Building Retrofit to Achieve Sustainability Goals:

Progress Report

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Presented to:
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CIVL 460: Civil Engineering Design & Practice IV
Smith Engineering and Applied Science
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Statement of originality

"We do hereby verify that this written report is our own individual work and contains our own original ideas, concepts, and designs. No portion of this report has been copied in whole or in part from another source, with the exception of properly referenced material."

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Envera
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November 21st, 2025
120 Bremner Blvd Fourth Floor, Toronto, ON M5J 0A8
York Region North District Road Maintenance Facility Sustainable Retrofit Project

Dear Ms. Erin Holwell and Mr. Hayden Bellows,

As discussed in the progress meeting on October 24th, 2025, the following report, *Building Retrofit to Achieve Sustainability Goals – Progress Report*, is for Envera's CIVL 460 Capstone Project. This report specifies:

- project definition
- project design concepts
- background information
- timeline
- budget estimation
- evaluation of project success

If you have any concerns, inquiries, or comments regarding the report, please contact the team by email, and we will happily respond or schedule a Microsoft Teams meeting for further discussion.

Kind regards,

Rheya Dutkiewicz, Lily-Anna Girard, Sophia Mariani, and Jordan Raftis

Executive Summary

Envera has been selected to develop a deep energy retrofit for Entuitive at the York Region North District Road Maintenance Facility. The two-storey, 725 m^2 facility, which was constructed in the lates 1990s, comprises of office space, two small washrooms, two kitchenettes, two locker rooms, two truck maintenance bays, and a wash bash for commercial vehicles. This capstone project aims to evaluate the implementation of a retrofit for the commercial building to achieve EnerPHit certification and support the facility's ongoing operational needs.

The project is guided by several key constraints including continuing facility operation, significant air leakage through the existing main doors, and strict EnerPHit and Net Zero Carbon requirements. Multiple stakeholders influence project decisions, including Entuitive, local energy providers, employees, regulatory authorities, and the local community.

To address these requirements, the building retrofit design is organized into five main subsystems: building envelope, mechanical and electrical (M&E), renewable energy, water efficiency, and structural. A comprehensive weighted evaluation matrix (WEM) was developed for each subsystem to compare alternative innovative designs in terms of economic feasibility, implementation, integration with existing systems, maintenance requirements, and other criteria specific to each subassembly.

The proposed retrofit integrates envelope upgrades using insulated metal panels and high-efficiency truck bay doors systems. The electrified mechanical systems feature cold-climate heat pumps paired with a backup boiler, balancing sustainability with reliability. Centralized ventilation and hot water circulation further reduce overall energy consumption.

In addition to the major structural upgrades, the building retrofit incorporates a rooftop solar PV array, enhanced battery energy storage, along with six DC fast chargers to support the transition to electrical vehicles (EV). Water-efficiency measures, such as greywater recycling, rainwater harvesting systems, and low-flow fixtures, were implemented to reduce dependency on the local municipal water supply.

Once the first four subassemblies were finalized, Envera conducted a structural review in accordance with NBCC 2020 and CSA S16 to confirm the building could support the additional loads from the new roof assemblies and mechanical equipment. The total cost of the retrofit assessment is expected to cost near $3,384,207.60.

A preliminary carbon emission and risk assessment was developed, enabling Envera to establish the future plans for improvement to reduce carbon emissions, enhance system reliability, reduce system and subassembly vulnerabilities, and ensure a high-performing design for Entuitive.

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1.0 Introduction

Envera has been awarded the design contract to develop a building retrofit for the York Region North District Road Maintenance Facility to achieve EnerPHit Certification, in collaboration with Entuitive. Envera will collaborate with stakeholders, including Entuitive engineers, Erin Holwell and Hayden Bellows, as the client, Queen's University representatives, including Zaid Kasim as the project manager, and EnerPHit Certification Bodies.

The two-storey maintenance building in Georgina, Ontario, is to undergo a deep energy retrofit to reduce the building's carbon footprint and achieve an EnerPHit Certificate, a Passive House Institute certification that has been developed for existing buildings. Meaning the building envelope must undergo regulated upgrades to implement insulated exterior wall, roofing, and door systems, additional energy sources including solar panels and electric vehicle charging stations, and mechanical upgrades incorporating sustainable plumbing and heat pumps that focus on water reuse. All proposed upgrades will be completed to achieve a minimum air tightness of 1.0 air changes per hour at 50 Pa (1.0 ACH50), reducing thermal bridges, and achieving at least 20% energy savings [1].

The 725 m^2 building was constructed in the late 1990s and contains office space, two truck maintenance shops, and a wash bay for municipally owned vehicles, including snowplows and triaxle dump trucks. The building has a steel frame, sheet walls, roll-up garage doors, infrared heating, and traditional plumbing systems. The design package will consist of two phases. Phase 1 is a feasibility study to assess building system modification, and Phase 2 is a structural impact assessment. A project budget has not been specified, meaning Envera will collaborate with Entuitive to produce a design that achieves the EnerPHit Certification and justifies cost. The retrofit design will be completed in accordance with the EnerPHit Certificate Standard, the National Building Code of Canada (NBCC 2020), and the project specifications.

2.0 Background Information

For Envera to complete the design, the necessary information and standards will be collected in collaboration with Entuitive and additional online research. The York Region North District Road Maintenance Facility was originally built in the late 1990s to operate two large shop bays and a truck washing station. Six large 24 m^2 maintenance bay doors allow egress for the maintained vehicles, each using up to 2,000 W to operate, causing interior bay temperatures to fluctuate [1]. To shift towards a more sustainable business model, the York Region Roads Department aims to complete a retrofit to achieve the EnerPhit Certification standard. EnerPHit is a building standard developed by the Passive House Institute for refurbishing existing buildings that cannot be renovated to adhere to the Passive House Classic Standard, which is tailored towards new builds, due to extensive construction and cost barriers [2].

The EnerPHit certification focuses on energy efficiency by lowering the overall energy use intensity of the building, including heating, cooling, and dehumidification demand, in combination with the installation of renewable energy generation methods, such as solar panels, to lower the building's carbon emissions. The retrofit standard focuses on five major refurbishment principles: insulation, thermal bridge-free design, airtightness, Passive House windows, and ventilation with heat recovery. Through Phase 1 of the design, each applicable retrofit principle will be evaluated against the client's needs for the maintenance building, concerning total project cost, safety, and applicable industrial renovations. The standard employs two methods, the first, the energy demand method, requires the building to consume a maximum of 30 kWh/(m^2a) as determined through the Passive House Planning Package (PHPP) for Southern Ontario retrofits. The second method, the building component method, is applied to a retrofit when it is determined that, due to building layout, the 30 kWh/(m^2a) limit for the heating demand must be exceeded. Under this method, each of the five principles of the building is targeted individually to meet the required EnerPHit certification criteria [3] [4]. In reference to the York Region North District Road Maintenance Facility, renewable energy sources, altering mechanical systems fossil fuel sources, and building envelope upgrades focusing on insulation, air tightness, and thermal bridging are paramount to achieve the EnerPHit certification. These goals are being achieved through prioritizing the installation of rooftop solar panels, the removal of existing gas-powered heating and the implementation of boilers, and roof and wall insulating panels.

In addition to the client's business goals, the Canadian Government has developed the Canada Green Buildings strategy, which aims to prioritize increasing the rate of energy-efficient, climate-resilient, and deep building retrofits. Canada has a net-zero emissions goal for the commercial sector by 2050. Within Canada, there are over 480,000 commercial and institutional buildings that, in combination with residential buildings, account for 18% of national greenhouse gas (GHG) emissions [5]. The direct building emissions are over 96% and are a result of the combustion of fossil fuels for heating sources, electricity for cooling, and lighting, which the EnerPHit retrofit certificate aims to eliminate [5]. In addition, Canada's Energy Efficiency Act (EE Act) includes recent amendments regarding energy efficiency and testing standards for energy-using products, including air conditioners, heat pumps, and commercial gas-fired furnaces that must be assessed prior to installation and use [6] [7]. Due to the rise in regulatory pressures, the York Region, being a public client, must adhere to the Canada Green Building strategy to improve the construction standard to incorporate products with low carbon emissions and implement energy sources not reliant on fossil fuels.

The most recent success under the EE Act was the Ken Soble Tower Passive House Retrofit (EnerPHit) Project in Hamilton, Ontario, where Entuitive was responsible for the design of the building envelope and structural restoration [8]. The 18-storey affordable housing building was CityHouse Hamilton's oldest residential social high-rise, which was deteriorating [8]. The federal government invested $16.5 million to complete the retrofit to achieve climate resilience, thermal comfort, and supply housing for vulnerable seniors [9]. Throughout the design, Entuitive modelled thermal bridge conditions, floor air leakage testing plans, and a building air leakage testing plan [8] [6].

3.0 Problem Definition

The following section of this report consists of specific details and considerations that Envera will account for when proposing a retrofit design to align with sustainability goals established by the client, Entuitive. Specifically, the section defines the project's scope, objectives, deliverables, constraints, and stakeholders in a manner that supports technical feasibility, performance measures, and compliance with EnerPHit standards and Net Zero Carbon targets.

3.1 Project Scope

This project includes a two-phase feasibility study and structural assessment to determine the required modifications needed to achieve the appropriate standards. Phase one will evaluate energy retrofit measures aimed at reducing overall Energy Use Intensity (EUI). This phase will focus on upgrades to the building envelope, improvements to mechanical and electrical systems, and the potential integration of on-site power generation methods, such as Solar Photovoltaic (PV) arrays. Phase two will assess the structural implications of these retrofit measures, ensuring that envelope modifications, roof mounted PV systems, and insulation loads do not compromise the existing steel frame or metal siding performance. Where required, structural reinforcement strategies will be evaluated for constructability and cost effectiveness. This project is limited to the conceptual and feasibility stages. It does not include construction activates, detailed tendering, or physical implementation of retrofit measures. The outcome will form the technical foundation for Entuitive's future implementation planning.

3.2 Objectives and Deliverables

The primary objective for this retrofit design is to identify strategies that enable the building to maintain its functionality as a winter maintenance facility, while implementing a deep energy retrofit. Quantitatively, the project aims to: reduce the facilities EUI between 50-80%, as seen in most EnerPHit retrofits [2], achieve an airtightness target of ≤ 1.0 ACH50 [2], and incorporate renewable systems capable of offsetting 20-30% of total energy consumption [3]. While doing this, no more than 5% of additional stress with be added on existing steel framing under retrofit loads [4] and improve operational uptime of 95% during the retrofit [4]. These targets reflect a holistic approach that reduces emissions while maintaining practicality, safety, and viable feasibility.

To communicate all work produced, Envera will present six major deliverables to the client throughout the term of this project. These six deliverables include the initial work plan, the progress report, the poster presentation, the draft final report, an oral presentation, and the final report. In Table 1 below, the six project deliverables are outlined, with their specific client-oriented purpose:

Table 1: Capstone deliverables.

Classification	**Description**
Work Plan *(October 9th, 2024)*	The prepared Work Plan defines the scope, roles of each group member, the schedule, and preliminary research collection for this retrofit. This information is essential for Entuitive, as it provides the client with insight into the project stages, and communicates all work completed.
Progress Report *(November 21st, 2024)*	The Progress Report summarizes Phase One findings, including preliminary energy modeling, structural condition review, comparisons of retrofit measures, and a proposed final design. All information within the Progress Report will be essential for Entuitive, to understand Enveras timeline, and proposed solution. Feedback will be given from Entuitive, which in turn will help Envera for future project objectives.
Poster Presentation *(January 12th, 2025)*	The Poster Presentation will visually communicate the technical framework and feasibility outcomes that the group has established in a concise manner.
Draft Final Report *(March 20th, 2025)*	The Draft Final Report will provide a detailed analysis of the chosen retrofit solutions, including an in-depth cost benefits evaluation, potential energy simulation results, and further structural load assessments. Feedback from Entuitive and Queen's University members will be given and implemented into the Final Report.
Oral Presentation *(Late March 2025)*	The Oral Presentation will present key technical conclusions from the project to fellow classmates and offer a chance for Envera to be critiqued on presentation styles.
Final Report *(April 17th, 2025)*	The Final Report for this project will deliver complete technical documentation, energy modeling data, retrofit drawings, and overall performance metrics.

3.3 Constraints

Given the current information and research completed, the project is subject to several constraints that will guide the feasibility assessment and design recommendations. Table 2 below will summarize key constraints, their severity to the project, and their respective description:

Table 2: Retrofit constraints.

Constraint	Severity	Description
Facility Operation Continuity	High	The winter maintenance facility must remain operational, limiting construction windows and required retrofit strategies that minimize down time. Due to the maximum allowable service interruption being $\leq 5\%$ of operational hours, scheduling around peak operational hours will be crucial.
Structural System (Steel Framing and Metal Siding)	High	Limits on load-bearing capacity and thermal bridging mitigation will constrain insulation thickness, roof mounted PV loads, etc. This will heavily influence the groups decision when considering retrofit solutions.
Air Leakage through Bay Doors	High	The presence of the six 24 m^2 bay doors within the facility account for $> 30\%$ of envelope heat loss. Solutions must enhance sealing and reduce infiltration without compromising operational functionality.
EnerPHit and Net Zero Carbon Requirements	High	Having mandatory airtightness of ≤ 1.0 ACH at 50 Pa and high R-values, restricts viable wall/roof assemblies, as these criteria narrow the material and detailing options for the retrofit.
Budgetary Limits	Medium	Without a defined capital budget, all recommendations must be justifiable and demonstrate a strong lifecycle. This will impact decisions being made and influence the group into choosing solutions that will return payback in < 10 years.
Software Limitations	Medium	Due to limited SAP2000 licensing, structural analysis relies on Microsoft Excel and hand calculations, which limits 3D load distribution accuracy and thermal bridge modeling. However, simplified analysis methods will be validated through cross-checking with reference data.

Although each constraint will affect the project differently, budgetary and software limitations are two constraints that per discussion with the Client, are not critical for the proposed solution, and are outside of Enveras scope. Due to this, they are only classified as medium severity but will still be considered.

3.4 Stakeholders

Due to the requirements, location, and size of the facility, Envera has produced a list of 12 stakeholders that will be impacted during the planning, execution, and completion phases of this project.

To begin, Entuitive, specifically Erin Holwell and Hayden Bellows, are the clients for this project. They will provide project direction, approve proposed design solutions, and offer professional feedback on feasibility. They are also responsible for ensuring the retrofit design aligns with EnerPHit standards, Net Zero Carbon energy standards and the York Region Roads Department sustainability goals. Entuitive's active involvement ensures that all proposed solutions are practical, cost-effective, and aligned with both client and sustainability expectations.

Following Entuitive, Envera is a stakeholder that will be conducting all research, performing structural and energy feasibility assessments, and providing design options to Entuitive. The team is also accountable for preparing progress reports, final deliverables, and presentations in accordance with academic expectations. As the executing body, Envera will integrate input from all stakeholders to develop feasible and data-driven retrofit strategies. The team's technical performance and ability to balance sustainability with functionality will directly influence the success and academic evaluation of the project.

Queen's University, specifically CIVL 460 instructor Dr. Moore and project manager Zaid Kasim, is the academic institution overseeing the capstone project, ensuring academic requirements are met. They will provide supervision, resources, and evaluate project deliverables. Their involvement ensures academic integrity, adherence to research and reporting standards, and that project outcomes align with course learning objectives.

The York Region Roads Department is another important stakeholder, as they hold ultimate authority over decisions related to funding, scope, and adaptation of retrofit measures. Their priorities include sustainability targets, reducing operational costs, and ensuring the facility continues to function effectively as a winter maintenance hub. Their decision-making will also affect contractor selection, material sourcing, and the timing of implementation.

The District Road Maintenance Facility is in York Region, near the town of Georgia. Due to this, York Region oversees the operations of the winter maintenance facility, providing tools, vehicles, and staff. They are responsible for ensuring the facility remains operational during retrofit planning and that public services, such as road and sidewalk plowing, are not disrupted. Their cooperation will be crucial in coordinating scheduling and temporary adjustments during construction phases to minimize service interruptions and maintain safety for both staff and the public.

Due to the nature of this project being a sustainable retrofit, energy providers, such as Hydro One [5], Enbridge Gas [6], etc., are the electricity and natural gas providers for the facility, who will provide critical information for decision-making. Energy supply characteristics, such as grid reliability, carbon intensity, and utility costs, directly influence the feasibility of proposed upgrades. Their technical data will inform decisions on renewable energy integration, heat recovery, and energy storage systems.

Along with energy providers, EnerPHit certification bodies (Passive House Canada) oversee compliance with EnerPHit standards, providing formal certification that the retrofit meets performance criteria for airtightness, insulation, and energy efficiency. Their approval validates the success of the project's sustainability objectives [1]. They also serve as a key reference point for performance testing and design validation, ensuring that all retrofit measures are auditable and meet the stringent requirements of a Net Zero Carbon facility.

Within the District Road Maintenance Facility, supervisors, managers and employees work at the facility and depend on uninterrupted building access and functionality. Construction or retrofit work has the potential to interfere with daily operations, creating both productivity and safety concerns. These internal stakeholders provide valuable insight into daily operational needs, allowing the project team to tailor retrofit measures that minimize disruption and enhance working conditions.

Regulatory bodies, including the Ontario Building Code inspectors and municipal permitting offices, must ensure that all retrofit measures comply with safety, energy efficiency, and construction standards. Their oversight ensures legal compliance and the safety of all structural and energy-related modifications.

Located in proximity to the facility, nearby property owners and businesses may be affected by construction activities, noise, traffic, or other temporary disruptions, making them stakeholders throughout the duration of the project. Although their involvement is indirect, effective communication and mitigation strategies, such as controlled working hours and site safety measures, will be essential in maintaining good relations.

Additionally, the population of Georgina relies on the facility for snow and ice removal, road upkeep, and safe winter roadways. Any disruptions to the facilities' function could directly impact community mobility, safety, and quality of life during the winter months. Public transparency about the project's schedule and contingency plans will be critical in maintaining trust and ensuring continued service reliability during implementation.

Lastly, should retrofit implementation move forward, contractors and material suppliers will become key stakeholders in executing the design recommendations. Their role includes ensuring constructability, cost control, and adherence to design intent. They will work closely with the design team and regulatory bodies to translate retrofit plans into tangible outcomes. Expertise in sustainable construction practices and familiarity with high-performance building materials will both be crucial for achieving EnerPHit level performance.

3.4.1 Stakeholder Classifications

Each of these stakeholders will have different influence, interest levels and communication needs, which in turn will affect their priority within the project. To classify each stakeholder, their influence and interest levels first must be explained, as outlined in Table 3.

Table 3: Influence and interest level classifications.

Level	Influence Definition	Interest Definition
High	High influence level refers to stakeholders that can approve, or veto proposed retrofit design solutions, control budget and those who hold authority/ regulation power over retrofit design standards.	High interest level refers to stakeholders who's work, or operational requirements are directly impacted by retrofit performance outcomes, like job safety and function.
Medium	Medium influence level refers to those who actively participate in the activities that happen within the maintenance facility and spend a considerable amount of time around the facility for work purposes, but do not directly control design approvals or long-term performance.	Medium interest level is allotted to stakeholders who care about the maintenance facility's daily operations, and are affected by operational changes during retrofits, like construction and closures.
Low	Low influence level refers to stakeholders who have no direct correlation to the activities within the maintenance facility, making them unfit to make suggestions for this retrofit.	Low interest level applies to individuals who rely on the maintenance facility, but do not have a high concern for internal upgrades, or changes being done.

From influence and interest level, the stakeholders can then be classified as either primary, secondary or tertiary, with the associated descriptions in Table 4 below.

Table 4: Primary, secondary and tertiary classifications.

Classification	Description
Primary Stakeholder	Primary stakeholders are those who are directly involved in the project's decision-making, execution or outcomes. They have significant influence on the project's success and are directly

	impacted by its results. Their engagement is critical throughout all project phases.
Secondary Stakeholder	Secondary stakeholders are those who are indirectly involved in the project. They may provide support, oversight, regulation or services but are not directly responsible for decision-making or daily project activities. They are affected by the project's outcomes.
Tertiary Stakeholder	Tertiary Stakeholders are those who are peripherally affected by the project. They do not influence the project directly, but may experience indirect impacts such as environmental, economic, or social effects resulting from the project's implementation.

Based on each stakeholder's alignment with the three classifications above, Table 5 below summarizes each category that all 12 stakeholders have been put into.

Table 5: Full stakeholder classifications.

Stakeholder	**Influence Level**	**Interest Level**	**Classification**
Entuitive	High	High	Primary
Envera	High	High	Primary
Facility Owner	Medium	High	Primary
Queen's University	Medium	High	Primary
Energy Providers	Medium	Low	Primary
EnerPHit Certification Bodies	High	Medium	Primary
York Region	High	Medium	Secondary
Supervisors, Managers and Employees	Medium	High	Secondary
Regulatory Authorities	High	Medium	Secondary
Nearby Property Owners and Businesses	Low	Medium	Tertiary
Nearby Georgia Residents	Low	Low	Tertiary
Contractors and Suppliers (future phase)	Medium	Medium	Tertiary

4.0 Project Timeline

The following section outlines the major tasks throughout the project, a timeline, an overview of deliverables, and project expectations.

4.1 Major Tasks

To ensure the completion of the facility's retrofit, Envera developed a detailed work breakdown structure (WBS), as seen in Figure 3 in Appendix A: Work Breakdown Structure. All stages of the project are outlined across five main phases in the Gantt chart, as seen in Figure 4, Figure 5, and Figure 6 in Appendix B: Gantt Chart with Responsibilities. A general outline is as follows:

Phase 1 – Project Definition: Identifies the project objectives, constraints, stakeholders, and initial planning. Completed by October 9th, 2025.

Phase 2 – Research: Initial project research once Envera understands the expectations of Entuitive. Research pertinent details such as the building's location, loads, and applicable energy standards. Completed by October 15th, 2025.

Phase 3 – Preliminary Design: Once research is complete, Envera will focus on designing alternative solutions for the building's subassemblies: building envelope, mechanical and electrical (M&E), renewable energy, water efficiency, and structural. Envera will identify the preferred retrofit strategy using developed weighted evaluation scoring. Phase 3 will be completed by November 21st, 2025.

Phase 4 – Final Design: Once the preliminary design is established, Envera will continue to evaluate the subassemblies and the system as a whole, coordinating with Entuitive to ensure their expectations are met. Additionally, the environmental impact, applicable loads, building envelope, and other details as required will all be finalized. Phase 4 will be completed by December 1st, 2025.

Phase 5 – Design Proposal: The deliverable section of the project, where finer details will be assessed, conclusions will be drawn, and the final report and presentation will be made. Phase 5 will be completed by April 17th, 2025.

Refer to Appendix B: Gantt Chart with Responsibilities for a breakdown of delegated tasks and designated team leads and reviewers. All individual expectations and the conflict resolution plan are outlined in the Envera Team Charter. Responsibilities were assigned based on assumed role and previous experiences:

Rheya Dutkiewicz – Project Manager: Define initial project conditions, review the supplied engineering drawings, determine evaluation categories and weights, and implement the evaluation matrix. Assess the building envelope alternative designs. She will also assess the project's feasibility.

Lily-Anna Girard – Environmental Coordinator: Research applicable energy standards and potential energy generation technologies. Investigate the environmental impact of alternative solutions and methods to improve the building's water efficiency. Develop a detailed plan for the final solution's environmental impact and develop a long-term environmental mitigation plan if needed. She will also create the project schedule and edit the Gantt Chart.

Sophia Mariani – Structural Coordinator: Define the initial project scope and stakeholders. She will assess site conditions and the nearby environment to support load calculations, determine applicable forces and loads, calculate final design loads, and develop a maintenance plan to ensure the structural integrity of the proposed retrofit.

Jordan Raftis – M&E Coordinator: Develop preliminary project concepts, review similar projects, and develop the Envera website. Evaluate the mechanical and electrical structure of alternative solutions and prepare a detailed cost estimate for the final solution.

4.2 Timeline Estimates

The detailed Gantt Chart in Appendix B: Gantt Chart with Responsibilities outlines the main tasks and deliverables required for the project's overall success. The five project phases are outlined with the main activities, with some tasks extending into the next phase to allow time for iteration and refinement.

Tasks are divided into three main categories with varying colours. Deliverables are shown in red, which ensure Envera remains on task. Milestones are shown in yellow, acting as key indicators for progress reporting and submissions for review. Activities shown in blue act as ongoing work or research required to meet Entuitive's project requirements. Additionally, leeway time is built into the schedule to account for unexpected delays, such as illness or the need for additional work on a task.

4.3 Evaluation of the Project's Success

The team will evaluate the project's success based on its alignment with the proposed timeline, deliverables, and outlined objectives. In the early stages, progress will be assessed against the timeline to track milestones and deliverables. As the project advances into later phases, the proposed design will be evaluated in relation to the established objectives and client expectations. Key areas of assessment will include energy performance, structural integrity, cost-effectiveness, and the integration of equitable engineering practices.

Evaluation methods will be based on detailed carbon emission calculations, an environmental impact assessment, SAP models, design load calculations, a detailed cost estimate, the payback period, and an assessment of the social impacts of the design. The evaluation matrix developed in Phase 3 will be used to compare the subassembly alternative solutions to select the most suitable and efficient final design for Entuitive.

Lastly, a feasibility assessment will determine the project's practicality in the real-world application. A comparison of the actual outcomes against the initial outcomes will be presented in the final report in Phase 5. The final report will also present recommendations for future improvements based on the feasibility assessment.

4.4 Deviations from the Initial Timeline

To adapt to changing conditions and ensure the overall success of the project, the proposed timeline and Gantt chart from October 6th Work Plan was modified. Original and broad project objectives were developed into specific and detailed scopes with designated task leads. After completing initial background research, it was determined that to develop the most well-research and efficient retrofit design, the building itself could be broken down into subassemblies. To do so, the project manager, Rheya, evaluated various envelope designs and bay door systems that could be implemented to achieve EnerPHit standards. The M&E coordinator, Jordan, evaluated different M&E systems to conserve energy and improve the efficiency of the building. The environmental coordinator, Lily-Anna, evaluated renewable power generation technologies, methods to integrate renewable energy, as well as systems that could be implemented to reuse and reduce energy. Once the subassembly alternative designs were evaluated and selected, the structural coordinator, Sophia, would evaluate the retrofit building's structural integrity and determine how the building can support the new systems under regular and seismic conditions.

Another deviation to the timeline was initially, alternatives were developed prior to the criteria for the weighted evaluation matrix. The team later decided that to reduce bias and to develop a cohesive design, the criteria was established first, then design alternatives were developed, and the various ideas were compared using the established criteria. Refer to Table 38 in Appendix C: Breakdown of Timeline Deviations for a detailed breakdown of the deviations from the initial Gantt chart.

5.0 Weighted Evaluation Matrix

Weighted Evaluation Matrices (WEM) and varying criteria were developed to assess each proposed design solution for building systems, including building envelope, mechanical and electrical, renewable energy sources, and water efficiency solutions.

5.1 Criteria Description for Building Envelope

To achieve the EnerPHit Certification standards, there are specific upgrades that are required to be completed to the building envelope. To select the optimal roofing, paneling, sealing, and door products, each will be evaluated against the stated WEM criteria outlined in Table 6.

Table 6: WEM criteria for building envelope subassembly.

Criteria	Description	Weight (/5)
Economic Feasibility	Compares various capital, installation, product, lifecycle, and maintenance costs, while considering federal greenhouse gas emission	3
Implementation Feasibility	Assesses the ease of installation and time required to complete the installation process. In combination with the number of personnel required to complete the installation.	4
Integration	The ease of combining selected products with the preexisting structure and their impact on structural systems.	5
Serviceability/ Maintenance	Compare the warranty and approximate life span of each proposed product to select the longest last product.	2
Effectiveness	Evaluates the various products against the EnerPHit Certification standards to ensure the certification can be awarded to the full design.	5

5.2 Criteria Description for Mechanical and Electrical

To evaluate the proposed mechanical and electrical systems, the WEM matrix below will be used to compare potential mechanical and electrical retrofit options. The proposed system which will include heating, ventilation, cooling, domestic hot water, electrification components and major electrical distribution upgrades will be assed in Table 7. This criterion helps ensure the selected system will align with EnerPHit performance targets, enhance the long-term performance of the building and allow for simple integration within the existing facility.

Table 7: WEM criteria for mechanical and electrical subassembly.

Criteria	Description	Weight (/5)
Economic Feasibility	Evaluates the lifecycle cost effectiveness, including up front capital, installation, operating energy, maintenance and payback. Acknowledge Ontario incentives where applicable	3
Implementation Feasibility	Practicality of delivery and construction (lead times, structural and electrical capacity, permitting, code compliance and available contractor expertise	4
Integration	Compatibility with existing building envelopes/structure, roof loading and curbs for RTUs, electrical distribution, controls, and future electrification	5
Maintenance	Ease and frequency of maintenance, parts availability, required downtime and access (roof safety, filters, coils, sensors).	2

Reliability	Assesses system reliability, backup capability and resilience to extreme weather or power interruptions to ensure consistent performance	3

5.3 Criteria Description for Renewable Energy Solutions

To evaluate systems that can generate renewable energy at the building location, the WEM will consider the economic feasibility of the design, its implementation, the system's integration with the rest of the building, any maintenance requirements, actual energy production, and lastly, the emissions that would be generated from the system. Refer to Table 8 for a detailed description of each criterion, as well as its associated weight.

Table 8: WEM criteria for renewable energy solutions.

Criteria	Description	Weight (/5)
Economic Feasibility	Evaluates the cost-effectiveness of the system with the initial start-up cost, operating expenses, and pay-back period. Also considers financial incentives, government subsidies, and other forms of financial aids.	3
Implementation Feasibility	Measures how the renewable system can be implemented, considering regulatory approvals and available technical expertise.	4
Integration	Examines how the system can be integrated with the current building structure and existing energy infrastructure.	5
Maintenance	Evaluates the frequency and ease of maintenance of the system, including technical support, downtime, and part availability.	2
Energy Production	Measures the energy output produced/conserved, as well as the resource availability.	4
Environmental Impact	Assesses the greenhouse gas emissions associated with the solution and any environmental destruction.	3

5.4 Criteria Description for Water Efficiency Solutions

To promote water efficiency, the WEM will consider the economic feasibility of the system, its implementation as a solution, the design's integration with the rest of the building, maintenance requirements, its water reuse/conservation, and the environmental impact. Refer to Table 9 for a detailed description of each criterion, as well as its associated weight.

Table 9: WEM criteria for water efficiency subassembly.

Criteria	Description	Weight (/5)
Economic Feasibility	Assesses the initial start-up and operational costs of the system, as well as any associated fixtures	3
Implementation Feasibility	Examines how the design can be installed and operated on a day-to-day basis. Also consider the availability of resources and construction requirements.	4
Integration	Evaluates how the design can be integrated with the current infrastructure and plumbing systems.	5
Maintenance	Considers the ease and frequency of maintenance, where systems with limited intervention or automatic monitoring are prioritized.	2
Water Reuse/ Conservation	Considers the total volume of water that is reused or reduced.	5

6.0 Conceptual Design

From the outlined WEM criterion, various conceptual designs were developed for each building subsystem including the building envelope, mechanical and electrical, renewable energy, and water efficiency.

6.1 Building Envelope Upgrades

In response to the building envelope upgrades to achieve the EnerPHit Certification, the roof and wall system must be insulated, while air sealing around windows and doors must be completed, while insulated bay doors and man doors must be installed opposed to standard doors, to achieve the required air tightness to reduce greenhouse gas emissions and energy usage [7].

6.1.1 Roof and Exterior Wall Upgrades

To effectively insulate the roof and exterior walls, either an insulating panel or insulated metal panels will achieve high R-values, a measure of a material's thermal resistance to heat flow, meaning the larger the value, the greater the thermal resistance, the greater the selected product's ability to aid in reaching the EnerPHit Certification. Comparing a high-performance insulating membrane and prefabricated insulated panels, the optimal product solution can be selected. The selected product will be used in combination with insulated doors and windows, and sealant, as per the EnerPHit Certification.

6.1.1.1 Design 1: Insulating Panels

Henery Blueskin VPTech is an integrated panel with weather-resistive barrier (WRB) that is installed under traditional siding and roofing, with continuous insulation, and seam sealing aimed to improve energy efficiency and reduce installation time and associate labour costs by up to 30%. The insulated panels are designed to withstand colder temperatures while acting as a secondary waterproofing layer for sloped roofs on commercial buildings protecting the building from heavy rainfall, ice, and air leakage. In reference to the Maintenance Facility location, the town of Georgina, Ontario experiences average winter temperatures of approximately -25˚C with heavy snowfall throughout winter months, Blueskin VPTech will actively combat ice dams and leakage [8].

With respect to economic feasibility, Blueskin VPTech is sold in panels that are 4'x12' at approximately $80 per panel. The surface area of the exterior walls and roof is roughly 14,500 ft^2, meaning the material cost of the product is roughly $36,250. Including labour and miscellaneous and miscellaneous material costs, the total cost is approximately $290,000.

In reference to the EnerPHit Certification, a building must not exceed 1.0 air changes per hour, tested at 50 Pa (1.0 ACH50). This information is gathered through a Blower Door Test, wherein the airtightness of a residential or commercial building is tested using a blower door fan to ensure the installation completed, and products selected are effective. With respect to Blueskin VPTech, on average, there is a significant decrease to 1.5 ACH50. Meaning, this insulator would be required to be used in combination with other stronger window and door sealants or insulators [9]. In addition, the VPTech insulating panels have an R-value of 10 total R-value of 22.5 at 2.25 inches thick. Wherein, the R-value is a measure of a material's thermal resistance to heat flow, meaning the larger the value, the more effective the insulation is at hold in conditioned air [10]. The value is required to be a minimum value of 24 as outlined by Natural Resources Canada under their Prefabricated Exterior Energy Retrofit initiative to improve the GHG emissions from commercial buildings [11]. Refer to Table 10 for the filled WEM.

Table 10: Building envelope Design 1 filled WEM.

Criteria	Description	Score	Weighted Score (/5)
Economic Feasibility	• A comparatively inexpensive solution, however, other materials to complete the roof and wall system will be required to be purchased.	5	15
Implementation Feasibility	• Installation requires multiple subtrades to complete full wall and roof system • More time consuming than a prefabricated system	3	12
Integration	• Independent from other building systems, however, does require other products to be used in combination including wall panels, roofing materials, miscellaneous.	3	15

Maintenance	• Blueskin has a 25-year warranty that ensures insulation and relative airtightness until the need for replacement. • After 25 years all components of the roofing and exterior wall systems would have to be replaced.	4	8
Effectiveness	• Does not meet the required EnerPHit Standards as 1.0 ACH50 is not achieved.	1	5
	Total		**55**

6.1.1.2 Design 2: Insulated Metal Panels

Kingspan metal insulated wall and roof panels offer a comprehensive solution to ensure airtightness, lowering the number of materials installed, and increasing longevity. Although metal roofing and wall panels have a higher capital cost in comparison to traditional layered wall and roofing systems, the paneling offers superior thermal performance that reduces annual energy consumption extending the overall life span of the building, HVAC systems [12] [13].

Metal roofing panels created by Kingspan have a total R-value of up to 46 while the wall panels have an R-value of up to 72, which is substantially higher than the minimum value of 24. These values vary slightly depending on the selected thickness of the panel. Kingspan offers a 30-year thermal performance warranty in addition to roofing and paneling being a cost-effective solution in comparison to traditional building materials due to the short installation time, and fewer required trades onsite, resulting in a reduction in construction time. In addition, with the installation of Kingspan panels the building can achieve air leakage rates as low as 0.08 ACH50 [14].

With respect to cost, Kingspan has an average cost per square foot of $26.64 per ft^2 in Toronto, Ontario which includes all labour and materials [15]. From the approximate total surface area, the total cost is $386,280. The cost of Kingspan is more than the estimated amount of Blueskin VPTech, the longevity and adherence to EnerPHit Certificate supersedes the larger cost. Refer to Table 11 for the filled WEM.

Table 11: Building envelope Design 2 filled WEM.

Criteria	**Description**	**Score**	**Weighted Score (/5)**
Economic Feasibility	• Higher principal and installation cost; however, the life span is longer and requires fewer personnel.	4	12
Implementation Feasibility	• Installation requires fewer subtrades to complete full wall and roof system	4	16

	• Less time-consuming than a traditional system with multiple components. • Requires specialized equipment, for example lifts, to install panels due to their weight.		
Integration	• Independent from other building systems and does not require additional materials to complete the system.	4	20
Maintenance	• Kingspan has a 30-year thermal performance warranty that ensures insulation and required airtightness until the need for replacement. • After 30 years the components may need to be replaced depending on ware.	5	25
Effectiveness	• Exceeds EnerPHit Standards as air leakage rates are as low as 0.8 ACH50.	5	25
		Total	**83**

In reference to both proposed design solutions to insulate the building roof and walls to achieve an airtightness of at least 1.0 ACH50, Kingspan prefabricated panels are the optimal solution.

6.1.2 Bay Door Upgrades

In addition to the roof and exterior wall upgrades, the six bay doors around the perimeter of the maintenance facility must be upgraded. To do this, two options have been considered, and are as follows.

6.1.2.1 Overhead Rolling Steel Bay Doors

Overhead rolling steel bay doors are a common industrial solution for high-cycle access points within a maintenance facility. They consist of interlocking insulated steel slats that coil around a barrel directly above the opening, making them ideal where ceiling clearance is a concern [16]. These insulated slats are typically constructed with double-layer galvanized steel and filled with CFC-free polyurethane foam insulation, which provides them with strong thermal resistance [17]. With these insulated steel slats, thermal resistance and air leakage are something to consider when choosing the appropriate option. To do this, R-values are calculated which measure how an insulating material resists heat flow, and U-values, which are calculated to measure heat transfer [16]. At Candoor Overhead Doors Ltd, manufacturers report rolling steel doors have panel R-values up to 8, which is quite high, with U-values of approximately $0.125\ W/m^2 * K$, meaning the panel material insulates well [17]. However, once the whole system is in place, U-values typically reach approximately $0.84\,W/m^2 * K$, due to perimeter leakage, and thermal bridging at the head box, and guide rails [17]. With air leakage values from 3 to 5 $m^3/h * m^2$, at 50 Pa, though upgraded seals can reduce leakage to near 1 $m^3/h * m^2$, at 50 Pa [17]. Rolling steel doors also offer robust cycle life, typically 50,000 to 100,000 cycles, and strong physical security [17].

EnerPHit requires a U-value $\leq 0.85\, W/m^2 * K$, and component air leakage (ASTM E283) $\leq 0.6\, m^3/h * m^2$ at 50 Pa for retrofit elements [2]. This means, most insulated rolling steel doors are only marginally compliant with U-value targets and typically fail airtightness requirements without secondary barriers [1].

Maintenance for rolling steel doors includes regular inspection and lubrication of rollers, drums, seals, and motors, with heavier maintenance frequency in high-use applications, like winter months within a maintenance facility [16]. Insulated costs generally range from $3,000 to $10,000 per door, depending on size, insulation, and automation features [17]. Meaning, total cost of material for all six bay doors may range from $18,000 to $60,000 excluding labour costs. Overall, overhead rolling steel doors provide durability, compact storage, and high security, but need additional air-sealing or insulating measures to comply fully with EnerPHit. Refer to Table 12 for the filled WEM.

Table 12: Building envelope overhead rolling steel bay doors filled WEM.

Criteria	**Description**	**Score**	**Weighted Score (/5)**
Economic Feasibility	• Inexpensive compared to other bay door options. • Have a long-life cycle and are strong, so replacement and maintenance would be infrequent.	4	12
Implementation Feasibility	• Rolling doors are typical for garage or bay doors, meaning the replacement of the current rolling doors would not require a specialized subtrade.	4	16
Integration	• The maintenance facility currently has rolling doors, meaning the current tracks may be reused.	5	25
Maintenance	• Rolling steel bay doors have a cycle life of 50,000 to 100,000 cycles with strong materials, meaning replacement will be infrequent. • Regular safety maintenance includes inspections and lubrication, especially during the winter months.	5	10
Effectiveness	• Compliant with EnerPHit Certification as the U-value is $0.84\, W/m^2 * K \leq 0.85\, W/m^2 * K$, but requires the addition of a secondary barrier to exceed air leakage.	4	20
		Total	**83**

After the completion of the matrices, it was determined that overhead rolling doors are the optimal design solution to minimize principal and maintenance costs, while complying with EnerPHit standards.

6.1.2.2 Bi-fold Bay Doors

Bi-fold Bay doors consist of hinged panels, often thermally broken aluminum frames with insulated or glazed panels, that fold outward from the building façade [18]. This design preserves internal headroom and maximizes clear opening, making them suitable for workshops or maintenance bays with large equipment and overhead cranes [18]. Once fully installed, high-performance bi-fold doors achieve U-values between 0.25 and 0.40 $W/m^2 * K$ and airtightness of $\leq 0.6\, m^3/h * m^2$ at 50 Pa when tested according to ASTM E283, fully meeting EnerPHit retrofit standards [19]. Cycle life typically ranges from 20,000 to 50,000 cycles, adequate for moderate-frequency operation [19].

The Swift Bi-Folding Door, a commercially available system, exemplifies the high-performance characteristics of this door type, as it is a side-hung, fast-acting, thermally insulated bi-folding door designed for industrial applications [19]. The door achieves a test U-value of $0.40\, W/m^2 * K$, with 52 mm thick insulated galvanized steel panels filled with CFC-free polyurethane foam. Meaning bi-fold doors would integrate seamlessly with EnerPHit Certification and NBCC requirements, as they meet the U-value target of $\leq 0.85\, W/m^2 * K$, for opaque elements and the airtightness requirement of $0.6\, m^3/h * m^2$ at 50 Pa, supporting envelope insulation and air barrier alignment [1]. Maintenance needs are more frequent and include hinge inspections, hydraulic or lift-strap servicing, and seal replacement as needed [19]. Insulated costs range from $7,000 to $15,000 per door, depending on size and control system, making them have a higher upfront cost, and slightly lower cycle life compared to overhead rolling steel doors. Meaning the total cost excluding labour for the 6 bay door ranges from $42,000 to $90,000.

Overall, bi-fold bay doors represent a balance between performance, durability, and operational efficiency for EnerPHit level retrofits, but have higher upfront costs and fewer cycles per life. Refer to Table 13 for the filled WEM.

Table 13: Building envelope swift bi-folding door filled WEM.

Criteria	**Description**	**Score**	**Weighted Score (/5)**
Economic Feasibility	• Higher cost in comparison to other bay door options and would require frequent replacement.	2	6
Implementation Feasibility	• Installation is not complex and does not require a specialized subtrade.	4	16

Integration	• The maintenance facility currently has rolling doors, and bi-fold doors can operate on the current tracks.	5	25
Maintenance	• Bi-fold doors have a cycle life of 20,000 to 50,000 cycles. Which is low compared to other product options, meaning replacement would be frequent. • Regular safety maintenance includes inspections and lubrication, especially during the winter months.	2	10
Effectiveness	• Exceeds EnerPHit Standards as the U-value is $0.6\, m^3/h * m^2 \leq 0.85\, W/m^2 * K$.	5	25
		Total	**82**

6.2 Mechanical and Electrical Systems

To achieve the EnerPHit targets Mechanical and Electrical Systems would need upgrades with the aim of minimizing the heating of the space, enhancing ventilation, and allowing future electrification with the ability to operate throughout the winter. The focus of EnerPHit is efficient heat production and mechanical ventilation with heat recovery, as well as better airtightness and envelope insulation, to achieve an average target of about 25 kWh per m^2 per year of heating demand and air tightness of close to 1.0 ACH50. Passive House Canada observed that retrofit projects under EnerPHit are usually associated with high performance insulation, better air tightness and heat-recovery ventilation systems to guarantee comfort and energy efficiency [20].

6.2.1 Space Heating, Cooling and Ventilation

In Georgina, Ontario, the winter design dry-bulb temperature is around 24 to 26 degrees °C and the amount for heating degree-days of an average of 4,500 the base was 18 degrees °C, meaning space heating, cooling and ventilation will be the greatest loads for this facility [21].

6.2.1.1 Design 1: Cold-Climate Air-to-Water Heat Pump with Hydronic Distribution and HRV/DOAS

In this first design option, the truck bay doors and occupied areas will be supplied with cold-climate air to water heat pump (AWHP), which replaces the current fossil fuel heating as the main heating source. The fan coil units, hydronic unit heaters and radiant floor loops in the truck bays would be constantly supplied with hot water. Canadian AWHPS have been designed specifically to work efficiently in cold climates and manufactures report AWHPS have a stable performance of up top -20 degrees °C and lower.

Natural resources Canada (NRCan) recommends air to water heat pumps as an appropriate solution to hydronic buildings and when they are well sized, they are much more efficient that electrical resistance or conventional boilers [22].

The AWHP is combined with a specific outdoor air system (DOAS) or a centralized HRV/ERV to help achieve EnerPHot requirements of the mechanical ventilation with heat recovery. Defined by Passive House and Canadian guidelines mechanical ventilation heat recovery (MVHR/HRV) efficiencies are 60-80% significantly lowering ventilation heating loads. NRCan identifies HRVs/ERVs as the technologies of choice in minimizing ventilation of buildings and energy star certified units are offer in Canada [22].

Both the NRCan's retrofit Hub and Ontario's Save on Energy Retrofit program recognize high efficiency HVAC and heat recovery upgrades as a measure for energy and emissions reduction. Refer to Table 14 for the filled WEM [22].

Table 14: Mechanical and electrical Design 1 AWHP Hydronic Heating with HRV/DOAS filled WEM.

Criteria	**Description**	**Score**	**Weighted Score (/5)**
Economic Feasibility	• Moderate capital cost due to new AWHPs, hydronic upgrades, and HRV.	3	9
Implementation Feasibility	• Requires significant mechanical changes and new distribution but no fuel change.	4	12
Integration	• Fully compatible with electrification, HRV, and EnerPHit performance goals.	5	25
Serviceability/ Maintenance	• More equipment and controls than existing, but all standard commercial products.	3	6
Reliability	• Good performance in cold climates, but limited redundancy in extreme events.	4	12
	Total		64

This option performed strongly in integration and long-term energy performance, making it a core part of the final design. However, the limitations in reliability during extreme cold led to adopting a hybrid approach with a backup boiler for the final solution.

6.2.1.2 Design 2: Hybrid Heat Pump + Condensing Gas Boiler Backup

The key heating system in this concept is the cold climate air source heat pump (air to air or air to water), which operates as the main heating system, with a high efficiency condensing gas boiler as backup and peak loads. For example, when it is below -20 degrees °C or during frost cycles [23].

Heat pumps can make twice or more efficiency improvements to overall conventual heating system and thus become cost effective over the long term when gas is used as backup. Although it is not as good as complete electrification, EnerPHit emphasizes on total space heating demand and primary energy. A heat pump is still used as the main source which will push the energy consumption and emissions down 50 - 70%, in combination with the enhanced envelope and efficient ventilation. This hybrid design gives a compromise between decarbonization and operational reliability which is very important for a facility that needs to maintain operational throughout the winter. Refer to Table 15 for the filled WEM.

Table 15: Mechanical and electrical Design 2 hybrid heat pump with gas boiler backup filled WEM.

Criteria	Description	Score	Weighted Score (/5)
Economic Feasibility	• Higher upfront cost than gas-only systems, but lifecycle savings from heat pump efficiency.	4	12
Implementation Feasibility	• Uses familiar boiler systems with added heat pumps, simplifying installation.	4	16
Integration	• Excellent compatibility with hydronic piping, plant layout, and staged electrification.	5	20
Serviceability/ Maintenance	• Two systems to maintain, but both are standard and widely supported.	3	6
Reliability	• Heat pump covers base heating; boiler ensures full reliability during extreme cold.	5	15
	Total		69

This concept scored highest overall because it balances electrification with operational reliability required for winter maintenance operations. Its strong performance in reliability and feasibility is the reason this hybrid strategy was selected as the final heating approach.

6.2.1.3 Design 3: VRF System for Offices with DOAS and Optimized Garage Ventilation

A variable refrigerant flow (VRF) system is used in office, locker and administration areas, in which it offers zoned cooling and heating, and in certain areas at the same time. A separate outdoor air system (DOAS) which has energy recovery is used to supply the occupied areas with 100% outdoor air with an independent ventilation which is not tied to sensible heating and cooling. The truck bay doors have powerful unit heaters (electric/hydronic) and demand-based exhaust/ventilation with CO_2 and NO sensors to ensure indoor air quality without wasting ventilation energy.

The save on energy documentation on commercial heat pumps list VRF as one of the standard high efficiency systems to be used in commercial retrofit, capable of providing zoning of heating/ cooling as well as can be used with DOAS [24].

This design offers a high comfort and controllability system in all areas of the building while the garage ventilation focuses on safety and operational practicality. Refer to Table 16 for the filled WEM.

Table 16: Mechanical and electrical Design 3: VRF for offices with dedicated ventilation filled WEM.

Criteria	**Description**	**Score**	**Weighted Score (/5)**
Economic Feasibility	• Higher cost than simpler systems due to VRF and DOAS equipment.	3	9
Implementation Feasibility	• Straightforward in office areas, but less practical to extend into large truck bays.	3	12
Integration	• Good integration for zoned office spaces and DOAS, but weaker fit for large garage heating.	4	20
Serviceability/ Maintenance	• Requires specialized VRF servicing, though products are common in commercial buildings.	3	6
Reliability	• Reliable performance in office zones; less suitable as a primary system for large open bays.	4	12
	Total		59

While VRF offered excellent controllability for office spaces, its weaker suitability for large truck bays made it a secondary solution. As a result, only the office VRF concept was incorporated into the final design, not a full-building VRF system.

6.2.2 Domestic Hot Water (DHW) Systems

DHW systems are domestic water heaters, which are compact devices designed to provide hot, running water on demand, which is essential for the facility.

6.2.2.1 Design 4: CO_2 Heat Pump Water Heater (HPWH)

The first design will use a CO_2 (R744) commercial heat pump water heater that will supply hot water for the whole facility. CO_2 HPWHs are specifically designed and engineered for cold climates to maintain performance [25].

The Canadian Trade sources report COP values between 1 and 3 for the HPWH which means it sues significantly less energy than gas or electric resistance systems [26].

These commercial scaled systems typically range from 40,000 - 80,000 CAD once installed. Energy star indicates that these heat pump water heaters can save 10,000 kWh per year which is around $1500/year [27]. Refer to Table 17 for the filled WEM.

Table 17: Mechanical and electrical Design 4 CO_2 commercial HPW filled WEM.

Criteria	Description	Score	Weighted Score (/5)
Economic Feasibility	• High capital cost but strong potential energy and emissions savings over time.	3	9
Implementation Feasibility	• Requires dedicated plant space and design effort, but packaged units are available.	3	12
Integration	• Aligns very well with fully electric DHW and EnerPHit decarbonization goals.	4	20
Serviceability/ Maintenance	• Specialized refrigerant and limited local expertise increase maintenance complexity.	2	4
Reliability	• Robust cold-climate performance, but reliant on specific OEM support and parts.	4	12
	Total		57

This option provides strong emissions reductions but has a much higher capital cost and more complex maintenance requirements. These limitations led to selecting a hybrid HPWH system instead of a full CO_2 system.

6.2.2.2 Design 4: Hybrid DHW - HPWH with Electric Backup

In this alternative, a smaller HPWH is used to supply base DHW demands and an electric gas-fired tank provides peak demands. A typical commercial HPWH (non-CO_2) system would current $2,500 - $5,000 CAD to install and a backup around $2,000 - $4,000 CAD, which makes this concept cheaper than an entire CO_2 based HPWH plant.

Hybrid configurations also have the advantage of having HPWH COP values (2-3) and the backup is needed because of extreme conditions

The design will emit less than gas-only systems and is also less expensive to capitalize on and easier to set up, which will offer an appealing solution in the course of phased electrification [28]. Refer to Table 18 for the filled WEM.

Table 18: Mechanical and electrical Design 5 hybrid DHW - HPWH with electric backup filled WEM.

Criteria	Description	Score	Weighted Score (/5)
Economic Feasibility	• Lower capital cost than a full CO_2 plant while still reducing operating energy use.	4	9
Implementation Feasibility	• Uses standard commercial HPWH equipment with a conventional electric storage tank.	4	16
Integration	• Works well with existing DHW distribution and supports staged electrification.	4	20
Serviceability/ Maintenance	• Uses common components with simple backup and straightforward replacement.	4	8
Reliability	• Heat pump serves base load, with an electric tank covering peaks and providing redundancy.	4	12
		Total	68

This option achieved one of the highest totals due to its low cost, easy installation, and strong integration with electrification goals. These advantages made it the selected DHW approach in the final design.

6.2.3 Electrical Distribution, Lighting and Controls

The heating and DHW electrification will necessitate the upgrade of the facilities service and distribution. Natural Resources Canada recommends integrating the two together [11].

6.2.3.1 Design 6: Electrical Service Upgrade and Panel Reconfiguration

The Ontario cost data suggests moderate commercial service and panel upgrades as usually ranging between $5,000 and $25,000 CAD based on the amperage enhancement, trenching and utility requirement [29].

This plan will have the capacity to include the heat pump and HPWHs feeders, and future rooftop PV and EV charging reserved conduits. These measures are in line with NRCan Retrofit Hub of the future proof infrastructure. Refer to Table 19 for the filled WEM.

Table 19: Mechanical and electrical Design 6 electrical service and distribution upgrade filled WEM.

Criteria	Description	Score	Weighted Score (/5)
Economic Feasibility	• Moderate cost but essential to enable future mechanical and DHW electrification.	4	12
Implementation Feasibility	• Standard commercial service and panel upgrades using familiar construction practices.	3	12

Integration	• Provides capacity for heat pumps, HPWHs, EV chargers, and future rooftop PV.	5	25
Serviceability/ Maintenance	• Once installed, panels and feeders have typical inspection and maintenance needs.	3	6
Reliability	• Increased service capacity and modern gear improve overall electrical system robustness.	4	12
		Total	67

This measure ranked highly in integration because full electrification requires expanded service capacity. Due to its necessity for supporting mechanical electrification, this upgrade was directly carried into the final design.

6.2.3.2 Design 7: LED Lighting and Retrofit and Basic Controls

Replacing all existing light fixtures with LED upgrades will reduce electrical load and complement mechanical electrification. NRCan list LED fixtures and ENERGY STAR certified luminaries as high impact measure for a retrofit [30].

Retrofit costs of commercial LEDs are usually $2-5 CAD/ft2, which translate to a cost of $30,000 - $60,000 CAD depending on fixture replacement. Ontario IESO and save on Energy programs offer incentives that will reduce the net cost. The implementation of LEDs will reduce energy use by 40 - 60% [31]. Refer to Table 20 for a filled WEM.

Table 20: Mechanical and electrical Design 7 LED lighting and controls retrofit filled WEM.

Criteria	**Description**	**Score**	**Weighted Score (/5)**
Economic Feasibility	• Low cost per square foot with strong energy savings and short payback.	5	15
Implementation Feasibility	• Fixture-for-fixture LED replacement with minimal disruption to operations.	5	20
Integration	• Reduces electrical loads and complements the electrified HVAC and DHW systems.	4	20
Serviceability/ Maintenance	• Long-life LED fixtures and drivers reduce maintenance frequency.	4	8
Reliability	• New technology with high reliability and strong manufacturer support.	5	15
		Total	78

This option scored the highest overall because of exceptional economic feasibility, ease of implementation, and major energy savings. It is fully adopted in the final design as a low-cost, high-impact upgrade.

6.2.3.3 Design 8: Building Automation System (BAS)

A BAS combined management of heat pumps and DOAS/HRV, garage ventilation, lighting and scheduling into automated smart system [32].

Industry data puts the cost estimate of a BAS installations of about $50,000 - $100,000 CAD in the case of a facility this size. The energy consumption of the whole building would typically be cut about 10-20% by properly configured BAS systems which increase the energy performance and operational reliability [33]. Refer to Table 21 for the filled WEM.

Table 21: Mechanical and electrical Design 8 building automation system integration filled WEM.

Criteria	Description	Score	Weighted Score (/5)
Economic Feasibility	• Moderate upfront cost with long-term savings from reduced energy use and better control.	3	9
Implementation Feasibility	• Requires integration and commissioning effort but uses standard BAS platforms.	3	12
Integration	• Provides unified control of HVAC, ventilation, DHW, and lighting for optimized operation.	5	25
Serviceability/ Maintenance	• Needs ongoing software support, firmware updates, and specialist technicians.	2	4
Reliability	• Improves overall system reliability when properly configured and maintained.	4	12
	Total		62

Although the BAS has moderate capital cost it scored very high in integration and reliability, making it essential to coordinate the electrified HVAC and ventilation systems. This is why it was included as part of the final M&E strategy.

6.3 Renewable Energy and Green Energy

In response to the building energy upgrades required to achieve EnerPHit Certification, the building must incorporate renewable energy generation methods, as well as strategies to reduce the facilities and occupants' dependency on fossil fuels.

6.3.1 Design 1: Solar photovoltaic (PV) systems

Mounting a solar PV system on the roof would offset a major portion of the building's yearly electrical usage while utilizing unused roof surface area. By generating electricity through solar power, greenhouse gas emissions are reduced, which in turn minimizes the building's carbon footprint. Producing renewable energy on-site is not only environmentally sustainable but may also enhance the reputation of the building and Entuitive.

For a larger home with higher energy demands, a solar system that produces 12,000 – 18,000 kWh annually, would typically cost from $25,000 to $35,000, depending on property specifics [34]. For businesses requiring 100-500 kW costs around $2.5 per watt of capacity installed [35]. Therefore, a 175 kW system may cost around $437,500. While the initial cost of solar panels is significant, the Ontario payback period is typically between 8 – 12 years [36]. After this period, free electricity is available for the duration of the panels, which is often 25 – 30 years [36].

The average peak sunlight in Ontario ranges from 3 to 4.5 hours per day [37]. Considering climate change impacts, specifically the reduction in cloud cover that has increased annual sunshine hours, an assumed average of 4 hours per day is used to estimate solar energy capture [38]. From there, the system will generate 700 kWh per day, resulting in a total energy production of 255,500 kWh per year.

A typical 450-watt panel typically weighs around 50 lbs, therefore 389 panels would be required. Typically, commercial solar panels are 6.5 ft by 3 ft, or 1.81 m^2 [39].

Installing solar PV system can also generate incentives. Systems less than 10 kW of current capacity are eligible for an incentive or rebate of $1000 per kW DC [40]. Systems greater than 10 kW can receive $860 per kW-AC. In turn, business rebates can cover up to 50% of eligible project costs [40]. Refer to Table 22 for the filled WEM.

Table 22: Renewable energy solar panels filled WEM.

Criteria	Description	Score	Weighted Score (/5)
Economic Feasibility	• Upfront investment but strong payback period with a long lifespan. • Eligible for rebates for up to 50% of the costs.	4	12
Implementation Feasibility	• Large roof space available.	4	16
Integration	• Rooftop mounting avoids interrupting other structures and nearby buildings. • Rood structural system and cladding may be reassessed.	4	20
Maintenance	• Cleaning a few times per year, or more based on weather conditions. • Infrequent professional inspections. • Popular demand for solar power has resulted in many trained personnel.	5	10
Energy Production	• Generates adequate supplemental power due to large roof area.	4	16

	• Energy dependent on power.		
Environmental Impact	• Requires metals and materials. • Lifetime carbon offset.	4	12
		Total	**86**

Based on the high scoring, 86, the facility will incorporate solar panels as an option for renewable energy generation.

6.3.2 Design 2: Kinetic Flooring

Kinetic flooring is an innovative renewable energy technology that converts the pressure and motion of foot traffic into electricity. It takes the vertical movement of each step and converts it into a rotational motion that drives a small generator, producing electricity. Different movements, such as walking or dancing, can generate between 1 and 10 Watts. This electricity is then stored for immediate or short-term use [41].

Kinetic flooring is a sustainable and renewable energy source that does not produce carbon emissions, contributing to a greener urban environment. By utilizing high-traffic spaces with heavy pedestrian foot traffic, the tiles can reduce dependence on local power infrastructure without needing additional land [42]. Visible, footstep-powered installations can inspire users to engage in energy conservation. Kinetic tiles depend on pedestrian traffic, which on its own produce little energy and can have variably [42]. Human traffic varies depending on the day, week, or even season. This renewable energy, as innovative and creative as it is, is still in the early stages of development and few electricians and engineers are trained in kinetic tile implementation [42].

At the Wurth Italy, Egna headquarters, kinetic floor tiles were installed to convert daily foot traffic into meaningful energy contributions. Approximately 400 visitors daily with an average of 1,200 steps of each day generated a notable amount of energy [41]. On average, each person can generate up to 7 Watts at 12 volts DC, enough to run an LED streetlamp for 30 seconds, or to partially charge a phone or laptop [43].

For the building retrofit, assuming 50 daily pedestrians, each taking 1,200 footsteps, at 7 watts per footstep, generates 420 kWh of energy each day. Assuming standard assuming standard 9:00 AM to 5:00 PM operating hours results in an average energy output of 52.5 kWh.

The city of Cambridge estimated that to purchase approximately 26 square meters (17 kinetic tiles) would cost $35,000 for the tiles and an additional $15,000 for installation [43].

Electricity during peak energy hours costs 39.1 cents/kwh [44]. Therefore, the cost of generating the equivalent amount of energy form the municipal grid would cost approximately $20.5.

Therefore, the payback period would take approximately working 2439 days. Refer to Table 23 for a filled WEM.

Table 23: Renewable energy kinetic flooring filled WEM.

Criteria	Description	Score	Weighted Score (/5)
Economic feasibility	• Costly solution, with payback period of approximately 7 years, excluding regular maintenance.	1	3
Implementation feasibility	• May require subfloor modifications. The floor must be able to withstand the weight, vibration, and foot traffic. • Implementation must not interfere with CSA structural standards.	2	8
Integration	• Requires energy connections. Can increase the power and electrical demand of the building.	3	15
Maintenance	• Requires specialized and trained personnel. • Requires frequent maintenance to remove debris from tile cracks and replaces tiles for frequent wear.	2	4
Energy production	• Produces little energy, 420 kw/day.	2	8
Environmental impact	• Materials must be mined and transported, generating emissions.	3	9
		Total	**47**

Due to the low scoring of 47 points for transforming kinetic energy, in comparison to the higher scoring for solar energy, this form of renewable energy will not be implemented in the facility.

6.3.3 Design 3: Battery Energy Storage

Incorporating a battery storage unit would allow peak shifting, minimize energy charges, and would promote serviceability during outages, allowing the facility to remain operational in major storms. Battery energy storage also supports regional net-zero targets, enabling green energy sources like nuclear, solar, and wind generation to store energy and distribute when needed [45].

Based on the selected renewable energy solution, a battery energy storage unit could capture excess energy and release when required. Ultimately, this would reduce the reliance on fossil fuels and lower carbon emissions. However, energy storage units have environmental impacts, due to the material extraction for metals that are mined. This can result in habitat damage and ethical labour concerns. Battery storage units must also be disposed of properly, such as through recycling programs, to reduce overall waste.

For a medium commercial facility, typical capacity is between 200 to 500 kWh, with a cost range of $400 to $450 per kWh [46]. Assuming the most conservative range, the system should cost approximately $ 225,000, with an additional 20% for installation and commission, resulting in a total cost of $ 270,000 [46]. Refer to Table 24 for the filled WEM.

Table 24: Renewable energy battery energy storage filled WEM.

Criteria	**Description**	**Score**	**Weighted Score (/5)**
Economic feasibility	• Costly system but ultimately necessary to maximize efficient and capacity of on-site renewable energy source.	4	12
Implementation feasibility	• Follows manufacturer instructions. • Requires adequate land space. • Requires the use of a crane and construction equipment to install.	3	12
Integration	• Must meet fire and safety codes for battery storage units attached to buildings, such as the Ontario Electrical Safety Code, the Ontario Fire Code, NFPA855, and UL9540. • Must not be located where flooding could occur. • Must have space surrounding it to allow for ventilation.	2	10
Maintenance	• Requires regular maintenance and inspections. • Must be inspected by trained personnel.	3	6
Energy production	• Does not produce energy, but conserves renewable energy, ultimately increasing the efficiency of on-site energy production.	2	8
Environmental impact	• Materials are mined and often shipped internationally. • Applicable components must be properly sorted and recycled.	3	9
		Total	**57**

The battery storage unit will be integrated into the system to maximize solar energy.

6.3.4 Design 4: Electric Vehicle (EV) Charging Stations

To prepare the site for electrification with the anticipated increase of electrical vehicles (EVs), incorporating EV charging stations will be necessary to support long-term decarbonization objectives. Overnight charging in fleet depots and charging at destination locations such as warehouses and industrial buildings is expected to play a critical role in the electrification of medium and heavy-duty vehicles [47].

While EV charging stations promote the use of renewable energy sources, the associated materials have their own set of environmental impacts. The construction and maintenance of charging infrastructure require metals, concrete, and plastics. The extraction, processing, and transportation of such resources also requires energy and often results in habitat degradation and pollution. When selecting a company to source EV infrastructure from, it is crucial to ensure that materials are sourced sustainably and that they can be recycles to reduce the ecological footprint of charging station deployment [48].

In Ontario, typically costs of installing an EV charging stations for electric single occupancy vehicles range from $1,500 to $3,000 [49]. Such costs include the charger unit, installation by a licenced electrician, and potential extra work for upgrades and maintenance. Additional costs for permits and custom work may vary. Multiple EV charging options exist; level 1, level 2, and level 3, increasing with efficiently and performance.

To accommodate the rapid turnaround time of commercial vehicles, level 3 chargers will be installed, which have a 25-30 min charging time and require a DC outlet [50]. Entuitve has suggested implemented four to eight chargers, but since level 3 chargers will be used, six chargers will be implemented, accounting for future growth without excessive spending. Various sources suggest that level 3 EV charging stations can cost around $ 200,000 per port, including installation, with a power output from 50 kW to 500 kW [51] [52].

Costs will vary depending on the distance to the power source, installation complexity, and any infrastructure upgrades required to support the charging stations. Several programs exist to support EV infrastructure development, including the EV Charger Incentive Program by Green Economy Canada, which offers financial rebates for public charging stations and light-duty fleet infrastructure [53]. These programs can fund between 50% to 70% of total eligible project costs, subject to specific funding caps [53]. The Zero Emission Vehicle Infrastructure Program provides funding for EV charger deployment in public spaces, on-street, at workplaces, and for vehicle fleets with a maximum contribution of 50%, up to a maximum 5 million per project [54].

Based on the installation of six level 3 EV chargers that have a power output of closer to 400 kW, the design will cost around 1.2 million dollars. If 50% of these costs are eligible for funding, the net project cost would be approximately $600,000. The payback period for EV fast chargers typically ranges from 3 to 7 years but can be reduced to 5 to 3 years with government grants, subsidies, and high usage [55]. Refer to Table 25 for the filled WEM.

Table 25: Renewable energy electric vehicle infrastructure filled weighted evaluation matrix.

Criteria	Description	Score	Weighted Score (/5)
Economic feasibility	• High installation cost but short payback period. • Can qualify for government incentives and grants	3	9
Implementation feasibility	• Installing EV chargers is straightforward for trained personnel.	5	20
Integration	• The EV charging station must function within the electrical capacity of the building. Based on the energy demand, a service upgrade may be required.	4	20
Maintenance	• Requires regular maintenance from trained electricians who are regularly available.	4	8
Energy production	• No energy production but promotes renewable energy over fossil fuel consumption.	3	12
Environmental impact	• Materials and transportation requirements for EV deployment can result in habitat destruction and pollution. • Sourcing sustainable and recycling materials can help mitigate such impacts.	3	9
	Total		**78**

Based on the current demand for EV infrastructure and the high scoring of this system, EV infrastructure will be implemented for the building retrofit.

6.4 Water Efficiency

To reduce the facility's water consumption and overall dependence on municipal water, the following sections outline alternatives systems designed improve the sustainability of the retrofit.

6.4.1 Design 1: Greywater recycling

Greywater comes from bathroom sinks, showers, tubs, and washing machines. Greywater does not include water that has come into contact with feces, but it may have come into contact with food, grease, hair, or cleaning products [56]. To plants, greywater can be a valuable fertilizer, as opposed to lakes, where it is a pollutant. As a result, greywater is commonly used to irrigate vegetation and could even be used for truck washing or power washing. Greywater reuse provides economic benefits, as the required water supply will depend less on the municipal water supply.

A study conducted by Colorado State University showed that greywater reuse with simple methods like buckets in residential homes provide a potential water saving of up to 13% of total water use compared to rainwater harvesting, which only saves up to 5% [57]. This is largely due to greywater providing a steady water source, even during the summer months when little to no rain occurs.

For indoor use, greywater require treatment, or disinfection at a minimum. Systems for indoor greywater reuse require special plumbing features, to allow for backflow prevention. All systems must be installed by a certified plumber and maintenance is vital.

At the commercial level, it is often easiest to treat all the budling’s wastewater, which includes blackwater and greywater. Membrane bioreactor systems are used to treat, store, and reuse the wastewater for toilet flushing, irrigation, and cooling systems. An advanced system like this reduces the fresh water taken from the municipal water supply up to 75% [58]. This method also decreases energy costs associated with plumbing.

A regular greywater recycling system collects wastewater from showers, bathtubs, sinks, and laundry machines, and diverts it to a separate pipe system. Collected water is filtered to remove larger particles, such as scum and hair. The water is then disinfected and is stored for reuse [59]. For retrofits, plumbing is adjusted so the greywater flows via dedicated pipes to the recycling system. Systems can be installed in utility rooms, garages, or workshops. To meet the demand of users, there are even apps that can connect to the system to ensure it is working well. The Hydraloop H600 is an excellent example of a recycling system that costs $14,095, based on a quotation from a sales representative, and saves up to 45% of water use with a storage of 600 L [60].

Overall, greywater reuse can vary based on complexity and cost. Simple solutions can be quite affordable, but are less efficient, whereas more advanced systems provide greater water savings at a higher cost with technical expertise requirements.

The scoring for this system is based on a greywater reuse recycling system that plans for future needs and technology, such as the Hydraloop H600. Refer to Table 26 for the filled WEM.

Table 26: Water efficiency greywater recycling system filled WEM.

Criteria	Description	Score (/5)	Weighted Score
Economic feasibility	• Costly solution with long payback period.	2	6
Implementation feasibility	• Recycling system is simple to install, however requires dedicated piping system.	3	12
Integration	• Fits in well with the current building design and can easily be stored in the garage.	5	25
Maintenance	• Requires expertise and regular serviceability and maintenance.	3	6
Water reuse/conservation	• Saves up to 45% of freshwater use.	4	12
	Total		**61**

The greywater recycling system will be implemented in the facility's retrofit to reuse water and promote sustainable and efficient water practices.

6.4.2 Design 2: Rainwater Harvesting

To harvest rainwater, roof runoff from the large catchment area could be collected in a cistern to be reused in either vehicle washing or possibly landscaping [61]. Any water that is used for car washing, must be kept in a controlled location to prevent car wash pollutants from entering any sources that could lead to bodies of water, preventing unnecessary contamination of ecosystems and fish habitats [62].

A drawback for rainwater harvesting is that it can be inconsistent due to droughts during summer months, and heavy snows during winter months. Therefore, rainwater may not be an effective year-round supply, as it will not be regularly replenished [63].

Since the roof of the building is already sloped, any rainwater will naturally roll off. A conveyance system comprised of channels and pipes can direct collected rainwater to the cistern. It is crucial to design an easily accessible conveyance system to ensure it can be easily repaired or inspected during regular maintenance. Cisterns can be installed below grade for aesthetic and convenience.

The general formula for determining how much rainfall can be captured is for every one millimetre of rain that falls across a square meter of the roof catchment area, one litre of water can be captured. The roof catchment area of the building is approximately 724.8 m^2 and Georgina receives approximately 787 mm of annual rainfall [64]. In theory, the building will collect approximately 570,418 L per year. Unfortunately, not all rain is collected, as some rainfall will be lost due to leaks, absorption, evaporation, and heavy rains resulting in overflow. An adjustment for losses can be made, by assuming 30% is lost. As a result, the true maximum rainfall collection is closer to 399,293 L. This annual rainfall is not feasible to collect, therefore the rainwater harvesting system could simply collect from a designated portion of the catchment area, to accommodate truck washing, irrigation, power washing, and other cleaning needs.

The Sustainable Technologies Evaluation program estimated for the design of a 50,000 L rainwater harvesting system with a below-ground concrete cistern to cost approximately $90,590, as seen below Table 27.

Table 27: Rainwater Harvesting cost approximation.

Break Down		**Cost**
Pre-Construction		$655
Materials and Installation		$77,664
Project Management and Overhead		$8,299
Excavation		$2,751
Inspections		$1,221
	Total	**$90,590**

The scoring for this system is based on the implementation of a 50,000 L below-ground concrete cistern design, as seen in Table 27.

Table 28: Water efficiency rainwater harvesting system filled WEM.

Criteria	**Description**	**Score**	**Weighted Score (/5)**
Economic feasibility	• Rather expensive solution that requires regular maintenance with unknown costs. • Could have economic impacts on nearby structures, especially with below ground structure.	1	3
Implementation feasibility	• System requires a below ground concrete structure. • Requires a conveyance system that cannot interfere with nearby structures to capture roof runoff.	2	8

Integration	• Below ground cistern will need to be approved of by an engineer to confirm it does not impact the soil bearing capacity for the building or nearby roads.	3	15
Maintenance	• Requires trained and specialized personnel. • Does not require frequent maintenance, other than cleaning.	4	8
Water reuse/conservation	• Has the capacity to conserve at least 50,000 L of water. • Roof catchment area has the capacity to catch additional water; therefore, based on future demand, a second cistern could be implemented.	5	25
		Total	**59**

The rainwater harvesting system will also be implemented to capture roof runoff and reduce the dependency on the municipal water supply.

6.4.3 Design 3: Fixture Upgrades

Small upgrades can be implemented to reduce overall water consumption. For kitchen faucets, the installation of an aerator whose flow rate is less than 7.0 L/min [65]. In bathrooms, a faucet aerator would use less hot water. To reduce the amount of potable water wasted, faucets that deliver less than 4.7 L/min of water could be installed [65]. A low-flow toilet that uses 4.8 L or less per flush can be installed to further reduce potable water use. If a washing machine is present, a model with ENERGY STAR certification can save 25% more energy and use 33% less water than a standard model [65]. Low-flow fixtures can cost as low as $50 for a toilet, showerheads for $12, and faucets closer to $20 [66]. There exist five toilets, two showers, and six faucets that require replacing, totaling a cost of $394. Refer to Table 29 for the filled WEM.

Table 29: Water efficiency fixture upgrades filled WEM.

Criteria	Description	Score	Weighted Score (/5)
Economic feasibility	• Very low-cost solutions, however current fixtures may not have achieved their payback period yet.	5	15
Implementation feasibility	• Design fixtures can easily replace old fixtures.	5	20
Integration	• Fits well with the rest of the building and don't not require specialized equipment.	5	25

Maintenance	• Requires little to serviceability/maintenance and don't not require specialized personnel.	5	10
Water reuse/ conservation	• Fixture dependent water conservation but does not reuse water.	2	10
	Total		**80**

Overall, these are inexpensive solutions to reduce overall water usage and can easily be paired with an additional solution.

7.0 Retrofit Solution

The final retrofit design for the York Region North District Road Maintenance Facility integrates building envelope upgrades, with high-efficiency mechanical and electrical systems, renewable energy production, and water-efficiency strategies into a unified solution. Collectively, the measures outlined in this section are projected to reduce annual site energy consumption by 45-60%, decrease infiltration by 70-85%, and support future net-zero readiness through electrification and on-site renewable generation [67] [68].

7.1 Building Envelope

The following section will discuss building envelope upgrades.

7.1.1 Exterior Walls and Roof

The selected enclosure upgrade utilizes Kingspan insulated metal panels for both the exterior walls and roof, forming a continuous, thermally efficient, airtight assembly. These panels provide substantially higher R-values than the existing construction and eliminate thermal bridging through their interlocking, gasketed connection system. Their installation creates a continuous thermal layer that aligns with EnerPHit standards for thermal performance and airtightness.

On the roof, the insulated panel retrofit will be paired with a continuous adhered air and vapour barrier, to ensure long-term durability and airtightness, while strengthening the structural capacity required to support the future rooftop solar PV array. The combined wall and roof upgrades are expected to reduce the facility's heating load by approximately 25-30% and achieve the target infiltration rate of ≤ 1.0 ACH50 [2].

7.1.2 Bay Doors

The facility's six bay doors are at large, the main source of uncontrolled air leakage within the facility. To address this, the final design replaces the existing roll-up systems with insulated overhead rolling steel doors engineered for high-cycle industrial use. These doors, equipped with insulated slats, improved perimeter sealing, and enhanced guide-rail interfaces, significantly reduce uncontrolled infiltration. Secondary air sealing at the head box, jambs, and sill further integrates the door system into the upgraded air barrier. With this improvement, infiltration losses through the bay doors are expected to decrease by 40-60%, providing substantially more stable temperature conditions in the truck bays.

7.2 Mechanical & Electrical

The proposed Mechanical and Electrical (M&E) retrofit is designed to meet the EnerPHit and Net Zero Carbon standard while ensuring reliability for a winter maintenance facility. Based off the preliminary designs and matrices this design solution organizes the building into three mechanical systems space heating/cooling, ventilation, and domestic hot water and then upgrades the electrical and control systems to support full electrification.

7.2.1 Mechanical System

Below are the mechanical system upgrades.

7.2.1.1 Building and Truck Bay Heating

The facility is heated through a central hydronic loop that distributes hot water to all major zones. This loop is supplied primarily by two Mitsubishi Ecodan CAHV-P500YA-HPB cold-climate air-to-water heat pumps, each providing approximately 45 kW of heating capacity and delivering water temperatures between 25-70°C, even under outdoor temperatures approaching -20°C. These units are installed on grade-mounted concrete pads adjacent to the mechanical room to avoid additional roof loading and simplify maintenance.

To ensure operational reliability during extreme cold weather or during heat pump defrost cycles, the system includes a high-efficiency Lochinvar Crest FBN-1500 condensing boiler. This unit provides 96-98% thermal efficiency and serves as a redundant, peak-load heating source, enabling the facility to maintain a 95% operational uptime target during winter storms.

In the truck bays and wash bay, the existing gas-fired infrared heaters are removed and replaced with hydronically supplied Modine HSB unit heaters. These units provide uniform, controllable heating that integrates seamlessly with the central hydronic loop. Ventilation within the bays is controlled through a network of CO and NOx sensors that automatically modulate exhaust fans in response to vehicle activity. makeup air is tempered through the HRV/DOAS system to minimize heat loss during high ventilation periods.

7.2.1.2 Office and Support Space Conditioning

Administrative areas are conditioned using Rheem RQRM commercial split-system heat pumps, which provide both heating and cooling through existing ductwork. These systems offer improved energy efficiency compared to the existing equipment and enable independent zone control for office, locker, and meeting areas.

7.2.1.3 Mechanical Ventilation System

Ventilation air is supplied by a centralized Lifebreath 2000EFD commercial heat recovery ventilator, designed to deliver approximately 2,000 CFM of outdoor air with a heat-recovery efficiency of around 65% [69]. Installed on a new roof curb, the HRV recovers thermal energy from exhaust air to reduce heating loads by 40-50% relative to the current system. The HRV/DOAS integrates into the BAS to allow scheduling, optimization, and fault detection.

7.2.1.4 Domestic Hot Water System

The domestic hot water system follows a parallel strategy to the space heating system by combining high-efficiency heat pump technology with a resilient backup system. The primary source of hot water is an A.O. Smith CAHP-120 heat pump water heater, which achieves a coefficient of performance of approximately 4.2 and significantly reduces energy consumption [70]. An electric resistance storage heater provides redundancy and manages peak loads, ensuring reliable hot water supply for wash bays and staff facilities.

7.2.2 Electrical System

Below are the electrical system upgrades.

7.2.2.1 Electrical Service Expansion

To support the electrified heating systems, HRV/DOAS, EV charging infrastructure, battery storage, and PV system, the building’s electrical service is upgraded to a 600-amp, 600-volt, three-phase service [71]. Distribution panels are reconfigured with dedicated feeders to each major mechanical system, ensuring adequate capacity and flexibility for future expansion [67].

7.2.2.2 Lighting and Controls

All interior and exterior fixtures are replaced with high efficiency LED luminaires, including Lithonia I-BEAM high-bay fixtures for the truck bays. These fixtures deliver significantly higher luminous efficacy and longer service life, while occupancy sensors, photocells, and programmable schedules further optimize electrical consumption.

7.2.2.3 Building Automation System

A BACnet-based building automation system coordinates the operation of the heat pumps, condensing boiler, HRV/DOAS, domestic hot water system, battery storage, and lighting. Through optimized equipment staging, setpoint scheduling, and real-time monitoring, the BAS is expected to reduce overall energy consumption by 10-20% while improving operational visibility and reliability [72].

7.3 Renewable Energy

Following the building envelope upgrades; renewable energy sources will be discussed next.

7.3.1 Solar PV System

The renewable energy strategy Envera chose to move forward with, incorporates a rooftop solar PV array sized to approximately 175 kW, which is expected to generate roughly 255,500 kWh annually based on Ontario's average peak sunlight hours. This offsets an estimated 20-30% of the facility's total electrical consumption after mechanical electrification. The array is positioned to avoid shading, maintain access clearances, and distribute structural loading consistently. Electrical integration allows the PV system to supply energy directly to building loads or charge the battery storage system.

7.3.2 Power Charging Stations

To support future fleet electrification, the design includes infrastructure for six level 3 DC fast-charging stations capable of serving both single-occupancy vehicles and municipal fleet vehicles. The upgraded electrical service accommodates the high instantaneous demand of these chargers, while new conduit routing and protective elements allow chargers to be installed without major future construction. With anticipated federal incentives covering up to half of eligible costs, the chargers contribute meaningfully to long-term decarbonization objectives.

7.3.3 Battery Energy Storage

To manage peak demand store excess solar production, and maintain operational reliability during winter storm events, a medium scale battery energy storage system, sized in the range of 200-500 kWh, will be installed. The system is housed in a dedicated, code-compliant enclosure designed in accordance with NFPA 855, UL 9540, and the Ontario Electrical Safety Code. By reducing peak demand charges and increasing self-consumption of solar energy, the battery storage system is expected to lower operating costs and improve power resilience for critical winter operations.

7.4 Water Efficiency

Lastly, water efficiency additions will be discussed.

7.4.1 Greywater Recycling

A hydraloop Cascade greywater recycling system is implemented to treat water from showers and sinks for reuse in toilet flushing. This system reduces potable water consumption by up to 45% and integrates into the facility's new plumbing configuration with minimal disruption.

7.4.2 Rainwater Harvesting

Rainwater from the upgraded insulated metal roof is collected and routed to a below-grade 50,000 L concrete cistern. With annual rainfall volumes providing up to 400,000 L of recoverable water after losses, this system supports wash bay pre-rinsing, irrigation, and non-potable cleaning functions.

7.4.3 Fixture Upgrades

All fixture groups, including toilets, urinals, faucets, and showerheads will be replaced with high-efficiency, low-flow models. These upgrades will provide immediate reductions in water consumption of 15-20% with minimal maintenance requirements and no impact on staff operations.

7.5 Preliminary Design Calculations

With the addition of building envelope, renewable energy, mechanical and electrical, and water efficiency system upgrades, the structural elements of the maintenance facility were analyzed to ensure affected columns, beams, and girders could adequately support the additional loads. The original steel-framed building was designed to meet past versions of the NBCC, meaning it must now be assessed against the NBCC 2020 and the Canadian Standards Association (CSA) S16, Design of Steel Structures 2014.

7.5.1 Solar PV System

The renewable energy strategy Envera chose to move forward with, incorporates a rooftop solar PV array sized to approximately 175 kW, which is expected to generate roughly 255,500 kWh annually based on Ontario's average peak sunlight hours. This offsets an estimated 20-30% of the facility's total electrical consumption after mechanical electrification. The array is positioned to avoid shading, maintain access clearances, and distribute structural loading consistently. Electrical integration allows the PV system to supply energy directly to building loads or charge the battery storage system.

7.5.2 Mechanical System Alterations

The existing rooftop packaged HVAC unit, Carrier 48TJ009, possessing a weight of approximately 600 kg, which was located above the office core, will be removed. It is replaced with grade-mounted heating pumps and one new rooftop HRV, a Lifebreath 2000EFD HRV, weighing approximately 400 kg in the same rooftop location.

7.5.3 Structural Loading

Prior to assessing structural members, the additional and updated dead, live, and snow loads were determined. The area of the roof was determined to be approximately 725 $m^{2,}$ wherein the weight of the solar panels, Kingspan prefabricated panels, and the RTU HRV would apply pressure. In addition to dead loads, the live loads of the maintenance facility were determined and selected as it operates as an office space with regular occupancy. Further, the snow load accounting for the ground snow load of Georgina, Ontario, was used to compute the snow load from Equation 1 as stated in the NBCC 2020 [4] [73] [74]. The remaining coefficients and final load calculations are highlighted in Figure 13 in Appendix E: Structural Calculations.

Equation 1: NBCC 2020 Snow Load.

$$S = I_s[S_s(C_b C_w C_s C_a) + S_r]$$

The totals of varying load pressures are shown in Table 30.

Table 30: Dead, live, and snow loads acting on the maintenance facility.

Dead Loads				
Product	**Weight**	**Units**	**Pressure**	**Units**
KingSpan Quadcore - 91 mm thick	7900.32	kg	0.107	kPa
Solar Panel Weight	8819.65	kg	0.119	kPa
Lifebreath 2000EFD HRV Weight	400	kg	0.005	kPa
Total			**0.232**	**kpa**
Live Load				
Roof	-	-	1	kPa
Office Space			4.8	kPa
Snow Load				
S - Georgina, Ontario			**1.66**	**kPa**

As all lateral roof pressures were determined, Table 4.1.3.2-A NBCC 2020 was used to determine the governing load combinations. In each case D, L, and S were used to denote the dead, live, and snow loads, respectively. Load Case 2 governed, as highlighted in Table 31.

Table 31: Load combinations for the roof.

Load Combinations			
Case 1	1.4D	0.33	kPa
Case 2	**1.25D + 1.5L +1.0S**	**3.45**	**kPa**
Case 3	1.25D + 1.5S +1.0L	3.78	kPa

From the governing total load pressure of 3.45 kPa, analysis of the columns, girders, and beams was completed.

7.5.4 Structural Analysis

Within the steel structure, three classifications of columns support the axial load: the corner, edge, and interior columns, each with varying tributary areas. The corner and interior columns are W200x21 columns, while the edge columns are W200x27, each with an average unbraced length of 2200 m, and an assumed yield strength of 350 MPa. The applied axial load and resistance of each column type were determined and are highlighted in Figure 14 in Appendix E: Structural Calculations. As the applied axial load was less than the axial resistance of each column, the column sizes are adequate to support the additional loads as summarized in Table 32 below.

Table 32: Applied axial load and compression resistance values for column types.

	Corner W200x21	Edge W200x27	Interior W200x21	Units
Applied Axial Load	42.5	36.3	157	kN
Compression Resistance	498	639	498	kN

With respect to beams and joists, each carried and supported the applied loads. Joists span across the four bays of the facility, reinforced at the midspan, each with varying lengths with respect to bay size. The resulting factored moments from the applied loads were determined and are highlighted in Figure 15 in Appendix E: Structural Calculations. Each joist spanning the bays is simply supported and will support the additional loads, considering the applied factored moments range from approximately 8.4 to 11 kN/m, substantially less than the moment resistance for a structural steel joist.

The roof system is also composed of W200X21 and W200X27 exterior and interior beams, respectively, each 6 m in length, and an assumed yield strength of 350 MPa. The exterior beams carry the factored uniformly distributed loads (UDLs) from the roof dead loads, in addition to the resulting support reactions from the girders and are laterally braced throughout the length. In contrast, the interior beams support the reactions of girders from two bays, doubling the applied loading. As the loading patterns are the same for both types of beams, the shear force and bending moment diagrams will follow the same pattern as shown in Figure 1, where the peak of the parabolic bending moment diagram is the location of the maximum applied load, which must be less than the determined moment resistance.

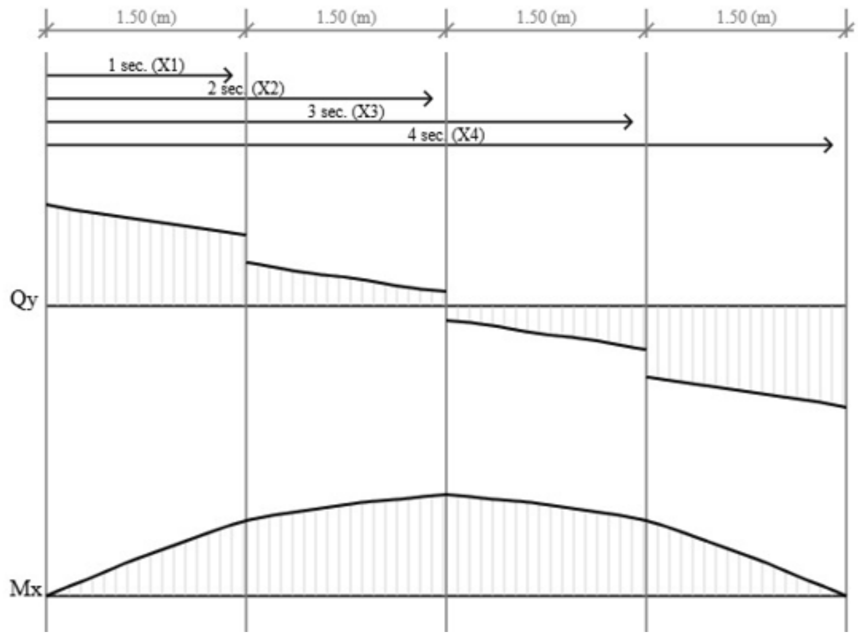

Figure 1: Shear Force Diagram and Bending Moment Diagram of interior and exterior beams.

In addition to the interior and exterior roof beams, the second-floor office core is supported by W410x39 beams, located in the most Eastern Bay of the facility. The beams carry both the dead and live loads from the roof and from the office space, as highlighted in Table 30.

To calculate the moment resistance of each beam, the classification of the web and flange for each cross-section was determined and is highlighted in Figure 16 and Figure 17 in Appendix E: Structural Calculations for the roof and second storey beams. The classification of the section in buckling was determined using Table 2 in CSA S16:9, shown in FIGURE [75]. As each beam was determined to be at least a Class 2, was used to determine the moment resistance, calculated using Equation 2 as stated in Clause 13.5 of the NBCC [4].

Equation 2: Class 2 moment resistant equation, NBCC 2020.

$$M_r = \varphi_s Z_x F_y$$

The comparison between the applied moment and the moment resistance is shown in Table 33 below, while the applied factored moments highlighted in red exceed the members' determined moment resistance, meaning additional reinforcement must be installed to ensure building safety.

Table 33: Beam applied moment and moment resistance comparison.

Moment Type	Variable	Exterior W200x21	Interior W200x27	Second Floor W410x39	Units
Applied Factored	M_f	111	197	193	kNm
Resistance	M_r	64.6	83.0	217	kNm

To adequately support the additional applied loads, welded steel bracing will be applied to increase the moment resistance of these members.

7.6 Building Retrofit Carbon Emissions

Envera is committed to estimating carbon emissions from the earliest stages of the retrofit process to identify opportunities for improvement and support the project's long-term decarbonization goals. In Canada, buildings account for 28% of energy use and 26% of greenhouse gas emissions [76]. By incorporating carbon emissions at the preliminary design stage, the identified system can be optimized, and further improvements can be made as Envera advances with the design process.

7.6.1 Building Envelope Emissions Estimate

The building envelope subassembly consists of Kingspan metal panels, which have an embodied carbon value approximately 28% lower than insulated concrete and tilt-up concrete alternatives [77] [77]. A study of a 150,000 ft^2 warehouse in Philadelphia demonstrates the environmental performance of Kingspan metal panels over a 60-year life cycle, showing a total carbon value of 247,7777.85 kg CO_2 for the full facility [77]. For the Entuitive facility, the required panel surface area is approximately 14,500 ft^2, resulting in a proportional carbon estimate of 23,951.9 kg CO_2.

The insulated overhead rolling steel doors will further reduce overall carbon emissions use by improving thermal performance and minimizing heating and cooling emissions. However, the embodied carbon associated with steel manufacturing remains highly significant. The total door surface area is 144.06 m^2, and with an assumed thickness of 5 cm, the estimated volume is near 7.203 m^3. Assuming the density of steel to be 2.7 g/cm^3, the doors weigh approximately 19.45 tonnes. According to IEA estimates, steel production generates 1.4 tons of CO_2 for every ton of steel produced [78], resulting in an embodied carbon value of approximately 27.23 tonnes, or 27,227.34 kg CO_2, for the rolling steel doors.

7.6.2 Mechanical & Electrical Emissions Estimate

The retrofit involves replacing all major fuel-burning systems with high-efficiency electric equipment, with the result of 75-85% reduction in operational GHG emissions. Heating is exclusively provided by two Mitsubishi CAHV Air to Water Heat Pumps so that minimal natural gas is consumed, but a condensing boiler is used for peak loads, adding negligible residual emissions. The Lifebreath HRV, Rheem office heat pumps and A.O. Smith heat pump water heater further reduce energy demand while LED lighting and BAS controls reduce electrical use by an additional 15-20%.

The mechanical and electrical subassembly incorporates a heat pump that produces approximately 1,404 kg CO_2 annually, along with a backup generator for winter months and defrost cycles, which contributes an additional 2,500 kg CO_2 annually [79]. When assessing the carbon emissions generated from the office VRF system, the main source of carbon emissions is generated from the R-410A refrigerant, which has a total lifecycle of 1924 kg CO_2 [80] .

The Energy Star certified DHW system enables the unit to use approximately 15% less energy than conventional commercial systems through efficient heat exchange processes [81]. A typical natural-gas system emits around 33,000 kg CO_2 annually; therefore, with Energy Star certification, emissions can be reduced to approximately 28,050 kg CO_2 annually. To further minimize this impact, Envera is assessing the feasibility of a solar water heating system, which would reduce annual emissions to approximately 643 kg of CO_2 annually. This value will be used for subsequent carbon emission estimates.

Upgrading the facility's lighting system to LED will reduce electricity-related carbon emissions, as LEDs consume 50 – 70% less energy than traditional lighting systems [82]. Industrial buildings typically consume around 7 kWh per ft^2 annually for lighting [83]. The two-storey facility includes a second-floor area of 184 m^2 and a first-floor area of 720 m^2. Therefore, the total usable interior space that requires lighting is near 20,494.5 ft^2. Using the established benchmark, the facility's lighting demand is estimated at 143,461.4 kWh annually. Applying Ontario's average grid emission factor of 53 g CO_2 per kWh results in operational emissions of approximately 7,603 kg CO_2 annually [84]. Accounting for manufacturing emissions, and taking a conservating approach, the total embodied and operational lighting emissions are approximately 3,801.7 kg annually.

The BAS system collects data from sensors throughout the building to optimize the M&E performance. It effectively reduces carbon emissions by establishing thresholds, schedules, and controls for heating, lighting, and other building operations, ensuring that energy is used efficiently. As noted previously, BAS upgrades can reduce building energy by approximately 20% annually. For comparison, if the facility is assumed to operate similarly to a supermarket, it has an annual energy consumption of 5,000 WMHh (5,000,000 kWh) [85]. Ontario's average grid emission factor converts this to approximately 265,000 kg CO_2 annually. Applying a 20% reduction results in an annual emission value of approximately 212,000 kg CO_2 [85]. This represents the estimated carbon emissions associated with the facility once the BAS optimization is implemented.

7.6.3 Renewable Energy

PV systems, or solar panels, have steadily increased in efficiency from 14.0% in 2007 to 20.9% in 2024, while their life-cycle carbon emission have decreased from 76 g CO_2 per kWh to 36 g CO_2 kWh [86]. This life cycle accounts for manufacturing, transport, operation, and end-of-life management. Taking a conservative approach, the life cycle will be approximated with 76 g CO_2 per kWh.

Battery storage units, by contrast, have higher carbon emissions due to the significant mining and refining of sourced materials, battery material production, cell production, and battery pack assembly. The cell production and pack assembly consume the most electricity. For battery packs produced using 100% renewable electricity and recycled materials, carbon emissions range from 0 – 60 kg CO_2 per kWh [87]. When including the full battery life cycle, this increases to approximately 59 – 119 kg CO_2 per kWh.

The embodied carbon emission with producing a single DC fast charger is approximately 1,287 kg CO_2 [88]. The operational emissions from EV charging are not produced by the charger itself, but by the electricity generation at the local power grid. Emissions can be reduced by implementing selective charging, where charging occurs during lower periods of lower grid carbon intensity [89]. This would reduce EV emissions from 35 to 56 g of CO_2 per km to 28 to 40 g CO_2 per km [89].

Assuming a fleet vehicle travels 400 km a day, it produces 16,000 g CO_2 a day. Therefore, assuming each charger charges at least four fleet vehicles a day, the total emissions associated with electricity production for those vehicles would be approximately 64 kg CO_2 per day.

7.6.4 Water Efficiency

The water efficiency subassembly also carries its own embodied and operational carbon emissions. For the greywater recycling system, there is no information available for the carbon emissions generated during the manufacturing process of the Hydraloop H600 model; however, the integrated unit's annual power consumption of 460 kWh was provided. For this assessment, that value was assumed to represent the entire life cycle, including operational, and associated premise plumbing. Given that Ontario emits an average of 53 g CO_2 per kWh, the greywater recycling system produces approximately 24.38 kg of CO_2 per year [84].

Based on a study from the Environment Agency in England Wales, a rainwater harvesting system with a 40,000 L tank embodies 23,908 kg of CO_2, while a 60,000 L tank embodies 33,487 kg CO_2 [90] . These emissions are attributed to tank production, plumbing infrastructure, and transportation [90]. The average between the two values was used to approximate Envera's 50,000 L below ground concrete cistern.

Assuming that at least four showers are taken per day using standard fixtures, total emissions increased to 4,535.92 kg CO_2 annually [91]. It is assumed that light hand washing, and other water use can be negligible. Table 34 shows a breakdown of the estimated carbon emissions for the systems that were implemented.

Table 34: Summary of estimated carbon emissions from the proposed subassembly designs.

System	**Notes**	**Carbon footprint (kg)**	**Time**
Building Envelope			
Insulated metal Panels	Estimated based an industrial warehouse with Kingspan metal panels.	23,951.90	Life Cycle
Steel Bay Doors	Approximated using the carbon emissions generated from steel production.	27,227.30	Life Cycle
Mechanical and Electrical			
Heat Pump	Based on environmental impact assessment of heat pumps.	1,404	Annual
Back Up Boiler	Based on environmental impact assessment of boilers.	2,500	Annual
VRF for Offices	Approximated using emissions generated from the R-410A refrigerant.	1.924	Life Cycle
Domestic Hot Water	Back-calculated from the efficiency of electrified hot water systems. Envera will improve the system moving forward with upgrading the system to a solar water heating system.	643	Annual
Facility Lighting	Estimated electricity using the benchmark of an industrial building consuming 7 kWh per ft^2 for lighting alone. Applied the 20% saving due to the implemented BAS system.	3,041.36	Annual
Renewable Energy			
Solar panels	Solar panels consume 36 g CO_2 per kWh.	252	Daily
Battery Storage Unit	Battery storage units generate 119 kg CO_2 per kWh across its lifecycle, assuming the most conservative approach.	59,500	Life Cycle
Level 3 EV Chargers	Production creates 1287 kg CO_2 per charger. There are six chargers.	7,722	Production

Electricity Generation	Average carbon emissions generated from the EV stations. Assuming four trucks per charger driving 400 km daily. 64 kg CO_2 per charger per day.	384	Daily
Water Efficiency			
Greywater Recycling	Based on the provided 460 kWh and applying the Ontario power grid conversion of 53 CO_2 g per kWh.	24.38	Annual
Rainwater Harvesting	Estimated from a rainwater harvesting report with a 40,000 L and 60,000 L below-ground concrete cistern.	28,697.5	Life Cycle
Fixtures	Electricity generated based on showers, equating to 907 kg of CO_2 annually; other fixtures may be negligible. Assuming four showers per shower daily.	3,628.70	Annual
Total CO_2 over a 60-year life cycle		14,749,987	

Over the 60-year minimum lifespan of the facility, the estimated carbon emissions approached 15 million kg. With a longer lifespan, efficiency increases.

Systems generating higher carbon emissions will be evaluated to consider their trade-offs. Envera will review the backup boiler and determine what alternatives could be implemented to provide a reliable option without compromising the project's environmental impact. Envera will begin this assessment by exploring smaller systems.

The rainwater harvesting system will also be reviewed. Since the below-ground cistern uses concrete, other, more sustainable materials will be explored. Moving forward, Envera proposes implementing the innovative Net-Zero Carbon Concrete, which reduces carbon-intensive cement [92]. Contractors and sales representatives will be contacted

8.0 Budget for the cost of the project

Combining all system components together, the final retrofit design is projected to cost $3,384,207.60. Considering there was no budget constraint, Envera kept costs reasonable while selecting components, and well within various retrofits completed in the past. A breakdown of each systems cost can be found in Table 35 below.

Table 35: Estimated total retrofit design cost.

System Components	Price

Building Envelope		
• Roof and Wall Panels (14,500 ft2 total)		$386,280
• Overhead Rolling Steel Doors (6 total)		$18,000 - $60,000
	Total	**$446,280**
Mechanical and Electrical		
• Air-to-Water Heat Pumps (2 units) [93]		$140,000
• Backup Boiler System [94]		$65,000
• Hydronic Distribution (Truck/Wash Bays)		$80,000
• Hydronic Unit Heaters [95]		$20,000
• Truck Bay Exhaust System		$60,000
• Office Heat Pumps (3 units) [96]		$56,000
• HRV Ventilation System [97]		$60,000
• Domestic Hot Water System [98]		$38,000
• Electrical Service Upgrade [99]		$280,000
• Lighting Retrofit [100]		$85,000
• Building Automation System [101]		$90,000
	Total	**$974,000**
Renewable Energy		
• Solar PV System		$437,500
• Battery Energy Storage		$270,000
• EV Charging Stations		$600,000
	Total	**$1,307,500**
Water Efficiency		
• Greywater Resue		$14,095
• Rainwater Harvesting		$90,590
• Fixture Upgrades		$394
	Total	**$92,393**
Project Totals		
	Subtotal	**$2,820,173**
	20% contingency	$564,034.60
	Total Cost	**$3,384,207.60**

9.0 Preliminary Risk Assessment

When looking ahead, an early-stage evaluation of risks associated with the final retrofit design must be considered to ensure overall safety of all system components, and implementation down the line.

9.1 Risk Details

The final retrofit design incorporates significant modifications to the facility's exterior walls, roof assemblies, bay doors, energy sources, mechanical and electrical systems, and water efficiency. The most notable risks relate to the constructability challenges during panel installation, airtightness performance of new rolling steel bay doors, roof capacity for the PV system, the increased demand associated with EV charging, heat pumps, and HRV systems. However, all systems will be addressed as potential risks. To assess these risks, a rating between 1 (lower risk), 2 (moderate risk), and 3 (higher risk) will be given out for each system under a specific criterion. A description of each rating can be seen in Table 36 below.

Table 36: Risk assessment rating.

Rating	Description
1 = Lower Risk	Lower risk means there is a low probability of underperformance, minimal operational impact, low-cost sensitivity, routine maintenance, and straightforward installation. These components are reliable, use proven technologies, and pose little risk to facility operations if issues arise. An example would be standard interior lighting or fixture upgrades. If a light fails, it can be quickly replaced without affecting operations or requiring specialized skills.
2 = Moderate Risk	Moderate risk means there is a medium probability of underperformance, noticeable operational impact, moderate cost sensitivity, scheduled or occasional specialized maintenance, and moderate installation complexity. These components may involve newer technology or require coordination with other systems, meaning failures could disrupt operations temporarily and require some expertise to resolve. An example would be bay doors with tight air-tight requirements. If installation is imperfect, it could affect indoor climate control or energy efficiency, requiring some corrective work.
3 = Higher Risk	Higher risk implies there is a significantly high probability of underperformance, significant operational impact, high-cost sensitivity, intensive maintenance requirements, and complex or specialized installation. These components are critical to facility operations or rely on advanced technology, and failures could cause major disruption, safety concerns, or large financial impacts. An example of this would be the battery energy storage system or electrical service expansions. A failure could halt operations, require costly repairs, and demand specialized technicians for troubleshooting.

To further categorize each system's risk, it will be assessed on the probability of underperformance, impact on facility operations, cost sensitivity, maintenance demand, and installation complexity.

Probability of underperformance measures the likelihood that a component or system will fail to meet its design specifications, operational expectations, or performance targets, as outlined in section 7.0 Retrofit Solution. Therefore, high probability indicates a component is more likely to fail or underperform during its service life.

Impact on facility operations assesses the severity of consequences to facility functionality if a component fails or underperforms. Components with high operational impact could cause significant disruptions, reduce productivity, compromise safety, or interrupt critical processes. Low-impact components may fail without noticeably affecting daily operations.

Cost sensitivity evaluates the financial implications associated with the failure, repair, or replacement of a component, which includes initial installation costs, ongoing operational costs, and potential unplanned expenses in the event of malfunction. High-cost sensitivity indicates that a failure would result in substantial financial impact.

Maintenance demand reflects the level of routine and ongoing maintenance required to ensure reliable operation of the component. Components with high maintenance demand require frequent inspections, specialized expertise, or intensive preventive measures to avoid failure. While on the other hand, low maintenance demand indicates minimal ongoing effort is required.

Lastly, Installation complexity measures the difficulty associated with integrating a component into the facility. Factors include structural modifications, coordination with other systems, precision requirements, safety considerations, and the need for specialized labor or equipment. High complexity indicates that installation is challenging and may require specialized planning or expertise. A completed assessment of each component and criterion ranking can be seen below in Table 37**.**

Table 37: Completed preliminary risk assessment.

1 = Lower Risk 2 = Moderate Risk 3 = Higher Risk					
Component	**Probability of Underperformance**	**Impact on Facility Operations**	**Cost Sensitivity**	**Maintenance Demand**	**Installation Complexity**
Exterior Walls & Roof	**1**	**2**	**2**	**1**	**2**
Bay Doors	**2**	**2**	**2**	**2**	**2**

Solar PV System	2	2	3	1	3
EV Charging Stations	2	3	2	2	2
Battery Energy Storage	1	2	3	1	2
Building & Truck Bay Heating	2	3	2	2	2
Office & Support Space Conditioning	1	2	2	1	2
Mechanical Ventilation	2	2	2	2	2
Domestic Hot Water System	1	2	2	1	2
Electrical Service Expansion	2	3	3	2	3
Lighting & Controls	1	2	2	1	1
Automation System	2	3	2	1	2
Greywater Recycling	2	2	2	2	2
Rainwater Harvesting	2	1	2	2	2
Fixture Upgrades	1	1	1	1	1

From the table above, it is apparent that a few components rise concerns when it comes to risks, specifically the electrical service expansion. However, most other components stay within the low to moderate risk category which is expected.

9.2 Mitigation

To manage the risks identified within the retrofit design, targeted mitigation strategies will be applied to each system. For the exterior walls and roof, a detailed structural and thermal assessment will be performed before installation. Quality-assurance protocols, including continuous thermal and air leakage testing will be implemented throughout the installation process to ensure performance targets are met. This approach reflects the recommended practice in Natural resources Canada's major retrofit guidance, which emphasizes choosing measures that demonstrable savings and working with qualified contractors.

In the case of bay doors, mitigation will focus on off-site prefabrication, which helps streamline the installation process and reduce on-site complexity. After-install testing for airtightness and door operation will verify that the installed system meets performance requirements. As well, staff training for operation and upkeep will further reduce risk over the doors service life.

To reduce risk associated with the solar PV system, a structural roof assessment in section 7.5 Preliminary Design Calculations can be referred to, to communicate the buildings safety in supporting the added load. Only certified panels and mounting hardware will be used, and a real-time performance monitoring system will be installed to detect underperformance early. Regular maintenance, including cleaning and electrical inspections, will also help maintain expected energy yield and avoid systemic failures.

For the EV charging stations, integration with the facility's electrical system will be carefully coordinated to avoid service disruption. Standardized, modular charging equipment will be selected to simplify installation and maintenance. Staff will receive training on safe usage and fault response, and a maintenance schedule will be established with regular diagnostics to reduce downtime.

Because battery energy storage systems pose higher operational and safety risks, installation and commissioning will strictly follow manufacturer guidelines. A fire and safety monitoring system will be incorporated, with continuous diagnostics and protective mechanisms. Maintenance will be conducted by trained personnel, and redundancy in control systems (e.g., alarm systems) will ensure early detection of any issue.

To mitigate risk for building and truck bay heating, the HVAC and heat pump system will be sized based on detailed load calculations. After installation, commissioning tests will verify system capacity and efficiency under load, while periodic maintenance and performance monitoring will ensure long-term reliability.

Upgrades to office and support space conditioning will be supported by detailed HVAC-design modeling and commissioning. Controls and set points will be optimized for energy efficiency without compromising occupant comfort, and operations staff will be trained on both day-to-day operation and preventative maintenance tasks.

The mechanical ventilation system will undergo commissioning to validate design airflow and filtration under real-world conditions. A maintenance plan with scheduled filter replacements and inspections will help sustain performance, and staff will be trained on basic maintenance tasks to avoid underperformance.

For the domestic hot water system, certified and appropriately sized units will be used, and post-installation testing will verify water delivery, temperature regulation, and leak-free operation. A maintenance schedule will be established that includes periodic inspections and performance checks to minimize operational risk.

Addressing electrical service expansion, a detailed load analysis and phased implementation plan will reduce the risk of service interruption. QA/QC processes will be put in place to guarantee the installation meets design tolerances, and protective devices will be installed to safeguard against overcurrent or fault conditions. After completion, periodic inspections and testing will verify system integrity.

Mitigating lighting and controls risk involves using proven, energy-efficient fixtures and control systems. Before commissioning, the controls will be preprogrammed and functionally tested to ensure compatibility. These measures align with retrofit best practices that emphasize low-risk, high-benefit interventions.

For the automation system, risk will be reduced through early system integration and rigorous testing. Subsystems (HVAC, PV, energy storage, etc.) will be connected in a test environment before deployment to catch incompatibilities. Staff will receive training in operation and troubleshooting, and routine updates will be scheduled to maintain system stability.

In the case of greywater recycling, certified filtration and plumbing components will be used to ensure water quality and system safety. System commissioning will include flow and contamination testing, while a regular maintenance schedule for cleaning filters and inspecting pumps will help avoid underperformance.

Rainwater harvesting risk will be mitigated by sizing tanks and piping according to local precipitation data, installing overflow and filtration mechanisms, and planning regular maintenance for tanks and filters. These steps minimize the risk of system failure or contamination.

Finally, for fixture upgrades, standardized, proven products will be chosen to limit complexity. Installation will follow established construction practices and be accompanied by basic QA inspections to ensure correct implementation. Because these upgrades are relatively simple, the mitigation strategy primarily focuses on ensuring quality control and consistency.

10.0 Innovation

To enhance Enveras platform, and maintain project management, it was necessary to include an innovative aspect to the project.

10.1 Website

The team has developed and designed the website for Envera (envera.ca) as a central point of management of the project as well as key deliverables for the client to access. The website serves as a system that pulls together all the project deliverables, documentation and progress updates into a single and covenant place. This will make the client and stakeholders informed and aware of constant developments in the project life cycle.

The site also improves transparency and accountability through a systematic description of the timelines, milestones, and outputs. It is also a dynamic communication tool between project teams and external partners. This makes it much easier for information to be shared and coordinated effectively.

Besides being used as a management platform, the team is also developing a flagship Retrofit Processor, the feature of which is aimed at supporting early works in retrofit planning and assessment for clients to reduce costs on initial assessments of buildings to better understand feasibility of any project.

The home screen of the site as shown in the figure below is the website's home screen which emphasizes clarity, accessibility and modern design to reflect Envera's vision and identity.

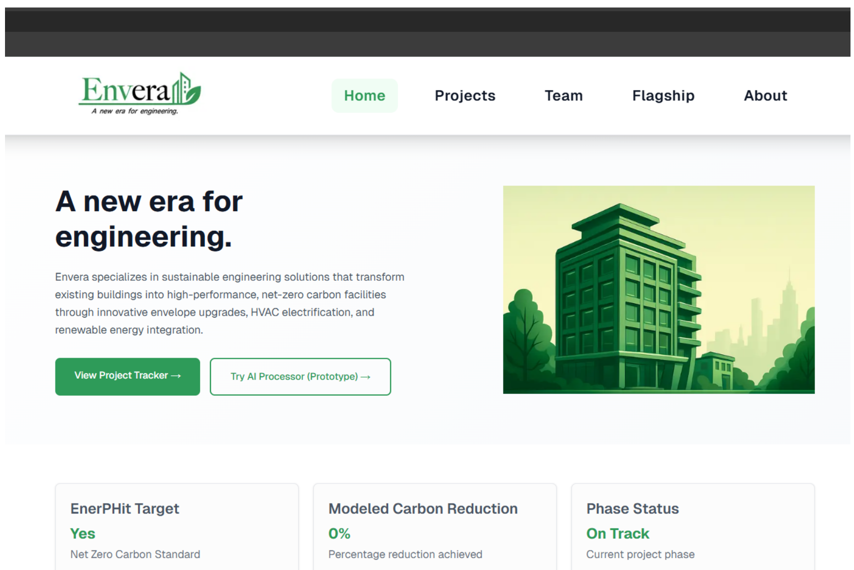

Figure 2: Envera's website homepage.

11.0 Conclusions

The work Envera has completed, demonstrates substantial technical progress toward delivering a coordinated and feasible deep energy retrofit for the York Region North District Road Maintenance Facility. Through detailed subsystem analyses, iterative design development, and a rigorous weighted evaluation process, Envera has established a retrofit strategy that not only addresses EnerPHit performance requirements but also responds to the operational demands, climatic conditions, and structural constraints of a functioning municipal maintenance facility.

The selected envelope design, high-performance Kingspan insulated metal panels paired with upgraded overhead rolling steel bay doors, was chosen based on its superior airtightness (approaching 0.08 ACH50), robust thermal performance, and seamless constructibility within the existing steel-frame building. This solution directly targets one of the facility's most significant sources of heat loss, the six 24 m² bay doors, while reducing long-term maintenance and ensuring the envelope can reliably support EnerPHit-level performance. Mechanical and electrical system upgrades were evaluated extensively with respect to heating demand, cold-climate reliability, and integration with future electrification goals. The hybrid air-to-water heat pump system with a high-efficiency condensing boiler backup was selected due to its ability to balance low-carbon heating with the uninterrupted operational reliability required for winter road maintenance. Complementary mechanical upgrades, including HRV-based ventilation, DOAS for the office zones, updated electrical distribution, and LED lighting with BAS controls, collectively reduce energy consumption while improving indoor environmental quality and maintaining compatibility with the existing service configuration.

The incorporation of renewable energy systems strengthens the facility's transition toward net-zero readiness. Preliminary PV analysis confirms that the proposed rooftop solar array, paired with battery energy storage, can offset a significant portion of the facility's annual electrical load while simultaneously enhancing resilience during outages. The planned DC fast chargers further support York Region's long-term fleet electrification strategy, enabling the site to adapt to evolving municipal transportation needs. Water-efficiency upgrades, including a combined greywater recycling and rainwater harvesting system, deliver measurable reductions in potable water demand, support sustainable site operations, and align with contemporary municipal and provincial conservation priorities.

The structural assessment completed, verifies that the proposed retrofit measures, including PV loading and rooftop mechanical equipment, can be supported by the existing steel framing with negligible reinforcement. This confirmation significantly strengthens the feasibility of the selected design and reduces anticipated retrofit costs and construction complexity.

Overall, the integrated retrofit solution developed in this progress phase positions Entuitive and the York Region Roads Department to achieve meaningful reductions in operational carbon emissions, improved thermal comfort, enhanced system reliability, and long-term adaptability.

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Appendix A: Work Breakdown Structure

Figure 3 illustrates a visual representation of the Envera Gantt chart, with the activities, deliverables, and milestones for each of the five identified phases.

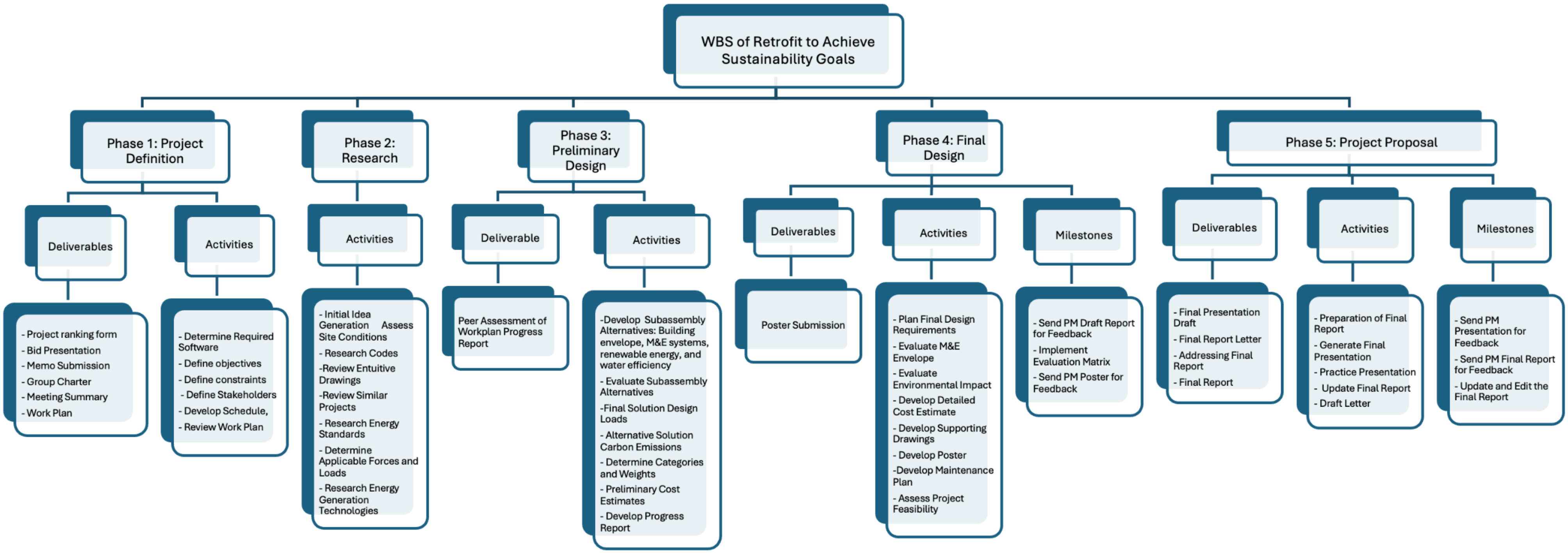


Figure 3: Work breakdown structure (WBS) for Envera.

Appendix B: Gantt Chart with Responsibilities

Figure 4, Figure 5, and Figure 6 demonstrate proposed timeline of Envera with tasks identified as a deliverables, an activity, or a milestones, with an associated task leader.

CIVL 460 - Group E - Gantt Chart

Project Start Date:	2025-09-08
Printed Gantt Chart Date:	2025-11-18

Legend
Activity
Deliverable
Milestone

Task Name	Category	Task Lead	Reviewer	Progress	Start	Days
Phase 1: Project Definition						
Project Ranking Form	Deliverable	Lily	All	100.00%	08-Sep	1
Bid Presentation	Deliverable	Sophia	All	100.00%	09-Sep	1
Memo Submission	Deliverable	Rheya	All	100.00%	10-Sep	1
Group Charter	Deliverable	Lily	All	100.00%	19-Sep	1
Meeting Summary to Clients	Deliverable	Rheya	All	100.00%	26-Sep	1
Determine Required Software	Activity	Jordan	Lily	100.00%	26-Sep	1
Define Project Scope	Activity	Sophia	All	100.00%	26-Sep	8
Define Objectives	Activity	Sophia	All	100.00%	26-Sep	8
Define Constraints	Activity	Rheya	All	100.00%	26-Sep	8
Define Stakeholders	Activity	Sophia	All	100.00%	26-Sep	10
Develop Project Schedule	Activity	Lily	Sophia	100.00%	26-Sep	10
Review and Edit Work Plan	Activity	Lily	All	100.00%	30-Sep	9
Work Plan Submission	Deliverable	Jordan	All	100.00%	09-Oct	1
Phase 2: Research						
Initial Idea Generation	Activity	Jordan	All	100.00%	26-Sep	10
Assess Site Conditions	Activity	Sophia	Rheya	100.00%	28-Sep	7
Research Applicable Codes	Activity	Rheya	Lily	100.00%	28-Sep	7
Review Entuitive Drawings	Activity	Jordan	Sophia	100.00%	28-Sep	7
Review Similar Projects/Case Studies	Activity	Jordan	Rheya	100.00%	28-Sep	12
Research Energy Standards	Activity	Lily	Rheya	100.00%	28-Sep	12
Determine Applicables Loads and Forces	Activity	Sophia	Jordan	100.00%	30-Sep	12
Research Energy Generation Technologies	Activity	Lily	Rheya	100.00%	04-Oct	12
Phase 3: Preliminary Design						
Peer Assessment of Workplan	Deliverable	All	All	100.00%	17-Oct	1
Develop Progress Report	Activity	Sophia	All	100.00%	15-Oct	30
Develop Subassemblies	Activity	Jordan	All	100.00%	15-Oct	1
Determine Categories and Weights	Activity	Rheya	All	100.00%	15-Oct	2
Develop M&E Alternatives	Activity	Jordan	Sophia	100.00%	15-Oct	5
Develop Envelopppe Alternatives	Activity	Rheya	Sophia	100.00%	15-Oct	5
Develop Renewable Energy Alternatives	Activity	Lily	Sophia	100.00%	15-Oct	5
Develop Water Efficiency Alternatives	Activity	Lily	Sophia	100.00%	15-Oct	5
Evaluate Subassembly Alternatives with WEM	Activity	All	All	100.00%	20-Oct	3
Evaluate Solution Design Loads	Activity	Sophia	Jordan	100.00%	23-Oct	14
Alternative Solution Carbon Emissions	Activity	Lily	Rheya	100.00%	23-Oct	14
Preliminary Cost Estimates	Activity	Jordan	Sophia	100.00%	11-Nov	5
Send PM Progress Report for Feedback	Milestone	Rheya	All	0.00%	18-Nov	1
Progress Report	Deliverable	Jordan	All		21-Nov	1

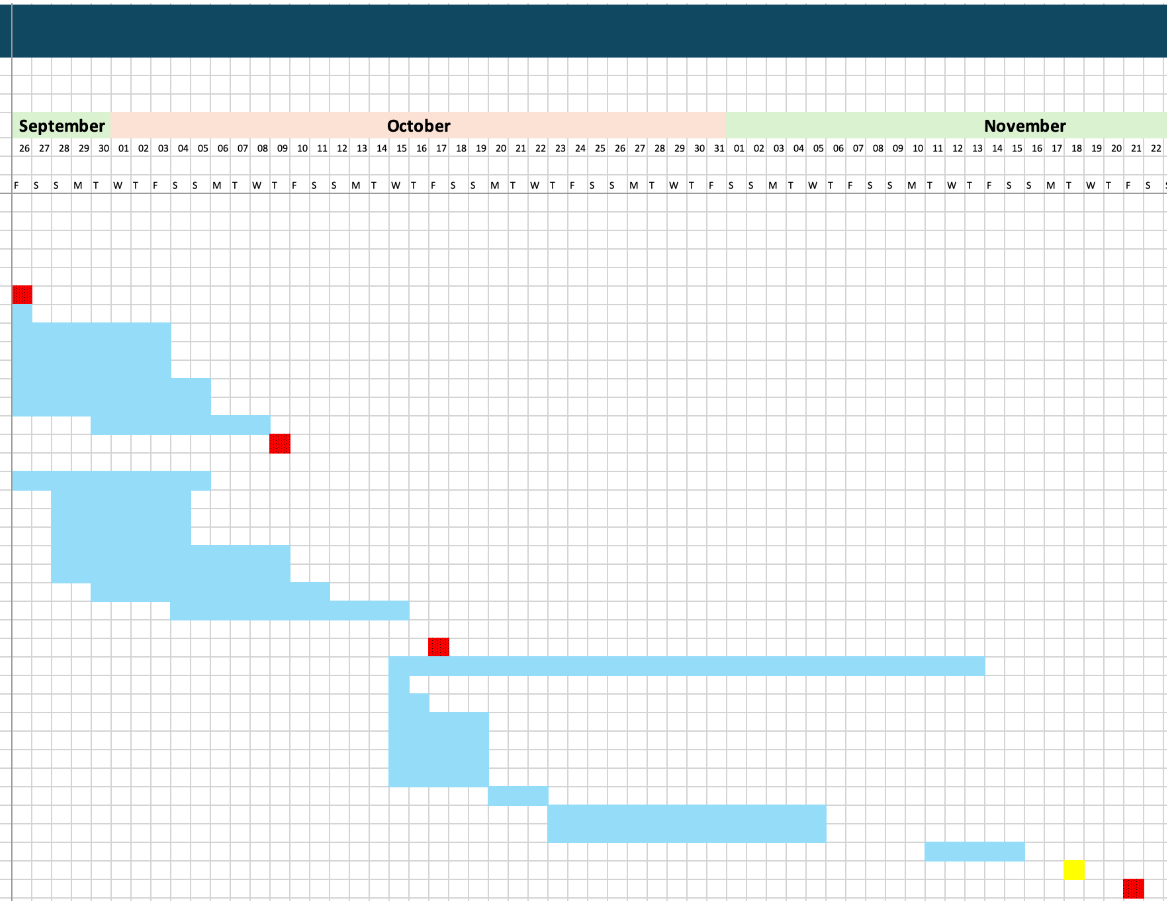


Figure 4: Gantt Chart with designated team leads and reviewers for Phase 1, Phase 2, and Phase 3 from September 26th to November 22nd.

CIVL 460 - Group E - Gantt Chart

Project Start Date:	2025-09-08
Printed Gantt Chart Date:	2025-11-18

Legend	
Activity	
Deliverable	
Milestone	

Task Name	Category	Task Lead	Reviewer	Progress	Start	Days
Phase 4: Final Design						
Plan Additional Final Design Requirements	Activity	Lily	All		21-Nov	2
Detailed Evaluation of the M&E Envelope	Activity	Jordan	Sophia		23-Nov	6
Detailed Environmental Impact Assessment	Activity	Lily	Rheya		25-Nov	7
Develop Detailed Cost Estimate	Activity	Jordan	Sophia		02-Dec	10
Develop Supporting AutoCAD Drawings	Activity	Sophia	Rheya		02-Dec	10
Develop Poster	Activity	Lily	All		02-Jan	10
Send PM Poster for Feedback	Milestone	Lily	All		05-Jan	1
Poster Submission	Deliverable	Lily	All		12-Jan	1
Develop Maintenance Plan	Activity	Sophia	All		13-Jan	5
Assess Project Feasibility	Activity	Rheya	All		15-Jan	4
Leeway for Edits	Milestone	Lily	All		19-Jan	14
Phase 5: Project Proposal						
Preparation of Final Report	Activity	Rheya	All		28-Jan	50
Generate Final Presentation	Activity	Sophia	All		21-Feb	6
Send PM Presentation for Feedback	Milestone	Jordan	All		27-Feb	1
Practice Final Presentation	Activity	Sophia	All		05-Mar	5
Final Presentation	Deliverable	Rheya	All		11-Mar	1
Draft Final Report	Deliverable	Lily	All		20-Mar	1
Update Final Report Based on Draft	Activity	Lily	All		23-Mar	16
Send PM Final Report for Feedback	Milestone	Rheya	All		28-Nov	1
Draft Letter	Activity	Rheya	All		09-Apr	7
Update and Edit Final Report / Leeway	Milestone	Jordan	All		11-Apr	5
Letter Addressing Final Report	Deliverable	Sophia	All		17-Apr	1
Revised Final Report	Deliverable	Lily	All		17-Apr	1

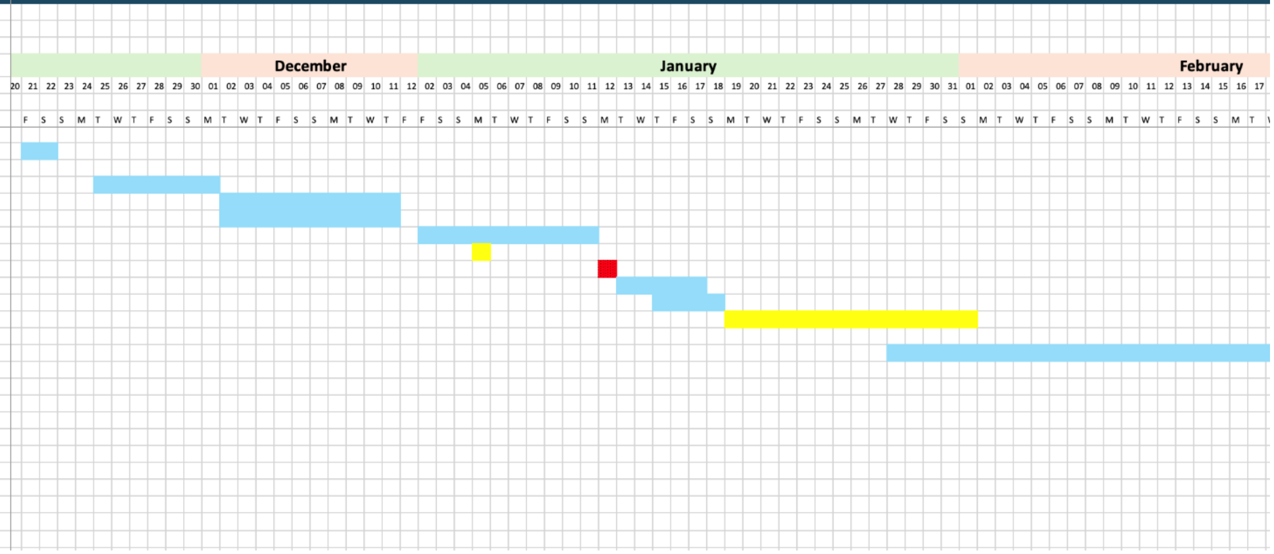


Figure 5: Gantt Chart with designated team leads and reviewers for Phase 4 and the beginning of Phase 5 from November 22nd to February 17th.

CIVL 460 - Group E - Gantt Chart

Project Start Date:	2025-09-08
Printed Gantt Chart Date:	2025-11-18

Legend	
Activity	
Deliverable	
Milestone	

Task Name	Category	Task Lead	Reviewer	Progress	Start	Days
Phase 5: Project Proposal						
Preparation of Final Report	Activity	Rheya	All		28-Jan	50
Generate Final Presentation	Activity	Sophia	All		21-Feb	6
Send PM Presentation for Feedback	Milestone	Jordan	All		27-Feb	1
Practice Final Presentation	Activity	Sophia	All		05-Mar	5
Final Presentation	Deliverable	Rheya	All		11-Mar	1
Draft Final Report	Deliverable	Lily	All		20-Mar	1
Update Final Report Based on Draft	Activity	Lily	All		23-Mar	16
Send PM Final Report for Feedback	Milestone	Rheya	All		28-Nov	1
Draft Letter	Activity	Rheya	All		09-Apr	7
Update and Edit Final Report / Leeway	Milestone	Jordan	All		11-Apr	5
Letter Addressing Final Report	Deliverable	Sophia	All		17-Apr	1
Revised Final Report	Deliverable	Lily	All		17-Apr	1

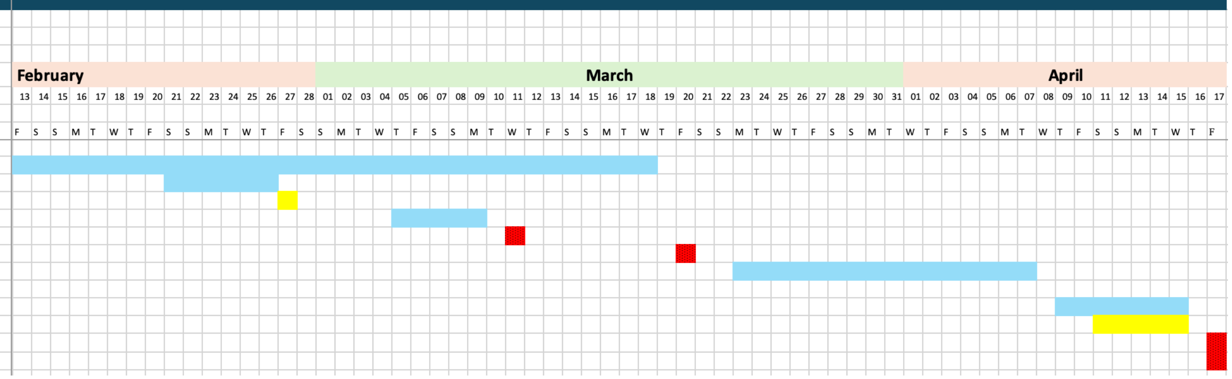


Figure 6: Gantt Chart with designated team leads and reviewers for the end of Phase 4 and Phase 5 from February 13th to April 17th.

Appendix C: Breakdown of Timeline Deviations

Table 38 below provides a detailed breakdown of the timeline modifications that were implemented in the Gantt chart of Envera.

Table 38: Major deviations to the timeline

Timeline Modification	Gantt Chart Task from the Progress Report	Gantt Chart Task from the Updated Work Plan	Reason:
Developing and evaluating alternative design solutions was further specific to various subassemblies, with specific task leaders.	- Develop subassemblies - Develop Envelope Alternatives - Develop Renewable Energy Alternatives - Develop Water Efficiency Alternatives - Evaluate Subassembly Alternatives - Proposed - Evaluate Solution Design Loads	- Develop Alternative Solutions	Ensures that solutions are well-researched and specific. Ensures that the final building retrofit design accounts for innovative and efficient solutions.
Updated dates to reflect additional time to evaluate design alternatives	- 5 days were assigned for each subsystem alternative	- 5 days were assigned for each subsystem alternative - 8 days was assigned to evaluate the different design alternatives	After subsystems were updated, the timeline had to accommodate additional research for more developed designs.
Determined the weights and categories for the WEM prior to the design alternatives	- Determined the categories and weights on October 15th, prior to developing alternative solutions	- Determined the categories and weights on October 25th, after to developing alternative solutions	To avoid bias criteria, Envera discussed the criteria that the company should focus on prior to determining what alternative options are available.
Evaluate the system design loads after the subassemblies were selected.	- Evaluation of system subassemblies moved to after the M&E, envelope renewable energy, and water efficiency solutions were selected.	- Evaluation of subassemblies was after the system design loads were evaluated.	Moving the structural assessment of the retrofit allows for the team to have the most up-to-date design that fits the new subassemblies.

Appendix D: Engineering Drawing

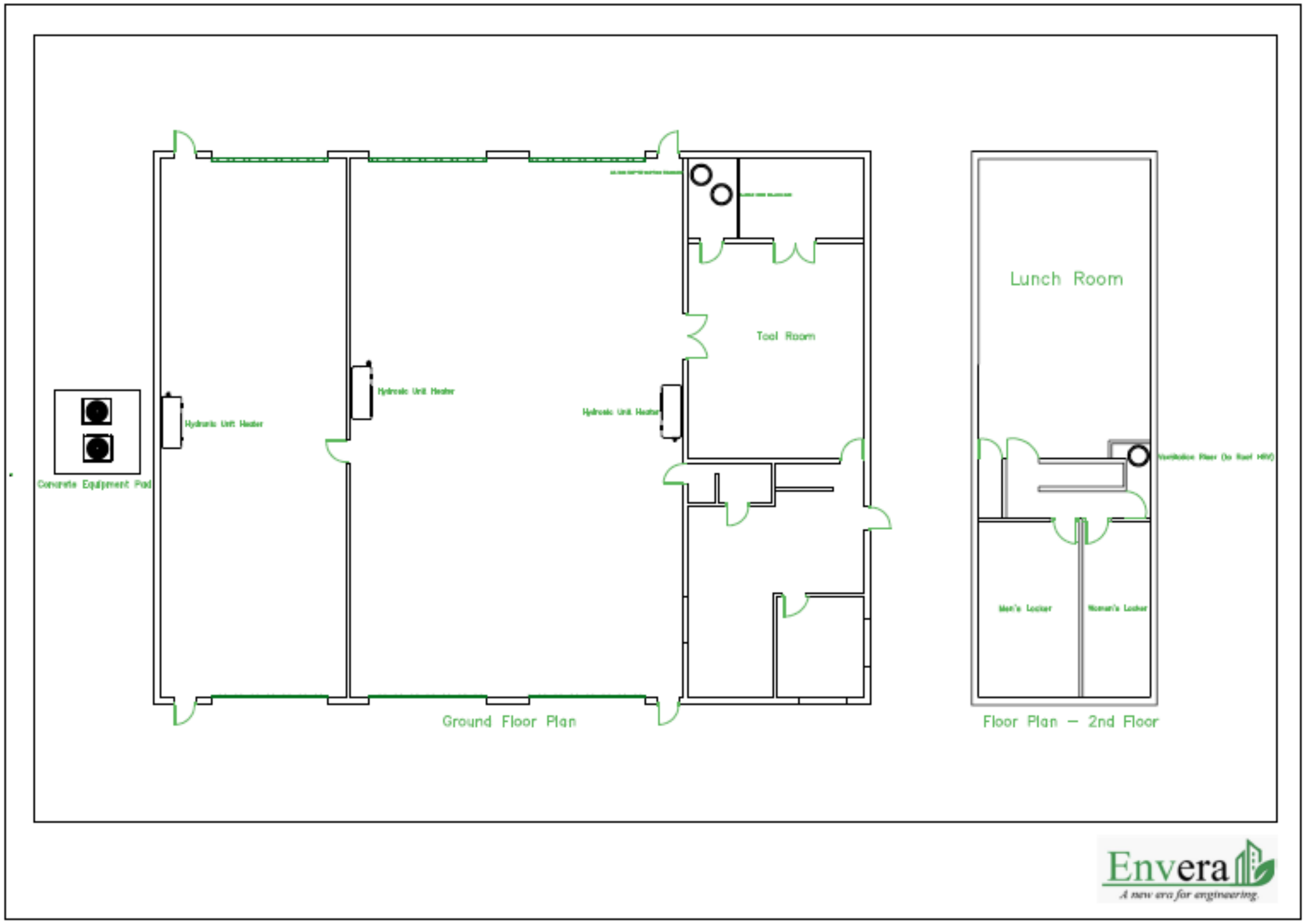


Figure 7: Plan showing exterior heat pumps, hydronic unit heaters in truck bays, mechanical room equipment, and HRV riser to rooftop ventilation unit. Office areas are conditioned by the heat pump system using existing ductwork

Appendix E: Building Renders

Figure 8: West elevation render: Rainwater collection system not shown in renderings below.

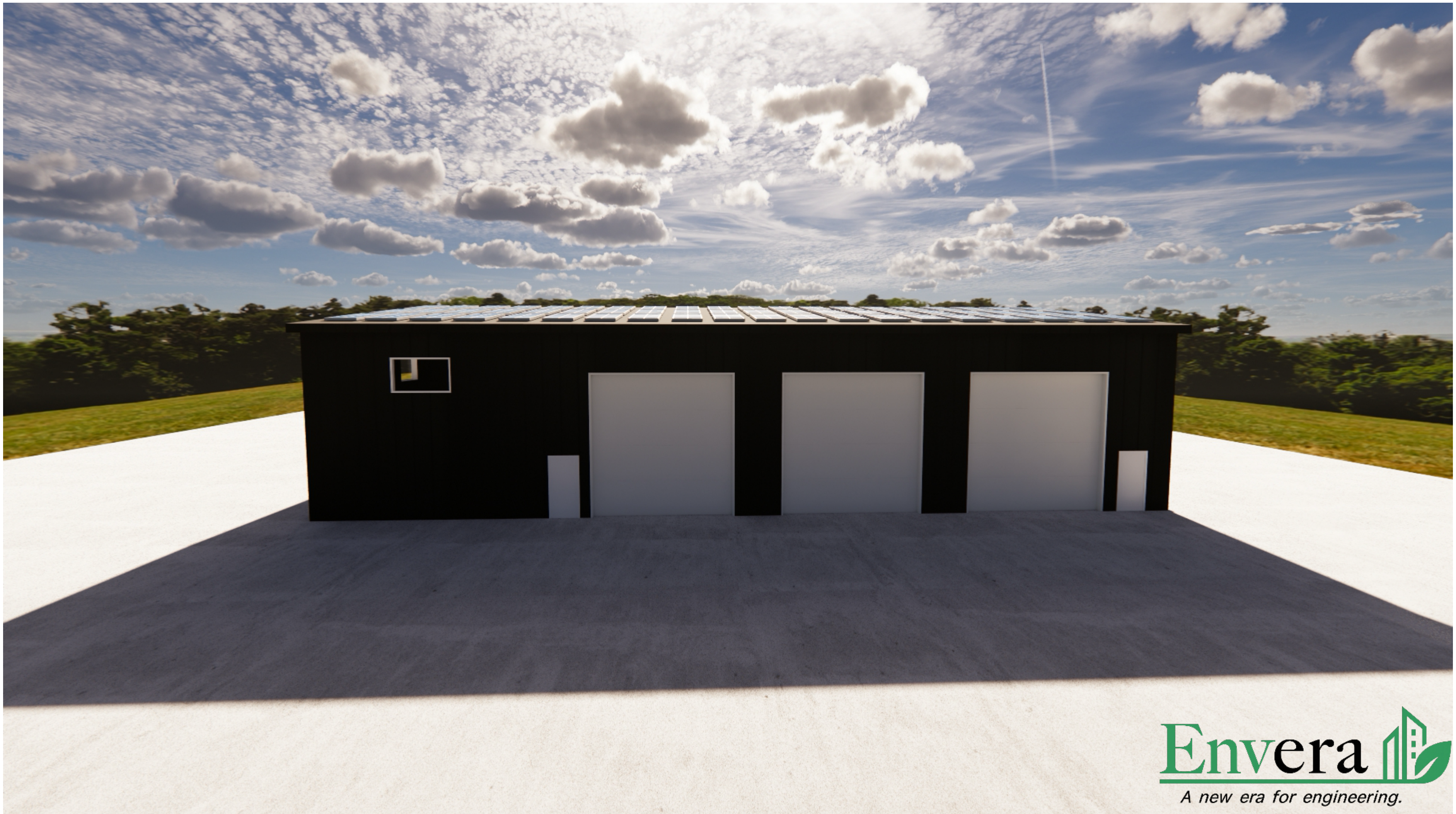


Figure 9: East elevation render.

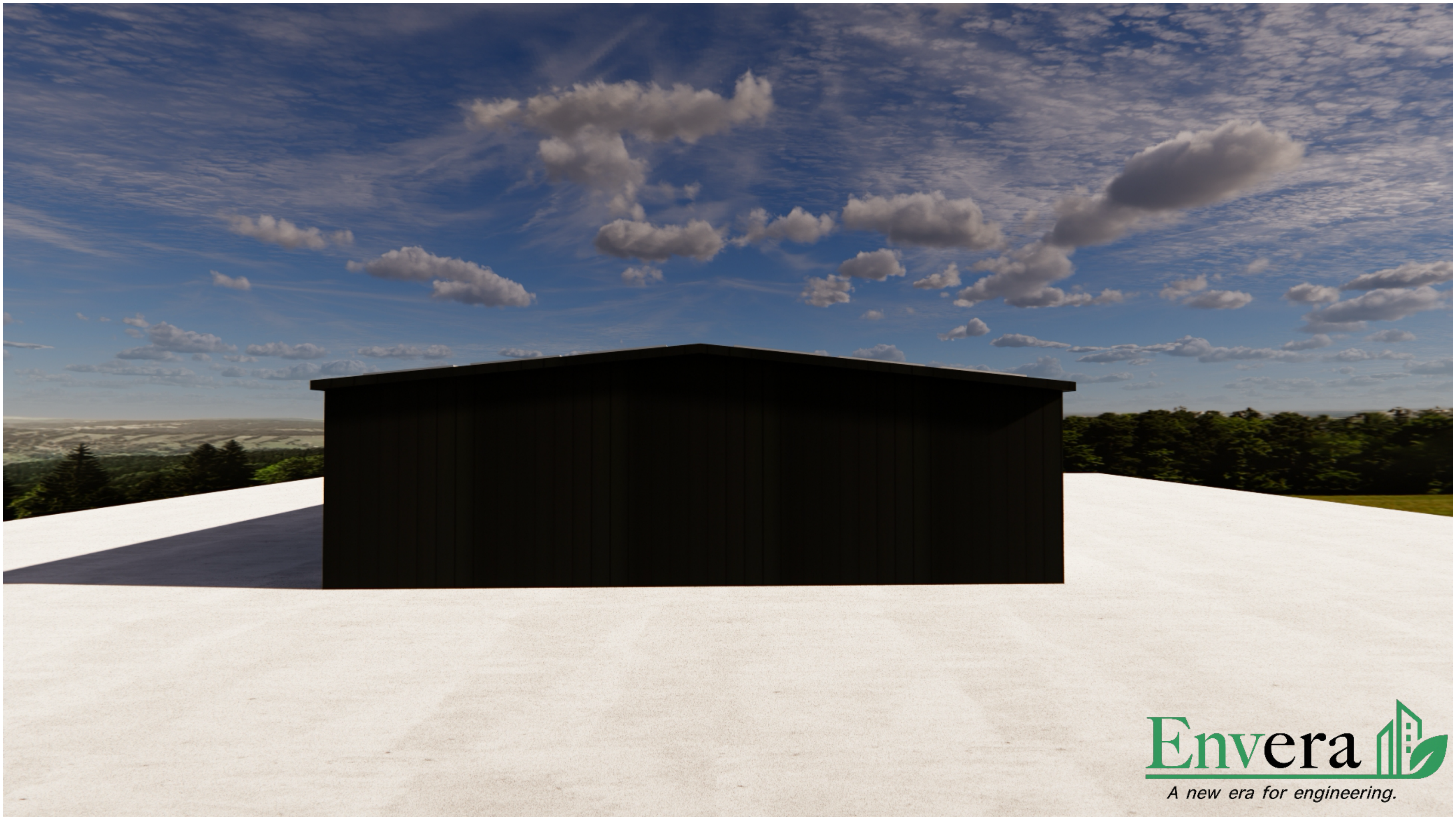


Figure 10: North elevation render: Mechanical pad located on this side (not shown).

Figure 11: South elevation render.

Figure 12: South-east elevation render.

Appendix E: Structural Calculations

Dead Loads				
Product	**Weight**	**Units**	**Pressure**	**Units**
KingSpan Quadcore - 91 mm thic	7900.32	kg	0.107	kPa
Solar Panel Weight	8819.65	kg	0.119	kPa
Lifebreath 2000EFD HRV Weight	400	kg	0.005	kPa
Total			**0.232**	**kpa**
Live Load				
Roof	-	-	1	kPa
Office Space			4.8	kPa
Snow Load				
S - Georgina, Ontario			**1.66**	**kPa**

Roof Dimensions		
Width	24	m
Length	30.2	m
Area	724.8	m2
S	**1.66**	**kPa**
Is	1	
Ss	2.1	kPa
Sr	0.4	kPa
Cb	0.8	
Cw	0.75	
Cs	1	
Ca	1	

Load Combinations			
Case 1	1.4D	0.324	kPa
Case 2	**1.25D + 1.5L +1.0S**	**3.450**	**kPa**
Case 3	1.25D + 1.5S +1.0L	3.780	kPa

Figure 13: Applied loads and load combinations.

General Values		
Φs	0.85	
n	1.34	
Elastice Modulu	200000	MPa
Fy	350	MPa
L	2200	mm

	Corner	Edge	Interior		
	W200x21	W200x27	W200x21	Units	Notes
Applied Axial Load	42.43061545	36.22126	157.3037	kN	
Tributary Area	12.3	10.5	45.6	m2	
Compression Resistanc	498.0085814	638.6258	498.0086	kN	
Fe	379.3884088	397.0028	379.3884	MPa	
Cross-Sectional Area	2700	3390	2700	mm2	
KL/rx	25.73099415	25.20046	25.73099		
KL/ry	72.13114754	70.51282	72.13115		GOVERNS
rx	85.5	87.3	85.5	mm	
ry	30.5	31.2	30.5	mm	
λ	0.96048811	0.938939	0.960488		

Figure 14: Column analysis calculations.

Joists					
	Bay 1	**Bay 2**	**Bay 3**	**Bay 4**	**Units**
Length	4.1	3.5	3.6	3.9	m
UDL	5.179540836	5.179540836	5.179540836	5.179541	kN/m
Point Load	21.23611743	18.12839293	18.64634701	20.20021	kN
Support Rxns	10.61805871	9.064196464	9.323173505	10.1001	kN
Mf	10.88351018	7.931171906	8.390856155	9.847602	kNm

Figure 15: Joist analysis calculations.

Beams	Exterior W200x21	Interior W200x27	Units
Length	6	6	m
Point Loads	10.61805871	19.68225518	kN
Support Rxns	56.3275066	107.2164953	kN
Mf	110.5831627	196.8224752	kNm
	Class 3 (Flange)	Class 2 (Flange)	
bel/t	10.390625	7.916666667	
bel	66.5	66.5	mm
t	6.4	8.4	mm
200 (or 170)/(Fy)^0.5	10.69044968	9.086882225	
	Class 2 (Web)	Class 2 (Web)	
h/w	29.71875	32.79310345	
h	190.2	190.2	mm
w	6.4	5.8	mm
1700/(Fy)^0.5	90.86882225	90.86882225	
Mr	64.5575	83.0025	
Φs	0.85	0.85	kNm
Zx	217000	279000	mm3
Fy	350	350	MPa

Figure 16: Exterior and interior beam analysis calculations.

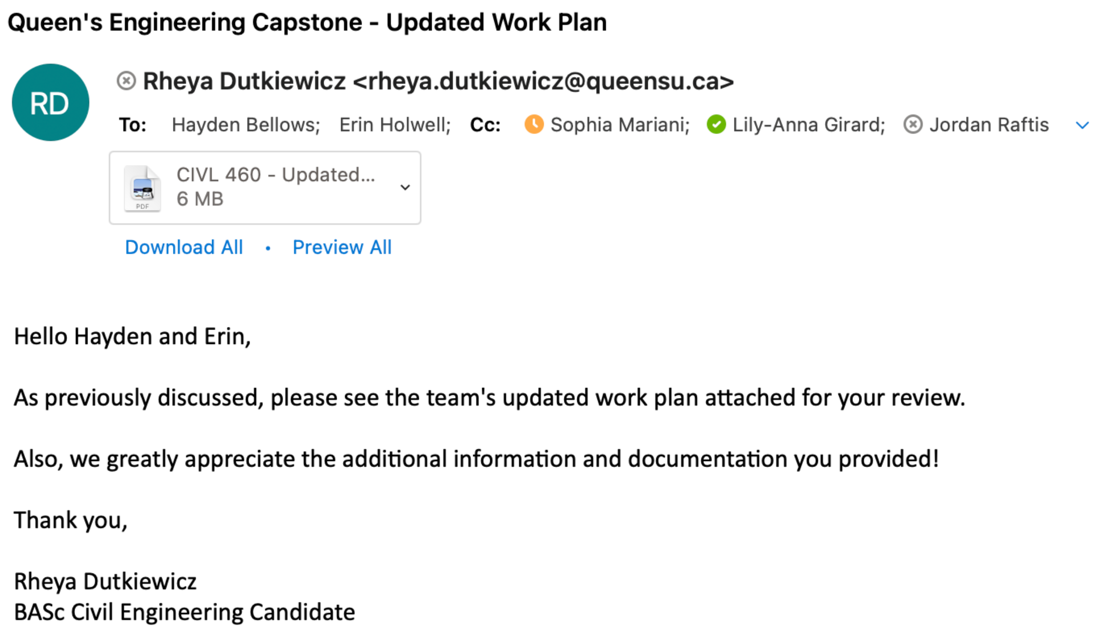
Second Floor W410x39			
Length	6	m	
Live Load Reduction Factor			
A trib (B)	23.4	m2	Greater than 20 m2
LLRF	0.94715023		NBCC 4.1.5.8(3)
Loads			
Pressures	10.9875089	kPa	
ULD	42.8512846	kN/m	
Mf	192.830781	kNm	wL2/8
Class 2 (Flange)			
bel/t	7.95454545		
bel	70	mm	
t	8.8	mm	
(170)/(Fy)^0.5	9.08688223		
Class 2 (Web)			
h/w	59.59375		
h	381.4	mm	
w	6.4	mm	
1700/(Fy)^0.5	90.8688223		
Mr	217.175	kNm	
Φs	0.85		
Zx	730000	mm3	
Fy	350	MPa	

UDL per beam	14.15742	25.89773
Shear Values		
1	56.32751	107.2165
2	42.17008	81.31877
3	31.55202	61.63652
4	17.3946	35.73879
A1	73.87319	132.5962
A2	36.70997	64.22625

Figure 17: Second floor beam and shear force diagram analysis calculations.

Appendix F: Work Plan Sent to Client

Refer to Figure 18 below for the Envera work plan sent to the clients, Hayden Bellows and Erin Holwell


Queen's Engineering Capstone - Updated Work Plan

RD

Rheya Dutkiewicz <rheya.dutkiewicz@queensu.ca>

To: Hayden Bellows; Erin Holwell; **Cc:** Sophia Mariani; Lily-Anna Girard; Jordan Raftis

CIVL 460 - Updated...
6 MB

Download All • Preview All

Hello Hayden and Erin,

As previously discussed, please see the team's updated work plan attached for your review.

Also, we greatly appreciate the additional information and documentation you provided!

Thank you,

Rheya Dutkiewicz
BASc Civil Engineering Candidate

Figure 18: Updated work plan sent to clients at Entuitive on November 20th.

Appendix G: Envera Time Trackers

Queen's University | Faculty of Engineering and Applied Science

CIVL 460 Engineering Design & Practice
FW 2025/2026

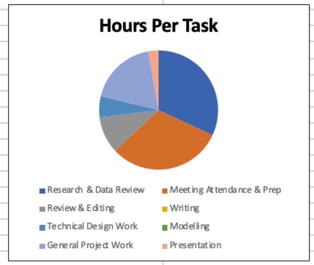
Student Name: Rheya Dutkiewicz
Project Name: Building Retrofit
Group Name: Envera

Hours to date: 70.5

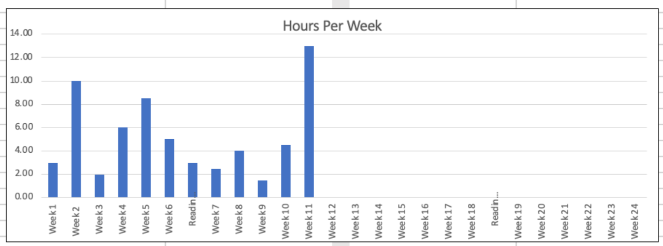
Date	Activity	Time Spent
September 4, 2025	Research & Data Review	3
September 8, 2025	Meeting Attendance & Prep	5
September 9, 2025	Presentation	2
September 10, 2025	Research & Data Review	3
September 18, 2025	Research & Data Review	2
September 22, 2025	Meeting Attendance & Prep	2
September 25, 2025	Meeting Attendance & Prep	2
September 26, 2025	Meeting Attendance & Prep	2
September 29, 2025	Meeting Attendance & Prep	6
October 1, 2025	General Project Work	1
October 2, 2025	Meeting Attendance & Prep	1.5
October 5, 2025	General Project Work	4.5
October 6, 2025	Review & Editing	4
October 7, 2025	Review & Editing	1
October 14, 2025	Research & Data Review	3
October 20, 2025	Meeting Attendance & Prep	2
October 21, 2025	Research & Data Review	0.5
October 27, 2025	Research & Data Review	2
October 29, 2025	Research & Data Review	2
November 2, 2025	General Project Work	3
November 3, 2025	General Project Work	1.5
November 10, 2025	Research & Data Review	3
November 13, 2025	Meeting Attendance & Prep	0.5
November 14, 2025	Meeting Attendance & Prep	1
November 17, 2025	Technical Design Work	4
November 18, 2025	General Project Work	3
November 20, 2025	Research & Data Review	4
November 21, 2025	Review & Editing	2
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	

Hours Per Week	
Week 1	3.00
Week 2	10.00
Week 3	2.00
Week 4	6.00
Week 5	8.50
Week 6	5.00
Reading Week	3.00
Week 7	2.50
Week 8	4.00
Week 9	1.50
Week 10	4.50
Week 11	13.00
Week 12	0.00
Week 13	0.00
Week 14	0.00
Week 15	0.00
Week 16	0.00
Week 17	0.00
Week 18	0.00
Reading Week	0.00
Week 19	0.00
Week 20	0.00
Week 21	0.00
Week 22	0.00
Week 23	0.00
Week 24	0.00

Hours Per Task	
Research & Data Review	22.5
Meeting Attendance & Prep	22
Review & Editing	7
Writing	0
Technical Design Work	4
Modelling	0
General Project Work	13
Presentation	2



	Start	End
Week 1	September 1, 2025	September 5, 2025
Week 2	September 8, 2025	September 12, 2025
Week 3	September 15, 2025	September 19, 2025
Week 4	September 22, 2025	September 26, 2025
Week 5	September 29, 2025	October 3, 2025
Week 6	October 6, 2025	October 10, 2025
Reading Week	October 13, 2025	October 17, 2025
Week 7	October 20, 2025	October 24, 2025
Week 8	October 27, 2025	October 31, 2025
Week 9	November 3, 2025	November 7, 2025
Week 10	November 10, 2025	November 14, 2025
Week 11	November 17, 2025	November 21, 2025
Week 12	November 24, 2025	November 28, 2025
Week 13	January 5, 2026	January 9, 2026
Week 14	January 12, 2026	January 16, 2026
Week 15	January 19, 2026	January 23, 2026
Week 16	January 26, 2026	January 30, 2026
Week 17	February 2, 2026	February 6, 2026
Week 18	February 9, 2026	February 13, 2026
Reading Week	February 16, 2026	February 20, 2026
Week 19	February 23, 2026	February 27, 2026
Week 20	March 2, 2026	March 6, 2026
Week 21	March 9, 2026	March 13, 2026
Week 22	March 16, 2026	March 20, 2026
Week 23	March 23, 2026	March 27, 2026
Week 24	March 30, 2026	April 3, 2026



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CIVL 460 Engineering Design & Practice
FW 2025/2026

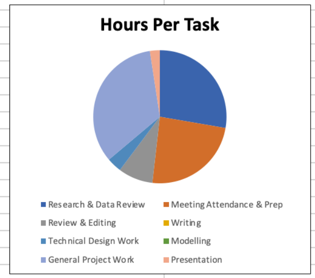
Student Name: Lily-Anna Girard
Project Name: Building Retrofit
Group Name: Envera

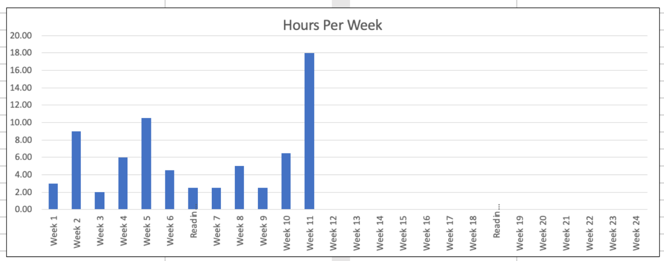
Hours to date: 83

Date	Activity	Time Spent
September 5, 2025	Research & Data Review	3
September 8, 2025	Meeting Attendance & Prep	3
September 8, 2025	General Project Work	2
September 9, 2025	Presentation	2
September 10, 2025	Research & Data Review	2
September 19, 2025	Research & Data Review	2
September 22, 2025	Meeting Attendance & Prep	2
September 25, 2025	Meeting Attendance & Prep	2
September 26, 2025	Meeting Attendance & Prep	2
September 29, 2025	General Project Work	7
September 30, 2025	Meeting Attendance & Prep	2
October 2, 2025	Meeting Attendance & Prep	0.5
October 3, 2025	Meeting Attendance & Prep	1
October 5, 2025	General Project Work	3
October 6, 2025	Review & Editing	3
October 7, 2025	Review & Editing	1
October 9, 2025	Meeting Attendance & Prep	0.5
October 13, 2025	Research & Data Review	2
October 16, 2025	Meeting Attendance & Prep	0.5
October 20, 2025	Research & Data Review	2
October 23, 2025	Meeting Attendance & Prep	0.5
October 27, 2025	Research & Data Review	2
October 30, 2025	Research & Data Review	3
November 4, 2025	Research & Data Review	2
November 6, 2025	Meeting Attendance & Prep	0.5
November 9, 2025	Research & Data Review	2
November 10, 2025	Meeting Attendance & Prep	2
November 11, 2025	Research & Data Review	3
November 13, 2025	Meeting Attendance & Prep	0.5
November 14, 2025	Meeting Attendance & Prep	1
November 15, 2025	General Project Work	4
November 16, 2025	General Project Work	2
November 17, 2025	Meeting Attendance & Prep	2
November 17, 2025	General Project Work	3
November 18, 2025	General Project Work	4
November 19, 2025	Technical Design Work	3
November 19, 2025	Review & Editing	1
November 20, 2025	General Project Work	3
November 21, 2025	Review & Editing	2
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	

Hours Per Week	
Week 1	3.00
Week 2	9.00
Week 3	2.00
Week 4	6.00
Week 5	10.50
Week 6	4.50
Reading Week	2.50
Week 7	2.50
Week 8	5.00
Week 9	2.50
Week 10	6.50
Week 11	18.00
Week 12	0.00
Week 13	0.00
Week 14	0.00
Week 15	0.00
Week 16	0.00
Week 17	0.00
Week 18	0.00
Reading Week	0.00
Week 19	0.00
Week 20	0.00
Week 21	0.00
Week 22	0.00
Week 23	0.00
Week 24	0.00

Hours Per Task	
Research & Data Review	23
Meeting Attendance & Prep	20
Review & Editing	7
Writing	0
Technical Design Work	3
Modelling	0
General Project Work	28
Presentation	2





	Start	End
Week 1	September 1, 2025	September 5, 2025
Week 2	September 8, 2025	September 12, 2025
Week 3	September 15, 2025	September 19, 2025
Week 4	September 22, 2025	September 26, 2025
Week 5	September 29, 2025	October 3, 2025
Week 6	October 6, 2025	October 10, 2025
Reading Week	October 13, 2025	October 17, 2025
Week 7	October 20, 2025	October 24, 2025
Week 8	October 27, 2025	October 31, 2025
Week 9	November 3, 2025	November 7, 2025
Week 10	November 10, 2025	November 14, 2025
Week 11	November 17, 2025	November 21, 2025
Week 12	November 24, 2025	November 28, 2025
Week 13	January 5, 2026	January 9, 2026
Week 14	January 12, 2026	January 16, 2026
Week 15	January 19, 2026	January 23, 2026
Week 16	January 26, 2026	January 30, 2026
Week 17	February 2, 2026	February 6, 2026
Week 18	February 9, 2026	February 13, 2026
Reading Week	February 16, 2026	February 20, 2026
Week 19	February 23, 2026	February 27, 2026
Week 20	March 2, 2026	March 6, 2026
Week 21	March 9, 2026	March 13, 2026
Week 22	March 16, 2026	March 20, 2026
Week 23	March 23, 2026	March 27, 2026
Week 24	March 30, 2026	April 3, 2026

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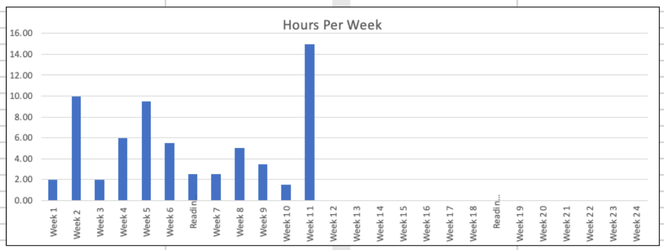
CIVL 460 Engineering Design & Practice
FW 2025/2026

Student Name: Sophia Mariani
Project Name: Building Retrofit
Group Name: Envera

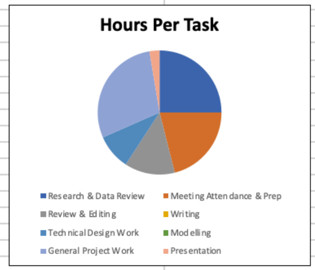
Hours to date: 76

Date	Activity	Time Spent
September 5, 2025	Research & Data Review	2
September 8, 2025	Meeting Attendance & Prep	3
September 8, 2025	Review & Editing	2
September 9, 2025	Presentation	2
September 10, 2025	Research & Data Review	3
September 19, 2025	Research & Data Review	2
September 22, 2025	Meeting Attendance & Prep	2
September 25, 2025	Meeting Attendance & Prep	2
September 26, 2025	Meeting Attendance & Prep	2
September 29, 2025	General Project Work	6
September 30, 2025	Meeting Attendance & Prep	2
October 2, 2025	Meeting Attendance & Prep	0.5
October 3, 2025	Meeting Attendance & Prep	1
October 5, 2025	General Project Work	4
October 6, 2025	Review & Editing	3
October 7, 2025	Review & Editing	2
October 9, 2025	Meeting Attendance & Prep	0.5
October 13, 2025	Research & Data Review	2
October 16, 2025	Meeting Attendance & Prep	0.5
October 20, 2025	Research & Data Review	2
October 23, 2025	Meeting Attendance & Prep	0.5
October 27, 2025	Research & Data Review	2
October 30, 2025	Research & Data Review	3
November 1, 2025	Research & Data Review	2
November 4, 2025	General Project Work	3
November 6, 2025	Meeting Attendance & Prep	0.5
November 9, 2025	Research & Data Review	1
November 13, 2025	Meeting Attendance & Prep	0.5
November 14, 2025	Meeting Attendance & Prep	1
November 15, 2025	General Project Work	4
November 17, 2025	General Project Work	3
November 19, 2025	General Project Work	2
November 20, 2025	Technical Design Work	7
November 21, 2025	Review & Editing	3
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	

Hours Per Week	
Week 1	2.00
Week 2	10.00
Week 3	2.00
Week 4	6.00
Week 5	9.50
Week 6	5.50
Reading Week	2.50
Week 7	2.50
Week 8	5.00
Week 9	3.50
Week 10	1.50
Week 11	15.00
Week 12	0.00
Week 13	0.00
Week 14	0.00
Week 15	0.00
Week 16	0.00
Week 17	0.00
Week 18	0.00
Reading Week	0.00
Week 19	0.00
Week 20	0.00
Week 21	0.00
Week 22	0.00
Week 23	0.00
Week 24	0.00



Hours Per Task	
Research & Data Review	19
Meeting Attendance & Prep	16
Review & Editing	10
Writing	0
Technical Design Work	7
Modelling	0
General Project Work	22
Presentation	2



	Start	End
Week 1	September 1, 2025	September 5, 2025
Week 2	September 8, 2025	September 12, 2025
Week 3	September 15, 2025	September 19, 2025
Week 4	September 22, 2025	September 26, 2025
Week 5	September 29, 2025	October 3, 2025
Week 6	October 6, 2025	October 10, 2025
Reading Week	October 13, 2025	October 17, 2025
Week 7	October 20, 2025	October 24, 2025
Week 8	October 27, 2025	October 31, 2025
Week 9	November 3, 2025	November 7, 2025
Week 10	November 10, 2025	November 14, 2025
Week 11	November 17, 2025	November 21, 2025
Week 12	November 24, 2025	November 28, 2025
Week 13	January 5, 2026	January 9, 2026
Week 14	January 12, 2026	January 16, 2026
Week 15	January 19, 2026	January 23, 2026
Week 16	January 26, 2026	January 30, 2026
Week 17	February 2, 2026	February 6, 2026
Week 18	February 9, 2026	February 13, 2026
Reading Week	February 16, 2026	February 20, 2026
Week 19	February 23, 2026	February 27, 2026
Week 20	March 2, 2026	March 6, 2026
Week 21	March 9, 2026	March 13, 2026
Week 22	March 16, 2026	March 20, 2026
Week 23	March 23, 2026	March 27, 2026
Week 24	March 30, 2026	April 3, 2026

Queen's University · Faculty of Engineering and Applied Science

CIVL 460 Engineering Design & Practice
FW 2025/2026

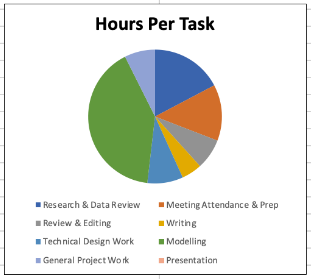
Student Name: Jordan Raftis
Project Name: Building Retrofit
Group Name: Envera

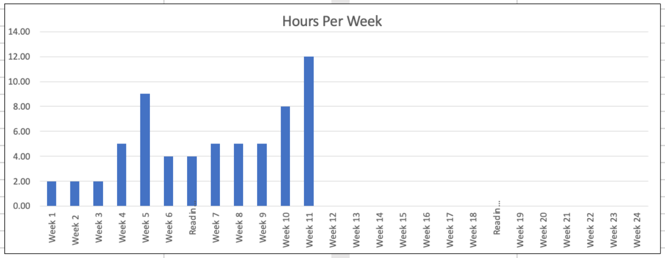
Hours to date: **81**

Date	Activity	Time Spent
September 4, 2025	Research & Data Review	2
September 8, 2025	Meeting Attendance & Prep	2
September 13, 2025	Review & Editing	2
September 19, 2025	Research & Data Review	2
September 22, 2025	Meeting Attendance & Prep	2
September 25, 2025	Meeting Attendance & Prep	1
September 26, 2025	Meeting Attendance & Prep	2
September 29, 2025	General Project Work	3
September 30, 2025	Meeting Attendance & Prep	2
October 2, 2025	Technical Design Work	2
October 3, 2025	Meeting Attendance & Prep	2
October 4, 2025	Modelling	5
October 5, 2025	Review & Editing	1
October 6, 2025	General Project Work	1
October 7, 2025	Review & Editing	1
October 9, 2025	Modelling	2
October 13, 2025	Technical Design Work	2
October 16, 2025	General Project Work	2
October 20, 2025	Modelling	2
October 23, 2025	Modelling	3
October 27, 2025	Research & Data Review	2
October 30, 2025	Modelling	3
November 4, 2025	Writing	2
November 6, 2025	Research & Data Review	3
November 9, 2025	Research & Data Review	2
November 12, 2025	Technical Design Work	3
November 14, 2025	Modelling	5
November 15, 2025	Research & Data Review	3
November 16, 2025	Modelling	5
November 17, 2025	Writing	2
November 20, 2025	Modelling	8
November 21, 2025	Review & Editing	2
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	
	Research & Data Review	

Hours Per Week	
Week 1	2.00
Week 2	2.00
Week 3	2.00
Week 4	5.00
Week 5	9.00
Week 6	4.00
Reading Week	4.00
Week 7	5.00
Week 8	5.00
Week 9	5.00
Week 10	8.00
Week 11	12.00
Week 12	0.00
Week 13	0.00
Week 14	0.00
Week 15	0.00
Week 16	0.00
Week 17	0.00
Week 18	0.00
Reading Week	0.00
Week 19	0.00
Week 20	0.00
Week 21	0.00
Week 22	0.00
Week 23	0.00
Week 24	0.00

Hours Per Task	
Research & Data Review	14
Meeting Attendance & Prep	11
Review & Editing	6
Writing	4
Technical Design Work	7
Modelling	33
General Project Work	6
Presentation	0





	Start	End
Week 1	September 1, 2025	September 5, 2025
Week 2	September 8, 2025	September 12, 2025
Week 3	September 15, 2025	September 19, 2025
Week 4	September 22, 2025	September 26, 2025
Week 5	September 29, 2025	October 3, 2025
Week 6	October 6, 2025	October 10, 2025
Reading Week	October 13, 2025	October 17, 2025
Week 7	October 20, 2025	October 24, 2025
Week 8	October 27, 2025	October 31, 2025
Week 9	November 3, 2025	November 7, 2025
Week 10	November 10, 2025	November 14, 2025
Week 11	November 17, 2025	November 21, 2025
Week 12	November 24, 2025	November 28, 2025
Week 13	January 5, 2026	January 9, 2026
Week 14	January 12, 2026	January 16, 2026
Week 15	January 19, 2026	January 23, 2026
Week 16	January 26, 2026	January 30, 2026
Week 17	February 2, 2026	February 6, 2026
Week 18	February 9, 2026	February 13, 2026
Reading Week	February 16, 2026	February 20, 2026
Week 19	February 23, 2026	February 27, 2026
Week 20	March 2, 2026	March 6, 2026
Week 21	March 9, 2026	March 13, 2026
Week 22	March 16, 2026	March 20, 2026
Week 23	March 23, 2026	March 27, 2026
Week 24	March 30, 2026	April 3, 2026