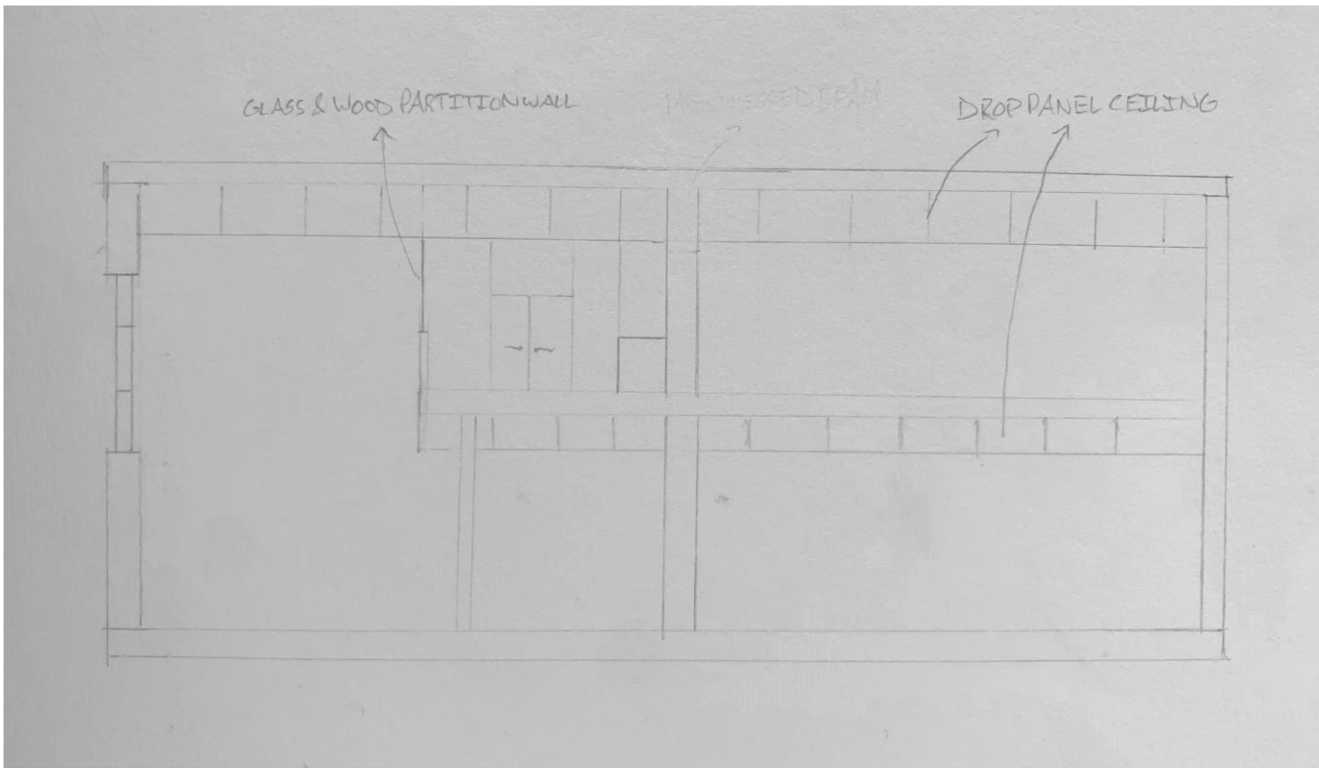


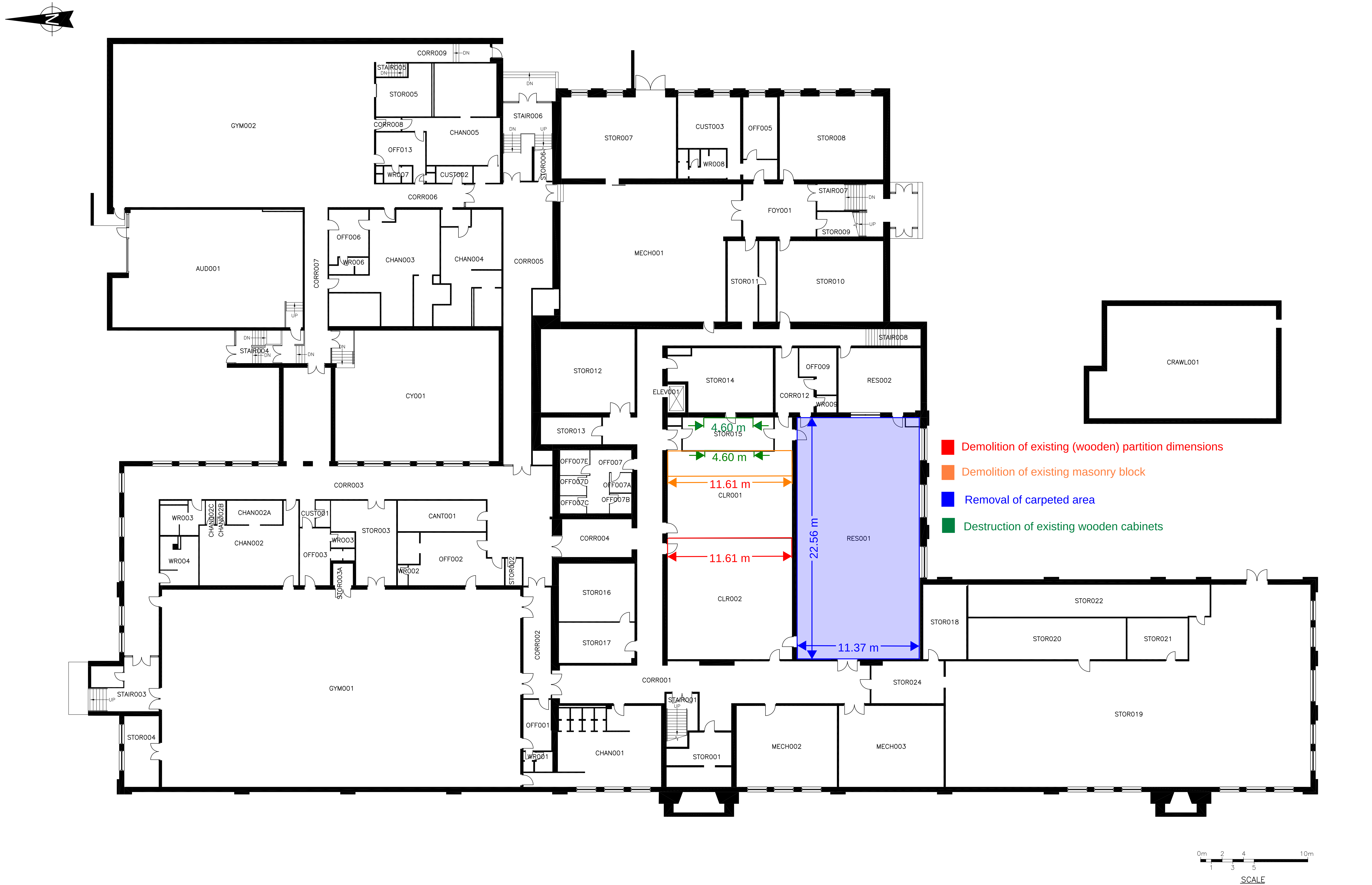
Figure 22: An Elevation View Concept Sketch After Renovation

NEW TECHNICAL SCHOOL KINGSTON ONT.
DRAWING No 3
COLIN DREVER - ARCHITECT, JULY-1929
KINGSTON, ONTARIO.
ALFRED STREET WING
EXISTING COLLEGIATE WING
EXISTING COLLEGIATE INSTITUTE
1892 WING
W 250 x 28
4.77m
Report Sample Calculations
WWF 650 x 400
11.35m
W 250 x 28
5.64m
WWF 700 x 175
11.35m
W 250 x 28
5.74m
WWF 700 x 196
11.35m
W 360 x 45
3.92m
W 250 x 28
3.92m
UPPER PART OF GIRLS' GYMNASIUM # 10
GALLERY # 118
GALLERY # 117
ELECTRIC SHOP # 102
CAFETERIA
AUTOMOBILE SHOP # 116
TOOL ROOM # 114
MACHINE SHOP # 112
DRAUGHTING ROOM # 103
STAIR HALL # 104
TEACHERS # 106
WOOD WORKING SHOP # 107
LUMBER ROOM # 108
FINISH ROOM # 109
BOYS' TOILET # 110
DOORS
PLUMBING SYMBOLS
ELECTRIC SYMBOLS
PLAN OF FIRST FLOOR
SCALE, 1/8 INCH = ONE FT.

New Technical School Kingston Ont.
DRAWING No 3
Colin Drever - Architect, July-1929
Kingston, Ontario

PLAN OF FIRST FLOOR


New Technical School Kingston Ont.
DRAWING No 3
Colin Drever - Architect, July-1920
Kingston, Ontario
ALFRED STREET WING
EXISTING COLLEGIATE WING
EXISTING COLLEGIATE INSTITUTE
1892 WING
6.76 sqm
Report Sample Calculations
45.26 sqm
8.11 sqm
49.45 sqm
8.11 sqm
42.60 sqm
4.44 sqm
Upper Part of Girls Gymnasium #118
Upper Part of Boys' Gymnasium #9
Gallery #118
Gallery #117
Corridor #120
Stair Hall #101
Electric Shop #102
Draughting Room #103
Stair Hall #104
Teachers #106
Wood Working Shop #107
Lumber Room #108
Finish Room #109
Boys' Toilet #110
Vestibule #111
Machine Shop #112
Tool Room #114
Instructors Room #115
CAFETERIA
Automobile Shop #116
Corridor #113
Doors
Plumbing Symbols
Electric Symbols
1/2" Scale Detail Thro. Corridor Partition Showing Metal Lockers
Note: This area now used as kitchen cafeteria
PLAN OF FIRST FLOOR
SCALE, 1/8 INCH = ONE FT.



LEVEL 0 PLAN

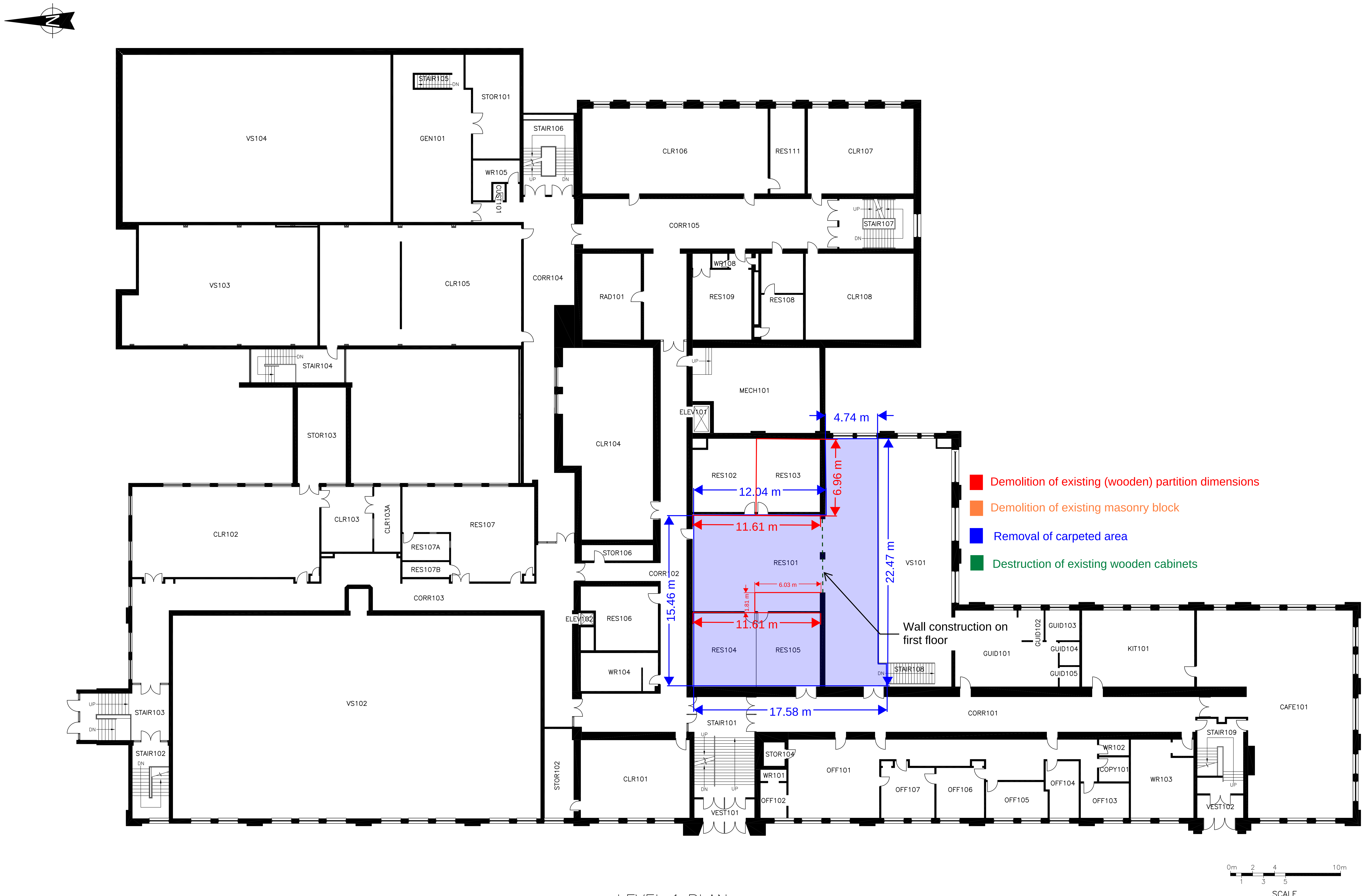
5			DR'N BY: P.D.
4			DATE: MARCH 2022
3			APP'D BY:
2			SCALE: AS SHOWN
1			FILE NO. 303
0	DATE	REVISION	DWG. 1 OF 5

Queen's University
FACILITIES

235 FRONTENAC ST.

BLDG. No.	BLOCK	LEVEL	C.A.D.D. REF.
303		0	303–00

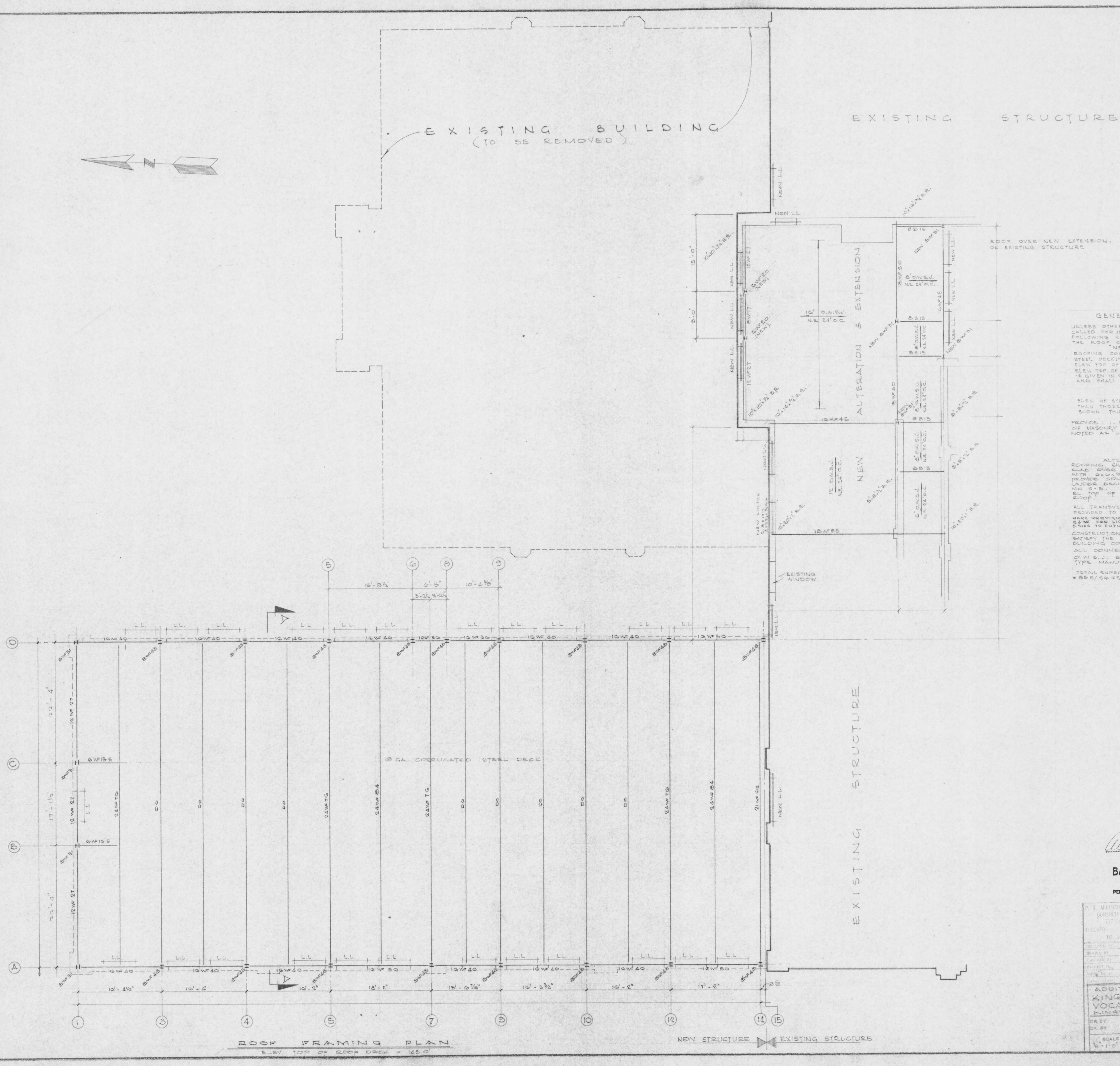
PROJECT No. / FILE No.	DRAWING No.	REV.
303	A001	0



LEVEL 1 PLAN

5		DR'N BY: P.D.	Queen's University FACILITIES
4		DATE: MARCH 2022	
3		APP'D BY:	235 FRONTENAC ST.
2		SCALE: AS SHOWN	BLDG. No. 303 / BLOCK / LEVEL 1 / C.A.D.D. REF. 303-01
1		FILE NO. 303	PROJECT No. / FILE No. 303 / DRAWING No. A002 / REV. 0
0 DATE	REVISION	DWG. 2 OF 5	

Appendix H: Supporting Documents for Roof Design Scope Component



GENERAL NOTES

UNLESS OTHERWISE NOTED ON DRG. OR CALLED FOR IN THE SPECIFICATIONS, THE FOLLOWING REQUIREMENTS SHALL GOVERN THE ROOF CONSTRUCTION.

"NEW WING"

ROOFING CONSISTS OF 18 GA. CORRUGATED STEEL DECKING.

ELEV. TOP OF ROOF = 145.0'

ELEV. TOP OF ALL STRUCTURAL MEMBERS IS GIVEN IN RELATION TO TOP ROOF EL., AND SHALL BE AS FOLLOWS: 144.88'

ELEV. OF STEEL MEMBERS DIFFERENT THAN THOSE SHOWN ABOVE, ARE SHOWN THUS

PROVIDE: 1 - 3½x4x5/16 L FOR EACH 4" WIDTH OF MASONRY WALL FOR EACH LOOSE LINTEL NOTED AS "L.L.".

ALTERATION & EXTENSION

ROOFING SHALL CONSIST OF 2" CONCRETE SLAB OVER O.W.S.J. AND BE REINFORCED WITH 6x6x6/6 MESH.

PROVIDE CONCRETE PAD ON EXISTING WALL UNDER EACH B.R. AS SPECIFIED ON DWG NO. S-3.

EL. TOP OF ROOF SHALL MATCH EXISTING ROOF.

ALL TRANSVERSAL CONNECTIONS SHALL BE PROVIDED TO RESIST WIND STRESSES.

MAKE PROVISION FOR HOLES TO BE CUT IN WEBS OF 24 WF FOR LIGHT MECHANICAL CONDUITS (POSITION & SIZE TO FUTURE DETAIL).

CONSTRUCTION OF THE WHOLE STRUCTURE SHALL SATISFY THE REQUIREMENTS OF THE "NATIONAL BUILDING CODE OF CANADA."

ALL CONNECTIONS TO BE RIVETED.

O.W.S.J. SHALL BE OF "TRUSCON" OR EQUAL TYPE MANUFACTURE

TOTAL SUPERIMPOSED LOAD OVER O.W.S.J. = = 85 #/SQ. FT.

Albert B. Hillman
Chairman.

BALL BROTHERS LIMITED
PER H. J. Ball

P. T. MIKLUCHIN & ASSOCIATES
CONSULTING ENGINEERS
717 CHURCH ST.
TORONTO ONTARIO
TEL. WA. 4-7063

DESIGNED BY
DRAWN BY
CHECKED BY
PROJECT No.
SHEET No.
DATE

REGISTERED PROFESSIONAL ENGINEER
CIVIL
P. MIKLUCHIN
PROVINCE OF ONTARIO

ADDITIONS & ALTERATIONS TO
KINGSTON COLLEGIATE AND VOCATIONAL INSTITUTE
KINGSTON ~ ONTARIO

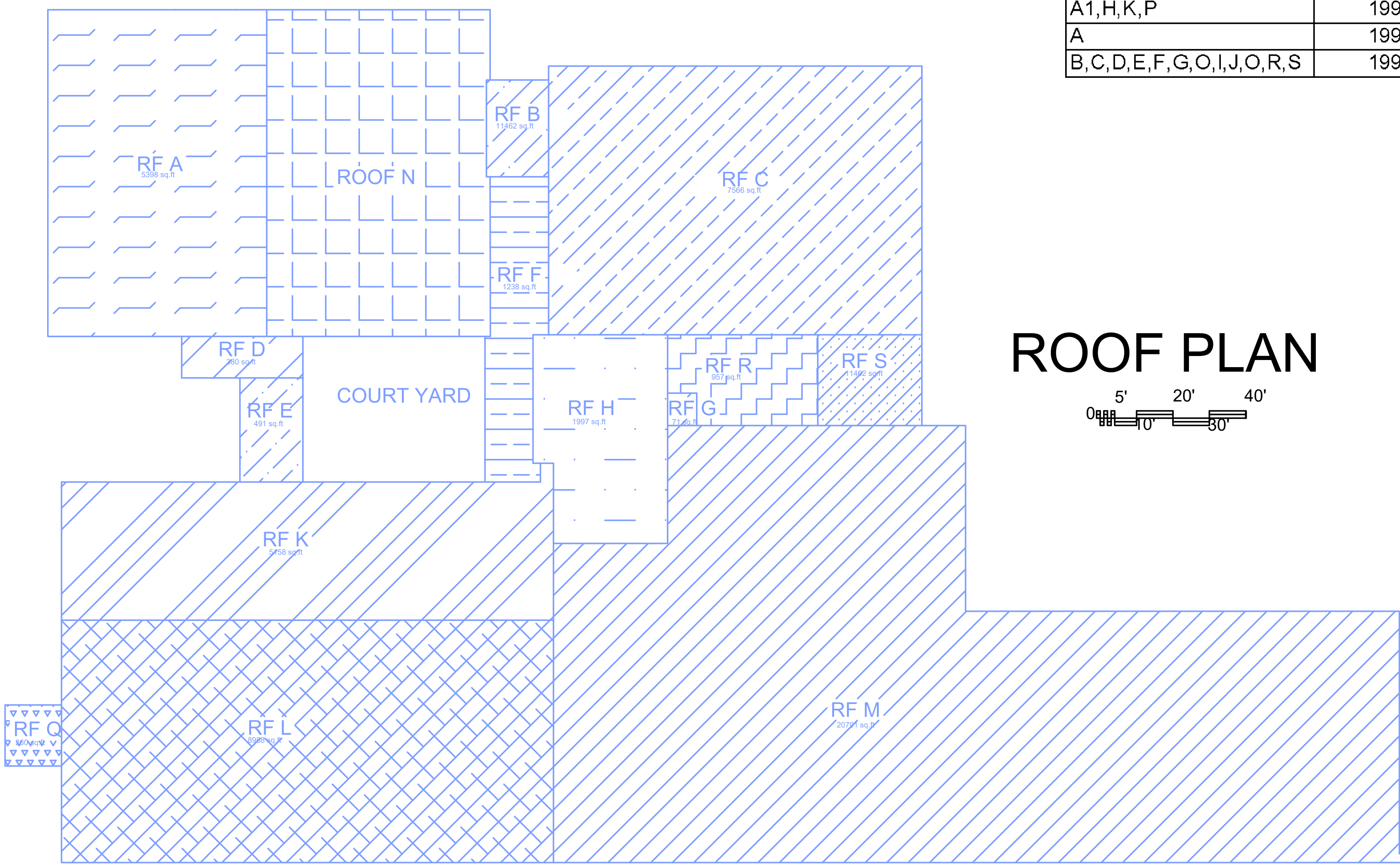
DR. BY
CK. BY
SCALE 1/8" = 1'-0"

DREVER & SMITH
M.M.R.A.I.C.
ARCHITECTS
81 BROCK STREET
KINGSTON, ONT.

DWG. No. S-5
DATE

ROOF REPLACEMENT	
ROOF	YEAR
A	1990
A1,H,K,P	1993
A	1994
B,C,D,E,F,G,O,I,J,O,R,S	1998

ROOF PLAN



LIMESTONE DISTRICT SCHOOL BOARD
220 PORTSMOUTH AVENUE; POSTAL BAG 610
KINGSTON, ON
K7L 4X4
TEL: (613)544-6925
FAX: (613)544-8569

Roof Plan

November 2009

PRODUCED BY FACILITY SERVICES

K.C.V.I
235 Frontenac St.
Kingston, ON
K7L 3S7
FC01

Figure 23: Cross Section of a Green Roof (Green Roofs 2013)

Variable	Value		
	Conventional Roofs	**Cool Roofs**	**Green Roofs**
Study Period	50 Years		
Installation Cost Premium (over Conventional)	N/A	$2.625/m^2	$182/m^2
Maintenance Cost Premium (over Conventional)	N/A	$0.21/m^2	$2.90/m^2
Lifespan	17 Years	17 Years	40 Years
Replacement Cost (% of Installation Cost)	100	100	33.3 (Plants and growing medium are salvaged)
Disposal Cost	$3.97/m^2	$3.97/m^2	$1.29/m^2
Design Characteristics	N/A	Aged Solar Reflectance of 0.55	11.45 cm (4.5 in) growing medium, Leaf Area Index of 2, irrigated
Discount Rate	3.75% (Residential), 7% (Commercial and Industrial)		
Inflation Rate	1.64%		
Energy Price Inflation Rate	2.4%		
Average Energy Cost	$0.165/kWh (Residential), $0.205 kWh (Commercial)		
Average Natural Gas Cost	$0.26/m^3		

Figure 24: Life Cycle Costs of Green Roofs (Peck and Lilauwala 2016)

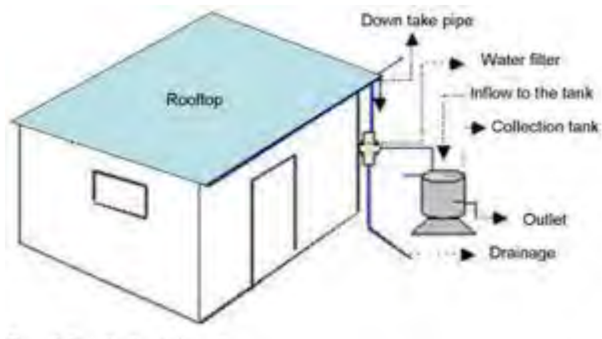


Figure 25: General Design of a Blue Roof Water Catchment System for a Flat Roof (Awawdeh et al. 2012)

Figure 26: Green-Blue Roof at the Chungwoon Middle School (Shafique et al. 2016)

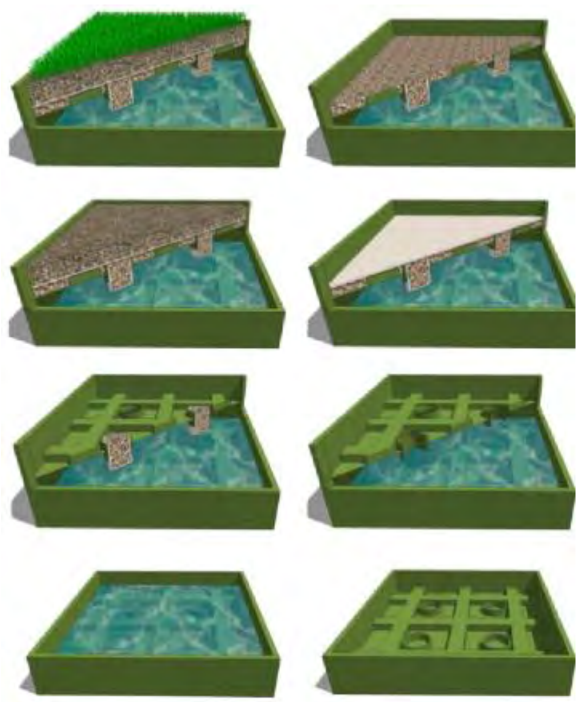


Figure 27: The Interior Structure of the Green-Blue Roof (Shafique et al. 2016)

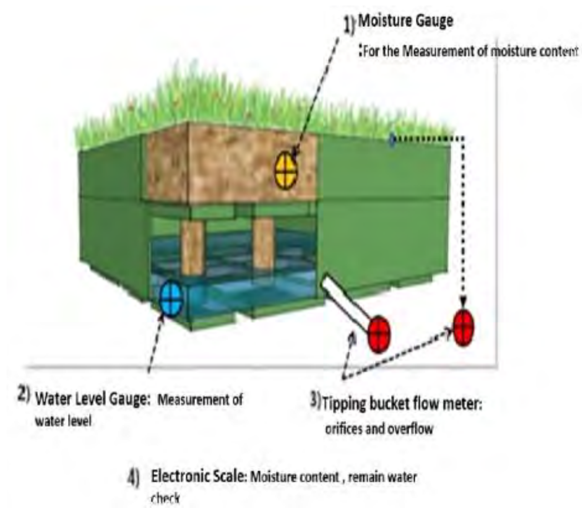


Figure 28: Cross-Sectional Design of the Green-Blue Roof (Shafique et al. 2016)

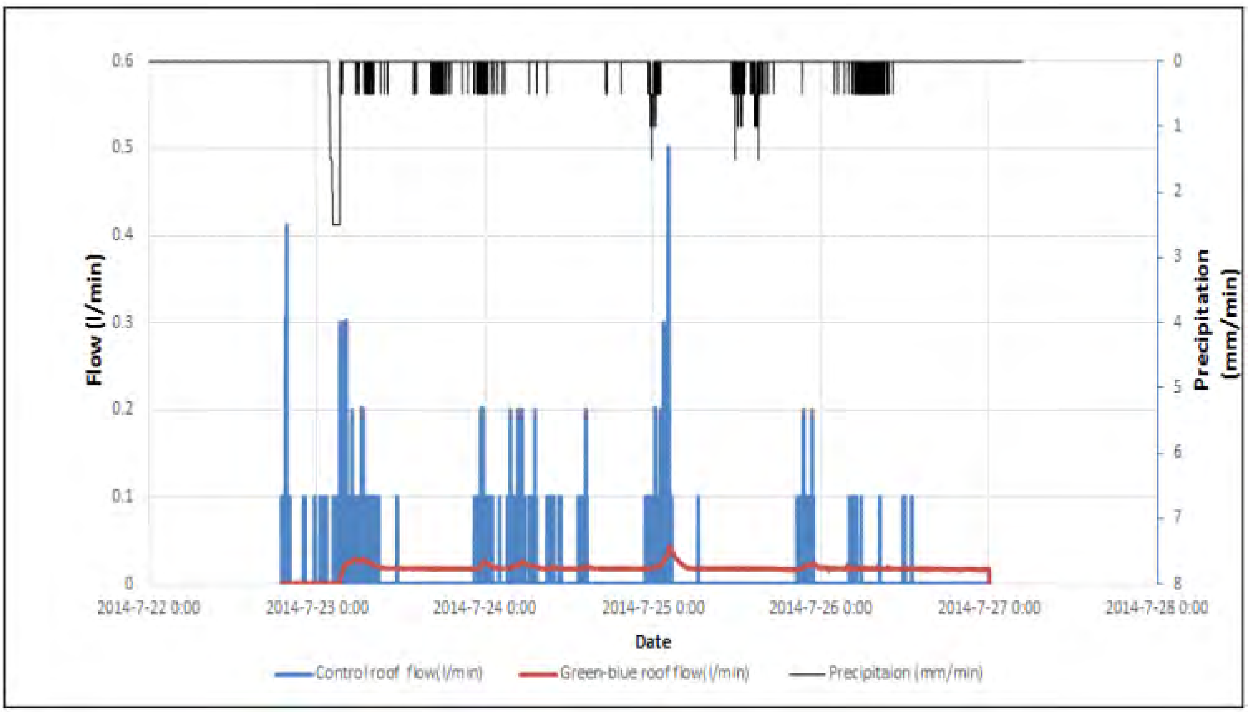


Figure 29: Variation of the Water Flows from the Control Roof and Green-Blue Roof During the Rainfall Event (Shafique et al. 2016)

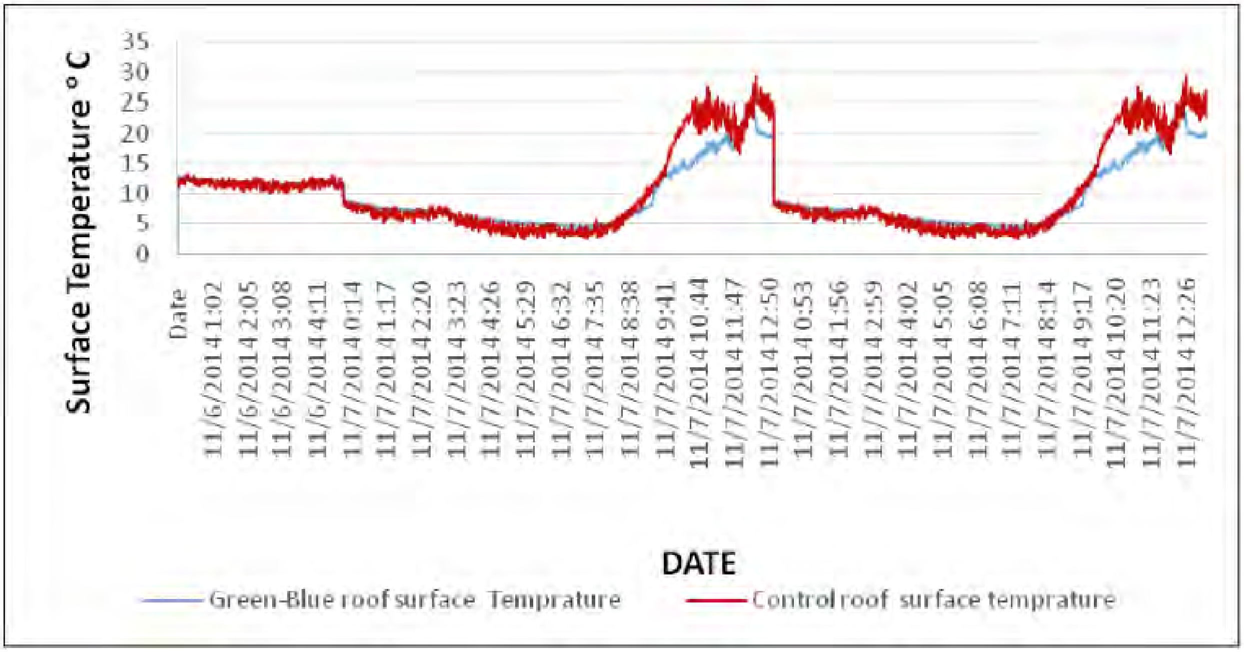


Figure 30: Variation of the Surface Temperature from Both Roofs (Shafique et al. 2016)

Appendix I: Cost of Ownership Analysis

Cases:
Base - Do Nothing, replace windows like for like every X years
Option 1: 3.625" wide metal studs + 3.625" of spray foam in terracotta section + 6" wide metal studs + 6" of spray foam in reinforced concrete section + double pane secondary glazed windows for all window:
Option 2: 4" wide metal studs + 4" of spray foam in terracotta section + 6" wide metal studs + 6" of spray foam in reinforced concrete section + double pane secondary glazed windows for all window:
Option 3: 3.625" wide metal studs + 3.625" of spray foam + double pane secondary glazed windows (everywhere)
Option 4: 4" wide metal studs + 4" of spray foam + double pane secondary glazed windows (everywhere)
Option 5: 3.625" wide metal studs + 3.5" of batt insulation + double pane secondary glazed windows (everywhere)
Option 6: 6" wide metal studs + 6" of batt insulation + double pane secondary glazed windows (everywhere)
Option 7: 3.625" wide metal studs + 3" of EPS + double pane secondary glazed windows (everywhere)
Option 8: 4" wide metal studs + 4" of EPS + double pane secondary glazed windows (everywhere)
Option 9: 6" wide metal studs + 6" of EPS + double pane secondary glazed windows (everywhere)

KCVI Wall Composition Energy Efficiency Improvements - Preliminary										
Options:	**Base**	**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**	**Option 6**	**Option 7**	**Option 8**	**Option 9**
Capital changes relative to Base case										
Total Construction ($)	**$ -**	**$ 1,083,315**	**$ 1,061,281**	**$ 1,007,883**	**$ 972,695**	**$ 740,164**	**$ 677,539**	**$ 763,342**	**$ 746,120**	**$ 827,618**
Cost difference compared to base case (+/-)	**$ -**	**$ 1,083,315**	**$ 1,061,281**	**$ 1,007,883**	**$ 972,695**	**$ 740,164**	**$ 677,539**	**$ 763,342**	**$ 746,120**	**$ 827,618**
Operating Costs										
Annual Fuel/Energy Input		155,827	155,410	161,987	160,778	170,738	161,162	171,148	165,718	159,127
Electricity [kWh]	-	-	-	-	-	-	-	-	-	-
[$]	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Natural Gas [m3]	396,447	155,827	155,410	161,987	160,778	170,738	161,162	171,148	165,718	159,127
[$]	$ 111,005	$ 43,632	$ 43,515	$ 45,356	$ 45,018	$ 47,807	$ 45,125	$ 47,921	$ 46,401	$ 44,555
Carbon [Tonnes]	748	294	293	305	303	322	304	323	313	300
[$]	$ 49,342	$ 19,394	$ 19,342	$ 20,161	$ 20,011	$ 21,250	$ 20,058	$ 21,301	$ 20,625	$ 19,805
TOTAL FUEL COST $	**$ 160,347.20**	**$ 63,026.07**	**$ 62,857.33**	**$ 65,517.22**	**$ 65,028.32**	**$ 69,056.79**	**$ 65,183.81**	**$ 69,222.64**	**$ 67,026.40**	**$ 64,360.47**
Savings vs Base		**$ 97,321.13**	**$ 97,489.87**	**$ 94,829.98**	**$ 95,318.88**	**$ 91,290.41**	**$ 95,163.39**	**$ 91,124.57**	**$ 93,320.80**	**$ 95,986.73**
Periodic Cost - Window Replacement in year 10	**380,446**	**656,734**	**656,734**	**656,734**	**656,734**	**656,734**	**656,734**	**656,734**	**656,734**	**656,734**
Adaptive Space Reuse Upfront Cost	**-**	**45,074**	**45,074**	**45,074**	**45,074**	**45,074**	**45,074**	**45,074**	**45,074**	**45,074**
GHG Performance										
GHG Grid Electricity (tonnes/yr)	-	-	-	-	-	-	-	-	-	-
GHG Natural Gas (tonnes/yr)	748	294	293	305	303	322	304	323	313	300
Total GHG Emissions (tonnes/yr)	748	294	293	305	303	322	304	323	313	300
Reductions % from Base		**61%**	**61%**	**59%**	**59%**	**57%**	**59%**	**57%**	**58%**	**60%**
Financials	3%	Discount rate								
Net Present Value (10 yr NPV) @ 3% Disc	**- 1,870,932**	**- 500,043**	**- 476,440**	**- 447,766**	**- 408,034**	**- 212,949**	**- 114,323**	**237,669**	**- 200,032**	**- 256,749**
Net Present Value (15 yr NPV) @ 3% Disc	**- 3,156,107**	**512,957**	**537,289**	**554,476**	**596,319**	**774,008**	**889,358**	**748,571**	**795,693**	**750,488**
Net Present Value (20 yr NPV) @ 3% Disc	**- 3,815,593**	**913,225**	**938,251**	**944,498**	**988,352**	**1,149,472**	**1,280,752**	**1,123,354**	**1,179,508**	**1,145,268**
Net Present Value (25 yr NPV) @ 3% Disc	**- 4,443,681**	**- 80,619**	**- 54,932**	**- 59,104**	**- 13,335**	**132,005**	**278,456**	**105,238**	**169,994**	**146,197**
Net Present Value (30 yr NPV) @ 3% Disc	**- 5,965,306**	**1,205,884**	**1,232,200**	**1,218,106**	**1,265,698**	**1,396,011**	**1,556,909**	**1,368,624**	**1,441,574**	**1,427,722**
Net Present Value (40 yr NPV) @ 3% Disc	**- 7,077,592**	**1,880,975**	**1,908,461**	**1,875,916**	**1,926,900**	**2,029,268**	**2,217,032**	**2,000,731**	**2,088,916**	**2,093,556**
Net Present Value (50 yr NPV) @ 3% Disc	**- 9,525,178**	**1,052,943**	**1,081,491**	**1,032,209**	**1,086,270**	**1,163,291**	**1,375,424**	**1,133,710**	**1,235,713**	**1,257,128**
Net Present Value (60 yr NPV) @ 3% Disc	**- 12,681,726**	**3,849,796**	**3,879,307**	**3,814,845**	**3,871,696**	**3,925,726**	**4,159,963**	**3,895,199**	**4,009,737**	**4,046,366**
Net Present Value (70 yr NPV) @ 3% Disc	**- 13,511,777**	**4,353,587**	**4,383,972**	**4,305,741**	**4,365,122**	**4,398,299**	**4,652,584**	**4,366,913**	**4,492,820**	**4,543,249**

	Base	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8	Option 9
Initial Investment	0	-1083315.41	-1061281.01	-1007882.65	-972695.38	-740163.52	-677539	-763342	-746120	-827618
UFC for windows and ASR	-$ 380,446	-$ 701,808	-$ 701,808	-$ 701,808	-$ 701,808	-$ 701,808	-$ 701,808	-$ 701,808	-$ 701,808	-$ 701,808
Operational Cost 1	-$ 160,347	-$ 63,026	-$ 62,857	-$ 65,517	-$ 65,028	-$ 69,057	-$ 65,184	-$ 69,223	-$ 67,026	-$ 64,360
Operational Cost 2	-$ 163,554	-$ 64,287	-$ 64,114	-$ 66,828	-$ 66,329	-$ 70,438	-$ 66,487	-$ 70,607	-$ 68,367	-$ 65,648
Operational Cost 3	-$ 166,825	-$ 65,572	-$ 65,397	-$ 68,164	-$ 67,655	-$ 71,847	-$ 67,817	-$ 72,019	-$ 69,734	-$ 66,961
Operational Cost 4	-$ 170,162	-$ 66,884	-$ 66,705	-$ 69,527	-$ 69,009	-$ 73,284	-$ 69,174	-$ 73,460	-$ 71,129	-$ 68,300
Operational Cost 5	-$ 173,565	-$ 68,221	-$ 68,039	-$ 70,918	-$ 70,389	-$ 74,749	-$ 70,557	-$ 74,929	-$ 72,552	-$ 69,666
Operational Cost 6	-$ 177,036	-$ 69,586	-$ 69,400	-$ 72,336	-$ 71,797	-$ 76,244	-$ 71,968	-$ 76,427	-$ 74,003	-$ 71,059
Operational Cost 7	-$ 180,577	-$ 70,978	-$ 70,788	-$ 73,783	-$ 73,232	-$ 77,769	-$ 73,408	-$ 77,956	-$ 75,483	-$ 72,480
Operational Cost 8	-$ 184,189	-$ 72,397	-$ 72,203	-$ 75,259	-$ 74,697	-$ 79,325	-$ 74,876	-$ 79,515	-$ 76,992	-$ 73,930
Operational Cost 9	-$ 187,872	-$ 73,845	-$ 73,647	-$ 76,764	-$ 76,191	-$ 80,911	-$ 76,373	-$ 81,105	-$ 78,532	-$ 75,409
Operational Cost 10	-$ 191,630	-$ 75,322	-$ 75,120	-$ 78,299	-$ 77,715	-$ 82,529	-$ 77,901	-$ 82,727	-$ 80,103	-$ 76,917
Operational Cost 11	-$ 195,462	-$ 76,828	-$ 76,623	-$ 79,865	-$ 79,269	-$ 84,180	-$ 79,459	-$ 84,382	-$ 81,705	-$ 78,455
Operational Cost 12	-$ 199,372	-$ 78,365	-$ 78,155	-$ 81,462	-$ 80,855	-$ 85,863	-$ 81,048	-$ 86,070	-$ 83,339	-$ 80,024
Operational Cost 13	-$ 203,359	-$ 79,932	-$ 79,718	-$ 83,092	-$ 82,472	-$ 87,581	-$ 82,669	-$ 87,791	-$ 85,006	-$ 81,625
Operational Cost 14	-$ 207,426	-$ 81,531	-$ 81,313	-$ 84,754	-$ 84,121	-$ 89,332	-$ 84,322	-$ 89,547	-$ 86,706	-$ 83,257
Operational Cost 15	-$ 211,575	-$ 83,162	-$ 82,939	-$ 86,449	-$ 85,803	-$ 91,119	-$ 86,009	-$ 91,338	-$ 88,440	-$ 84,922
Operational Cost 16	-$ 215,806	-$ 84,825	-$ 84,598	-$ 88,178	-$ 87,520	-$ 92,941	-$ 87,729	-$ 93,165	-$ 90,209	-$ 86,621
Operational Cost 17	-$ 220,122	-$ 86,521	-$ 86,290	-$ 89,941	-$ 89,270	-$ 94,800	-$ 89,483	-$ 95,028	-$ 92,013	-$ 88,353
Operational Cost 18	-$ 224,525	-$ 88,252	-$ 88,015	-$ 91,740	-$ 91,055	-$ 96,696	-$ 91,273	-$ 96,928	-$ 93,853	-$ 90,120
Operational Cost 19	-$ 229,015	-$ 90,017	-$ 89,776	-$ 93,575	-$ 92,876	-$ 98,630	-$ 93,099	-$ 98,867	-$ 95,730	-$ 91,923
Operational Cost 20	-$ 233,596	-$ 91,817	-$ 91,571	-$ 95,446	-$ 94,734	-$ 100,603	-$ 94,960	-$ 100,844	-$ 97,645	-$ 93,761
Operational Cost 21	-$ 238,268	-$ 93,653	-$ 93,403	-$ 97,355	-$ 96,629	-$ 102,615	-$ 96,860	-$ 102,861	-$ 99,598	-$ 95,636
Operational Cost 22	-$ 243,033	-$ 95,526	-$ 95,271	-$ 99,302	-$ 98,561	-$ 104,667	-$ 98,797	-$ 104,918	-$ 101,590	-$ 97,549
Operational Cost 23	-$ 247,894	-$ 97,437	-$ 97,176	-$ 101,288	-$ 100,532	-$ 106,760	-$ 100,773	-$ 107,017	-$ 103,621	-$ 99,500
Operational Cost 24	-$ 252,851	-$ 99,386	-$ 99,120	-$ 103,314	-$ 102,543	-$ 108,896	-$ 102,788	-$ 109,157	-$ 105,694	-$ 101,490
Operational Cost 25	-$ 257,908	-$ 101,373	-$ 101,102	-$ 105,380	-$ 104,594	-$ 111,074	-$ 104,844	-$ 111,340	-$ 107,808	-$ 103,520
Operational Cost 26	-$ 263,067	-$ 103,401	-$ 103,124	-$ 107,488	-$ 106,686	-$ 113,295	-$ 106,941	-$ 113,567	-$ 109,964	-$ 105,590
Operational Cost 27	-$ 268,328	-$ 105,469	-$ 105,187	-$ 109,638	-$ 108,820	-$ 115,561	-$ 109,080	-$ 115,838	-$ 112,163	-$ 107,702
Operational Cost 28	-$ 273,694	-$ 107,578	-$ 107,290	-$ 111,830	-$ 110,996	-$ 117,872	-$ 111,261	-$ 118,155	-$ 114,406	-$ 109,856
Operational Cost 29	-$ 279,168	-$ 109,730	-$ 109,436	-$ 114,067	-$ 113,216	-$ 120,230	-$ 113,487	-$ 120,518	-$ 116,695	-$ 112,053
Operational Cost 30	-$ 284,752	-$ 111,925	-$ 111,625	-$ 116,348	-$ 115,480	-$ 122,634	-$ 115,756	-$ 122,929	-$ 119,028	-$ 114,294
Operational Cost 31	-$ 290,447	-$ 114,163	-$ 113,857	-$ 118,675	-$ 117,790	-$ 125,087	-$ 118,071	-$ 125,387	-$ 121,409	-$ 116,580
Operational Cost 32	-$ 296,256	-$ 116,446	-$ 116,134	-$ 121,049	-$ 120,146	-$ 127,589	-$ 120,433	-$ 127,895	-$ 123,837	-$ 118,912
Operational Cost 33	-$ 302,181	-$ 118,775	-$ 118,457	-$ 123,470	-$ 122,549	-$ 130,140	-$ 122,842	-$ 130,453	-$ 126,314	-$ 121,290
Operational Cost 34	-$ 308,224	-$ 121,151	-$ 120,826	-$ 125,939	-$ 124,999	-$ 132,743	-$ 125,298	-$ 133,062	-$ 128,840	-$ 123,716
Operational Cost 35	-$ 314,389	-$ 123,574	-$ 123,243	-$ 128,458	-$ 127,499	-$ 135,398	-$ 127,804	-$ 135,723	-$ 131,417	-$ 126,190
Operational Cost 36	-$ 320,677	-$ 126,045	-$ 125,708	-$ 131,027	-$ 130,049	-$ 138,106	-$ 130,360	-$ 138,438	-$ 134,045	-$ 128,714
Operational Cost 37	-$ 327,090	-$ 128,566	-$ 128,222	-$ 133,648	-$ 132,650	-$ 140,868	-$ 132,968	-$ 141,206	-$ 136,726	-$ 131,288
Operational Cost 38	-$ 333,632	-$ 131,137	-$ 130,786	-$ 136,321	-$ 135,303	-$ 143,685	-$ 135,627	-$ 144,031	-$ 139,461	-$ 133,914
Operational Cost 39	-$ 340,305	-$ 133,760	-$ 133,402	-$ 139,047	-$ 138,010	-$ 146,559	-$ 138,340	-$ 146,911	-$ 142,250	-$ 136,592
Operational Cost 40	-$ 347,111	-$ 136,435	-$ 136,070	-$ 141,828	-$ 140,770	-$ 149,490	-$ 141,106	-$ 149,849	-$ 145,095	-$ 139,324
Operational Cost 41	-$ 354,053	-$ 139,164	-$ 138,791	-$ 144,665	-$ 143,585	-$ 152,480	-$ 143,928	-$ 152,846	-$ 147,997	-$ 142,110
Operational Cost 42	-$ 361,134	-$ 141,947	-$ 141,567	-$ 147,558	-$ 146,457	-$ 155,530	-$ 146,807	-$ 155,903	-$ 150,957	-$ 144,953
Operational Cost 43	-$ 368,357	-$ 144,786	-$ 144,399	-$ 150,509	-$ 149,386	-$ 158,640	-$ 149,743	-$ 159,021	-$ 153,976	-$ 147,852
Operational Cost 44	-$ 375,724	-$ 147,682	-$ 147,287	-$ 153,519	-$ 152,374	-$ 161,813	-$ 152,738	-$ 162,202	-$ 157,056	-$ 150,809
Operational Cost 45	-$ 383,238	-$ 150,636	-$ 150,232	-$ 156,590	-$ 155,421	-$ 165,049	-$ 155,793	-$ 165,446	-$ 160,197	-$ 153,825
Operational Cost 46	-$ 390,903	-$ 153,648	-$ 153,237	-$ 159,721	-$ 158,530	-$ 168,350	-$ 158,909	-$ 168,755	-$ 163,401	-$ 156,901
Operational Cost 47	-$ 398,721	-$ 156,721	-$ 156,302	-$ 162,916	-$ 161,700	-$ 171,717	-$ 162,087	-$ 172,130	-$ 166,669	-$ 160,039
Operational Cost 48	-$ 406,696	-$ 159,856	-$ 159,428	-$ 166,174	-$ 164,934	-$ 175,152	-$ 165,329	-$ 175,572	-$ 170,002	-$ 163,240
Operational Cost 49	-$ 414,829	-$ 163,053	-$ 162,616	-$ 169,498	-$ 168,233	-$ 178,655	-$ 168,635	-$ 179,084	-$ 173,402	-$ 166,505
Operational Cost 50	-$ 423,126	-$ 166,314	-$ 165,869	-$ 172,888	-$ 171,598	-$ 182,228	-$ 172,008	-$ 182,666	-$ 176,870	-$ 169,835
Operational Cost 51	-$ 431,589	-$ 169,640	-$ 169,186	-$ 176,345	-$ 175,029	-$ 185,872	-$ 175,448	-$ 186,319	-$ 180,407	-$ 173,232
Operational Cost 52	-$ 440,220	-$ 173,033	-$ 172,570	-$ 179,872	-$ 178,530	-$ 189,590	-$ 178,957	-$ 190,045	-$ 184,016	-$ 176,697
Operational Cost 53	-$ 449,025	-$ 176,494	-$ 176,021	-$ 183,470	-$ 182,101	-$ 193,382	-$ 182,536	-$ 193,846	-$ 187,696	-$ 180,230
Operational Cost 54	-$ 458,005	-$ 180,024	-$ 179,542	-$ 187,139	-$ 185,743	-$ 197,249	-$ 186,187	-$ 197,723	-$ 191,450	-$ 183,835
Operational Cost 55	-$ 467,165	-$ 183,624	-$ 183,132	-$ 190,882	-$ 189,458	-$ 201,194	-$ 189,911	-$ 201,677	-$ 195,279	-$ 187,512
Operational Cost 56	-$ 476,509	-$ 187,297	-$ 186,795	-$ 194,700	-$ 193,247	-$ 205,218	-$ 193,709	-$ 205,711	-$ 199,184	-$ 191,262
Operational Cost 57	-$ 486,039	-$ 191,042	-$ 190,531	-$ 198,594	-$ 197,112	-$ 209,323	-$ 197,583	-$ 209,825	-$ 203,168	-$ 195,087
Operational Cost 58	-$ 495,760	-$ 194,863	-$ 194,342	-$ 202,565	-$ 201,054	-$ 213,509	-$ 201,535	-$ 214,022	-$ 207,231	-$ 198,989
Operational Cost 59	-$ 505,675	-$ 198,761	-$ 198,228	-$ 206,617	-$ 205,075	-$ 217,779	-$ 205,565	-$ 218,302	-$ 211,376	-$ 202,969
Operational Cost 60	-$ 515,788	-$ 202,736	-$ 202,193	-$ 210,749	-$ 209,176	-$ 222,135	-$ 209,677	-$ 222,668	-$ 215,604	-$ 207,028
Operational Cost 61	-$ 526,104	-$ 206,790	-$ 206,237	-$ 214,964	-$ 213,360	-$ 226,577	-$ 213,870	-$ 227,122	-$ 219,916	-$ 211,169
Operational Cost 62	-$ 536,626	-$ 210,926	-$ 210,362	-$ 219,263	-$ 217,627	-$ 231,109	-$ 218,147	-$ 231,664	-$ 224,314	-$ 215,392
Operational Cost 63	-$ 547,359	-$ 215,145	-$ 214,569	-$ 223,649	-$ 221,980	-$ 235,731	-$ 222,510	-$ 236,297	-$ 228,800	-$ 219,700
Operational Cost 64	-$ 558,306	-$ 219,448	-$ 218,860	-$ 228,122	-$ 226,419	-$ 240,446	-$ 226,961	-$ 241,023	-$ 233,376	-$ 224,094
Operational Cost 65	-$ 569,472	-$ 223,837	-$ 223,237	-$ 232,684	-$ 230,948	-$ 245,255	-$ 231,500	-$ 245,844	-$ 238,044	-$ 228,576
Operational Cost 66	-$ 580,861	-$ 228,313	-$ 227,702	-$ 237,338	-$ 235,567	-$ 250,160	-$ 236,130	-$ 250,761	-$ 242,805	-$ 233,147
Operational Cost 67	-$ 592,479	-$ 232,880	-$ 232,256	-$ 242,084	-$ 240,278	-$ 255,163	-$ 240,852	-$ 255,776	-$ 247,661	-$ 237,810
Operational Cost 68	-$ 604,328	-$ 237,537	-$ 236,901	-$ 246,926	-$ 245,084	-$ 260,266	-$ 245,669	-$ 260,891	-$ 252,614	-$ 242,566
Operational Cost 69	-$ 616,415	-$ 242,288	-$ 241,639	-$ 251,865	-$ 249,985	-$ 265,472	-$ 250,583	-$ 266,109	-$ 257,666	-$ 247,418
Operational Cost 70	-$ 628,743	-$ 247,134	-$ 246,472	-$ 256,902	-$ 254,985	-$ 270,781	-$ 255,595	-$ 271,431	-$ 262,820	-$ 252,366
Operational Cost 71	-$ 641,318	-$ 252,076	-$ 251,402	-$ 262,040	-$ 260,085	-$ 276,197	-$ 260,706	-$ 276,860	-$ 268,076	-$ 257,413
Operational Cost 72	-$ 654,144	-$ 257,118	-$ 256,430	-$ 267,281	-$ 265,286	-$ 281,721	-$ 265,921	-$ 282,397	-$ 273,437	-$ 262,562
Operational Cost 73	-$ 667,227	-$ 262,260	-$ 261,558	-$ 272,626	-$ 270,592	-$ 287,355	-$ 271,239	-$ 288,045	-$ 278,906	-$ 267,813
Operational Cost 74	-$ 680,572	-$ 267,506	-$ 266,789	-$ 278,079	-$ 276,004	-$ 293,102	-$ 276,664	-$ 293,806	-$ 284,484	-$ 273,169
Operational Cost 75	-$ 694,183	-$ 272,856	-$ 272,125	-$ 283,640	-$ 281,524	-$ 298,964	-$ 282,197	-$ 299,682	-$ 290,174	-$ 278,633
Operational Cost 76	-$ 708,067	-$ 278,313	-$ 277,568	-$ 289,313	-$ 287,154	-$ 304,943	-$ 287,841	-$ 305,676	-$ 295,978	-$ 284,205
Operational Cost 77	-$ 722,228	-$ 283,879	-$ 283,119	-$ 295,100	-$ 292,897	-$ 311,042	-$ 293,598	-$ 311,789	-$ 301,897	-$ 289,889
Operational Cost 78	-$ 736,673	-$ 289,557	-$ 288,781	-$ 301,002	-$ 298,755	-$ 317,263	-$ 299,470	-$ 318,025	-$ 307,935	-$ 295,687
Operational Cost 79	-$ 751,406	-$ 295,348	-$ 294,557	-$ 307,022	-$ 304,731	-$ 323,608	-$ 305,459	-$ 324,386	-$ 314,094	-$ 301,601
Operational Cost 80	-$ 766,434	-$ 301,255	-$ 300,448	-$ 313,162	-$ 310,825	-$ 330,081	-$ 311,568	-$ 330,873	-$ 320,376	-$ 307,633
Operational Cost 81	-$ 781,763	-$ 307,280	-$ 306,457	-$ 319,425	-$ 317,042	-$ 336,682	-$ 317,800	-$ 337,491	-$ 326,783	-$ 313,786
Operational Cost 82	-$ 797,398	-$ 313,425	-$ 312,586	-$ 325,814	-$ 323,382	-$ 343,416	-$ 324,156	-$ 344,241	-$ 333,319	-$ 320,061
Operational Cost 83	-$ 813,346	-$ 319,694	-$ 318,838	-$ 332,330	-$ 329,850	-$ 350,284	-$ 330,639	-$ 351,125	-$ 339,985	-$ 326,462
Operational Cost 84	-$ 829,613	-$ 326,088	-$ 325,215	-$ 338,977	-$ 336,447	-$ 357,290	-$ 337,252	-$ 358,148	-$ 346,785	-$ 332,992
Operational Cost 85	-$ 846,205	-$ 332,610	-$ 331,719	-$ 345,756	-$ 343,176	-$ 364,436	-$ 343,997	-$ 365,311	-$ 353,721	-$ 339,652
Operational Cost 86	-$ 863,130	-$ 339,262	-$ 338,353	-$ 352,671	-$ 350,040	-$ 371,724	-$ 350,877	-$ 372,617	-$ 360,795	-$ 346,445
Operational Cost 87	-$ 880,392	-$ 346,047	-$ 345,120	-$ 359,725	-$ 357,040	-$ 379,159	-$ 357,894	-$ 380,069	-$ 368,011	-$ 353,374
Operational Cost 88	-$ 898,000	-$ 352,968	-$ 352,023	-$ 366,919	-$ 364,181	-$ 386,742	-$ 365,052	-$ 387,671	-$ 375,371	-$ 360,441
Operational Cost 89	-$ 915,960	-$ 360,027	-$ 359,063	-$ 374,258	-$ 371,465	-$ 394,477	-$ 372,353	-$ 395,424	-$ 382,879	-$ 367,650
Operational Cost 90	-$ 934,279	-$ 367,228	-$ 366,245	-$ 381,743	-$ 378,894	-$ 402,366	-$ 379,800	-$ 403,333	-$ 390,536	-$ 375,003
Operational Cost 91	-$ 952,965	-$ 374,572	-$ 373,569	-$ 389,378	-$ 386,472	-$ 410,414	-$ 387,396	-$ 411,399	-$ 398,347	-$ 382,503
Operational Cost 92	-$ 972,024	-$ 382,064	-$ 381,041	-$ 397,165	-$ 394,201	-$ 418,622	-$ 395,144	-$ 419,627	-$ 406,314	-$ 390,153
Operational Cost 93	-$ 991,465	-$ 389,705	-$ 388,662	-$ 405,108	-$ 402,085	-$ 426,994	-$ 403,047	-$ 428,020	-$ 414,440	-$ 397,956
Operational Cost 94	-$ 1,011,294	-$ 397,499	-$ 396,435	-$ 413,211	-$ 410,127	-$ 435,534	-$ 411,108	-$ 436,580	-$ 422,729	-$ 405,915
Operational Cost 95	-$ 1,031,520	-$ 405,449	-$ 404,364	-$ 421,475	-$ 418,330	-$ 444,245	-$ 419,330	-$ 445,312	-$ 431,183	-$ 414,033
Operational Cost 96	-$ 1,052,150	-$ 413,558	-$ 412,451	-$ 429,904	-$ 426,696	-$ 453,130	-$ 427,717	-$ 454,218	-$ 439,807	-$ 422,314
Operational Cost 97	-$ 1,073,193	-$ 421,829	-$ 420,700	-$ 438,502	-$ 435,230	-$ 462,193	-$ 436,271	-$ 463,302	-$ 448,603	-$ 430,760
Operational Cost 98	-$ 1,094,657	-$ 430,266	-$ 429,114	-$ 447,272	-$ 443,935	-$ 471,436	-$ 444,996	-$ 472,569	-$ 457,575	-$ 439,376
Operational Cost 99	-$ 1,116,550	-$ 438,871	-$ 437,696	-$ 456,218	-$ 452,814	-$ 480,865	-$ 453,896	-$ 482,020	-$ 466,727	-$ 448,163
Operational Cost 100	-$ 1,138,881	-$ 447,649	-$ 446,450	-$ 465,342	-$ 461,870	-$ 490,482	-$ 462,974	-$ 491,660	-$ 476,061	-$ 457,126
Operational Cost 101	-$ 1,161,659	-$ 456,602	-$ 455,379	-$ 474,649	-$ 471,107	-$ 500,292	-$ 472,234	-$ 501,493	-$ 485,583	-$ 466,269
Operational Cost 102	-$ 1,184,892	-$ 465,734	-$ 464,487	-$ 484,142	-$ 480,529	-$ 510,298	-$ 481,678	-$ 511,523	-$ 495,294	-$ 475,594
Operational Cost 103	-$ 1,208,590	-$ 475,048	-$ 473,776	-$ 493,825	-$ 490,140	-$ 520,504	-$ 491,312	-$ 521,754	-$ 505,200	-$ 485,106
Operational Cost 104	-$ 1,232,762	-$ 484,549	-$ 483,252	-$ 503,701	-$ 499,943	-$ 530,914	-$ 501,138	-$ 532,189	-$ 515,304	-$ 494,808
Operational Cost 105	-$ 1,257,417	-$ 494,240	-$ 492,917	-$ 513,775	-$ 509,942	-$ 541,532	-$ 511,161	-$ 542,833	-$ 525,610	-$ 504,704
NPV 10	$1,870,932	-$500,043	-$476,440	-$447,766	-$408,034	-$212,949	-$114,323	-$237,669	-$200,032	-$256,749
NPV 15	$3,156,107	$512,957	$537,289	$554,476	$596,319	$774,008	$889,358	$748,571	$795,693	$750,488
NPV 20	$3,815,593	$913,225	$938,251	$944,498	$988,352	$1,149,472	$1,280,752	$1,123,354	$1,179,508	$1,145,268
NPV 25	$4,443,681	-$80,619	-$54,932	-$59,104	-$13,335	$132,005	$278,456	$105,238	$169,994	$146,197
NPV 30	$5,965,306	$1,205,884	$1,232,200	$1,218,106	$1,265,698	$1,396,011	$1,556,909	$1,368,624	$1,441,574	$1,427,722
NPV 40	$7,077,592	$1,880,975	$1,908,461	$1,875,916	$1,926,900	$2,029,268	$2,217,032	$2,000,731	$2,088,916	$2,093,556
NPV 50	$9,525,178	$1,052,943	$1,081,491	$1,032,209	$1,086,270	$1,163,291	$1,375,424	$1,133,710	$1,235,713	$1,257,128
NPV 60	$12,681,726	$3,849,796	$3,879,307	$3,814,845	$3,871,696	$3,925,726	$4,159,963	$3,895,199	$4,009,737	$4,046,366
NPV 70	$13,511,777	$4,353,587	$4,383,972	$4,305,741	$4,365,122	$4,398,299	$4,652,584	$4,366,913	$4,492,820	$4,543,249
NPV 80	$17,756,752	$2,274,514	$2,305,691	$2,214,970	$2,276,647	$2,290,909	$2,563,379	$2,258,744	$2,394,963	$2,457,910
NPV 90	$23,880,211	$8,129,548	$8,161,443	$8,059,395	$8,123,154	$8,120,258	$8,409,224	$8,087,388	$8,232,960	$8,307,261
NPV 100	$24,499,643	-$4,116,032	-$4,083,484	-$4,195,808	-$4,130,160	-$4,148,618	-$3,844,691	-$4,182,129	-$4,028,073	-$3,943,473
NPV 105	$33,263,617	$4,534,829	$4,567,679	$4,450,582	$4,517,107	$4,491,419	$4,802,297	$4,457,610	$4,615,608	$4,704,993

2% opertaional cost escalation

3% Discount rate

Escalation for Window replacement

1	-$ 656,734	3%
25	-$ 1,375,056	3%
50	-$ 2,879,062	3%
75	-$ 6,028,116	3%
100	-$ 12,621,537	3%

Assuming lifespan of 25 years for windows

Escalation for Existing Window replacement

1	-$ 380,446	3%
15	-$ 592,722	3%
30	-$ 923,441	3%
45	-$ 1,438,691	3%
60	-$ 2,241,434	3%
75	-$ 3,492,081	3%
90	-$ 5,440,548	3%
105	-$ 8,476,197	3%

Assuming 15 year lifespan for existing windows

Escalation for fiberglass insulation replacement (3.5" thic

1	-$ 303,884	3%
40	-$ 1,288,663	3%
80	-$ 4,203,669	3%

Assuming lifespan of 40 years for fiberglass insulation
Assumes a 30% cost of demolition to replace fiberglass

Escalation for fiberglass insulation replacement (6" thickr

1	-$ 308,519	3%
40	-$ 1,308,321	3%
80	-$ 4,267,792	3%

Assuming lifespan of 40 years for fiberglass insulation
Assumes a 30% cost of demolition to replace fiberglass

Escalation for EPS replacement (3" thickness)

1	-$ 327,062	3%
60	-$ 2,504,995	3%

Assuming lifespan of 60 years for EPS insulation
Assumes a 30% cost of demolition to replace EPS

Escalation for EPS replacement (4" thickness)

1	-$ 398,914	3%
60	-$ 3,055,316	3%

Assuming lifespan of 60 years for EPS insulation
Assumes a 30% cost of demolition to replace EPS

Escalation for EPS replacement (6" thickness)

1	-$ 458,598	3%
60	-$ 3,512,441	3%

Assuming lifespan of 60 years for EPS insulation
Assumes a 30% cost of demolition to replace EPS

Cases:
Base - Do Nothing, replace windows like for like every 20 years
Option 1: 3.625" wide metal studs + 3.625" of spray foam in terracotta section + 6" wide metal studs + 6" of spray foam in reinforced concrete section + single pane secondary glazed windows for all windows
Option 2: 4" wide metal studs + 4" of spray foam in terracotta section + 6" wide metal studs + 6" of spray foam in reinforced concrete section + single pane secondary glazed windows for all windows
Option 3: 3.625" wide metal studs + 3.625" of spray foam + single pane secondary glazed windows (everywhere)
Option 4: 4" wide metal studs + 4" of spray foam + single pane secondary glazed windows (everywhere)
Option 5: 3.625" wide metal studs + 3.5" of batt insulation + single pane secondary glazed windows (everywhere)
Option 6: 6" wide metal studs + 6" of batt insulation + single pane secondary glazed windows (everywhere)
Option 7: 3.625" wide metal studs + 3" of EPS + single pane secondary glazed windows (everywhere)
Option 8: 4" wide metal studs + 4" of EPS + single pane secondary glazed windows (everywhere)
Option 9: 6" wide metal studs + 6" of EPS + single pane secondary glazed windows (everywhere)

KCVI Wall Composition Energy Efficiency Improvements - Preliminary										
Options:	**Base**	**Option 1**	**Option 2**	**Option 3**	**Option 4**	**Option 5**	**Option 6**	**Option 7**	**Option 8**	**Option 9**
Capital changes relative to Base case										
Total Construction ($)	**$ -**	**$ 1,083,315**	**$ 1,061,281**	**$ 1,007,883**	**$ 972,695**	**$ 740,164**	**$ 677,539**	**$ 763,342**	**$ 746,120**	**$ 827,618**
Cost difference compared to base case (+/-)	**$ -**	**$ 1,083,315**	**$ 1,061,281**	**$ 1,007,883**	**$ 972,695**	**$ 740,164**	**$ 677,539**	**$ 763,342**	**$ 746,120**	**$ 827,618**
Operating Costs										
Annual Fuel/Energy Input		186,536	186,119	192,696	191,487	201,447	191,871	201,857	196,427	189,836
Electricity [kWh]	-	-	-	-	-	-	-	-	-	-
[$]	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -	$ -
Natural Gas [m3]	396,447	186,536	186,119	192,696	191,487	201,447	191,871	201,857	196,427	189,836
[$]	$ 111,005	$ 52,230	$ 52,113	$ 53,955	$ 53,616	$ 56,405	$ 53,724	$ 56,520	$ 55,000	$ 53,154
Carbon [Tonnes]	748	352	351	363	361	380	362	381	370	358
[$]	$ 49,342	$ 23,216	$ 23,165	$ 23,983	$ 23,833	$ 25,072	$ 23,880	$ 25,123	$ 24,447	$ 23,627
TOTAL FUEL COST $	**$ 160,347.20**	**$ 75,446.65**	**$ 75,277.91**	**$ 77,937.80**	**$ 77,448.90**	**$ 81,477.38**	**$ 77,604.39**	**$ 81,643.22**	**$ 79,446.98**	**$ 76,781.05**
Savings vs Base		**$ 84,900.55**	**$ 85,069.29**	**$ 82,409.40**	**$ 82,898.30**	**$ 78,869.83**	**$ 82,742.81**	**$ 78,703.98**	**$ 80,900.22**	**$ 83,566.15**
Periodic Cost - Window Replacement in year 10	**380,446**	**380,446**	**380,446**	**380,446**	**380,446**	**380,446**	**380,446**	**380,446**	**380,446**	**380,446**
Adaptive Space Reuse Upfront Cost	**-**	**45,074**	**45,074**	**45,074**	**45,074**	**45,074**	**45,074**	**45,074**	**45,074**	**45,074**
GHG Performance										
GHG Grid Electricity (tonnes/yr)	-	-	-	-	-	-	-	-	-	-
GHG Natural Gas (tonnes/yr)	748	352	351	363	361	380	362	381	370	358
Total GHG Emissions (tonnes/yr)	748	352	351	363	361	380	362	381	370	358
Reductions % from Base		**53%**	**53%**	**51%**	**52%**	**49%**	**52%**	**49%**	**50%**	**52%**
Financials	3%	Discount rate								
Net Present Value (10 yr NPV) @ 3% Disc	**- 1,870,932**	**- 339,208**	**- 315,605**	**- 286,931**	**- 247,199**	**- 52,114**	**46,512**	**- 76,834**	**- 39,197**	**- 95,914**
Net Present Value (15 yr NPV) @ 3% Disc	**- 2,563,385**	**27,432**	**51,764**	**68,951**	**110,794**	**288,483**	**403,834**	**263,047**	**310,168**	**264,964**
Net Present Value (20 yr NPV) @ 3% Disc	**- 3,909,998**	**376,617**	**401,642**	**407,890**	**451,743**	**612,864**	**744,144**	**586,746**	**642,900**	**608,660**
Net Present Value (25 yr NPV) @ 3% Disc	**- 4,538,086**	**709,176**	**734,863**	**730,691**	**776,460**	**921,801**	**1,068,251**	**895,033**	**959,790**	**935,992**
Net Present Value (30 yr NPV) @ 3% Disc	**- 5,136,271**	**1,025,903**	**1,052,219**	**1,038,124**	**1,085,717**	**1,216,029**	**1,376,928**	**1,188,643**	**1,261,593**	**1,247,741**
Net Present Value (40 yr NPV) @ 3% Disc	**- 7,489,584**	**1,614,835**	**1,642,322**	**1,609,776**	**1,660,760**	**474,465**	**642,572**	**1,734,591**	**1,822,776**	**1,827,417**
Net Present Value (50 yr NPV) @ 3% Disc	**- 8,498,478**	**2,149,024**	**2,177,572**	**2,128,291**	**2,182,351**	**970,709**	**1,163,185**	**2,229,792**	**2,331,795**	**2,353,210**
Net Present Value (60 yr NPV) @ 3% Disc	**- 11,655,027**	**2,633,558**	**2,663,070**	**2,598,608**	**2,655,458**	**1,420,825**	**1,635,404**	**173,966**	**- 261,817**	**- 682,312**
Net Present Value (70 yr NPV) @ 3% Disc	**- 12,485,077**	**3,073,053**	**3,103,438**	**3,025,207**	**3,084,589**	**1,829,101**	**2,063,730**	**581,384**	**156,970**	**- 249,725**

	Base	Option 1	Option 2	Option 3	Option 4	Option 5	Option 6	Option 7	Option 8	Option 9
Initial Investment	0	-1083315.41	-1061281.01	-1007882.65	-972695.38	-740163.52	-677539	-763342	-746120	-827618
UFC for windows and ASR	-$ 380,446	-$ 425,520	-$ 425,520	-$ 425,520	-$ 425,520	-$ 425,520	-$ 425,520	-$ 425,520	-$ 425,520	-$ 425,520
Operational Cost 1	-$ 160,347	-$ 75,447	-$ 75,278	-$ 77,938	-$ 77,449	-$ 81,477	-$ 77,604	-$ 81,643	-$ 79,447	-$ 76,781
Operational Cost 2	-$ 163,554	-$ 76,956	-$ 76,783	-$ 79,497	-$ 78,998	-$ 83,107	-$ 79,156	-$ 83,276	-$ 81,036	-$ 78,317
Operational Cost 3	-$ 166,825	-$ 78,495	-$ 78,319	-$ 81,086	-$ 80,578	-$ 84,769	-$ 80,740	-$ 84,942	-$ 82,657	-$ 79,883
Operational Cost 4	-$ 170,162	-$ 80,065	-$ 79,886	-$ 82,708	-$ 82,189	-$ 86,464	-$ 82,354	-$ 86,640	-$ 84,310	-$ 81,481
Operational Cost 5	-$ 173,565	-$ 81,666	-$ 81,483	-$ 84,362	-$ 83,833	-$ 88,194	-$ 84,001	-$ 88,373	-$ 85,996	-$ 83,110
Operational Cost 6	-$ 177,036	-$ 83,299	-$ 83,113	-$ 86,050	-$ 85,510	-$ 89,958	-$ 85,682	-$ 90,141	-$ 87,716	-$ 84,772
Operational Cost 7	-$ 180,577	-$ 84,965	-$ 84,775	-$ 87,771	-$ 87,220	-$ 91,757	-$ 87,395	-$ 91,944	-$ 89,470	-$ 86,468
Operational Cost 8	-$ 184,189	-$ 86,664	-$ 86,471	-$ 89,526	-$ 88,964	-$ 93,592	-$ 89,143	-$ 93,782	-$ 91,260	-$ 88,197
Operational Cost 9	-$ 187,872	-$ 88,398	-$ 88,200	-$ 91,317	-$ 90,744	-$ 95,464	-$ 90,926	-$ 95,658	-$ 93,085	-$ 89,961
Operational Cost 10	-$ 191,630	-$ 90,166	-$ 89,964	-$ 93,143	-$ 92,559	-$ 97,373	-$ 92,744	-$ 97,571	-$ 94,946	-$ 91,760
Operational Cost 11	-$ 195,462	-$ 91,969	-$ 91,763	-$ 95,006	-$ 94,410	-$ 99,320	-$ 94,599	-$ 99,523	-$ 96,845	-$ 93,596
Operational Cost 12	-$ 199,372	-$ 93,808	-$ 93,599	-$ 96,906	-$ 96,298	-$ 101,307	-$ 96,491	-$ 101,513	-$ 98,782	-$ 95,468
Operational Cost 13	-$ 203,359	-$ 95,685	-$ 95,471	-$ 98,844	-$ 98,224	-$ 103,333	-$ 98,421	-$ 103,543	-$ 100,758	-$ 97,377
Operational Cost 14	-$ 207,426	-$ 97,598	-$ 97,380	-$ 100,821	-$ 100,188	-$ 105,400	-$ 100,390	-$ 105,614	-$ 102,773	-$ 99,324
Operational Cost 15	-$ 211,575	-$ 99,550	-$ 99,328	-$ 102,837	-$ 102,192	-$ 107,508	-$ 102,397	-$ 107,726	-$ 104,829	-$ 101,311
Operational Cost 16	-$ 215,806	-$ 101,541	-$ 101,314	-$ 104,894	-$ 104,236	-$ 109,658	-$ 104,445	-$ 109,881	-$ 106,925	-$ 103,337
Operational Cost 17	-$ 220,122	-$ 103,572	-$ 103,340	-$ 106,992	-$ 106,321	-$ 111,851	-$ 106,534	-$ 112,079	-$ 109,064	-$ 105,404
Operational Cost 18	-$ 224,525	-$ 105,644	-$ 105,407	-$ 109,132	-$ 108,447	-$ 114,088	-$ 108,665	-$ 114,320	-$ 111,245	-$ 107,512
Operational Cost 19	-$ 229,015	-$ 107,756	-$ 107,515	-$ 111,314	-$ 110,616	-$ 116,370	-$ 110,838	-$ 116,607	-$ 113,470	-$ 109,662
Operational Cost 20	-$ 233,596	-$ 109,912	-$ 109,666	-$ 113,541	-$ 112,828	-$ 118,697	-$ 113,055	-$ 118,939	-$ 115,739	-$ 111,855
Operational Cost 21	-$ 238,268	-$ 112,110	-$ 111,859	-$ 115,811	-$ 115,085	-$ 121,071	-$ 115,316	-$ 121,318	-$ 118,054	-$ 114,093
Operational Cost 22	-$ 243,033	-$ 114,352	-$ 114,096	-$ 118,128	-$ 117,387	-$ 123,493	-$ 117,622	-$ 123,744	-$ 120,415	-$ 116,374
Operational Cost 23	-$ 247,894	-$ 116,639	-$ 116,378	-$ 120,490	-$ 119,734	-$ 125,962	-$ 119,975	-$ 126,219	-$ 122,823	-$ 118,702
Operational Cost 24	-$ 252,851	-$ 118,972	-$ 118,706	-$ 122,900	-$ 122,129	-$ 128,482	-$ 122,374	-$ 128,743	-$ 125,280	-$ 121,076
Operational Cost 25	-$ 257,908	-$ 121,351	-$ 121,080	-$ 125,358	-$ 124,572	-$ 131,051	-$ 124,822	-$ 131,318	-$ 127,785	-$ 123,497
Operational Cost 26	-$ 263,067	-$ 123,778	-$ 123,501	-$ 127,865	-$ 127,063	-$ 133,672	-$ 127,318	-$ 133,944	-$ 130,341	-$ 125,967
Operational Cost 27	-$ 268,328	-$ 126,254	-$ 125,971	-$ 130,423	-$ 129,604	-$ 136,346	-$ 129,865	-$ 136,623	-$ 132,948	-$ 128,487
Operational Cost 28	-$ 273,694	-$ 128,779	-$ 128,491	-$ 133,031	-$ 132,196	-$ 139,073	-$ 132,462	-$ 139,356	-$ 135,607	-$ 131,057
Operational Cost 29	-$ 279,168	-$ 131,354	-$ 131,061	-$ 135,692	-$ 134,840	-$ 141,854	-$ 135,111	-$ 142,143	-$ 138,319	-$ 133,678
Operational Cost 30	-$ 284,752	-$ 133,982	-$ 133,682	-$ 138,405	-$ 137,537	-$ 144,691	-$ 137,813	-$ 144,986	-$ 141,085	-$ 136,351
Operational Cost 31	-$ 290,447	-$ 136,661	-$ 136,356	-$ 141,174	-$ 140,288	-$ 147,585	-$ 140,570	-$ 147,885	-$ 143,907	-$ 139,078
Operational Cost 32	-$ 296,256	-$ 139,394	-$ 139,083	-$ 143,997	-$ 143,094	-$ 150,537	-$ 143,381	-$ 150,843	-$ 146,785	-$ 141,860
Operational Cost 33	-$ 302,181	-$ 142,182	-$ 141,864	-$ 146,877	-$ 145,956	-$ 153,547	-$ 146,249	-$ 153,860	-$ 149,721	-$ 144,697
Operational Cost 34	-$ 308,224	-$ 145,026	-$ 144,702	-$ 149,814	-$ 148,875	-$ 156,618	-$ 149,174	-$ 156,937	-$ 152,715	-$ 147,591
Operational Cost 35	-$ 314,389	-$ 147,926	-$ 147,596	-$ 152,811	-$ 151,852	-$ 159,751	-$ 152,157	-$ 160,076	-$ 155,770	-$ 150,543
Operational Cost 36	-$ 320,677	-$ 150,885	-$ 150,548	-$ 155,867	-$ 154,889	-$ 162,946	-$ 155,200	-$ 163,277	-$ 158,885	-$ 153,554
Operational Cost 37	-$ 327,090	-$ 153,903	-$ 153,558	-$ 158,984	-$ 157,987	-$ 166,205	-$ 158,304	-$ 166,543	-$ 162,063	-$ 156,625
Operational Cost 38	-$ 333,632	-$ 156,981	-$ 156,630	-$ 162,164	-$ 161,147	-$ 169,529	-$ 161,470	-$ 169,874	-$ 165,304	-$ 159,757
Operational Cost 39	-$ 340,305	-$ 160,120	-$ 159,762	-$ 165,407	-$ 164,370	-$ 172,919	-$ 164,700	-$ 173,271	-$ 168,610	-$ 162,952
Operational Cost 40	-$ 347,111	-$ 163,323	-$ 162,957	-$ 168,715	-$ 167,657	-$ 176,378	-$ 167,994	-$ 176,737	-$ 171,982	-$ 166,211
Operational Cost 41	-$ 354,053	-$ 166,589	-$ 166,217	-$ 172,090	-$ 171,010	-$ 179,905	-$ 171,354	-$ 180,271	-$ 175,422	-$ 169,536
Operational Cost 42	-$ 361,134	-$ 169,921	-$ 169,541	-$ 175,532	-$ 174,430	-$ 183,503	-$ 174,781	-$ 183,877	-$ 178,931	-$ 172,926
Operational Cost 43	-$ 368,357	-$ 173,319	-$ 172,932	-$ 179,042	-$ 177,919	-$ 187,173	-$ 178,276	-$ 187,554	-$ 182,509	-$ 176,385
Operational Cost 44	-$ 375,724	-$ 176,786	-$ 176,390	-$ 182,623	-$ 181,477	-$ 190,917	-$ 181,842	-$ 191,306	-$ 186,159	-$ 179,913
Operational Cost 45	-$ 383,238	-$ 180,322	-$ 179,918	-$ 186,275	-$ 185,107	-$ 194,735	-$ 185,479	-$ 195,132	-$ 189,883	-$ 183,511
Operational Cost 46	-$ 390,903	-$ 183,928	-$ 183,517	-$ 190,001	-$ 188,809	-$ 198,630	-$ 189,188	-$ 199,034	-$ 193,680	-$ 187,181
Operational Cost 47	-$ 398,721	-$ 187,606	-$ 187,187	-$ 193,801	-$ 192,585	-$ 202,603	-$ 192,972	-$ 203,015	-$ 197,554	-$ 190,925
Operational Cost 48	-$ 406,696	-$ 191,359	-$ 190,931	-$ 197,677	-$ 196,437	-$ 206,655	-$ 196,831	-$ 207,075	-$ 201,505	-$ 194,743
Operational Cost 49	-$ 414,829	-$ 195,186	-$ 194,749	-$ 201,631	-$ 200,366	-$ 210,788	-$ 200,768	-$ 211,217	-$ 205,535	-$ 198,638
Operational Cost 50	-$ 423,126	-$ 199,090	-$ 198,644	-$ 205,663	-$ 204,373	-$ 215,003	-$ 204,783	-$ 215,441	-$ 209,646	-$ 202,611
Operational Cost 51	-$ 431,589	-$ 203,071	-$ 202,617	-$ 209,776	-$ 208,461	-$ 219,304	-$ 208,879	-$ 219,750	-$ 213,839	-$ 206,663
Operational Cost 52	-$ 440,220	-$ 207,133	-$ 206,669	-$ 213,972	-$ 212,630	-$ 223,690	-$ 213,057	-$ 224,145	-$ 218,115	-$ 210,796
Operational Cost 53	-$ 449,025	-$ 211,275	-$ 210,803	-$ 218,251	-$ 216,882	-$ 228,163	-$ 217,318	-$ 228,628	-$ 222,478	-$ 215,012
Operational Cost 54	-$ 458,005	-$ 215,501	-$ 215,019	-$ 222,616	-$ 221,220	-$ 232,727	-$ 221,664	-$ 233,200	-$ 226,927	-$ 219,312
Operational Cost 55	-$ 467,165	-$ 219,811	-$ 219,319	-$ 227,069	-$ 225,644	-$ 237,381	-$ 226,097	-$ 237,864	-$ 231,466	-$ 223,699
Operational Cost 56	-$ 476,509	-$ 224,207	-$ 223,706	-$ 231,610	-$ 230,157	-$ 242,129	-$ 230,619	-$ 242,622	-$ 236,095	-$ 228,173
Operational Cost 57	-$ 486,039	-$ 228,691	-$ 228,180	-$ 236,242	-$ 234,760	-$ 246,971	-$ 235,232	-$ 247,474	-$ 240,817	-$ 232,736
Operational Cost 58	-$ 495,760	-$ 233,265	-$ 232,743	-$ 240,967	-$ 239,456	-$ 251,911	-$ 239,936	-$ 252,424	-$ 245,633	-$ 237,391
Operational Cost 59	-$ 505,675	-$ 237,930	-$ 237,398	-$ 245,787	-$ 244,245	-$ 256,949	-$ 244,735	-$ 257,472	-$ 250,546	-$ 242,139
Operational Cost 60	-$ 515,788	-$ 242,689	-$ 242,146	-$ 250,702	-$ 249,130	-$ 262,088	-$ 249,630	-$ 262,621	-$ 255,557	-$ 246,981
Operational Cost 61	-$ 526,104	-$ 247,543	-$ 246,989	-$ 255,716	-$ 254,112	-$ 267,330	-$ 254,622	-$ 267,874	-$ 260,668	-$ 251,921
Operational Cost 62	-$ 536,626	-$ 252,494	-$ 251,929	-$ 260,831	-$ 259,194	-$ 272,676	-$ 259,715	-$ 273,231	-$ 265,881	-$ 256,959
Operational Cost 63	-$ 547,359	-$ 257,544	-$ 256,968	-$ 266,047	-$ 264,378	-$ 278,130	-$ 264,909	-$ 278,696	-$ 271,199	-$ 262,099
Operational Cost 64	-$ 558,306	-$ 262,694	-$ 262,107	-$ 271,368	-$ 269,666	-$ 283,693	-$ 270,207	-$ 284,270	-$ 276,623	-$ 267,341
Operational Cost 65	-$ 569,472	-$ 267,948	-$ 267,349	-$ 276,796	-$ 275,059	-$ 289,366	-$ 275,611	-$ 289,955	-$ 282,155	-$ 272,687
Operational Cost 66	-$ 580,861	-$ 273,307	-$ 272,696	-$ 282,331	-$ 280,560	-$ 295,154	-$ 281,124	-$ 295,754	-$ 287,799	-$ 278,141
Operational Cost 67	-$ 592,479	-$ 278,773	-$ 278,150	-$ 287,978	-$ 286,172	-$ 301,057	-$ 286,746	-$ 301,670	-$ 293,554	-$ 283,704
Operational Cost 68	-$ 604,328	-$ 284,349	-$ 283,713	-$ 293,738	-$ 291,895	-$ 307,078	-$ 292,481	-$ 307,703	-$ 299,426	-$ 289,378
Operational Cost 69	-$ 616,415	-$ 290,036	-$ 289,387	-$ 299,612	-$ 297,733	-$ 313,219	-$ 298,331	-$ 313,857	-$ 305,414	-$ 295,166
Operational Cost 70	-$ 628,743	-$ 295,837	-$ 295,175	-$ 305,605	-$ 303,688	-$ 319,484	-$ 304,297	-$ 320,134	-$ 311,522	-$ 301,069
Operational Cost 71	-$ 641,318	-$ 301,753	-$ 301,078	-$ 311,717	-$ 309,761	-$ 325,874	-$ 310,383	-$ 326,537	-$ 317,753	-$ 307,090
Operational Cost 72	-$ 654,144	-$ 307,788	-$ 307,100	-$ 317,951	-$ 315,957	-$ 332,391	-$ 316,591	-$ 333,068	-$ 324,108	-$ 313,232
Operational Cost 73	-$ 667,227	-$ 313,944	-$ 313,242	-$ 324,310	-$ 322,276	-$ 339,039	-$ 322,923	-$ 339,729	-$ 330,590	-$ 319,497
Operational Cost 74	-$ 680,572	-$ 320,223	-$ 319,507	-$ 330,796	-$ 328,721	-$ 345,820	-$ 329,381	-$ 346,523	-$ 337,202	-$ 325,887
Operational Cost 75	-$ 694,183	-$ 326,627	-$ 325,897	-$ 337,412	-$ 335,296	-$ 352,736	-$ 335,969	-$ 353,454	-$ 343,946	-$ 332,404
Operational Cost 76	-$ 708,067	-$ 333,160	-$ 332,415	-$ 344,161	-$ 342,002	-$ 359,791	-$ 342,688	-$ 360,523	-$ 350,825	-$ 339,052
Operational Cost 77	-$ 722,228	-$ 339,823	-$ 339,063	-$ 351,044	-$ 348,842	-$ 366,987	-$ 349,542	-$ 367,733	-$ 357,841	-$ 345,834
Operational Cost 78	-$ 736,673	-$ 346,620	-$ 345,844	-$ 358,065	-$ 355,818	-$ 374,326	-$ 356,533	-$ 375,088	-$ 364,998	-$ 352,750
Operational Cost 79	-$ 751,406	-$ 353,552	-$ 352,761	-$ 365,226	-$ 362,935	-$ 381,813	-$ 363,663	-$ 382,590	-$ 372,298	-$ 359,805
Operational Cost 80	-$ 766,434	-$ 360,623	-$ 359,817	-$ 372,530	-$ 370,194	-$ 389,449	-$ 370,937	-$ 390,242	-$ 379,744	-$ 367,001
Operational Cost 81	-$ 781,763	-$ 367,836	-$ 367,013	-$ 379,981	-$ 377,597	-$ 397,238	-$ 378,355	-$ 398,047	-$ 387,339	-$ 374,341
Operational Cost 82	-$ 797,398	-$ 375,192	-$ 374,353	-$ 387,581	-$ 385,149	-$ 405,183	-$ 385,923	-$ 406,007	-$ 395,086	-$ 381,828
Operational Cost 83	-$ 813,346	-$ 382,696	-$ 381,840	-$ 395,332	-$ 392,852	-$ 413,286	-$ 393,641	-$ 414,128	-$ 402,987	-$ 389,465
Operational Cost 84	-$ 829,613	-$ 390,350	-$ 389,477	-$ 403,239	-$ 400,709	-$ 421,552	-$ 401,514	-$ 422,410	-$ 411,047	-$ 397,254
Operational Cost 85	-$ 846,205	-$ 398,157	-$ 397,267	-$ 411,304	-$ 408,724	-$ 429,983	-$ 409,544	-$ 430,858	-$ 419,268	-$ 405,199
Operational Cost 86	-$ 863,130	-$ 406,120	-$ 405,212	-$ 419,530	-$ 416,898	-$ 438,583	-$ 417,735	-$ 439,476	-$ 427,653	-$ 413,303
Operational Cost 87	-$ 880,392	-$ 414,243	-$ 413,316	-$ 427,920	-$ 425,236	-$ 447,354	-$ 426,090	-$ 448,265	-$ 436,207	-$ 421,569
Operational Cost 88	-$ 898,000	-$ 422,527	-$ 421,582	-$ 436,479	-$ 433,741	-$ 456,302	-$ 434,612	-$ 457,230	-$ 444,931	-$ 430,001
Operational Cost 89	-$ 915,960	-$ 430,978	-$ 430,014	-$ 445,208	-$ 442,416	-$ 465,428	-$ 443,304	-$ 466,375	-$ 453,829	-$ 438,601
Operational Cost 90	-$ 934,279	-$ 439,598	-$ 438,614	-$ 454,112	-$ 451,264	-$ 474,736	-$ 452,170	-$ 475,702	-$ 462,906	-$ 447,373
Operational Cost 91	-$ 952,965	-$ 448,389	-$ 447,387	-$ 463,195	-$ 460,289	-$ 484,231	-$ 461,213	-$ 485,217	-$ 472,164	-$ 456,320
Operational Cost 92	-$ 972,024	-$ 457,357	-$ 456,334	-$ 472,459	-$ 469,495	-$ 493,916	-$ 470,437	-$ 494,921	-$ 481,607	-$ 465,446
Operational Cost 93	-$ 991,465	-$ 466,504	-$ 465,461	-$ 481,908	-$ 478,885	-$ 503,794	-$ 479,846	-$ 504,819	-$ 491,239	-$ 474,755
Operational Cost 94	-$ 1,011,294	-$ 475,835	-$ 474,770	-$ 491,546	-$ 488,463	-$ 513,870	-$ 489,443	-$ 514,916	-$ 501,064	-$ 484,250
Operational Cost 95	-$ 1,031,520	-$ 485,351	-$ 484,266	-$ 501,377	-$ 498,232	-$ 524,147	-$ 499,232	-$ 525,214	-$ 511,085	-$ 493,935
Operational Cost 96	-$ 1,052,150	-$ 495,058	-$ 493,951	-$ 511,404	-$ 508,196	-$ 534,630	-$ 509,217	-$ 535,718	-$ 521,307	-$ 503,814
Operational Cost 97	-$ 1,073,193	-$ 504,959	-$ 503,830	-$ 521,633	-$ 518,360	-$ 545,323	-$ 519,401	-$ 546,433	-$ 531,733	-$ 513,890
Operational Cost 98	-$ 1,094,657	-$ 515,059	-$ 513,907	-$ 532,065	-$ 528,728	-$ 556,229	-$ 529,789	-$ 557,361	-$ 542,368	-$ 524,168
Operational Cost 99	-$ 1,116,550	-$ 525,360	-$ 524,185	-$ 542,706	-$ 539,302	-$ 567,354	-$ 540,385	-$ 568,508	-$ 553,215	-$ 534,652
Operational Cost 100	-$ 1,138,881	-$ 535,867	-$ 534,668	-$ 553,561	-$ 550,088	-$ 578,701	-$ 551,192	-$ 579,879	-$ 564,280	-$ 545,345
NPV 10	$1,870,932	-$339,208	-$315,605	-$286,931	-$247,199	-$52,114	$46,512	-$76,834	-$39,197	-$95,914
NPV 15	$2,563,385	$27,432	$51,764	$68,951	$110,794	$288,483	$403,834	$263,047	$310,168	$264,964
NPV 20	$3,909,998	$376,617	$401,642	$407,890	$451,743	$612,864	$744,144	$586,746	$642,900	$608,660
NPV 25	$4,538,086	$709,176	$734,863	$730,691	$776,460	$921,801	$1,068,251	$895,033	$959,790	$935,992
NPV 30	$5,136,271	$1,025,903	$1,052,219	$1,038,124	$1,085,717	$1,216,029	$1,376,928	$1,188,643	$1,261,593	$1,247,741
NPV 40	$7,489,584	$1,614,835	$1,642,322	$1,609,776	$1,660,760	$474,465	$642,572	$1,734,591	$1,822,776	$1,827,417
NPV 50	$8,498,478	$2,149,024	$2,177,572	$2,128,291	$2,182,351	$970,709	$1,163,185	$2,229,792	$2,331,795	$2,353,210
NPV 60	$11,655,027	$2,633,558	$2,663,070	$2,598,608	$2,655,458	$1,420,825	$1,635,404	$173,966	-$261,817	-$682,312
NPV 70	$12,485,077	$3,073,053	$3,103,438	$3,025,207	$3,084,589	$1,829,101	$2,063,730	$581,384	$156,970	-$249,725
NPV 80	$17,286,251	$3,471,695	$3,502,873	$3,412,153	$3,473,829	-$2,004,242	-$1,815,552	$950,931	$536,829	$142,652
NPV 90	$17,969,161	$3,833,282	$3,865,178	$3,763,130	$3,826,889	-$1,668,339	-$1,463,154	$1,286,127	$881,379	$498,556
NPV 100	$25,900,235	$4,161,259	$4,193,806	$4,081,483	$4,147,130	-$1,363,660	-$1,143,514	$1,590,166	$1,193,902	$821,377

ASSUMPTIONS

2% opertaional cost escalation

3% Discount rate

Escalation for Window replacement

1	-$ 380,446	3%
20	-$ 687,127	3%
40	-$ 1,241,028	3%
60	-$ 2,241,434	3%
80	-$ 4,048,279	3%
100	-$ 7,311,642	3%

Assuming conservative lifespan of 20 years for windov

Escalation for fiberglass insulation replacement (3.5"

1	-$ 303,884	3%
40	-$ 1,288,663	3%
80	-$ 4,203,669	3%

Assuming lifespan of 40 years for fiberglass insulation
Assumes a 30% cost of demolition to replace fiberglas

Escalation for fiberglass insulation replacement (6" tl

1	-$ 308,519	3%
40	-$ 1,308,321	3%
80	-$ 4,267,792	3%

Assuming lifespan of 40 years for fiberglass insulation
Assumes a 30% cost of demolition to replace fiberglas

Escalation for EPS replacement (3" thickness)

1	-$ 327,062	3%
60	-$ 2,504,995	3%

Assuming lifespan of 60 years for EPS insulation
Assumes a 30% cost of demolition to replace EPS

Escalation for EPS replacement (4" thickness)

1	-$ 398,914	3%
60	-$ 3,055,316	3%

Assuming lifespan of 60 years for EPS insulation
Assumes a 30% cost of demolition to replace EPS

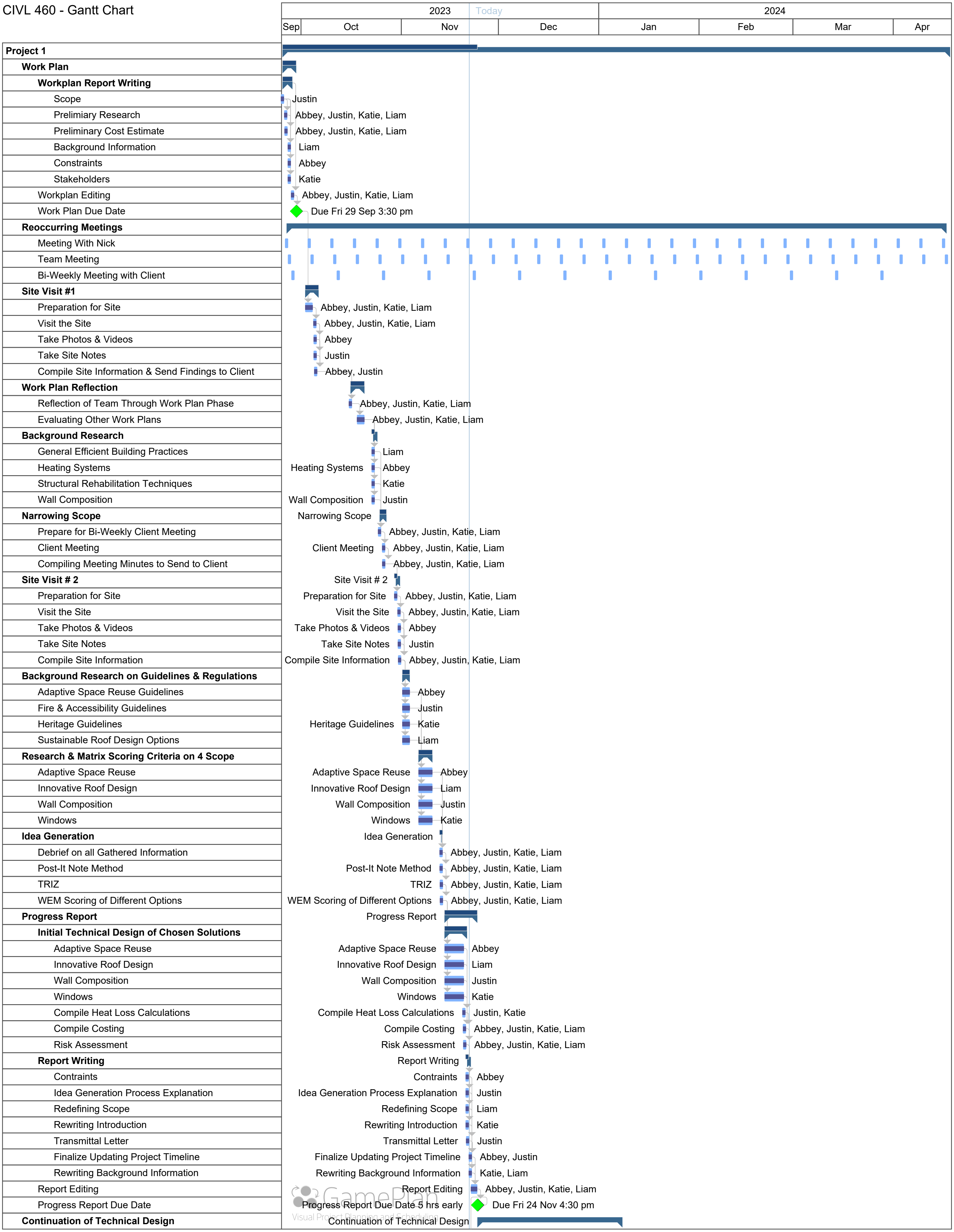
Escalation for EPS replacement (6" thickness)

1	-$ 458,598	3%
60	-$ 3,512,441	3%

Assuming lifespan of 60 years for EPS insulation
Assumes a 30% cost of demolition to replace EPS

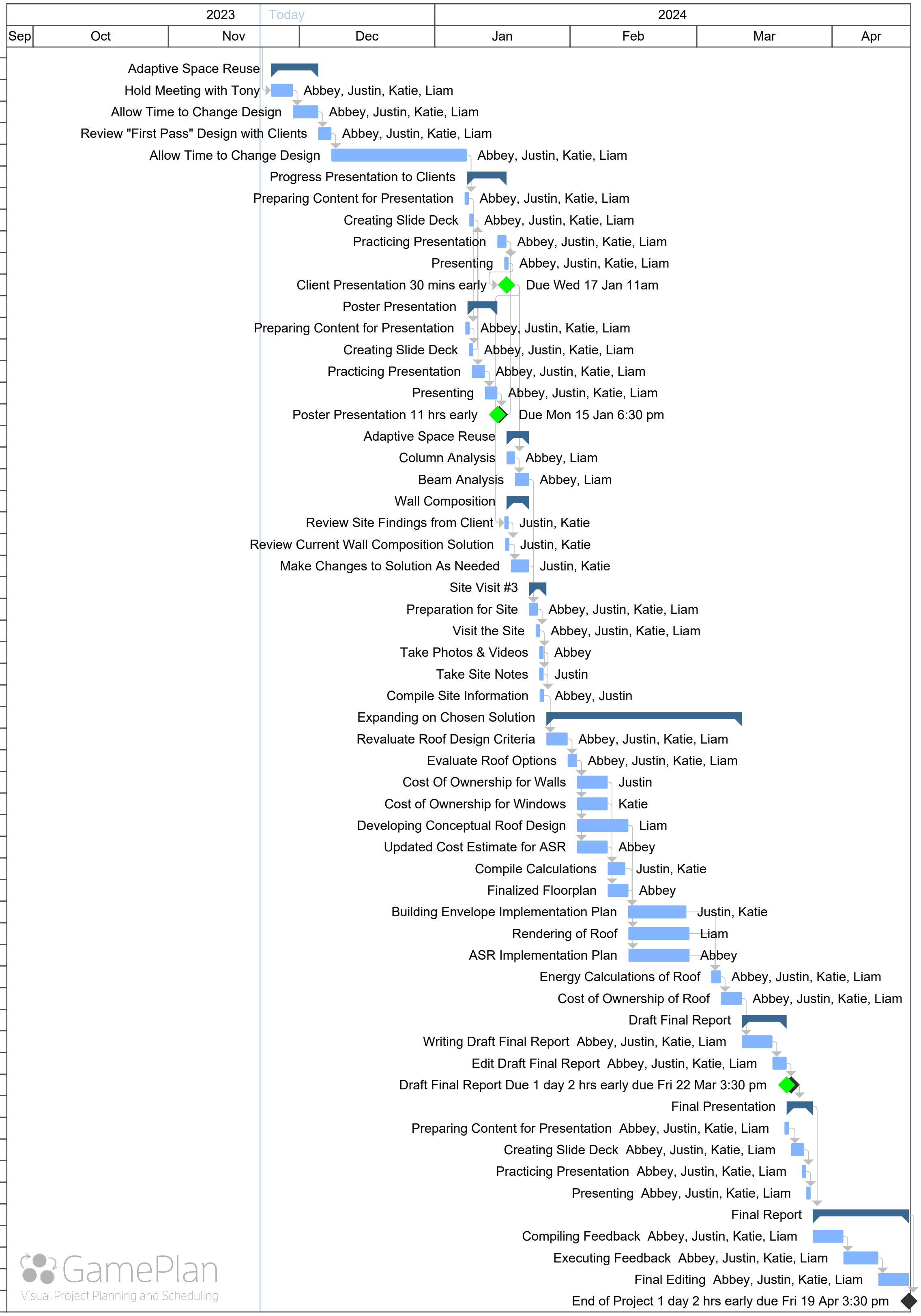
Appendix J: Team Member Hour Logs and Gantt Chart

CIVL 460 - Gantt Chart



CIVL 460 - Gantt Chart

Adaptive Space Reuse
Hold Meeting with Tony
Allow Time to Change Design
Review "First Pass" Design with Clients
Allow Time to Change Design
Progress Presentation to Clients
Preparing Content for Presentation
Creating Slide Deck
Practicing Presentation
Presenting
Client Presentation
Poster Presentation
Preparing Content for Presentation
Creating Slide Deck
Practicing Presentation
Presenting
Poster Presentation
Adaptive Space Reuse
Column Analysis
Beam Analysis
Wall Composition
Review Site Findings from Client
Review Current Wall Composition Solution
Make Changes to Solution As Needed
Site Visit #3
Preparation for Site
Visit the Site
Take Photos & Videos
Take Site Notes
Compile Site Information
Expanding on Chosen Solution
Revaluate Roof Design Criteria
Evaluate Roof Options
Cost Of Ownership for Walls
Cost of Ownership for Windows
Developing Conceptual Roof Design
Updated Cost Estimate for ASR
Compile Calculations
Finalized Floorplan
Building Envelope Implementation Plan
Rendering of Roof
ASR Implementation Plan
Energy Calculations of Roof
Cost of Ownership of Roof
Draft Final Report
Writing Draft Final Report
Edit Draft Final Report
Draft Final Report Due
Final Presentation
Preparing Content for Presentation
Creating Slide Deck
Practicing Presentation
Presenting
Final Report
Compiling Feedback
Executing Feedback
Final Editing
End of Project



Task	Subtask	Team Member Contribution (Hours)			
		Liam R.	Katie F.	Justin B.	Abbey M.
Workplan	Preliminary Research	3	3	3	3
	Constraints	0.5	0.5	0.5	1.5
	Stakeholders	0.5	1.5	0.5	0.5
	Background Information	1	1	1	1
	Scope Creation	2	2	2	2
	Work Breakdown Plan and Timeline	1	1	1	1
	Preliminary Cost Estimate	1	1	1	1
	Workplan Report Writing	10	10	10	10
	Workplan Editing	1	1	1	1
Background Research	Buidling Codes and Regulations	0	0	0	3
	Market Information	0	0	3	0
	Queen's University Guidelines	0	3	0	0
	Background Documents and Drawings	3	0	0	0
Site Visit 1	Preparation for Site	2	2	2	2
	Inspect Wall Composition	0.5	0.5	0.5	0.5
	Structural Component Review and Anlaysis	3	3	3	3
	Compare Building to As-Built Drawings	0.5	0.5	0.5	0.5
	Take Site Notes	0	0	6	0
	Take Photos and Videos	0	0	0	6
	Complile Site Information	0	0	3	3
Idea Generation	Develop solutions for Structural Problems	15	10	10	10
	Structural Calcualtions	5	5	5	5
	Modeling of Structral Systems	7	7	0	0
	Identifying Costs of Potential Solutions	2	2	2	2
	Propose and Research Possible Innovation	3	3	3	3
Progress Report	Redefining Scope	2	2	2	2
	Potential Innovative Solutions Brainstormed	10	10	10	10
	Detailed Cost Estimate	4	4	4	4
	Updating Timeline and Schedule	1	1	1	1
	Structural Calculations	7	4	4	7
	Modeling of Structral Systems	7	7	0	0
	Writing the Report	15	10	10	10
	Progress Report Editing	1	1	1	1
Second Site Visit	Review Areas Identified in Site Visit 1	2	2	2	2
	Look for Potential Innovation	2	2	2	2
	Take Site Notes	0	0	6	0
	Take Photos and Videos	0	0	0	6
	Compile Site Information	0	0	3	3
Progress Presentation to Clients	Preparing Content for Presentation	2	2	2	2
	Creating Slide Deck	2	2	2	2
	Practicing Presentation	2	2	2	2
Poster Presentation	Preparing Content for Presentation	2	2	2	2
	Creating Poster	2	2	2	2
	Practicing Presentation and Preparing for Questions	2	2	2	2
Selecting Solutions	Finalizing all Structural Remediation Plans	2	2	4	4
	Creating WEM to Decide Upon a Solution	2	8	2	8
	Further Research and In-Depth Analysis of Solution	3	3	3	3
	Project Specific Solution Imlimentation Plan	1	1	1	1
Draft/Final Report	Finalizing Scheudule	0	0	2	2
	Finalizing Cost Estimate	1	1	1	1
	Finalizing Calcualtions	5	5	0	0
	Finalizing Modeling	0	6	10	0
	Writing Draft Report	15	15	15	15
	Impliment Edits and Submit Final Report	1	1	1	1
Final Presentation	Preparing Content for Presentation	2	2	2	2
	Creating Slide Deck	2	2	2	2
	Practicing Presentation	2	2	2	2
	Summation of Each Team Member's Hours	160	160	160	160

CIVL 460 Engineering Design and Practice
Queen's University

Name: Justin Boult **Project:** KCVI Assessment

Hours per Week	Hours
Week 1	6.00
Week 2	5.00
Week 3	6.00
Week 4	10.00
Week 5	2.00
Reading Week	0.00
Week 6	3.50
Week 7	4.00
Week 8	8.00
Week 9	8.00
Week 10	15.50
Week 11	19.50
Week 12	0.00
Exam Week 1	0.00
Exam Week 2	0.00
Exam Week 3	0.00
Break Week 1	0.00
Break Week 2	0.00
Week 1	4.50
Week 2	3.00
Week 3	7.00
Week 4	11.00
Week 5	13.00
Week 6	8.00
Reading Week	0.00
Week 7	5.50
Week 8	20.00
Week 9	7.50
Week 10	12.50
Week 11	0.00
Week 12	0.00
Exam Week 1	0.00
Exam Week 2	0.00
Exam Week 3	0.00

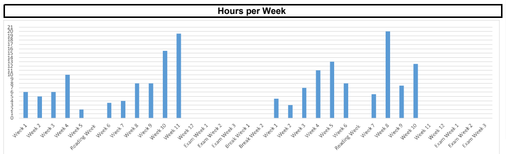
Hours per Task

Activity	Hour Tally
Background Research	6.5
Project Data Review & Interpretation	0
Meeting Attendance and Preparation - TAs/Clients	9.5
Meeting Attendance and Preparation - Group	45
Work Plan - Preperation	3
Work Plan - Review/Editing	1
Work Plan - Peer Review	0
Progress Report - Preperation	21
Progress Report - Review/Editing	2
Progress Report - Peer Review	0
Final Report - Preperation	25
Final Report Review/Editing	4
Technical Design Calculations/Work	44.5
Modelling	0
Budgeting - time and cost, Gantt Charts	3
SOQ - Preperation & Presentation	6
Poster Presentation - Preperation & Presentation	4.5
Final Presentation - Preperation & Presentation	0
Other	4.5

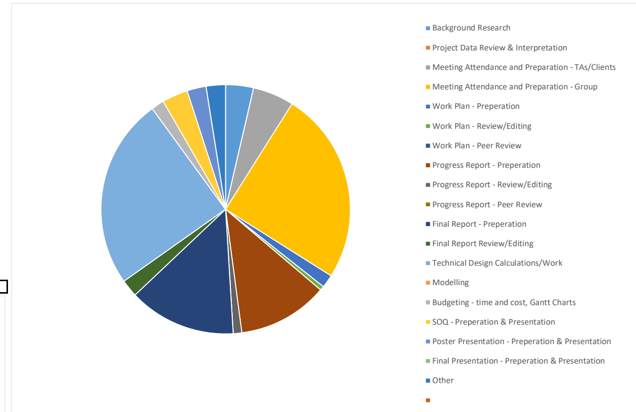
My hours: 179.50

Hours left in contract: -19.50

Hours per Week



Task Breakdown (general)



CIVL 460 Engineering Design and Practice
Queen's University

Name: Katie Fitzpatrick **Project:** PROJECT

Hours per Week	Hours
Week 1	6.00
Week 2	6.00
Week 3	5.00
Week 4	10.50
Week 5	3.00
Reading Week	1.00
Week 6	4.00
Week 7	4.00
Week 8	7.75
Week 9	4.75
Week 10	12.00
Week 11	15.50
Week 12	0.00
Exam Week 1	0.00
Exam Week 2	0.00
Exam Week 3	0.00
Break Week 1	0.00
Break Week 2	0.00
Week 1	9.00
Week 2	6.00
Week 3	7.50
Week 4	5.00
Week 5	7.00
Week 6	5.50
Reading Week	5.50
Week 7	4.50
Week 8	9.00
Week 9	8.00
Week 10	21.00
Week 11	0.00
Week 12	0.00
Exam Week 1	0.00
Exam Week 2	0.00
Exam Week 3	0.00

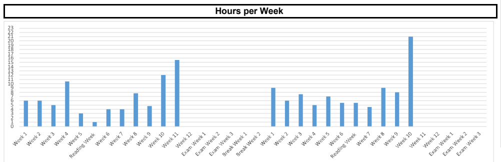
Hours per Task

Activity	Hour Tally
Background Research	1
Project Data Review & Interpretation	0
Meeting Attendance and Preparation - TAs/Clients	14.5
Meeting Attendance and Preparation - Group	51.75
Work Plan - Preperation	6.5
Work Plan - Review/Editing	2
Work Plan - Peer Review	2
Progress Report - Preperation	12.5
Progress Report - Review/Editing	6
Progress Report - Peer Review	0
Final Report - Preperation	20.5
Final Report Review/Editing	7
Technical Design Calculations/Work	18
Modelling	0
Budgeting - time and cost, Gantt Charts	1
SOQ - Preperation & Presentation	2
Poster Presentation - Preperation & Presentation	9
Final Presentation - Preperation & Presentation	0
Other	13.75

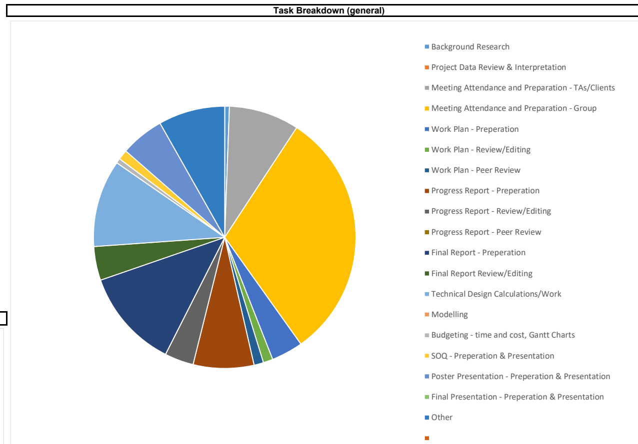
My hours: 167.50

Hours left in contract: -7.50

Hours per Week



Task Breakdown (general)



CIVL 460 Engineering Design and Practice
Queen's University

Name: Abbey MacTaggart **Project:** KCVI Assessment

Hours per Week	Hours
Week 1	6.00
Week 2	6.00
Week 3	6.00
Week 4	8.50
Week 5	6.00
Reading Week	3.00
Week 6	6.00
Week 7	6.00
Week 8	9.00
Week 9	7.50
Week 10	9.00
Week 11	11.00
Week 12	0.00
Exam Week 1	0.00
Exam Week 2	0.00
Exam Week 3	0.00
Break Week 1	0.00
Break Week 2	0.00
Week 1	6.00
Week 2	6.00
Week 3	6.00
Week 4	7.00
Week 5	7.00
Week 6	6.00
Reading Week	2.00
Week 7	9.50
Week 8	9.00
Week 9	15.00
Week 10	14.50
Week 11	0.00
Week 12	0.00
Exam Week 1	0.00
Exam Week 2	0.00
Exam Week 3	0.00

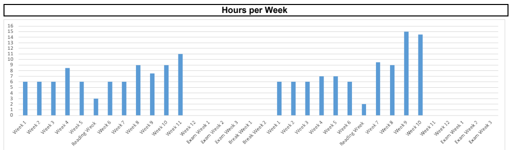
Hours per Task

Activity	Hour Tally
Background Research	1
Project Data Review & Interpretation	0
Meeting Attendance and Preparation - TAs/Clients	11.5
Meeting Attendance and Preparation - Group	1
Work Plan - Preperation	1
Work Plan - Review/Editing	1.5
Work Plan - Peer Review	2
Progress Report - Preperation	17
Progress Report - Review/Editing	4
Progress Report - Peer Review	0
Final Report - Preperation	17
Final Report Review/Editing	17
Technical Design Calculations/Work	20.5
Modelling	0
Budgeting - time and cost, Gantt Charts	0
SOQ - Preperation & Presentation	6
Poster Presentation - Preperation & Presentation	4.5
Final Presentation - Preperation & Presentation	0
Other	13

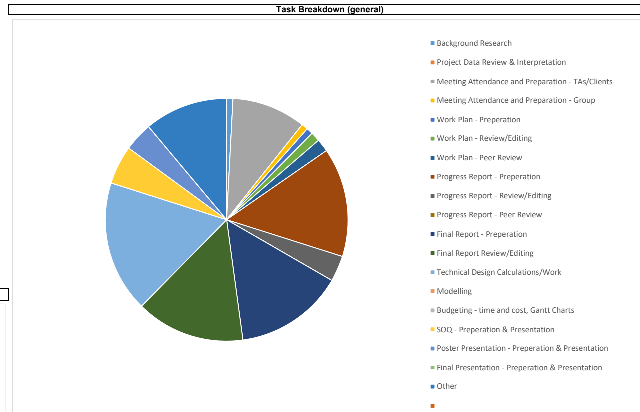
My hours: 172.00

Hours left in contract: -12.00

Hours per Week



Task Breakdown (general)



CIVL 460 Engineering Design and Practice
Queen's University

Name: Liam Reid **Project:** KCVI Assessment

Hours per Week

	Hours
Week 1	6.50
Week 2	6.00
Week 3	6.00
Week 4	8.50
Week 5	2.50
Reading Week	1.00
Week 6	6.00
Week 7	6.00
Week 8	10.50
Week 9	7.50
Week 10	10.00
Week 11	20.00
Week 12	0.00
Exam Week 1	0.00
Exam Week 2	0.00
Exam Week 3	0.00
Break Week 1	0.00
Break Week 2	0.00
Week 1	6.00
Week 2	6.00
Week 3	5.50
Week 4	7.50
Week 5	6.50
Week 6	6.50
Reading Week	2.00
Week 7	6.50
Week 8	8.00
Week 9	10.00
Week 10	15.50
Week 11	0.00
Week 12	0.00
Exam Week 1	0.00
Exam Week 2	0.00
Exam Week 3	0.00

Hours per Task

Activity	Hour Tally
Background Research	1
Project Data Review & Interpretation	0
Meeting Attendance and Preparation - TAs/Clients	11.5
Meeting Attendance and Preparation - Group	1
Work Plan - Preperation	1
Work Plan - Review/Editing	1.5
Work Plan - Peer Review	0
Progress Report - Preperation	17.5
Progress Report - Review/Editing	11
Progress Report - Peer Review	0
Final Report - Preperation	26
Final Report Review/Editing	13.5
Technical Design Calculations/Work	7.5
Modelling	0
Budgeting - time and cost, Gantt Charts	0
SOQ - Preperation & Presentation	6.5
Poster Presentation - Preperation & Presentation	4.5
Final Presentation - Preperation & Presentation	0
Other	6.5

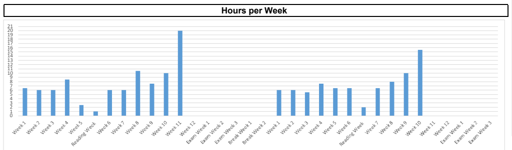
My hours:

170.50

Hours left in contract:

-10.50

Hours per Week



Task Breakdown (general)