Building Retrofit to Achieve Sustainability Goals:

Draft Final Report

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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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March 20th, 2026
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 March 9th, 2026, the following report, *Building Retrofit to Achieve Sustainability Goals – Draft Final Report*, is for Envera's CIVL 460 Capstone Project. This report specifies:

- project definition
- project design concepts
- background information
- timeline
- final design
- budget estimation
- evaluation of project success
- maintenance and service plan

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 thorugh sustainable and innovative design.

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 for main subsystems: building envelope, mechanical and electrical (M&E), renewable energy and water efficiency. 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 specific criteria specific.

The proposed retrofit integrates envelope upgrades using insulated metal panels and high-efficiency truck bay door 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 retrofit incorporates a rooftop solar PV array, battery energy storage, and four DC fast chargers to support the transition to electrical vehicles (EV). Water-efficiency measures, such as greywater recycling, rainwater harvesting, and low-flow fixtures, reduce dependency on the municipal water supply and conserve potable water.

Once the subassembly designs were selected, Envera conducted a carbon emissions assessment and a structural review in accordance with NBCC 2020 and CSA S16 to confirm the building could support the additional loads from the assemblies. The total cost of the retrofit assessment is expected to cost near $3,482,110.80.

A preliminary maintenance plan was developed to facilitate the transition to the retrofit design. Additionally, a detailed risk assessment was performed to categorize risks associated with each subassembly, with corresponding mitigation strategies outlined. Overall, Envera works to establish a streamlined system for reducing carbon emissions, enhance system reliability, minimize risks, while delivering a high-performing retrofit 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 consists of a two-phase feasibility study and structural assessment to identify high-level retrofit modifications required to achieve EnerPHit and Net Zero Carbon performance standards. Phase one evaluates energy retrofit measures aimed at reducing overall Energy Use Intensity (EUI), including upgrades to the building envelope, mechanical and electrical systems, and the preliminary feasibility of on-site renewable energy generation, such as Solar Photovoltaic (PV) arrays. Phase two assesses the structural implications of the shortlisted energy retrofit measures, ensuring that proposed envelope upgrades, roof mounted PV systems, and additional insulation loads do not compromise the performance of the existing steel frame or metal siding systems. Where necessary, conceptual structural reinforcement strategies are evaluated based on feasibility, constructability and relative cost. The scope of this project is strictly limited to conceptual design and feasibility-level assessment. Detailed structural design, construction sequencing, tendering, and physical implementation of retrofit measures are explicitly excluded. The outcomes will provide a technical basis to support Entuitive's future design and implementation process.

3.2 Objectives and Deliverables

The primary objective of this retrofit design is to identify strategies that allow the facility to maintain its functionality as a winter maintenance operations hub, while implementing a deep energy retrofit. Quantitatively, the project aims to: reduce the facilities Energy use Intensity (EUI) by 50-80%, consistent with EnerPHit retrofits performance ranges [2], achieve an airtightness target of ≤ 1.0 ACH50 [2], and incorporate on-site renewable energy systems capable of offsetting 20-30% of total energy consumption [3]. These performance targets were selected to reflect the facility's cold-climate location, large vehicle bay doors, and high ventilation and heating demands associated with winter operations. Considering this retrofit is to an existing steel-framed industrial building, structural constraints require no more than a 5% increase in stress be imposed on the existing steel framing under retrofit loads [4] while maintaining a minimum operational uptime of 95% during retrofit activities [4]. Collectively, these objectives support meaningful carbon reduction without compromising safety, durability, or essential facility operations.

To clearly 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, 2025)	The prepared Work Plan defines project scope, roles, schedule, and preliminary research collection for this retrofit, providing Entuitive with clear visibility into project structure, timeline, and anticipated deliverables.
Progress Report (November 21st, 2025)	Summarizes phase one findings, including preliminary energy modeling, structural condition assessment, and comparative evaluation of retrofit options enabling Entuitive to review interim results and guide final direction. Feedback will be given from Entuitive, which in turn will help Envera for future project objectives.
Poster Presentation (February 3rd, 2026)	Provides a concise visual summary of the retrofit strategy, key assumptions, and feasibility outcomes, supporting high-level technical communication.
Draft Final Report (March 20th, 2026)	Presents a detailed analysis of the selected retrofit solutions, including cost-benefits evaluation, energy performance projections, and structural load implications, allowing Entuitive and Queen's University to review and refine recommendations prior to finalization.
Oral Presentation (Late March 2026)	Communicates the project's key technical conclusions from the project to fellow classmates, offering a chance for Envera to be critiqued on presentation styles.

Final Report (April 17th, 2026)	Delivers complete technical documentation, including energy modeling data, performance metrics, and retrofit drawings.

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.

As per the table above, constraints classified as high severity impose non-negotiable performance, safety, or operational requirements that must be satisfied for the retrofit to remain viable. This includes maintaining facility operations, meeting EnerPHit performance thresholds, and preserving structural integrity. Medium severity constraints influence optimization and solution selection, but do not independently preclude retrofit feasibility. Failure to satisfy any of these would compromise safety, functionality, and certification eligibility. Although important, budgetary and software limitations are two constraints that per discussion with the Client, are not critical for the proposed solution, and will not override mandatory performance criteria. Within the preliminary risk assessment section, how these constraints govern design trade-offs is examined in greater detail and justifications have been made.

3.4 Stakeholders

Due to the requirements, location, and operational role of the District Road Maintenance Facility, Envera has prepared a list of 12 stakeholders that will be affected during the planning, execution, and completion phases of this retrofit project. For clarity, stakeholders are grouped based on their functional role in the project, including the client and design team, facility operators, regulatory and certification bodies, utilities, and the surrounding public.

3.4.1 Client and Project Team

To begin, Entuitive, specifically Erin Holwell and Hayden Bellows, are the clients for this project. They will provide overall project direction, review proposed retrofit strategies, and ensure alignment with EnerPHit standards, Net Zero Carbon objectives, and the York Region Roads Department sustainability goals. Envera serves as the executing project team, responsible for conducting energy and structural feasibility assessments, developing retrofit recommendations, and delivering all technical reports and presentations in accordance with academic and client expectations. Lastly, Queens University, specifically CIVL 460 instructor Dr. Moore and project manager Zaid Kasim, provides academic oversight, evaluates deliverables, and ensures that project outcomes align with course learning objectives and research standards.

3.4.2 Facility Ownership and Operations

The York Region Roads Department and the District Road Maintenance Facility operators are key stakeholders due to their responsibility for funding oversight, maintaining uninterrupted winter maintenance operations, long-term facility performance, and ensuring worker safety. Supervisors, managers, and facility employees are directly affected by retrofit measures and provide valuable insight into daily operational requirements, informing strategies that minimize disruption and maintain functionality throughout planning and implementation phases.

3.4.3 Regulatory and Certification Bodies

Regulatory authorities, including Ontario Building Code officials and municipal permitting offices, ensure that all proposed retrofit measures comply with safety, structural and energy efficiency requirements. In parallel, EnerPHit certification bodies such as Passive House Canada, oversee compliance with EnerPHit performance standards related to airtightness, insulation, and energy efficiency. Their involvement validates the technical credibility of the proposed retrofit and confirms alignment with Next Zero Carbon objectives.

3.4.4 Utilities and Energy Providers

Electricity and natural gas providers, including Hydro One [5] and Enbridge Gas [6], supply critical data related to energy availability, Carbon intensity, and utility costs. This information directly informs decisions related to energy modeling, renewable energy integration, and the feasibility of electrification or heat recovery strategies.

3.4.5 Public and Community Stakeholders

Nearby property owners, businesses and residents of Georgina are indirectly affected by potential construction activates, traffic, noise, and service disruptions. 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. In addition, the broader public relies on the facility for safe winter road maintenance. Public transparency about the project's schedule and contingency plans will be critical in maintaining trust and ensuring continued service reliability during implementation.

3.4.6 Future Implementation Stakeholders

Lastly, should retrofit implementation proceed beyond the feasibility stage, contractors and material suppliers will become key stakeholders responsible for constructability, cost control, and execution of the proposed design strategies. Their expertise in high-performance building systems and sustainable construction practices will be critical to achieving EnerPHit level performance.

3.4.7 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 were then classified as either primary, secondary or tertiary, which would further classify their ranking within this project. Table 4 below shows these classifications, with an associated description for each.

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 to which 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 7 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 8, Figure 9, and Figure 10 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. 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 4 may be subject to delays as the final design will have various contributing factors that are dependent on one another and if one factor is altered or impacted, this will affect others. Completed by February 3rd, 2026.

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, 2026.

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 building envelope alternative designs and evaluate the project's feasibility in collaboration with Sophia.

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, as well as forecasting for future conditions. Create the project schedule and edit the Gantt Chart.

Sophia Mariani – Structural Coordinator: Define the initial project scope and stakeholders. Assess site conditions and the nearby environment to support load calculations, determine applicable forces and loads, and calculate final design loads in collaboration with Rheya. Develop risk assessment along with mitigation strategies the long-term feasibility 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.

While each individual is responsible for their specific role, it is vital that communication is maintained throughout the project to ensure that all coordinators are involved in the decision-making process. This helps prevent bias research and conclusions while maintaining streamlined operations that contribute to the project's overall success.

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 to mitigate Envera falling behind the anticipated timeline.

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 design load calculations, carbon emission calculations, a risk and mitigation assessment, demolition planning, project cost, and maintenance budget, and the use of the Envera AI retrofit processor. 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. Furthermore, annual carbon emissions of the proposed design alternatives will be compared to the baseline design carbon emissions, serving as an effective method to monitor the environmental impact of the retrofit.

Lastly, the detailed risk assessment, along with corresponding mitigation strategies can be used to highlight areas of concern and propose future improvements based on the identified risks.

4.4 Timeline Deviations

To adapt to changing conditions and ensure the overall success of the project, the proposed timeline and Gantt chart from the November 21st Progress Report were modified. For deviations in the timeline from the Work Plan submission on October 21st to the Progress Report, refer to Envera's Progress Report.

Following the submission of the Progress Report, several modifications were made to the project timeline to accommodate evolving project needs and external changes. While certain tasks were beyond the scope of the project, such as developing a maintenance plan, creating a website with an AI retrofit processor, and forecasting for future conditions, with the guidance from the Project Manager, Envera felt that the addition of such sections would build client confidence and strengthen professional relations.

Changes to the poster and final presentation schedules were largely influenced by the course instructional team extending deadlines, which allowed Envera additional time to refine and develop project tasks. Envera also found that receiving feedback in person from the Project Mager fostered a more positive learning environment and improved collaboration compared to submitting drafts by email.

Overall, these updates allowed Envera to improve project outcomes and incorporate additional material for Entuitive. Refer to Table 41 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

Specific criterion is weighted higher, including integration and effectiveness. These were selected to have the greatest impact on scoring as the overarching goal of the retrofit is to achieve an EnerPHit Certification, and the certification eligibility tests conducted on retrofitted buildings largely concern air tightness, which is reliant on building envelope systems working effectively. Further, if new systems negatively impacted the preexisting structure, constructability, construction timeline, and cost would be affected causing difficulty and negate the benefits provided by improved systems.

After scoring in completed for each proposed system, if scores are close in value the system that scored evenly across all categories and complies with the EnerPHit Certification, either independently or with a secondary system, will be selected.

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 annual energy production, and lastly, the annual 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. Innovative solutions will be compared to determine how the design can most efficiently limit its dependency on the municipal water supply. 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 insulating panels or prefabricated insulated metal panels will achieve high R-values; defined as a measure of a material's thermal resistance to heat flow [8]. Meaning the larger the R-value, the greater the thermal resistance, and the greater the selected product's ability to aid in reaching the EnerPHit Certification and holding in conditioned air [8]Through 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, 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 seams sealing the product aims to improve energy efficiency, 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 [9].

With respect to economic feasibility, Blueskin VPTech is sold in panels that are 4'x12' at approximately $80 per panel [9]. 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 material costs, the total cost is approximately $290,000. Wherein, labour, contractor costs and markup, heavy machinery, scaffolding, removal of the existing system, additional siding and roofing materials, and reinstallation of the new complete siding and roofing systems cause a drastic increase in miscellaneous costs.

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 [10]. In addition, the VPTech insulating panels have an R-value of 22.5 at 2.25 inches thick. 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 completed 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. This is 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 0.8 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 for Blueskin

VPTech; however, 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 • Less time-consuming than a traditional system with multiple components. • Requires specialized equipment, for example lifts, to install panels due to their weight.	4	16
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 in addition to U-values, which are a 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 entire 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]. Air leakage values are found to range from 3 to 5 $m^3/h * m^2$, at 50 Pa, though to leakage can be reduced through, upgrading seals resulting in values near 1 $m^3/h * m^2$, at 50 Pa [17]. Rolling steel doors also offer long 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]. Meaning, most insulated rolling steel doors are compliant with U-value targets and typically fail airtightness requirements without secondary barriers [1]. Secondary barriers that work to improve airtightness include air curtains and ensuring high-speed door operating, as offered by Northern Dock Systems. Air curtains operate above the rolling steel door creating a 90% seal across the door opening, while allowing the door to remain open and personnel to enter and exit the facility without significant heat loss. The air curtain is mounted interlocked with the rolling door allowing for simultaneous activation, and a reduction in energy costs. Further, high speed door operation, 18” per second opposed to a typical 6” per second door speed, reduces the time bay doors are open [18]. With these additions, rolling steel bay doors offer compliance with EnerPHit Certification.

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. • High speed door operation and the addition of an air curtain allow for EnerPHit compliance.	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. This design option further does not place burden of regular maintenance or replacement onto facility staff post project closure.

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 [19]. This design preserves internal headroom and maximizes clear opening, making them suitable for workshops or maintenance bays with large equipment and overhead cranes [19]. 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, meeting EnerPHit retrofit standards [20]. Cycle life typically ranges from 20,000 to 50,000 cycles, adequate for moderate-frequency use; however, under high-frequency operation, regular replacement and maintenance is required [20].

The Swift Bi-Folding Door, a commercially available high-performance system, is a side-hung, fast-acting, thermally insulated bi-folding door designed for industrial applications [20]. 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 achieve 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]. However, maintenance needs are more frequent and include hinge inspections, hydraulic or lift-strap servicing, and seal replacement as needed [20]. 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 significantly 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 the achievement of operational efficiency for EnerPHit level retrofits, yet result in deficient cycle life, maintenance frequency, maintenance cost, and upfront costs. Refer to Table 13Table 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 EnerPHit targets while maintaining reliable winter operations, the Mechanical and Electrical systems require upgrades focused on reducing heating demand, enhancing ventilation performance and enabling staged electrification. 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 [21].

6.2.1 Space Heating, Cooling and Ventilation

Environment Canada climate data indicates a winter design dry-bulb temperature of approximately -24 °C to -26 °C for the Georgina region. With approximately 4,500 of the heating degree-days to be (base 18 °C), meaning space heating represents the greatest loads for this facility. [22].

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 areas and occupied spaces 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 to -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 [23].

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 [23].

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 [23].

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, capacity reduction below approximately -20 °C and the absence of a secondary heat source introduce reliability concerns for winter-critical operations. As a result, a hybrid configuration with a backup boiler was selected in the final design.

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

The primary heating system in this concept is a cold-climate air-to-water heat pump, operating as the base load heat source, with a high-efficiency condensing gas boiler providing backup heating, when it is below -20 degrees °C or during frost cycles [24].

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 areas are heated using high-capacity 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 [25].

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. Limiting VRF to office zones while maintaining hydronic heating in truck bays avoids unnecessary operational complexity, as both systems can be coordinated through the centralized Building Automation System. 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 [26].

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 [27].

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 [28]. 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 resistance storage tank provides peak demand coverage. 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 [29]. 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. Given the facility's DHW demand, this hybrid configuration provides sufficient performance without oversizing capital investment, making 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 [30]. However, the proposed scope includes major service capacity expansion to support full electrification, EV charging infrastructure, and future PV integration, resulting in significantly higher projected costs.

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 [31].

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% [32]. Refer to Table 20 for a filled WEM.

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% [32]. 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 [33].

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 [34]. Refer to Table 21 for the filled WEM.

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 [34]. 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 highly in integration and reliability, making it essential to coordinate the electrified HVAC and ventilation systems. Ongoing operation would be managed by facility maintenance staff, with periodic vendor-supported commissioning and software updates. 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 [35]. For businesses requiring 100-500 kW costs around $2.5 per W of capacity installed [36]. 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 [37]. After this period, free electricity is available for the duration of the panels, which is often 25 – 30 years [37].

The average peak sunlight in Ontario ranges from 3 to 4.5 hours per day [38]. 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 [39]. From there, the system will generate 700 kWh per day, however, to account for panel orientation, cleanliness, equipment quality, and gradual degradation, a performance factor of 0.75 is applied, resulting in a total energy production of 191,625 kWh per year, with Equation 1 [40].

Equation 1: Solar panel energy production.

$$Annual\ energy\ production = Sunlight\ Hrs * Power\ Capacity * Perfromance\ factor$$

For forecasted energy production, refer to 10.5 Forecasting Meteorological Conditions.

A typical 450 W 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 [41]. 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. • Energy dependent on solar availability.	4	16
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. Solar panel electrical components will be placed in the battery storage room, as seen in Figure 11 in Appendix D: Engineering Drawing.

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 W. This electricity is then stored for immediate or short-term use [42].

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 [43]. 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 [43]. 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 [43].

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 [42]. On average, each person can generate up to 7 W at 12 V DC, enough to run an LED streetlamp for 30 seconds, or to partially charge a phone or laptop [44].

For the building retrofit, assume there are 50 daily pedestrians who each take 1,200 footsteps daily. Each footstep lasts for about 0.5 s, at a generous 7 W per footstep, which generates 0.00097 Wh. Therefore, the energy output for each person is 1.2 Wh per day. Therefore, this low energy solution generates 58.2 Wh per day, with Equation 2.

Equation 2: Kinetic flooring energy generation.

$$Energy\ Generation = \frac{Energy}{Step} * Daily\ Steps * Amt\ of\ People$$

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 [44].

Electricity during peak energy hours costs 39.1 ¢ per kwh [45]. Therefore, the cost of generating the equivalent amount of energy each day from the municipal grid would cost approximately $0.023. Refer to Table 23 for a filled WEM.

Electricity during peak energy hours costs 39.1 ¢ per kwh [45]. Therefore, the cost of generating the equivalent amount of energy each day from the municipal grid would cost approximately $0.023. 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 long payback period. Innovative and creative solution therefore maintenance will require specialized services which can be costly	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 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, 58.2 Wh per 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 [46].

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 [47]. 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 [47]. 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. Will be located in the designated utility and electrical room on the first floor. • Must have space surrounding it to allow for ventilation.	3	15
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	**62**

The battery storage unit will be integrated into the system to maximize solar energy, and will be placed in the battery storage room, as seen in Figure 11 in Appendix D: Engineering Drawing.

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 [48].

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 [49].

In Ontario, typically costs of installing an EV charging stations for electric vehicles 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]. Entuitive has suggested implementing four to eight chargers, but since level 3 chargers will be used, four chargers will be implemented, accounting for future growth without excessive spending and limiting the dependency on the power availability. 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 four level 3 EV chargers that have a power output of closer to 400 kW, the design will cost around $800,000. If 50% of these costs are eligible for funding, the net project cost would be approximately $400,000. 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. While four EV chargers are proposed, Envera suggests beginning with three, and based on energy availability and demand, install the fourth once needed.

6.4 Water Efficiency

To reduce the facility's water consumption and overall dependence on municipal water, the following sections outline alternatives systems to improve the water efficiency 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.

For indoor use, greywater requires 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% [57]. 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 [58]. 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 [59].

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 vehicle washing or landscaping [60]. Any water used for car washing, must be kept in a controlled location to prevent car wash pollutants from entering sources that could lead to bodies of water, preventing unnecessary contamination of ecosystems and fish habitats [61].

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 [62]. 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 [63]. 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, with Equation 3.

Equation 3: Rooftop rainfall harvesting.

$$Rainfall\ Capture = Surface\ Area * Annual\ Rainfall * \ Performance\ Factor$$

This annual rainfall is not feasible to collect, therefore the rainwater harvesting system could collect from a designated portion of the catchment area to accommodate truck washing, irrigation, and other cleaning needs. The harvesting system will collect rainwater from the south end of the building with the concrete cistern located there as well, as seen in Figure 11 of Appendix D: Engineering Drawing.

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. The scoring for this system is based on the implementation of a 50,000 L below-ground concrete cistern design, as seen in Table 28.

Table 27: 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 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, as well as the groundwater table.	3	15
Maintenance	• Requires trained and specialized personnel. • Does not require frequent maintenance, other than cleaning.	4	8
Water reuse/conservation	• 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. The catchment area will only cover a portion of the roof, and the concrete cistern will be placed along the side of the building away from the garage doors, as seen in Figure 11 in Appendix D: Engineering Drawing.

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 [64]. 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 [64]. 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 [64]. Low-flow fixtures can cost as low as $50 for a toilet, showerheads for $12, and faucets closer to $20 [65]. There exist five toilets, two showers, and six faucets that require replacing, totaling a cost of $394. Refer to Table 28 for the filled WEM.

Table 28: 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 [66] [67]. These projected reductions are derived from preliminary benchmarking against PHPP performance targets, typical EnerPHit deep retrofit case studies, and envelope airtightness improvements associated with insulated panel retrofits. Detailed energy modeling and blower door verification will be conducted in subsequent design phases to validate and refine these estimates.

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 and an air curtain. 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%. To further the secondary barrier, an air curtain being installed at the top of each to further prevent heat loss, 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% [68]. 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 [69]. 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 [70]. Distribution panels are reconfigured with dedicated feeders to each major mechanical system, ensuring adequate capacity and flexibility for future expansion [66].

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 [71].

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 191,625 kWh annually based on Ontario's average peak sunlight hours and adjusted with a conservative performance factor. 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 four 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 Structural Alterations Design

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 that affected columns and beams 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 $m^{2,}$ over which the weight of the solar panels, Kingspan prefabricated panels, and the RTU HRV would apply pressure; this brief calculation is shown in Table 43 in Appendix F: Structural Calculations. 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 in Georgina, Ontario, was used to compute the snow load from Equation 4 as stated in the NBCC 2020 [4] [72] [73]. The remaining coefficients and snow load calculation are highlighted in Table 42 in Appendix F: Structural Calculations.

Equation 4: NBCC 2020 Snow Load.

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

The total values of various load pressures are shown in Table 29.

Table 29: 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				
Georgina, Ontario			**1.66**	**kPa**

Using the determined pressures acting on the roof and second floor, 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 3 governed, as highlighted in Table 30.

Table 30: Load combinations for the roof.

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**

From the governing total load pressure of 3.78 kPa, analysis of the columns 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 2.2 m, and an assumed yield strength of 350 MPa. The applied axial load and resistance of each column type were determined and highlighted in Table 42 and Table 45 in Appendix F: 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 31 below.

Table 31: Applied axial load and compression resistance values for column types.

Classification	Corner	Edge	Interior	Units
Beam Size	W200x21	W200x27	W200x21	mm
Applied Axial Load	46.49	39.69	172.35	kN
Compression Resistance	498.01	638.63	498.01	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 Table 46 in Appendix F: 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 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 joists 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.

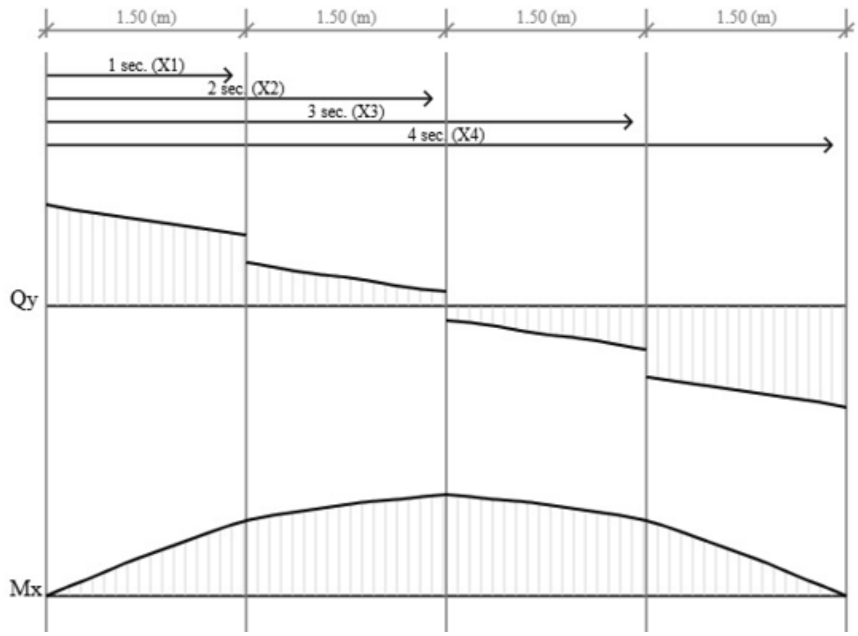

Figure 1: Shear Force Diagram and Bending Moment Diagram of interior and exterior beams.

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 29.

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 Table 47and Table 48 in Appendix F: 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 [74]. As each beam was determined to be at least a Class 2, Equation 5 was used to determine the moment resistance as stated in Clause 13.5 of the NBCC [4].

Equation 5: 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 32 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 32: Beam applied moment and moment resistance comparison.

Moment Type	Variable	Exterior W200x21	Interior W200x27	Second Floor W410x39	Units
Applied Factored	M_f	102.72	120.86	192.77	kNm
Resistance	M_r	68.36	87.89	217.18	kNm

As the calculated moment resistance is lower than the applied factored moment for the roof beams, additional structural support is required to support the structure.

7.5.5 Structural Retrofit Solution

As the applied factored moment of the exterior and interior beams that support the roof exceeded the moment resistance, additional reinforcement to improve flexural capacity is required. The beams supporting the roof are detailed in the original structural engineered drawings shown in Figure 17 in Appendix F: Structural Calculations for reference. To increase the flexural capacity of the insufficient members, steel cover plates will be applied to increase moment resistance. These welded cover plates were selected due to their fire capacity, connection integrity, ease of installation, and their ability to carry the pre-existing and additionally applied loads post-active retrofit.

The addition of welded cover plates works to increase the cross-sectional area of beam flanges, resulting in an increase in strain and moment resistance of the member. Once welded to the existing beam, the cover plates act compositely with the original member, effectively forming a built-up section capable of carrying both the pre-existing loads acting on the beam and the additional loads introduced as part of the retrofit. To adequately take the preexisting and newly applied factored moment, as opposed to simply the additional loads, shoring across the building will be installed to alleviate the existing members from supporting their respective loads while installation is completed, and will then be removed. The active retrofit method, therefore, restores the structural adequacy of the beams without requiring complete removal or replacement of the existing structural elements.

The use of welded cover plates, opposed to glued cover plates or glued fibre-reinforced polymer (FRP), which are both alternative methods of retrofitting for increased flexural capacity, allows for an increase in fire capacity of the structure. In situations of extreme temperature, the adhesive glue that attaches the FRP or glued cover plates may debond at temperatures exceeding 80˚ C, depending on the type of adhesive selected [75]. In contrast, welded steel plates provide direct mechanical connection and do not debond as adhesive applications do under high temperatures, which eliminate the potential of debonding and potential rapid collapse. The added plates will deform and undergo a loss in strength, potentially buckling, and decrease yield strength beginning at temperatures of approximately 300˚ C [76].

The use of welded cover plates allows the retrofit to be implemented with minimal disruption to the existing structural system. Plates can be installed along the tension flange of the beam, welded along the plate edges, allowing the strengthened beam to develop composite action with the existing section. This approach provides a structurally efficient method for increasing flexural resistance while maintaining the integrity of the existing structural framing.

7.5.6 Shoring

To facilitate the installation of welded steel cover plates on the existing roof beams, temporary shoring is required to relieve the members of their existing service loads. This approach ensures that welding and plate installation can be completed without introducing additional stresses or deformation into the structural system [77]. By temporarily transferring loads away from the existing beams, the retrofit can be executed safely while maintaining the integrity of the structure.

Considering the operational requirements of the York Region North District Road Maintenance Facility, all shoring and structural retrofit activities are scheduled to occur during the summer months, when winter maintenance operations are inactive. This approach minimizes disruption to facility operations and aligns with the project constraint of maintaining continuous service throughout the year. Where required, installation will be completed in localized zones to maintain partial access and flexibility within the construction areas.

7.5.6.1 Installation Process

The structural retrofit process will begin with site preparation and the installation of temporary steel shoring posts beneath critical beam locations. This phase is expected to occur within the first 1-2 weeks of the overall retrofit schedule, contributing to a total structural retrofit of approximately 6-8 weeks, based on typical construction sequencing and installations for localized steel reinforcement projects. Adjustable shoring members, such as pipe shores or screw jacks, will then be installed directly beneath the beams at calculated intervals based on the applied loads, span lengths, and expected load redistribution [78]. The load is then gradually transferred from the existing beams to the shoring system through controlled tightening of the supports, relieving the members of their service stresses. This process will be carried out incrementally to avoid sudden load shifts, with verification performed through visual inspection of member response and deflection monitoring to confirm that the intended load relief has been achieved.

Following the load redistribution, the welded steel cover plates will be installed along the tension flange of the existing beams to increase their moment resistance and restore adequate capacity.

Before installation, all beam surfaces will be prepared through cleaning, grinding, and removal of any coatings or corrosion to ensure proper weld penetration and bond quality [79]. Cover plates will then be positioned and secured using tack welds to maintain alignment before full welding is performed. Welding is conducted in accordance with CSA S16 and CSA W59 requirements, using controlled sequencing and intermittent weld passes to minimize heat-induced distortion, residual stresses, and potential weakening of the existing members. Where required, welding will be completed in stages along the beam length to further control thermal effects and maintain geometric stability.

Once the strengthened members have achieved the required capacity, the temporary shoring system will be removed, and the load will be gradually transferred back to the retrofitted beams through incremental release of the shoring supports. During this process, structural response is monitored to confirm that the upgraded members are performing as intended under the applied loads. Following complete removal of the shoring system, a final inspection of the structural elements is conducted to verify alignment, connection integrity, and overall performance under the updated loading conditions [78]. This final verification ensures that the retrofit has been successfully implemented and that the structure satisfies the required strength and serviceability criteria.

The implementation of temporary shoring and welded steel cover plate reinforcement address the increased loading demands associated with the proposed retrofit and are practical solutions. The outlined installation process ensures that structural strengthening can be completed safely and efficiently while maintaining the integrity of the existing framing system. By aligning construction activities with operational constraints and adhering to applicable Canadian design and fabrication standards, the proposed approach supports both the short-term constructability and long-term performance requirements of the facility.

7.5.7 Structural Calculations

To select the appropriately sized steel cover plates, the plastic moment resistance was determined. Assumptions included the welded cover plates possessing the same yield strength as the preexisting beams (350 MPa) and that both the beams and steel plates yield. In prior calculations, the plastic section modulus was taken from CSA S16; however, because additional depth is being added to the top and bottom flange, the cross-section is considered atypical, and the plastic moment must be determined manually and multiplied by the resistance factor to calculate the increased moment resistance of the section.

Prior to determining the moment acting on the cross-section, the location of the neutral axis was calculated through a force balance. As the beams have w-cross-sections, there are four forces acting, two in compression and two in tension, that are separated by the neutral axis. The addition of cover plates to both the top and bottom flanges ensures the forces acting in the cross-sectional area remain balanced. If one large cover plate were welded to the underside of the beam, the neutral axis would shift drastically downward, causing most of the beam to be in compression. For design calculations, ease of installation, and ensuring the beam can withstand the added thickness, the addition of two thinner cover plates was selected. Firstly, Equation 6 below was developed to calculate the location of the neutral axis.

Equation 6: Neutral axis location in the web of the w-cross-sectional area.

$$x = \frac{-\left(t_{Top\ Flange}\right)\left(w_{Flange}\right) + \left(t_{Bottom\ Flange}\right)\left(w_{Flange}\right) + \left(t_{Web}\right)\left(d_{Web}\right)}{2\left(t_{Web}\right)}$$

Wherein, t, w, and d represent thickness, width, and depth, respectively. After the neutral axis location was determined, each of the four previously identified compression and tension forces was calculated using Equation 7.

Equation 7: Compression or tension force equation.

$$F_{Compression/Tension} = \left(w_{Flange/Web}\right)\left(d_{Force}\right)\left(F_y\right)$$

Where the compression or tension force is determined by multiplying the width of the flange or web, the depth of the section over which the force acts, and the yield strength. From the calculated compression and tension forces, the distance from the top of the section to the location each force acts was calculated, wherein the flange forces act at the middle of both flanges, the compression forces in the web at the middle of the neutral axis, and the tension force in the web at the remaining web depth. Using the calculated forces and their respective locations from the top of the section, the plastic moment was taken about the top of the cross-section, assuming positive moments act in the clockwise direction. Once the respective plastic moments for each beam were determined, the plastic moment resistance was calculated using Equation 8.

Equation 8: Moment resistance equation using the plastic moment.

$$M_r = \varphi_s M_P$$

Wherein, each plastic moment is multiplied by the resistance factor, yielding an improved moment resistance. Table 33 highlights the cover plates added for each beam and the calculated moment resistances.

Table 33: Updated applied moments with additional cover plate dead weight, and associated moment resistance values.

Beam	W200x21	W200x27
Applied Moment	103.45 kNm	121.59 kNm
Top Cover Plate	6.35 mm	6.35 mm
Bottom Cover Plate	6.35 mm	6.35 mm
Plastic Moment Resistance	115.84 kNm	135.22 kNm

The thickness of cover plates was selected using readily available and commonly used steel cover plate products, wherein the thickness increased by 3.18 mm intervals. The various thicknesses were iteratively applied to reach an improved moment resistance greater than the applied moment. As various thicknesses were assessed, the self-weight of each steel cover plate was added to the pre-existing dead load from the self-weight of the standardized beam [80].

The increased flexural capacity was determined to be 12.4 kNm and 13.63 kNm larger than the applied moment for the W200x21 and W200x27 beams, respectively. The addition of two 6.35 mm plates offered the necessary available flexural capacity, while providing room for a potential increase in snow load as climate change continues to increase precipitation or for additional mechanical, electrical, or energy systems to be placed on the roof in the future. Detailed design and analysis calculations completed using Microsoft Excel are shown in Table 49 and Table 50 in Appendix F: Structural Calculations.

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 [81]. Envera has estimated the annual carbon emissions of some of the proposed solutions to compare to the baseline conditions. Estimates are based on referenced and available data sources. Calculations were conducted for components with sufficient reliable information to provide accurate predictions. As such, the following section may act as a representative example and not exhaustive.

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 [82]. 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 [82]. For the Entuitive facility, the required panel surface area is approximately 14,500 ft^2, resulting in a proportional embodied carbon estimate of 23,951.9 kg CO_2.

The insulated overhead rolling steel doors will further reduce overall carbon emissions 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 7.85 g/cm^3, the doors weigh approximately 56.54 ton. According to IEA estimates, steel production generates 1.4 tons of CO_2 for every ton of steel produced [83], resulting in an embodied carbon value of approximately 79.16 ton, or 79,161 kg CO_2, for the rolling steel doors.

The steel cover plates added to the beams have an associated embodied carbon impact. There are 20 beams, requiring a total of 40 steel plates. Using the plate dimensions outlined in Table 50 and Table 49, with a width of 0.133 m, a thickness of 0.00635 m, and a length of 6 m, the total volume for all 40 plates is 0.2027 m^3. With the same assumed density of steel of 7.85 g/cm^3, the total mass of the steel plates is 1.591 tons. According to IEA estimates, steel production generates 1.4 tons of CO_2 for every ton of steel produced [83], resulting in an embodied carbon value of approximately 2.23 ton, or 2,227.59 kg CO_2, for the steel plates.

7.6.2 Mechanical & Electrical Emissions Estimate

The retrofit involves replacing major fuel-burning systems with high-efficiency electric equipment, with the result of 75 to 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 to 20%.

The mechanical and electrical subassembly incorporates two 45 kW heat pumps that operate for an assumed 3,000 hours annually, with a COP of 1.76 [84]. Therefore, taking the grid factor of 53 g CO_2, the heat pumps are expected to generate 8,130.0 kg CO_2 annually. It is assumed that between 5 to 10 % of energy for annual heating is through the backup boiler, and it operates at 96% efficiency per the user manual; as a result, it produces an additional 2,475.50 kg CO_2 annually [85]. The baseline design will assume that the entire project is heated through a boiler of a similar capacity, operating at 96% efficiency for 3,000 hours, resulting in 49,514.00 kg CO_2 annually.

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 1,924 kg CO_2 [86] .

The Energy Star certified DHW system enables the unit to use approximately 15% less energy than conventional commercial systems through efficient heat exchange processes [87]. A typical natural-gas system emits around 33,000 kg CO_2 annually; 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 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 [88]. 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 approximately 904 m^2. Using the established benchmark of 10 W per m^2 for commercial LED lighting and assuming the lights are in use for 3,000 hours per year, the facility's lighting demand is estimated at 27,120 kWh annually. Applying Ontario's average grid emission factor of 53 g CO_2 per kWh results in operational emissions of approximately 1,437.36 kg CO_2 annually [89].

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 to 25% annually. Applying a 25% reduction results in an annual facility electrical emissions result in 1,078.02 kg CO_2 annually. To determine the baseline condition, the benchmark of 15 W per m^2 for commercial lighting was used without the savings factor.

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 per kWh [90]. This life cycle accounts for manufacturing, transport, operation, and end-of-life management. Meanwhile, solar panels generate electricity without annual combustion. To determine the baseline design carbon emissions, the total electricity generated from the solar PV system was multiplied by the local grid factor, equating to 10,156.13 kg CO_2 annually.

Battery storage units, by contrast, have higher embodied 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 [91]. Since the solar panels are paired with the battery storage unit, it must be accounted for in the proposed design carbon emissions calculation. Taking the total energy produced to be 191,625 kWh, a conservative efficiency factor of 90%, and the local electrical grid factor, the total carbon emissions produced is approximately 1,016 kg CO_2 per year.

The embodied carbon emission with producing a single DC fast charger is approximately 1,287 kg CO_2 [92]. The operational emissions from EV charging are not produced by the charger itself, but by the electricity generation at the local power grid. Assuming a fleet vehicle travels 400 km a day, at a rate of around 2.0 – 2.2 kwh per km, it requires 84.4 kwh per day. Multiplying this by the four chargers, each charging at least four vehicles a day for 365 days and the local grid factor, the system is expected to generate near 26,123.5 kg CO_2 annually. Emissions can be reduced by implementing selective charging, where charging occurs during lower periods of lower grid carbon intensity [93]. The baseline condition takes the same number of vehicles but applies a conservative tailpipe emissions factor of 250 g CO_2 per km travelled, totaling 584,000 kg CO_2 annually.

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 per year was provided. 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 [89]. The carbon emissions for the baseline design were found through estimated new treated water rather than recycled water on site. Therefore, the advanced water treatment energy use, 2 kWh per m^3, was paired with the electrical grid factor, assuming 600 L of water each day, to match the greywater recycling system [94]. Multiplying the values together results in an annual emission rate of 23.21 kg CO_2.

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 CO_2, while a 60,000 L tank embodies 33,487 kg CO_2 [95]. These emissions are attributed to tank production, plumbing infrastructure, and transportation [95]. The average between the two values can be used to approximate Envera's 50,000 L below ground concrete cistern embodied carbon emissions, 28,697.50 kg CO_2. For the annual carbon emissions, assume 0.5 kWh for low treatment needs and plumbing energy, multiply this by two cistern turnovers and the electrical grid factor, which equates to 2.65 kg CO_2 annually. To determine the baseline condition, 2 kWh per m^3 of treated water was multiplied by the electrical grid factor and the total amount of water, assuming two 50,000 L cistern turnovers. This totals to approximately 10.60 kg CO_2 annually.

Assuming that at least four showers are taken per day using standard fixtures, total emissions increased to 4,535.92 kg CO_2 annually, however this can be, however this is considered negligible since this value could be a high overestimate [96].

A summary of the estimated carbon emissions for the proposed subassembly designs in seen Table 34.

Table 34: Summary of proposed carbon emissions for subassembly designs.

Subassembly	Component	Emissions (kg CO_2)	Emission Timeline
Building Enveloppe	Kingspan Panels	23,952	Embodied
	Steel Doors	79,161	Embodied
	Steel Cover Plates	2,228	Embodied
Mechanical and Electrical	Heat Pump	8,130	Annual
	Backup Boiler	2,476	Annual
	VRF Refrigerant	1,924	Lifecycle
	DHW System	643	Annual
	Lighting System	1,078	Annual
Renewable Energy	Battery Storage Unit – Solar PV	1,016	Annual
	DC Fast Charger	5,148	Embodied
	DC Fast Charger	26,124	Annual
Water Efficiency	Greywater Recycling System	23	Annual
	Rainwater Harvesting – Concrete Cistern	28,698	Embodied
	Rainwater Harvesting	3	Annual

Table 35 shows a breakdown of the estimated annual carbon emissions for the systems that can be compared to baseline conditions.

Table 35: Summary of quantifiable annual carbon emissions of retrofit designs in comparison to the baseline design.

System	Retrofit Design ($kgCO_2e/yr$)	Baseline Design ($kgCO_2e/yr$)	Difference
Heat Pump + Backup Boiler	2,475.50	49,514.00	95.0% savings
Facility Lighting	1,437.36	2,156.04	33.3% savings
Solar Panels + Battery Storge Unit	1,015.61	10,156.13	90.0% savings
EV Charging	26,123.50	584,000	95.5% savings
Greywater Recycling	24.38	23.21	5.0% loss
Rainwater Harvesting	2.65	10.60	75% savings

Evidently, the proposed solutions show upwards of 95% annual carbon emissions savings. While the water efficiency solutions show less savings, the proposed subassembly modifications will minimize the dependency on the local water supply, and act as an effective method to conserve potable water.

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 [97].

8.0 Budget

The combined cost of all proposed retrofit systems is estimated at $3,482,110.80, including a 20% contingency. The project budget is divided into demolition, building envelope, mechanical and electrical, renewable energy, water efficiency, and structural systems to clearly represent each scope of work. The cost selection prioritized performance, constructability, and alignment with EnerPHit objectives while maintaining realistic industry pricing. A breakdown of each system's cost can be found in Table 37 below and where pricing ranges occur (e.g., overhead doors), the high-range value was used for total calculations. Annual maintenance costs are considered separately and are not included in the total project cost.

8.1 Demolition Budget

Selective demolition and site prep were included to remove existing systems and get the building ready for new equipment installation. Costs were based on Canadian industry ranges around $5-$30/ft^2 for demolition depending on complexity and access [98].

Table 36: Demolition Budget

Division	Item	Quantity	Unit Cost	Line Total
Site / General	Removal of existing mechanical systems	Lump Sum	-	$35,000
	Removal of existing electrical systems	Lump Sum	-	$8,000
	Site Prep	Lump Sum	-	$12,000
	Demo Subtotal			**$55,000**

Total costs were based on the final system designs using manufacturer data, industry guides, and available references. Where exact prices weren't available, typical values and conservative assumptions were used. A breakdown of costs can be found in Table 37 below.

8.2 Total Project Budget

Table 37: Project Budget

Division	Item	Quantity	Unit Cost	Line Total
Building Envelope	Kingspan roof and wall insulated metal panels	14,500 ft²	$26.64/ft²	$386,280
	Insulated overhead rolling steel doors	6 doors	$10,000 (high end allowance)	$60,000
	Building Envelope Subtotal			**$446,280**
Mechanical & Electrical	Air-to-water heat pumps	2 units	$70,000 each	$140,000
	Backup boiler system	1 lump sum	-	$65,000
	Hydronic distribution for truck/wash bays	1 lump sum	-	$80,000
	Hydronic unit heaters	1 lump sum	-	$20,000
	Truck bay exhaust / ventilation modifications	1 lump sum	-	$60,000
	Office heat pumps	3 units	approx. $18,667 each	$56,000
	HRV ventilation system	1 lump sum	-	$60,000
	Domestic hot water system	1 lump sum	-	$38,000
	Electrical service upgrade	1 lump sum	-	$280,000
	Lighting retrofit	1 lump sum	-	$85,000

	Building automation system	1 lump sum	-	$90,000
	Mechanical & Electrical Subtotal			**$974,000**
Renewable Energy	Solar PV system	175 kW	$2,500/kW	$437,500
	Battery energy storage	1 lump sum	-	$270,000
	DC fast charging stations *(net of assumed incentives)*	4 chargers	$100,000 each net	$400,000
	Renewable Energy Subtotal			**$1,107,500**
Water Efficiency	Greywater reuse system	1 system	-	$14,095
	Rainwater harvesting system with 50,000 L cistern	1 system	-	$90,590
	Low-flow fixture upgrades	5 toilets, 2 showers, 6 faucets	-	$394
	Water Efficiency Subtotal			**$105,079**
Structural Reinforcement	Steel cover plates (supply)	Material cost with tariffs, GST, duties, etc.	-	$12,000
	Welding & installation	2 welders, 1 spotter, 1 fire monitor (Labour costs)	-	$18,500
	Temporary shoring / jacking	$20/ft^2 building footprint approximately 7800ft^2	-	$156,000
	Equipment & access (crane, lifts)	TBD	-	$15,000
	Engineering review & inspection	1 lump sum	-	$10,000
	Bollards	6	$400	$2,400
	Structural Subtotal			**$213,900**

PROJECT TOTALS	**Direct Construction Subtotal**	**$2,846,759**
	Demolition Budget	**$55,000**
	Demolition + Construction Total	**$2,901,759**
	Contingency (20%)	**$580,351.80**
	Total Project Cost	**$3,482,110.80**

8.3 Yearly Maintenance Budget

If Envera were contracted for ongoing maintenance, annual servicing of mechanical and electrical systems would be required, including heat pumps, boiler, HRV, DHW, and battery storage.

Based on typical industry practice, maintenance costs are estimated at approximately 2-4% of the mechanical and electrical system cost, resulting in an annual cost of roughly $20,000-$40,000. A value of $35,000 was selected as a conservative estimate to reflect the complexity of the integrated systems and the need for regular inspection and specialized servicing [99]. This was not included in total project cost as it is currently out of Envera's scope.

Table 38: Yearly Maintenance Budget

Division	Item	Quantity	Unit Cost	Line Total
Site / General	Building envelope (panels, seals, doors)	Lump Sum	-	$3,000
	Mechanical systems (heat pumps, boiler, HRV, DHW)	Lump Sum	-	$15,000
	Electrical & controls (service, BAS, lighting, battery)	Lump Sum	-	$8,000
	Renewable energy (solar PV, EV chargers)	Lump Sum	-	$5,000
	Water systems (greywater, rainwater system)	Lump Sum	-	$4,000
	Annual Maintenance Subtotal			**$35,000**

For a 725 m² facility, the total cost represents approximately $4,803/m². This is consistent with typical deep energy retrofits that include electrification, envelope upgrades, and renewable integration.

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 39 below.

Table 39: 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 a 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. 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 labour 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 40**.**

Table 40: 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

While a few systems score high in operational impact and cost sensitivity, this does not necessarily correspond to a high probability of underperformance. For example, battery energy storage systems are assigned a low to moderate probability of underperformance due to their use of commercially available technology; however, they exhibit high-cost sensitivity because failures or degradation can result in significant replacement costs, safety concerns, and commissioning complexity. Similarly, the solar PV system is rated high for installation complexity due to roof access, structural coordination, and electrical integration requirements, while its probability of underperformance remains moderate given the reliability of certified PV components when properly installed. Electrical service expansion also presents the highest in combined cost sensitivity and installation complexity, making it a critical risk for retrofit feasibility. Additionally, EV charging infrastructure, building automation systems, and primary heating systems score high in operational impact, as failures or underperformance in these areas could directly disrupt winter maintenance operations and compromise facility functionality. While most building envelope, pluming and fixture upgrades remain within the low to moderate risk range, the performance and coordination of major electrical and mechanical systems represent the most significant risks requiring mitigation and staged implementation strategies.

9.2 Mitigation

To manage the risks identified within the retrofit design, targeted mitigation strategies are proposed based on system type and shared risk characteristics.

9.2.1 Envelope and Building Fabric Systems

For exterior walls, roofs, and bay doors, mitigation focuses on constructability and performance assurance. Detailed structural and thermal assessments will be conducted before installation, as seen in section 7.0 Retrofit Solution, supported by quality assurance and control measures such as staged airtightness testing and thermal inspections. Prefabrication of envelope components, where feasible, will reduce on-site complexity, while post-installation testing will verify compliance with performance targets.

9.2.2 Electrical and Energy Systems

Electrical service expansion, solar PV systems, EV charging infrastructure, and battery energy storage present elevated operational and cost-related risks due to system integration and safety considerations. Mitigation strategies include detailed electrical load analysis, phased implementation to minimize service disruption, and strict adherence to manufacturer and code requirements. Certified equipment and mounting systems will be used, supported by real-time performance monitoring and protective devices to detect faults early. Commissioning and maintenance will be performed by trained personnel to reduce safety and reliability risks.

9.2.3 Mechanical and Thermal Systems

Heating systems, mechanical ventilation, and domestic hot water systems will be mitigated through detailed load calculations, system commissioning, and performance verification under operational conditions. Preventative maintenance plans, including filter replacement, inspections, and diagnostics, will support long-term reliability. Staff training will also ensure proper operation and early identification of performance issues.

9.2.4 Control, Automation and Lighting

Lighting, controls, and building automation systems will prioritize proven technologies with low operational risk. Early system integration testing will be used to identify compatibility issues between subsystems, and functional testing will be completed prior to commissioning. Routine software updates and staff training will further reduce long-term operational risk.

9.2.5 Water Efficiency Systems

Greywater recycling and rainwater harvesting systems will be mitigated through certified components, commissioning tests for flow and water quality, and regular maintenance schedules. Proper sizing, filtration, and overflow provisions will reduce the risk of contamination or system failure.

9.2.6 Low Risk Interior Upgrades

Finally, fixture and lighting upgrades will utilize standardized, commercially proven products installed using conventional construction practices. Mitigation efforts will primarily focus on basic quality control during installation and routine inspection following implementation to ensure proper operation and consistency across the facility.

10.0 Maintenance and Service

The following section goes beyond the defined scope, but details maintenance and service plans for the intended upgrades of the retrofit.

10.1 Building Envelope

The proposed building envelope upgrades are not expected to introduce significant new maintenance requirements beyond those already established for the facility. Routine maintenance procedures currently used for the steel frame, sheet walls, and roll-up garage doors will continue following the retrofit. These procedures typically include periodic visual inspections of wall and roof panels, gaskets at panel joints and penetrations, servicing of bay door components, verification that flashing and drainage systems remain functional, and monitoring of sealant, which must be replaced every 10-12 years [100]. If damage or performance degradation occurs, localized repairs such as resealing panel joints, replacing individual insulated panels, or repairing worn door seals can be performed using standard building maintenance practices. Maintaining the existing inspection and repair schedule will help ensure that the upgraded enclosure continues to provide the intended levels of thermal performance, airtightness, and durability throughout the building's operational life.

10.2 Mechanical and Electrical

The proposed mechanical and electrical systems are designed to operate under a preventive maintenance program focused on the major active equipment.

Seasonal inspection of the air-to-water heat pumps should be completed to confirm proper operation, unobstructed airflow, drainage, and acceptable water circuit conditions [84]. The backup condensing boiler should be serviced annually by a qualified technician to ensure combustion efficiency, heat exchanger cleanliness, and safe operation [101]. The HRV/DOAS system should undergo at least two full inspections per year, including filter replacement, heat recovery core cleaning, blower inspection, intake and exhaust hood cleaning, and condensate drain check [101]. The heat pump water heater should also be inspected periodically, with sacrificial anode replacement typically required every two to three years to maintain tank integrity and system performance [102]. On the electrical side, maintenance requirements are expected to be relatively low and primarily consist of routine inspection of the upgraded service equipment, verification of lighting controls and occupancy sensors, and periodic review of the Building Automation System (BAS) to confirm alarms, schedules, and trend data are functioning correctly [103]. Since the retrofit incorporates LED lighting and centralized automation, long-term service requirements are reduced compared to conventional lighting systems, with maintenance largely limited to control calibration and occasional fixture replacement over the system life cycle [104].

10.3 Renewable Energy

Solar PV systems require regular maintenance and servicing to optimize energy efficiency. Through routine tasks such as checking for loose connections, defects, or malfunctions, minor issues can quickly be resolved prior to becoming major concerns. Furthermore, regular maintenance also ensures reliability, as faulty wiring can pose as an electrical and/or fire hazard. Hiring a professional with experience in PV solar maintenance twice a year is a proactive approach to mitigate potential issues and optimize energy performance [105]. In doing so, it is vital that personal protective equipment is worn to ensure the safety of technicians. Additionally, non-abrasive and eco-friendly cleaning agents should be used on panels to prevent runoff from contaminating nearby ecosystems. Solar panel typical energy output degrades between 0.5% and 0.8% each year, and regular maintenance can prevent this rate from increasing [105].

For maneuverability, Envera recommends installing bollards around EV infrastructure, especially due to the high volume of maintenance and service trucks at the location. Space and maneuverability must be considered throughout the design process and installation process for efficient operations.

To ensure EV infrastructure remains in good operating condition, daily maintenance can help extend the lifespan of charging stations. This includes ensuring that cables are securely stored before and after use, noticing signs of visible damage, and clearing debris and dirt from the connectors [106]. EV infrastructure also requires scheduled maintenance and inspections by qualified personnel. Qualified personnel must deem the charging connectors, communication systems, grounding components, and surge protection to be adequate and safe for operation [106].

Battery energy storage units can be paired with the solar PV system to store excess electricity that is generated during peak sunlight hours. To optimize and ensure safe operating conditions, battery storage units should be installed in a ventilated electrical storage room or battery enclosed space that complies with electrical and fire safety codes, such as the National Building Code of Canada (NBCC), the National Fire Code (NFC), the Ontario Electrical Safety Code (OESC) Section 64. The battery energy storage room must also have sufficient electrical capacity and should be continuously monitored with a surveillance system to note suspicious activity.

10.4 Water Efficiency

The greywater recycling system will require regular maintenance due to its role of treating water for non-potable applications. Maintenance activities include periodic water quality monitoring, filter and valve replacement to prevent bacteria and biofilm buildup, and inspections of pumps and the Hydraloop Cascade unit by qualified personnel.

Rainwater harvesting systems require maintenance such as cleaning gutters every three months, or more frequently based on current weather conditions. Leaves, branches, and debris should be removed to improve water quality and prevent clogging or potential structural degradation [107]. Filters and screens should be inspected on a monthly basis, while the storage tank and pumps should be checked annually [108]. Inspections should note signs of algae, mold, cracks, and accumulated debris [107]. To ensure a thorough inspection, check the roof for deteriorating materials, algae growth, and debris build-up.

Once water fixtures are installed, routine maintenance should include periodic checks for leaks, monitoring for mold or biological growth to ensure the safety of workers, and ensuring adequate flow rates to maintain efficient and hygienic operating conditions.

10.5 Forecasting Meteorological Conditions

As mentioned in Section 10.3 Renewable Energy, solar panel energy output typically degrades between 0.5% and 0.8% each year [105]. Given the current solar power output is approximately 191,625 kWh per year, the system is expected to generate between 177,000 kWh and 182,400 kWh after 10 years. After 20 years, the output is expected to range between 163,300 kWh and 173,400 kWh per year. After 30 years, the solar panels could generate between 150,600 kWh and 164,900 kWh. As solar panel performance degrades over time, regular maintenance is vital to extend their lifespan. Furthermore, excessive degradation may warrant panel replacement.

Additionally, solar panel use and energy generation should be continuously recorded to track true performance and update the expected degradation estimates for future needs.

A seasonal ARIMA model was applied to a monthly precipitation timeseries to forecast future precipitation patterns in Georgina using historical data collected from a weather station in Baldwin [109]. As seen in Figure 2 below, the model indicates that while precipitation fluctuates seasonally, there is no strong upward or downward trend in average rainfall, which may be a model limitation. Evidently, the prediction intervals widen over time, reflecting uncertainty in long-term forecasts.

This data highlights the importance of designing retrofits that can effectively manage high rainfall variability. Storage capacity must consider average rainfall volumes as well as any short-term spikes. The general formula for determining how much rainfall can be captured is outlined in Equation 3. The roof catchment area of the building is approximately 724.8 m^2. Taking the forecasted precipitation data to be approximately 917 mm of annual rainfall, in theory, the building will collect approximately 664,642 L per year. An adjustment for losses can be made, by assuming 30% is lost. As a result, the maximum rainfall collection is estimated to be approximately 465,249 L. Collecting runoff from the entire annual rainfall is not feasible, therefore the rainwater harvesting system will be designed to collected water from the south end of the building, where the concrete cistern will be located, as seen in Figure 11 in Appendix D: Engineering Drawing. This harvested water can be used for non-potable water needs. In addition, the stormwater management and irrigation systems must be regularly monitored and maintained to reduce the risk of flooding during major storm events that are not captured by the SARIMA model. Based on future water needs, Envera recommends upgrading the cistern to capture a larger volume of rainwater.

Please note that while statistical forecasting models such as SARIMA are based on historical data and used to predict future forecasts, they are limited in their availability to predict extreme weather events, such as high intensity rainfall or droughts. Flood protection measures, stormwater drainage systems, and site grading are vital for water management and to mitigate the potential for flooding.

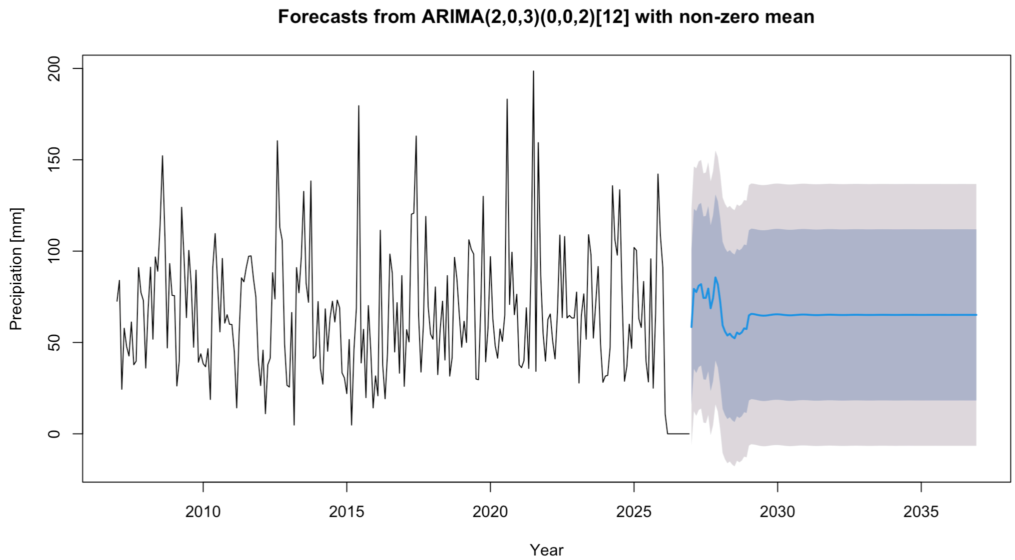

Figure 2: SARIMA forecast for precipitation in mm; data collected from weather station in Baldwin [109].

A seasonal ARIMA model was also applied to a monthly wind speed data to forecast future wind patterns in Georgina based on data collected at Toronto Pearson Airport [110], as this was the only dataset available with wind speed that could replicate weather conditions in Georgina. The forecasted results are seen below in Figure 3, which suggest that wind speeds are to remain relatively stable over-time. Please note that model limitations prevent the forecast of randomness; therefore, future peaks may fall outside of the confidence intervals. Due to the performance factor and overdesign as described in 7.5.7 Structural Calculations, the retrofit meets the outlined forecasted wind conditions.

Furthermore, rooftop systems, such as the rainwater harvesting system and the rooftop solar PV panels must be securely anchored to prevent damage caused by high wind speeds. Frequent inspections may be required to ensure all systems are effectively secured before and after heavy winds.

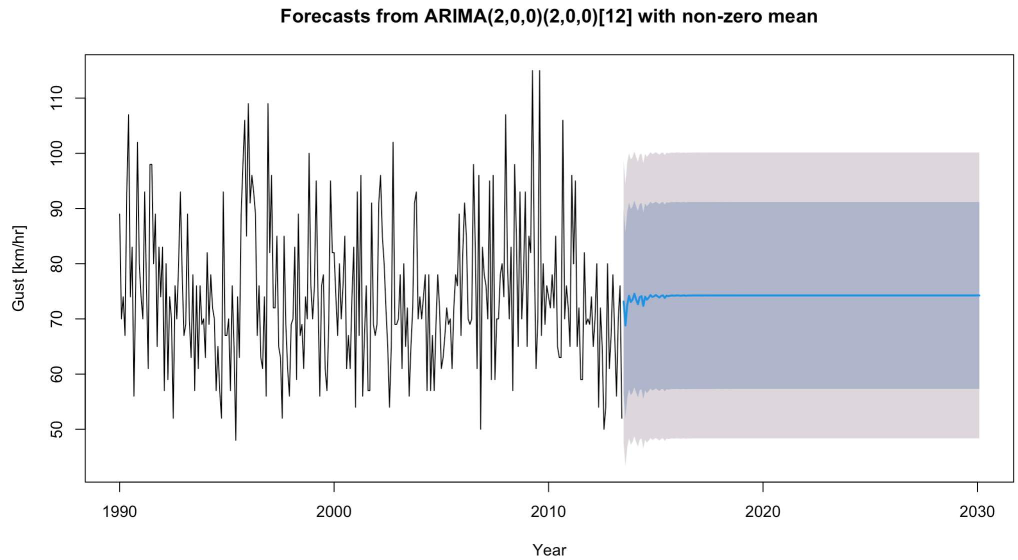

Figure 3: SARIMA forecast for wind in km/hr; data collected from Toronto Pearson Airport [110].

A seasonal ARIMA model was applied to monthly snow data to forecast future snow accumulation patterns in Georgina based on data collected at Toronto Pearson Airport [110], as this was a readily available dataset with snow that could replicate weather conditions in Georgina. The predicted forecast can be seen below in Figure 4, which indicates seasonal variability in snowfall and accumulation in winter months.

The structural components of the retrofit must account for snow load to ensure that the system can safely support snow accumulation during winter months. Structural elements must be designed to withstand snow loads. Due to the performance factor and overdesign as described in 7.5.7 Structural Calculations, the retrofit meets the outlined forecasted snow conditions.

Furthermore, rooftop solar PV systems must accommodate snow accumulation. The panels must be tilted and regularly cleared to reduce snow buildup to optimize solar energy performance throughout snowy conditions.

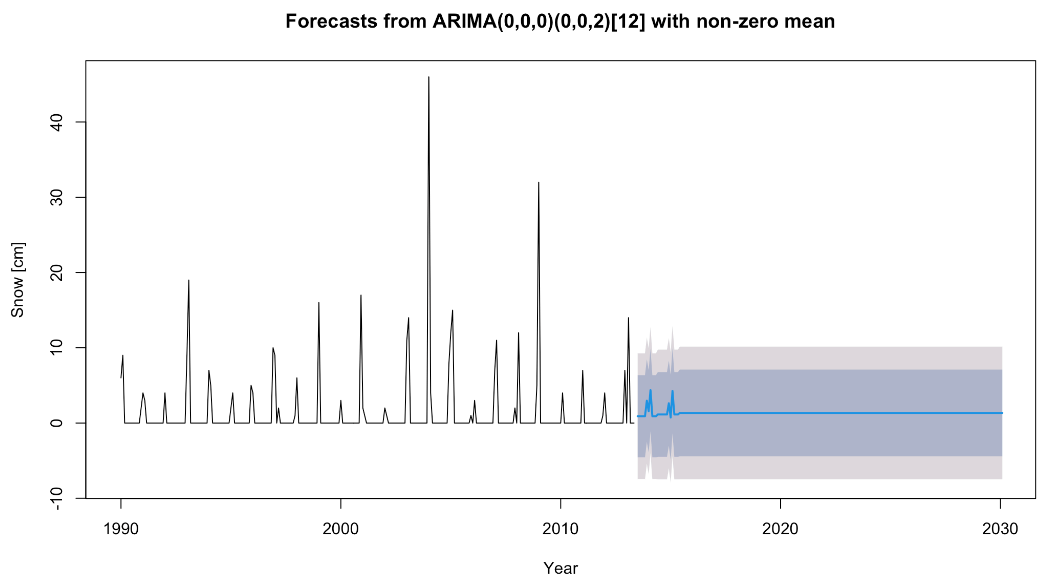

Figure 4: SARIMA forecast for snow in cm; data collected from Toronto Pearson Airport.

11.0 Innovation

To enhance Envera's project coordination and improve the deliverable management, the team integrated a digital innovation component into the retrofit strategy. This innovation supports structured documentation, communication, and project transfer for the client.

11.1 Website

The team has developed and designed a project-specific website (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 structure improves accessibility to project information and supports transparency throughout the project lifecycle to the client.

The platform includes clearly defined timelines, milestones, and deliverable tracking to support accountability and organized project management. By centralizing documentation and updates, the website reduces fragmentation of information and improves coordination between the project team and stakeholders.

In addition to document management within the website, 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 Figure 2 below is the website's home screen which emphasizes clarity, accessibility and modern design to reflect Envera's vision and identity.

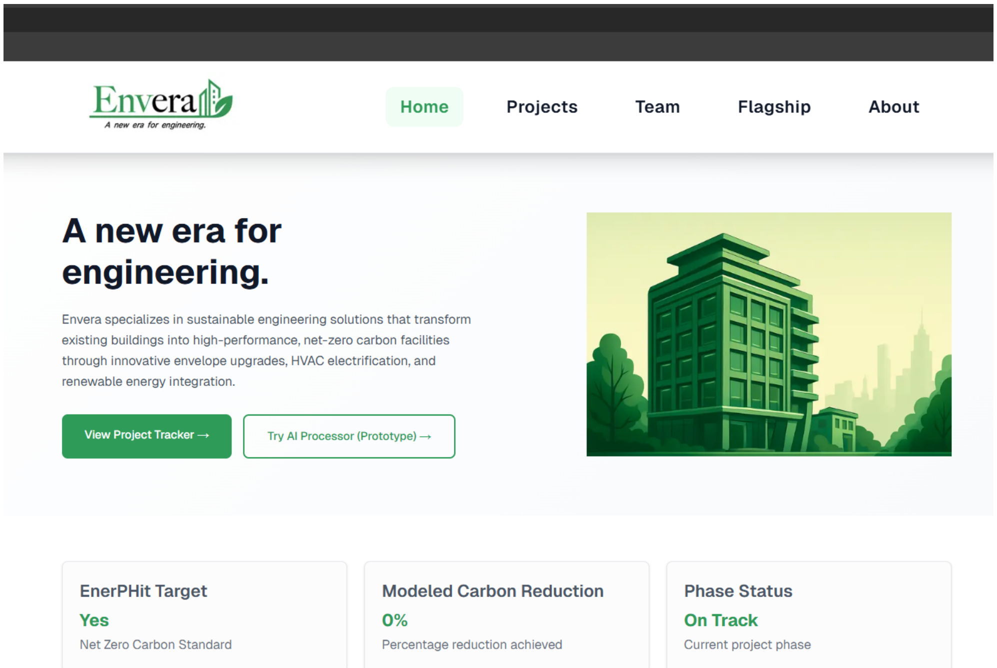

Figure 5: Envera's website homepage.

11.2 AI Retrofit Processor

As part of Envera's digital platform, the team developed their flagship Retrofit Processor, an interactive tool designed to support early-stage retrofit planning. The processor allows users to input key building characteristics and quickly generate preliminary insights into retrofit feasibility, potential energy improvements, and sustainability opportunities. By streamlining early assessments, the tool helps clients better understand project potential before committing to detailed engineering studies, ultimately improving decision-making and reducing preliminary assessment costs. Figure 6 below shows the processor with the Access Code being "ENVERA2025", showcasing Envera's new era for engineering.

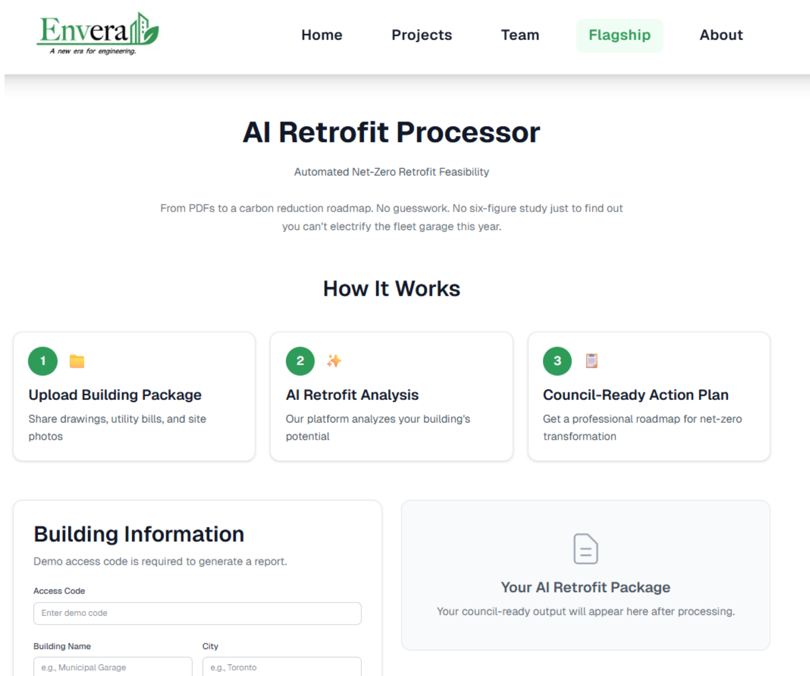

Figure 6: Envera's Retrofit Processor interface for preliminary building retrofit assessment.

12.0 Conclusions

To date, 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 while addressing the operational, climatic, and structural constraints of an active municipal maintenance facility.

The selected envelope system: high-performance Kingspan insulated metal panels combined with upgraded overhead rolling steel bay doors, was chosen for its airtightness, thermal performance, and constructability within the existing steel-frame building. This approach directly mitigates significant sources of heat loss from the six 24 m^2 bay doors, while reducing maintenance and ensuring the envelope can reliably support EnerPHit-level performance.

Mechanical and electrical system upgrades were evaluated based on heating demand, cold-climate reliability, and compatibility with future electrification. The hybrid air-to-water heat pump system with a high-efficiency condensing boiler backup was selected to balance low-carbon heating with winter operational reliability. Supporting upgrades, including HRV ventilation, DOAS for office zones, electrical distribution improvements, and LED lighting with BAS controls, further reduce energy consumption and enhance indoor environmental quality.

Renewable integration through a rooftop PV system and battery storage improves resilience and offsets a substantial portion of annual electrical demand, while planned DC fast chargers support fleet electrification. 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 conservation priorities.

From a structural perspective, the assessment confirmed that strengthening selected roof beams is required to safely support the additional loads introduced by the upgraded envelope systems, rooftop solar PV array, and associated mechanical components. This strengthening is achieved through the installation of welded steel cover plates along the tension flanges of critical beams, increasing flexural resistance while preserving the existing structural framework. To facilitate safe installation, temporary shoring systems are introduced beneath designated beam locations to relieve service loads during welding operations. Following installation, loads are gradually transferred back to the strengthened members, ensuring stable performance under updated loading conditions. This localized strengthening strategy allows the retrofit to be completed without major structural replacement, minimizing disruption to facility operations while maintaining long-term structural reliability and safety.

The proposed retrofit design emphasizes valuable social implications, particularly those in relation to occupant well-being, innovative design, and environmental impact. The listed upgrades work to improve the building envelope, typical energy-intensive mechanical and electrical systems, while also incorporating renewable energy generation, promoting green transportation, and enhancing water efficiency to reduce the reliance on the municipal water supply. Together, these system work to achieve EnerPHit standard, which can only be granted after successful project construction. Envera also works to promote sustainable design solutions and innovation through the production of its AI retrofit processor. Not only does this foster creative and data-driven design solutions, but it creates precedent for commercial buildings to prioritize sustainability and innovation at the forefront of their engineering design process.

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

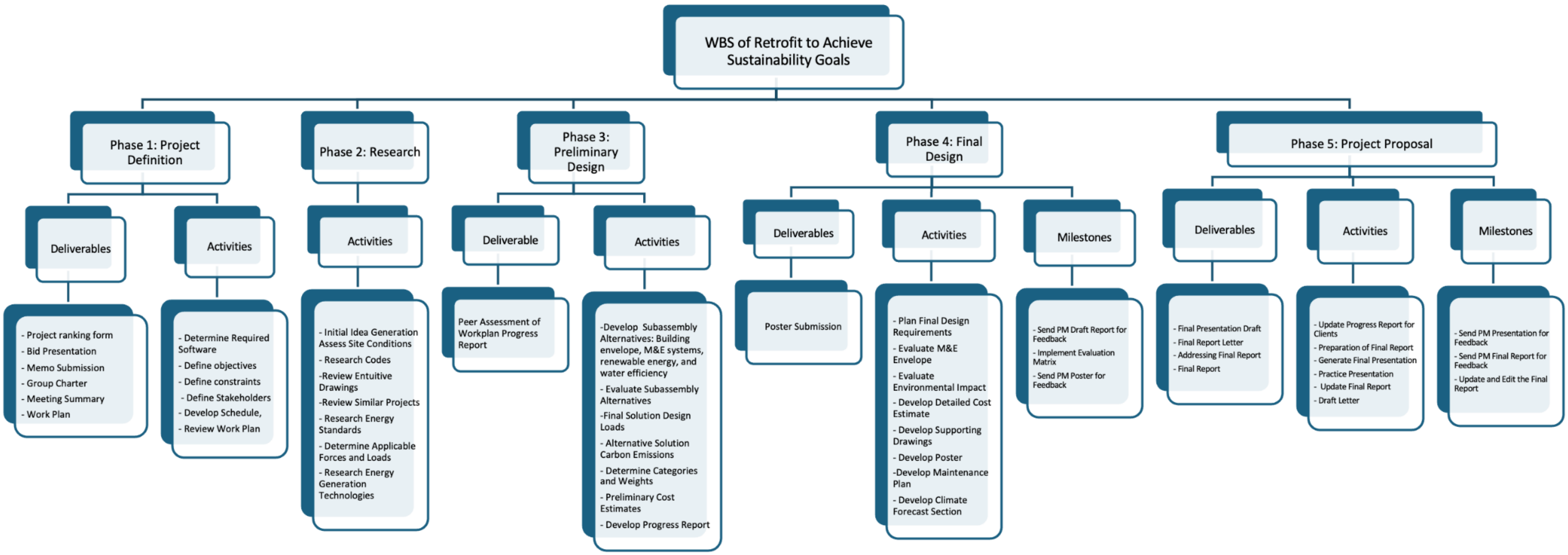


Figure 7: Work breakdown structure (WBS) for Envera.

Appendix B: Gantt Chart with Responsibilities

Figure 8, Figure 9, and Figure 10 demonstrate proposed timeline of Envera with tasks identified as a deliverables, an activity, or a

CIVL 460 - Group E - Gantt Chart

Project Start Date:	2025-09-08
Printed Gantt Chart Date:	2026-03-17

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 Enveloppe 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	100.00%	18-Nov	1
Progress Report	Deliverable	Jordan	All	100.00%	21-Nov	1

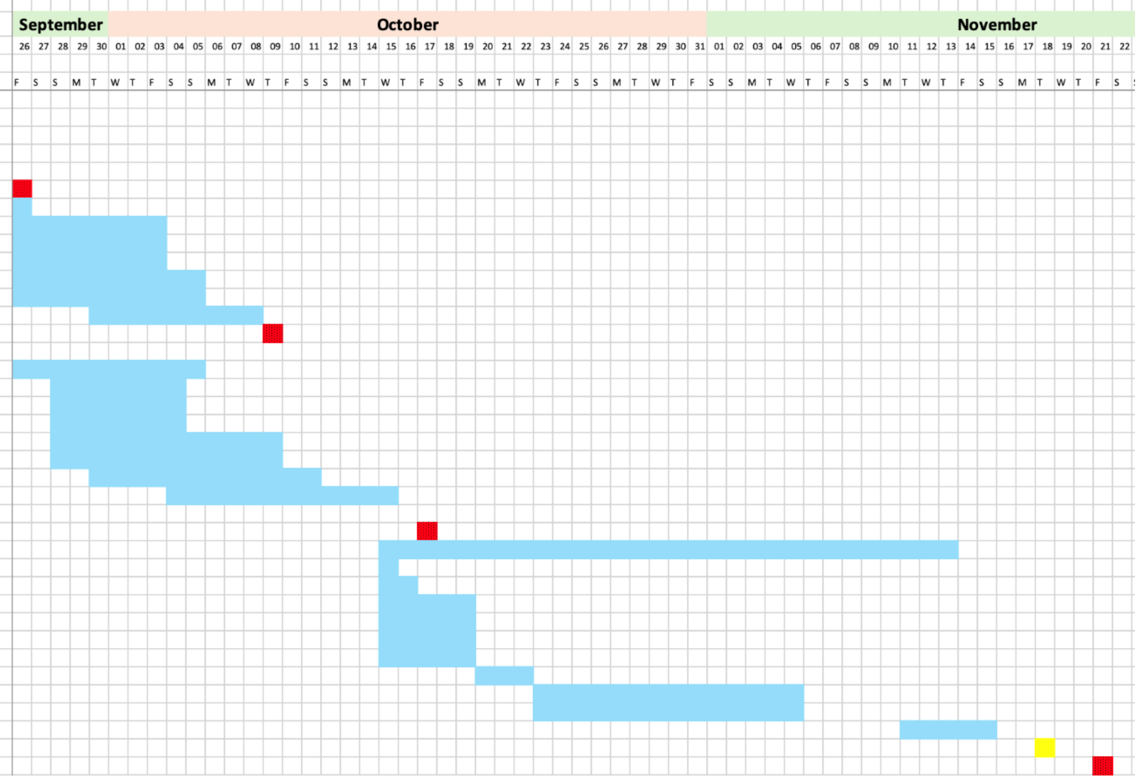
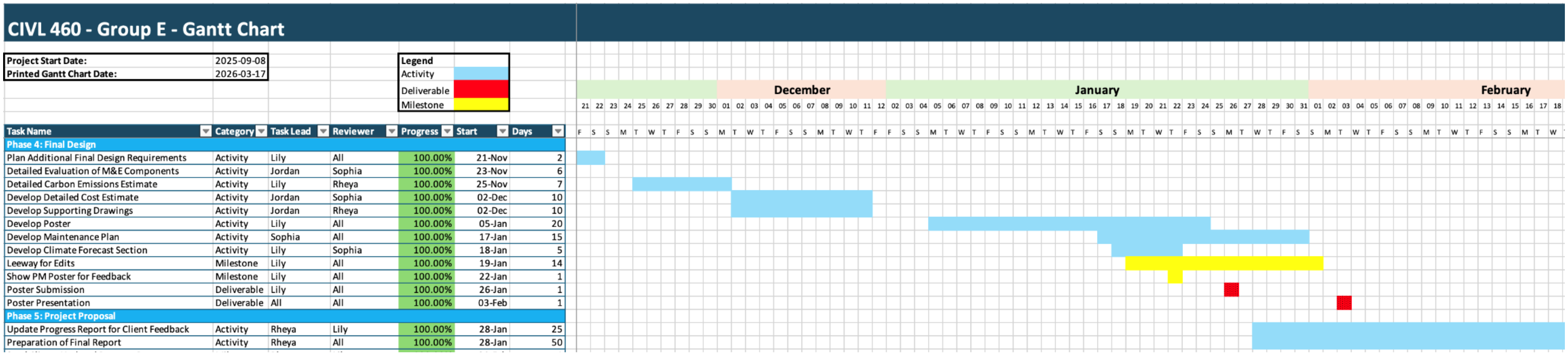


Figure 8: Gantt Chart with designated team leads and reviewers for Phase 1, Phase 2, and Phase 3 from September 26th to November 22nd.



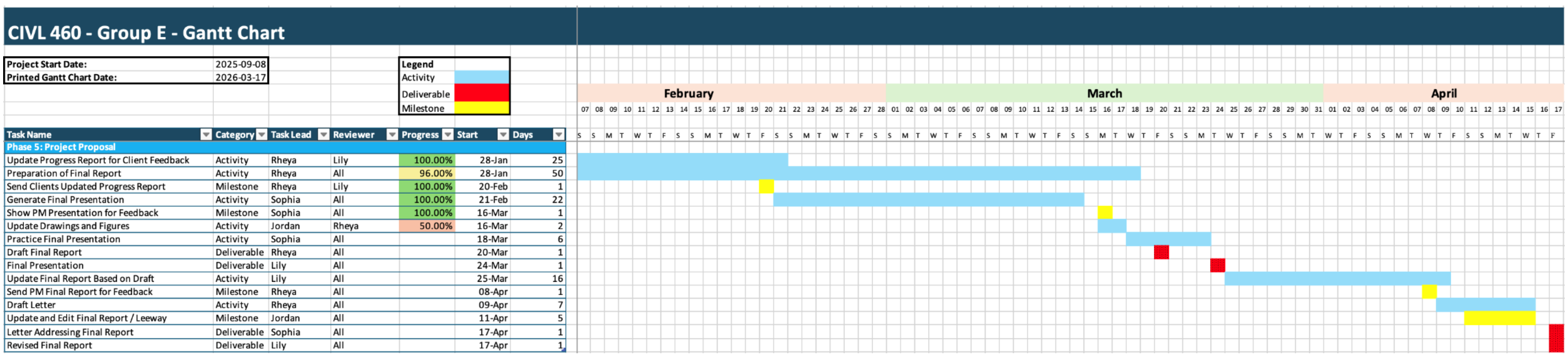
CIVL 460 - Group E - Gantt Chart

Project Start Date:	2025-09-08
Printed Gantt Chart Date:	2026-03-17

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	100.00%	21-Nov	2
Detailed Evaluation of M&E Components	Activity	Jordan	Sophia	100.00%	23-Nov	6
Detailed Carbon Emissions Estimate	Activity	Lily	Rheya	100.00%	25-Nov	7
Develop Detailed Cost Estimate	Activity	Jordan	Sophia	100.00%	02-Dec	10
Develop Supporting Drawings	Activity	Jordan	Rheya	100.00%	02-Dec	10
Develop Poster	Activity	Lily	All	100.00%	05-Jan	20
Develop Maintenance Plan	Activity	Sophia	All	100.00%	17-Jan	15
Develop Climate Forecast Section	Activity	Lily	Sophia	100.00%	18-Jan	5
Leeway for Edits	Milestone	Lily	All	100.00%	19-Jan	14
Show PM Poster for Feedback	Milestone	Lily	All	100.00%	22-Jan	1
Poster Submission	Deliverable	Lily	All	100.00%	26-Jan	1
Poster Presentation	Deliverable	All	All	100.00%	03-Feb	1
Phase 5: Project Proposal						
Update Progress Report for Client Feedback	Activity	Rheya	Lily	100.00%	28-Jan	25
Preparation of Final Report	Activity	Rheya	All	100.00%	28-Jan	50

Figure 9: Gantt Chart with designated team leads and reviewers for Phase 4 and the beginning of Phase 5 from November 21st to February 18th.



CIVL 460 - Group E - Gantt Chart

Project Start Date:	2025-09-08
Printed Gantt Chart Date:	2026-03-17

Legend	
Activity	
Deliverable	
Milestone	

Task Name	Category	Task Lead	Reviewer	Progress	Start	Days
Phase 5: Project Proposal						
Update Progress Report for Client Feedback	Activity	Rheya	Lily	100.00%	28-Jan	25
Preparation of Final Report	Activity	Rheya	All	96.00%	28-Jan	50
Send Clients Updated Progress Report	Milestone	Rheya	Lily	100.00%	20-Feb	1
Generate Final Presentation	Activity	Sophia	All	100.00%	21-Feb	22
Show PM Presentation for Feedback	Milestone	Sophia	All	100.00%	16-Mar	1
Update Drawings and Figures	Activity	Jordan	Rheya	50.00%	16-Mar	2
Practice Final Presentation	Activity	Sophia	All		18-Mar	6
Draft Final Report	Deliverable	Rheya	All		20-Mar	1
Final Presentation	Deliverable	Lily	All		24-Mar	1
Update Final Report Based on Draft	Activity	Lily	All		25-Mar	16
Send PM Final Report for Feedback	Milestone	Rheya	All		08-Apr	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 10: Gantt Chart with designated team leads and reviewers for the end of Phase 4 and Phase 5 from February 7th to April 17th.

Appendix C: Breakdown of Timeline Deviations

Table 41 below provides a detailed breakdown of the timeline modifications that were implemented in the Gantt chart of Envera after the submission of the Progress Report. Please note that items that were modified from the Work Plan in the Progress Report can be found in the Progress Report.

Table 41: Major deviations to the timeline

Item No.	Timeline Modification	Gantt Chart Task from the Draft Final Report	Gantt Chart Task from the Updated Progress Report	Reason:
1	- Time added to Maintenance Plan Development	- 15 days allocated	- 5 days allocated	- While a maintenance plan is beyond the scope of the project, Envera felt that adding future plans could exemplify their commitment to the project. To build confidence with the clients, it was decided to include a more detailed plan, requiring more time.
2	- Added a task for a climate forecast analysis	- Included forecasts analysis, allocated 5 days	- Not included	- When reviewing the maintenance plan, Envera and the PM felt that considering future weather patterns could be valued, since many components are weather dependent (structural systems, solar panels, and rainwater harvesting).
3	- More time allocated for developing the poster presentation	- 20 days allocated	- 10 days allocated	- The course instructor pushed the poster presentation date, based on feedback from other students in the class. This allowed for more time to work on the poster.
4	- Showed the poster presentation to the	- Showed the poster presentation for feedback on January 22nd	- Send the poster presentation for feedback on January 5th	- The course instructor pushed the poster presentation date. The date was pushed back and showed the presentation, rather than emailed.
5	- Poster submission date revised	- Submission date as January 26th	- Submission date as January 12th	- The course instructor pushed the poster presentation date, based on feedback from other students in the class.

6	- Added a task for presenting the poster.	- Included the poster presentation date on February 3rd	- Not included	- Envera was scheduled to present on February 3rd.
7	- Added a task for updating the Progress Report to send to the clients based on PM feedback	- Included updating the Progress Report, allocated 25 days	- Not included	- The PM informed Envera that the Updated Progress Report must be sent to the clients, which was not known throughout the initial planning process.
8	- Added a task for sending the Updated Progress Report to send to the clients	- Included sending the clients the Updated Progress Report, allocated 1 day	- Not included	- PM informed Envera that the Updated Progress Report must be sent to the clients, which was not known throughout the initial planning process.
9	- Allocated more time to generating the final presentation	- Allocated 22 days from February 21st	- Allocated 6 days from February 21st	- The course instructor pushed the final presentation submissions date, based on feedback from other students in the class. This allowed for more time to generate the final presentation.
10	- Showed PM final presentation at a later date	- Showed presentation on March 16th	- Was supposed to send the presentation on February 27th	- The course instructor pushed the final presentation submission date. The presentation was not sent to the PM, rather it was shown in an in-person meeting at a later date.
11	- Allocated more time to practice the final presentation and pushed back dates	- Allocated 6 days from March 18th	- Allocated 5 days from March 5th	- The course instructor pushed the presentation date. This allowed for more time to practice the final presentation and at a later date.
12	- Modified the presentation date	- Presentation scheduled for March 24th	- Presentation scheduled for March 11th	- The presentation dates were officially scheduled for March 24th and March 25th, with Envera scheduled to present on the 24th.

Appendix D: Engineering Drawing

Refer to Figure 11 for the Envera engineering drawings of the proposed retrofit.

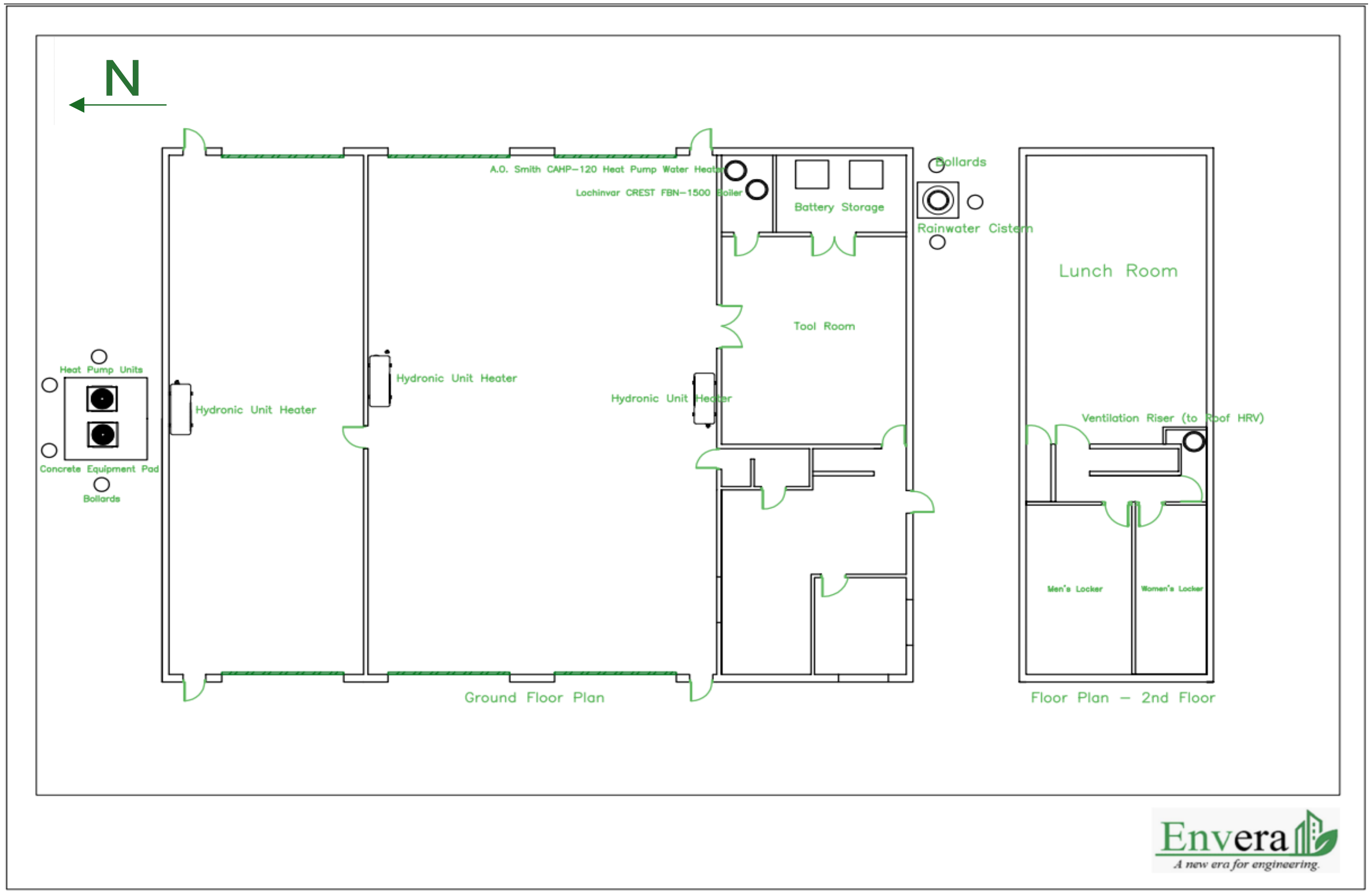


Figure 11: Plan showing exterior heat pumps, hydronic unit heaters in truck bays, mechanical room equipment, and HRV riser to rooftop ventilation unit. Office areas are conditioned by the heat pump system using existing ductwork.

Appendix E: Building Renders

Refer to Figure 12, Figure 13, Figure 14, Figure 15, Figure 16, and Figure 17 for the Envera building renders of the proposed retrofit.

Figure 12: West elevation render: Rainwater collection system not shown in renderings below.

Figure 13: East elevation render.

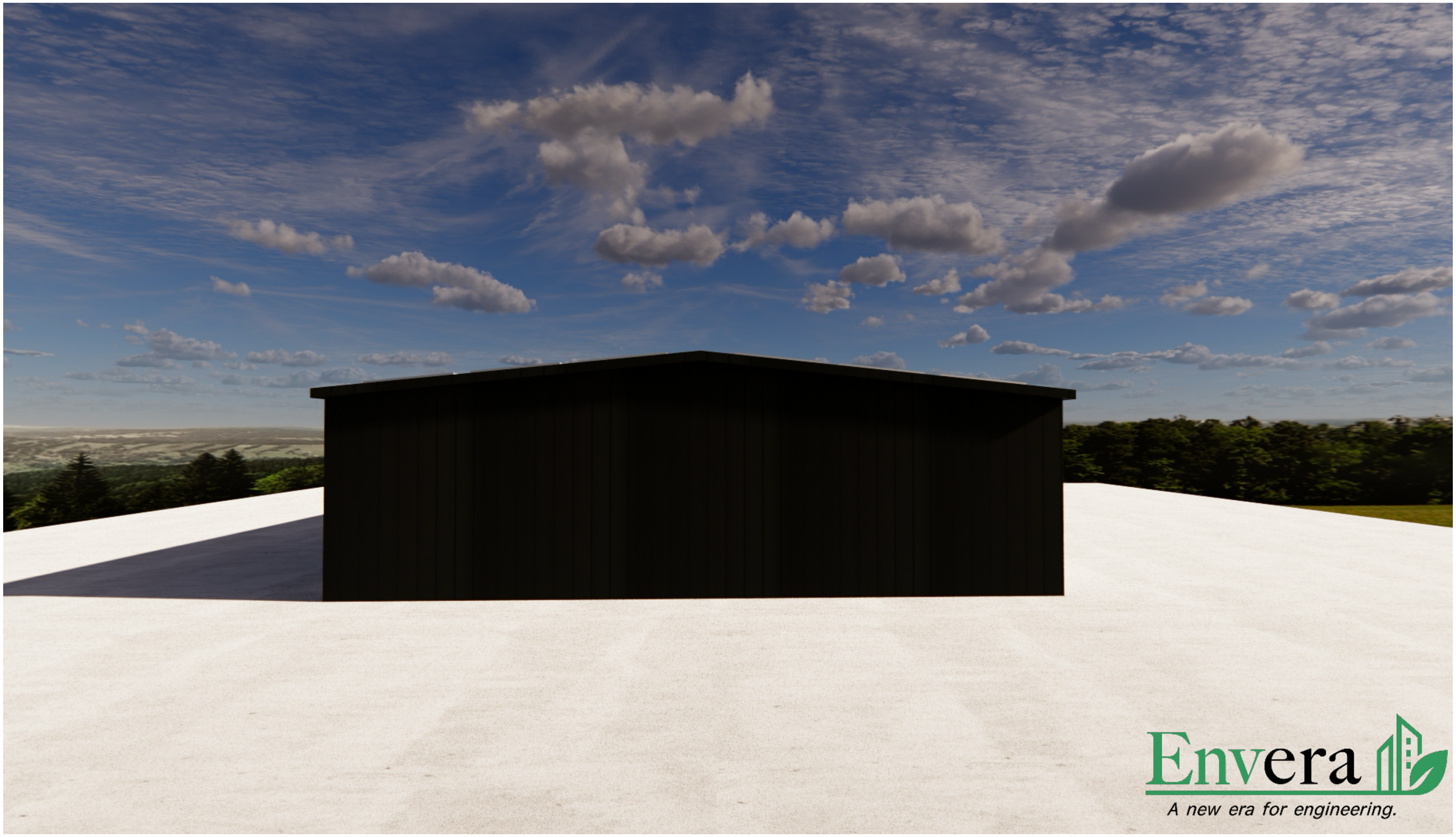


Figure 14: North elevation render: Mechanical pad located on this side (not shown).

Figure 15: South elevation render.

Figure 16: South-east elevation render.

Appendix F: Structural Calculations

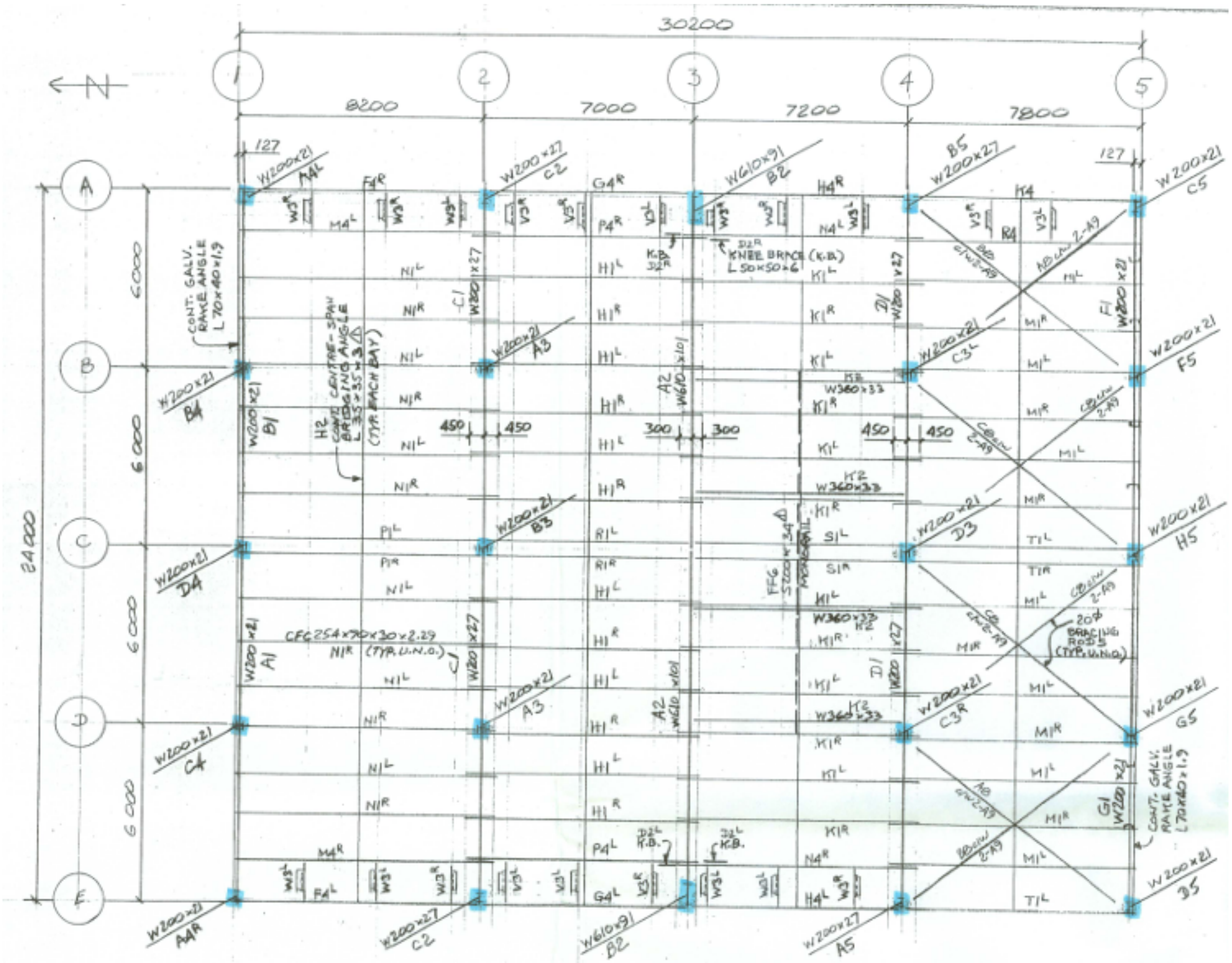


Figure 17: Original structural drawing detailing the supporting roof system.

Table 42: Snow load calculations for Georgina, Ontario.

Snow Load	1.66	kPa
Is	1	
Ss	2.1	kPa
Sr	0.4	kPa
Cb	0.8	
Cw	0.75	
Cs	1	
Ca	1	

Table 43: Roof dimensions and surface area calculations.

Roof Dimensions		
Width	24	m
Length	30.2	m
Area	724.8	m2

Table 44: General values used in column analysis.

General Values		
Φs	0.85	
n	1.34	
Elastic Modulus	200000	MPa
Fy	350	MPa
L	2200	mm

Table 45: Column analysis calculations.

	Corner W200x21	Edge W200x27	Interior W200x21	Units	Notes
Applied Axial Load	46.49	39.69	172.35	kN	
Tributary Area	12.30	10.50	45.60	m2	
Compression Resistance	498.01	638.63	498.01	kN	
Fe	379.39	397.00	379.39	MPa	
Cross-Sectional Area	2700.00	3390.00	2700.00	mm2	
KL/rx	25.73	25.20	25.73		
KL/ry	72.13	70.51	72.13		GOVERNS
rx	85.50	87.30	85.50	mm	
ry	30.50	31.20	30.50	mm	
λ	0.96	0.94	0.96		

Table 46: Joist analysis calculations.

Joists					
	Bay 1	**Bay 2**	**Bay 3**	**Bay 4**	**Units**
Length	4.10	3.50	3.60	3.90	m
UDL	5.17	5.17	5.17	5.17	kN/m
Point Load	21.22	18.11	18.63	20.18	kN
Support Rxns	10.61	9.06	9.31	10.09	kN
Mf	10.87	7.92	8.38	9.84	kNm

Table 47: Exterior and interior beam analysis calculations.

Beams	Exterior W200x21	Interior W200x27	Units
Length	6.00	6.00	m
Point Loads	10.61	19.66	kN
Additional Dead Loads	0.95	0.82	kN/m
Self-Weight Dead Loads	0.21	0.26	kN/m
Total Dead Loads	1.16	1.09	kN/m
Load Combination	15.75	13.75	kN/m
Support Rxns	63.17	70.74	kN
Mf	102.72	120.86	kNm
	Class 3 (Flange)	**Class 2 (Flange)**	
bel/t	10.39	7.92	-
bel	66.50	66.50	mm
t	6.40	8.40	mm
$(200 \text{ or } 170)/(Fy)^{0.5}$	10.69	9.09	-
	Class 2 (Web)	**Class 2 (Web)**	
h/w	29.72	32.79	-
h	190.20	190.20	mm
w	6.40	5.80	mm
$1700/(Fy)^{0.5}$	90.87	90.87	-
Mr	64.56	83.00	kNm
Φs	0.85	0.85	kNm
Zx	217000.00	279000.00	mm3
Fy	350.00	350.00	MPa

Table 48: Second floor beam and shear force diagram analysis calculations.

Second Floor W410x39			
Variable	**Value**	**Units**	**Notes**
Length	6.00	m	
Live Load Reduction Factor			
A trib (B)	23.40	m2	Greater than 20 m2
LLRF	0.95		NBCC 4.1.5.8(3)
Loads			
Pressures	10.98	kPa	
ULD	42.84	kN/m	
Mf	192.77	kNm	wL2/8
Class 2 (Flange)			
bel/t	7.95		
bel	70.00	mm	
t	8.80	mm	

$(170)/(Fy)^{0.5}$	9.09	
	Class 2 (Web)	
h/w	59.59	
h	381.40	mm
w	6.40	mm
$1700/(Fy)^{0.5}$	90.87	
Mr	217.18	kNm
Φs	0.85	
Zx	730000.00	mm3
Fy	350.00	MPa

Table 49: Updated loading conditions including self-weight of cover plates on roof beams.

Beams	**Exterior W200x21**	**Interior W200x27**	**Units**
Length	6.00	6.00	m
Point Loads	10.61	19.66	kN
Additional Dead Loads	0.95	0.82	kN/m
Self-Weight Dead Loads	0.34	0.39	kN/m
Total Dead Loads	1.29	1.22	kN/m
Load Combination	15.92	13.91	kN/m
Support Rxns	63.66	71.23	kN
Mf	103.45	121.59	kNm
	Class 3 (Flange)	**Class 2 (Flange)**	
bel/t	10.39	7.92	-
bel	66.50	66.50	mm
t	6.40	8.40	mm
$(200 \text{ or } 170)/(Fy)^{0.5}$	10.69	9.09	-
	Class 2 (Web)	**Class 2 (Web)**	
h/w	29.72	32.79	-
h	190.20	190.20	mm
w	6.40	5.80	mm
$1700/(Fy)^{0.5}$	90.87	90.87	-
Mr	64.56	83.00	kNm
Φs	0.85	0.85	kNm
Zx	217000.00	279000.00	mm3
Fy	350.00	350.00	MPa

Table 50: Cover plate calculations for roof beams.

Cover Plate Calculations			
Beams	**Exterior W200x21**	**Interior W200x27**	**Units**
Neutral Axis Calculations			
Depth	215.70	219.70	mm
Top Flange Thickness	12.75	14.75	mm
Top Cover Plate Thickness	6.35	6.35	mm
Bottom Cover Plate Thickness	6.35	6.35	mm
Bottom Flange Thickness	12.75	14.75	mm
Flange Width	133.00	133.00	mm
Web Thickness	5.00	5.80	mm
Web Depth	190.20	190.20	mm
Neutral Axis	95.10	95.10	mm
Compression and Tension Forces			
Yield Strength	350.00	350.00	MPa
Compression in Flange	593512.50	686612.50	N
Compression in Web	166425.00	193053.00	N
Tension in Web	166425.00	193053.00	N
Tension in Flange	593512.50	686612.50	N
Moment Calculations			
Top to CFlange	6.38	7.38	mm
Top to Cweb	60.30	62.30	mm
Top to Tweb	155.40	157.40	mm
Top to Tflange	209.33	212.33	mm
Plastic Moment	136.28	159.08	kNm
Resistance Factor	0.85	0.85	-
Plastic Moment Resistance	115.84	135.22	kNm

Appendix G: Forecasting Code

Refer to Figure 18, Figure 19, Figure 20, and Figure 21 for the R code used to conduct the SARIMA analysis.

```
1  ### Capstone Weather Forecasting
2  # North York Region
3
4  library(ggplot2)
5  library(tidyverse)
6  library(tseries)
7  library(forecast)
8  library(dplyr)
9  library(lubridate)
10 library(strucchange)
11 library(segmented)
12
13 # Code derived from CIVL 491 lecture notes
14
15 #setwd("~Desktop/CIVL 460/GeorginaWeather")
16 #For this command to work you need to go to Session > Set Working Directory > To Source File location
17 georgina_weather <- read.csv("combined_climate_daily_2007_2026_sorted.csv")
18
19 # Grab the precipitation column:
20 precip <- tibble(date = ymd(georgina_weather$Date),
21                  Year = georgina_weather$Year,
22                  Precipitation = georgina_weather$Total_Precip)
23
24 # Check to see if it worked!
25 head(precip)
26
27 Yearly_P <- precip %>%
28   group_by(Year) %>%
29   summarise(total = sum(Precipitation, na.rm = TRUE))
30
31 # Plot the result
32 barplot(Yearly_P$total,names.arg = Yearly_P$Year,ylab = "Precipitation [mm]",xlab = "Year", main = "Yearly Precipitation")
33
34 # Determine the mean precipitation
35 P <- mean(Yearly_P$total, na.rm = TRUE)
36
37 # We can use the temperature data to estimate ET as well!
38 H0 <- 6 # extraterrestrial solar radiation potential evaporation [mm/day]
39
40 #Now plot precip by month
41
42 precip <- georgina_weather %>%
43   transmute(
44     date = ymd(georgina_weather$date),
45     Precipitation = as.numeric(precip))
46
47 Monthly_P <- precip %>%
48   group_by(month = floor_date(date, "month")) %>%
49   summarise(total = sum(Precipitation, na.rm = TRUE))
50
```

Figure 18: Forecasting R code: lines 1 – 50.

```
51 barplot(
52   Monthly_P$total,
53   names.arg = format(Monthly_P$month, "%b %Y"),
54   ylab = "Precipitation [mm]",
55   xlab = "Month",
56   main = "Monthly Precipitation",
57   las = 2)
58 
59 daily <- georgina_weather %>%
60   mutate(
61     month  = as.integer(month),
62     precip = parse_number(precip),
63     temp   = parse_number(air_temp)
64   ) %>%
65   select(month, precip, temp)
66 
67 # Precipitation timeseries
68 start_year <- min(lubridate::year(Yearly_P$date), na.rm = TRUE)
69 
70 precip_ts <- ts(
71   Yearly_P$total,
72   start = start_year,
73   frequency = 1)
74 
75 plot(
76   precip_ts, ylab = "Annual Precipitation [mm]", xlab = "Year",
77   main= "Annual Precipitation Time Series")
78 
79 # Precipitation timeseries (month)
80 Monthly_P <- georgina_weather %>%
81   mutate(Precipitation = as.numeric(Total_Precip)) %>%
82   group_by(Year, Month) %>%
83   summarise(total = sum(Precipitation, na.rm = TRUE))
84 
85 Monthly_P$date <- make_date(Monthly_P$Year, Monthly_P$Month, 1)
86 
87 plot(
88   Monthly_P$date,
89   Monthly_P$total,
90   type = "l",
91   xlab = "Year",
92   ylab = "Monthly Precipitation (mm)",
93   main = "Monthly Precipitation Time Series")
94 
95 precip_ts <- ts(
96   Monthly_P$total,
97   start = c(min(Monthly_P$Year), min(Monthly_P$Month)),
98   frequency = 12)
99 
100 ### Forecasting ###
101 ### Using built-in auto.arima R function
102 sarima_precip <- auto.arima(precip_ts, seasonal = TRUE)
103 sarima_precip
```

Figure 19: Forecasting R code: lines 51 – 103.

```
105 acf(residuals(sarima_precip))
106 pacf(residuals(sarima_precip))
107
108 ### Forecast for precipitation
109
110 # next 5 years
111 Prediction5P <- forecast(sarima_precip, h = 60 )
112 plot(Prediction5P, ylab = "Precipiation [mm]", xlab ="Year")
113
114 # next 10 years
115 Prediction10P <- forecast(sarima_precip, h = 120 )
116 plot(Prediction10P, ylab = "Precipiation [mm]", xlab ="Year")
117 Prediction10P$mean
118 sum(Prediction10P$mean[1:12])
119
120 # next 16 years
121 Prediction50P <- forecast(sarima_precip, h = 600 )
122 plot(Prediction50P, ylab = "Precipiation [mm]", xlab ="Year")
123
124 ### Wind forecasting ###
125
126 #setwd("~Desktop/CIVL 460/GeorginaWeather")
127 #For this command to work you need to go to Session > Set Working Directory > To Source File location
128 pearson_weather <- read.csv("en_climate_monthly_ON_Pearson.csv")
129
130 pearson_weather$date <- make_date(pearson_weather$Year, pearson_weather$Month, 1)
131
132 plot(
133   pearson_weather$date,
134   pearson_weather$Spd.of.Max.Gust..km.h.,
135   type = "l",
136   xlab = "Year",
137   ylab = "Speed of Max Gust (km/h)",
138   main = "Monthly Maximum Gust Speed - Pearson Airport")
139
140 plot(
141   pearson_weather$date,
142   pearson_weather$Snow.Grnd.Last.Day..cm.,
143   type = "l",
144   xlab = "Year",
145   ylab = "Snow on Ground Last Day (cm)",
146   main = "Monthly Snow on Ground (Last Day) - Pearson Airport")
147
148 gust_ts <- ts(
149   pearson_weather$Spd.of.Max.Gust..km.h.,
150   start = c(min(pearson_weather$Year), min(pearson_weather$Month)),
151   frequency = 12)
152
153 snow_ts <- ts(
154   pearson_weather$Snow.Grnd.Last.Day..cm.,
155   start = c(min(pearson_weather$Year), min(pearson_weather$Month)),
156   frequency = 12)
```

Figure 20: Forecasting R code: lines 105 – 156.

```
158 ### Forecast for wind ###
159
160 sarima_gust <- auto.arima(gust_ts, seasonal = TRUE)
161 sarima_gust
162
163 acf(residuals(sarima_gust))
164 pacf(residuals(sarima_gust))
165
166 # next 5 years
167 Prediction5G <- forecast(sarima_gust, h = 60 )
168 plot(Prediction5G, ylab = "Gust [km/hr]", xlab ="Year")
169
170 # next 10 years
171 Prediction10G <- forecast(sarima_gust, h = 120 )
172 plot(Prediction10G, ylab = "Gust [km/hr]", xlab ="Year")
173
174 # next 16 years
175 Prediction50G <- forecast(sarima_gust, h = 200 )
176 plot(Prediction50G, ylab = "Gust [km/hr]", xlab ="Year")
177
178 ### Forecast for snow ###
179
180 sarima_snow <- auto.arima(snow_ts, seasonal = TRUE)
181 sarima_snow
182
183 acf(residuals(sarima_snow))
184 pacf(residuals(sarima_snow))
185
186 # next 5 years
187 Prediction5S <- forecast(sarima_snow, h = 60 )
188 plot(Prediction5S, ylab = "Snow [cm]", xlab ="Year")
189
190 # next 10 years
191 Prediction10S <- forecast(sarima_snow, h = 120 )
192 plot(Prediction10S, ylab = "Snow [cm]", xlab ="Year")
193
194 # next 16 years
195 Prediction50S <- forecast(sarima_snow, h = 200)
196 plot(Prediction50S, ylab = "Snow [cm]", xlab ="Year")
197
```

Figure 21: Forecasting R code: lines 158 – 196.

Appendix H: Envera Time Trackers

Refer to Figure 22, Figure 23, Figure 24, and Figure 25 for the Envera team individual time trackers.

Queen's University | Faculty of Engineering and Applied Science

CIVL 460 Engineering Design & Practice
FW 2025/2026

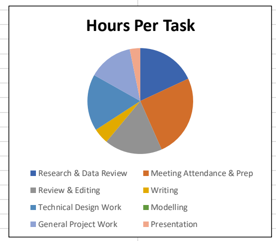
Student Name: Rheya Dutkiewicz
Project Name: Building Retrofit
Group Name: Envera

Hours to date: 124.5

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
January 15, 2026	Meeting Attendance & Prep	1.5
January 22, 2026	Meeting Attendance & Prep	1.5
January 23, 2026	Technical Design Work	5
January 26, 2026	Review & Editing	4
February 2, 2026	General Project Work	4
February 3, 2026	Presentation	2
February 11, 2026	Writing	4
February 12, 2026	Review & Editing	2
February 17, 2026	Review & Editing	5
February 20, 2026	Review & Editing	2
February 26, 2026	Meeting Attendance & Prep	1
March 5, 2026	Meeting Attendance & Prep	1
March 9, 2026	Meeting Attendance & Prep	1.5
March 10, 2026	Technical Design Work	2.5
March 11, 2026	Meeting Attendance & Prep	1
March 13, 2026	Technical Design Work	3
March 15, 2026	Technical Design Work	3
March 16, 2026	Meeting Attendance & Prep	1
March 16, 2026	Technical Design Work	4
March 17, 2026	Writing	2
March 18, 2026	Meeting Attendance & Prep	1
March 18, 2026	Review & Editing	2

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	1.50
Week 15	6.50
Week 16	4.00
Week 17	6.00
Week 18	6.00
Reading Week	7.00
Week 19	1.00
Week 20	1.00
Week 21	8.00
Week 22	10.00
Week 23	0.00
Week 24	0.00

Hours Per Task	
Research & Data Review	22.5
Meeting Attendance & Prep	31.5
Review & Editing	22
Writing	6
Technical Design Work	21.5
Modelling	0
General Project Work	17
Presentation	4



	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

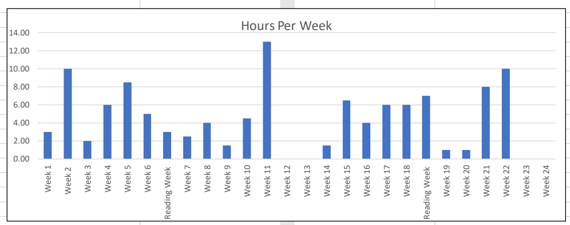


Figure 22: Rheya Dutkiewicz time tracker.

Queen's University | FACULTY OF ENGINEERING AND APPLIED SCIENCE

CIVL 460 Engineering Design & Practice
FW 2025/2026

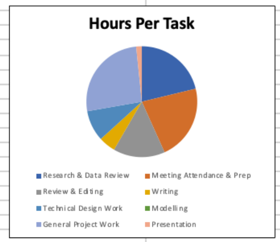
Student Name: Lily-Anna Girard
Project Name: Building Retrofit
Group Name: Envera

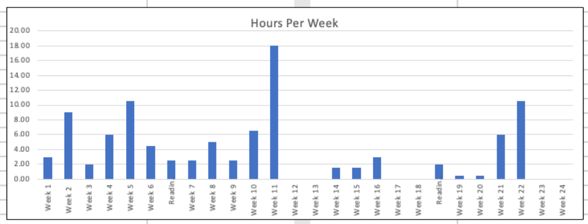
Hours to date: **122.5**

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
January 15, 2026	Meeting Attendance & Prep	1.5
January 22, 2026	Meeting Attendance & Prep	1.5
January 24, 2026	Technical Design Work	4
January 25, 2026	Research & Data Review	3
January 26, 2026	Review & Editing	3
February 1, 2026	General Project Work	4
February 3, 2026	Presentation	2
February 15, 2026	Review & Editing	6
February 18, 2026	Review & Editing	2
February 26, 2026	Meeting Attendance & Prep	0.5
March 5, 2026	Meeting Attendance & Prep	0.5
March 9, 2026	Meeting Attendance & Prep	1
March 10, 2026	Technical Design Work	4
March 11, 2026	Meeting Attendance & Prep	1
March 15, 2026	Writing	3
March 16, 2026	Meeting Attendance & Prep	1
March 17, 2026	Writing	3
March 18, 2026	Review & Editing	4
March 19, 2026	Review & Editing	2.5

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	1.50
Week 15	1.50
Week 16	3.00
Week 17	0.00
Week 18	0.00
Reading Week	2.00
Week 19	0.50
Week 20	0.50
Week 21	6.00
Week 22	10.50
Week 23	0.00
Week 24	0.00

Hours Per Task	
Research & Data Review	26
Meeting Attendance & Prep	27
Review & Editing	18.5
Writing	6
Technical Design Work	11
Modelling	0
General Project Work	32
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

Figure 23: Lily-Anna Girard time tracker.

Queen's University | Faculty of Engineering and Applied Science

CIVL 460 Engineering Design & Practice
FW 2025/2026

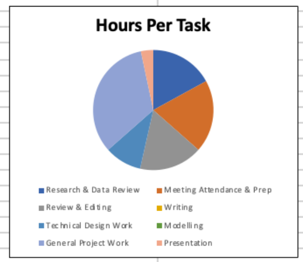
Student Name: Sophia Mariani
Project Name: Building Retrofit
Group Name: Envera

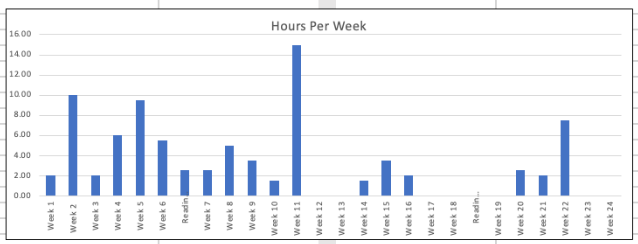
Hours to date: 120.5

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
January 15, 2026	Meeting Attendance & Prep	1.5
January 22, 2026	Meeting Attendance & Prep	1.5
January 23, 2026	Technical Design Work	2
January 24, 2026	Technical Design Work	1
January 26, 2026	Review & Editing	2
Feburary 2, 2026	General Project Work	3
Feburary 3, 2026	Presentation	2
Feburary 6, 2026	General Project Work	4.5
Feburary 7, 2026	General Project Work	3
Feburary 12, 2026	Meeting Attendance & Prep	0.5
Feburary 18, 2026	Review & Editing	3.5
Feburary 26, 2026	Meeting Attendance & Prep	1.5
March 5, 2026	Meeting Attendance & Prep	1.5
March 6, 2026	General Project Work	1
March 8, 2026	General Project Work	3
March 9, 2026	Meeting Attendance & Prep	1
March 11, 2026	Review & Editing	1
March 14, 2026	General Project Work	3.5
March 16, 2026	Research & Data Review	1.5
March 17, 2026	Technical Design Work	2
March 18, 2026	Review & Editing	1.5
March 19, 2026	Review & Editing	2.5

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	1.50
Week 15	3.50
Week 16	2.00
Week 17	0.00
Week 18	0.00
Reading Week	0.00
Week 19	0.00
Week 20	2.50
Week 21	2.00
Week 22	7.50
Week 23	0.00
Week 24	0.00

Hours Per Task	
Research & Data Review	20.5
Meeting Attendance & Prep	23.5
Review & Editing	20.5
Writing	0
Technical Design Work	12
Modelling	0
General Project Work	40
Presentation	4





	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

Figure 24: Sophia Mariani time tracker.

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

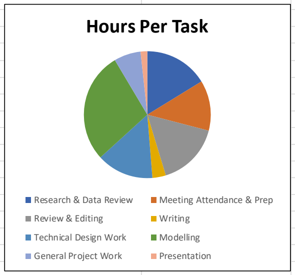
Hours to date: 117

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	2
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
January 15th, 2026	Meeting Attendance & Prep	1
January 22nd, 2026	Meeting Attendance & Prep	1
January 23rd, 2026	Review & Editing	1
January 24th, 2026	Review & Editing	2
February 2nd, 2026	General Project Work	2
February 3rd, 2026	Presentation	2
February 16th, 2026	Review & Editing	2
February 18th, 2026	Review & Editing	1
February 26th, 2026	Meeting Attendance & Prep	0.5
March 5th, 2026	Meeting Attendance & Prep	0.5
March 9th, 2026	Research & Data Review	1
March 10th, 2026	Technical Design Work	3
March 12th, 2026	Research & Data Review	2
March 15th, 2026	Review & Editing	3
March 15th, 2026	Technical Design Work	2
March 16th, 2026	Research & Data Review	2
March 17th, 2026	Technical Design Work	3
March 18th, 2026	Meeting Attendance & Prep	1
March 18th, 2026	Technical Design Work	2
March 18th, 2026	Review & Editing	1
March 19th, 2026	Review & Editing	2

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	5.00
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	19
Meeting Attendance & Prep	15
Review & Editing	19
Writing	4
Technical Design Work	17
Modelling	33
General Project Work	8
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



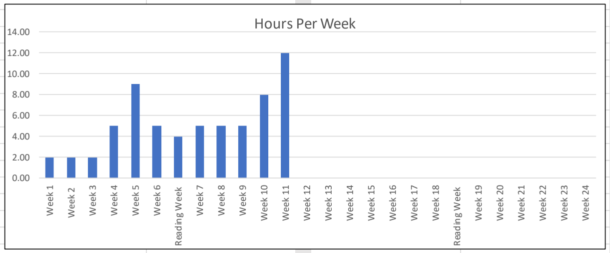


Figure 25: Jordan Raftis time tracker.