Middlesex Centre

Strategies for New Ilderton Arena to be Net-Zero Carbon Ready

Prepared for:
Municipality of Middlesex Centre

Prepared by:
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Disclaimer

This report is an academic exercise conducted by graduate students in the Masters in Environment and Sustainability (MES) program in the Centre for Environmental and Sustainability (CES) at Western University, London, Ontario, Canada. The named consulting company that produced this report is a fictional entity created for the purpose of this exercise. For information on this program, please visit www.uwo.ca/enviro.

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Executive Summary

The term "net-zero building" can be defined as a building that is strategically designed with a combination of energy efficiency and renewable energy generation that consumes only the energy that can be produced onsite through renewable sources over a given time period (U.S. Department of Energy, 2022). In order to reach Canada's goal of net-zero emissions by 2050, emitters of greenhouse gases will be required to either eliminate or offset carbon emissions. As a response to regulatory mandates, the federal, provincial, and municipal governments are transitioning into the realm of sustainability and opting towards zero energy building targets (U.S. Department of Energy, 2022). Achieving a net-zero energy building is an ambitious goal that is becoming more achievable over time due to revolutionary technologies and best practices.

Middlesex Centre has already proven its devotion to sustainable community infrastructure after the success of the net-zero Firehall in Coldstream, Ontario. With the addition of the proposed net-zero hockey arena for Ilderton, the municipality has the opportunity to aid in achieving Canada's net-zero targets and sustainable development goals well before the 2050 deadline. This new arena's goal is to be net-zero carbon ready and strive to include cutting-edge sustainable energy features. Middlesex Centre engaged Green Samaritan Consulting to analyze green building technologies and best industry practices to achieve the net-zero goal for the new Ilderton Arena. More importantly, this report aims to recommend technologies and building practices to Middlesex Centre in order to build a net-zero carbon ready arena that is feasible for the community size, budget, and sustainability goals.

Although building to net-zero standards costs approximately 1% to 8% more up-front than traditional buildings, net-zero buildings are highly efficient and produce as much energy, if not more, than they use. Net-zero building operational costs are therefore reduced compared to traditional buildings (Hutchinson, 2019). Zero-carbon building standards require 100% of the operational energy use to be offset by on- or off-site renewable energy and 100% of the embodied carbon emissions associated with the construction and materials of the project to be disclosed and offset (Populous, 2021). Zero-carbon buildings typically operate by phasing out combustion sources and utilizing renewable energy sources, which ultimately boost the resiliency of the building and electrical power (Populous, 2021). By incorporating net-zero building standards into the construction of the new Ilderton arena, Middlesex Centre stands to see greater long-term energy savings and lower operational costs despite the increased upfront capital costs.

This report describes multiple new and emerging technologies and best practices that have the potential to be applied in the context of an arena. Similar buildings such as Climate Pledge Arena in Seattle, Washington and the Woodstock Union Arena in Woodstock, Vermont are explored to act as inspiration for net-zero arena construction and facility operation within a North American context. Additionally, the research is expanded to include unique, leading-edge net-zero facilities within North America and Europe that could be scaled to fit the needs of a rural arena in southern Ontario.

From the extensive net-zero buildings research, a series of key findings for the best technology, best construction practices, and best operations strategies were identified. The key findings in this research included efficient energy storage systems such as the VisBlue vanadium redox flow battery, environmentally-preferable refrigerants, heat recovery systems, rainwater harvesting systems, software to monitor building energy use, incorporating a highly insulated building envelope, triple-glazed windows, shading devices, green roofs, implementing load reduction, passive strategies such as maximizing daylight

and natural ventilation, efficient systems such as optimally sized HVAC systems, and energy recovery using heat exchangers and air re-circulators.

Green Samaritan Consulting presents feasible recommendations to address critical net-zero building features such as renewable energy production and storage, construction materials, and building operations that can be applied to the new Ilderton net-zero arena in Middlesex Centre including:

<u>Technologies</u>

- On-site energy production using solar and geothermal energy
- Battery storage systems for clean energy
- Rainwater harvesting system for the collection and use of greywater

<u>Construction</u>

- Double- or triple-paned windows to limit heat loss and air leakage and reduce solar heat gain
- Super-insulated, thermal-bridge-free envelope to improve insultation
- Use of south-facing windows and overhangs or shades on east- and west-facing windows to maximize daylight and reduce solar heat gain

<u>Building Operations</u>

- Heating and cooling with electrically driven air-source heat pumps
- A heat recovery system
- Commissioning and recommissioning equipment to ensure optimal performance
- A building automation system to fully control the building
- Energy efficient lighting and lighting controls to lower consumption
- Low flow washroom fixtures to lower energy and water consumption

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1.0 Introduction

The Municipality of Middlesex Centre is one of the fastest growing communities surrounding the Northwestern region of London, Ontario, with a population of 17,000. The municipality's mission is to deliver the highest standard of municipal services in a sustainable, professional, and innovative matter. To aid in achieving this mission is the community services department which oversees the operation and management of parks, open spaces, and recreation facilities such as arenas, libraries, and community centres. In addition, the community services department supports local sports and special events.

In 2021, Middlesex Centre Council adopted the Middlesex Centre Community Improvement Plan (CIP) in order to encourage rehabilitation and redevelopment across the municipality. Middlesex Centre is currently upgrading the community services master plan which guides the direction for future recreational programming, services, and infrastructure. This plan presents future goals and objectives for the community that impact open space planning, parks, community centres, and arenas for the period of 2022 to 2026. Middlesex Centre is proud to be home to the first net-zero fire station in Canada and have embraced green technologies through building retrofits and the municipal fleet. As part of the Middlesex Centre CIP, the municipality is interested in continuing with their redevelopment plans with the intent on redeveloping the Ilderton Arena into a net-zero carbon arena.

The Government of Canada has enacted the *Canadian Net-Zero Emissions Accountability Act* of 2021, which outlines Canada's legislative commitment to achieve net-zero emissions by 2050. Achieving net-zero requires emitters of greenhouse gases to either eliminate or offset carbon emissions. This can be achieved through actions or technologies involved in constructing or retrofitting net-zero carbon buildings.

The U.S. Green Building Council (USGBC), the International Living Future Institute (ILFI), and the Canada Green Building Council (CaGBC) have developed certification programs to help and recognize high-performing net-zero projects. There are currently five dominant net-zero certifications in the industry: LEED Zero Energy, LEED Zero Carbon, ILFI Zero Energy, ILFI Zero Carbon, and Zero Carbon Building Standard. The differences and definitions of net-zero energy and net-zero carbon are outlined in the following table:

Table 1: *Certifications and definitions of net-zero energy and net-zero carbon.*
Source: Zeile, 2020

U.S. Green Building Council (USGBC)	LEED Zero Energy	**Offset** the project's **site & source energy** use with on-site renewable energy exported to the grid, off-site renewable energy, or carbon offsets
	LEED Zero Carbon	**Offset** the project's carbon emissions from **operational energy** and **occupant transportation** with on-site renewable energy exported to the grid, off-site renewable energy, or carbon offsets
International Living Future Institute (ILFI)	Zero Energy	**Offset** the project's **operational energy** use with on-site renewable energy
	Zero Carbon	**Reduce** and **offset** the project's **operational energy** use with new on-site or off-set renewable energy. **Reduce, disclose,** and **offset** the project's **embodied carbon**

		emissions with on-site carbon-sequestering materials or carbon offsets
Canada Green Building Council (CaGBC)	Zero Carbon Building Standard	**Reduce** and **offset** the project's **embodied carbon and refrigerants** and **operational carbon emissions**. Demonstrate superior **energy efficiency**.

The Canada Green Building Council (CaGBC) has developed a Zero Carbon Building Standard which defines a net-zero carbon building as a highly energy efficient building which produces or procures onsite carbon-free renewable energy, or incorporates high quality carbon offsets in order to counterbalance the annual carbon emissions from building materials and facility operations.

Middlesex Centre was originally looking into pursuing the CaGBC Zero Carbon Building Standard certification for the design of the new Ilderton Arena but has decided to not pursue any certifications and would rather incorporate many of the technologies and best practices of net-zero carbon buildings, as well as other sustainable building practices, to be as close to net-zero carbon as possible. Since the Ilderton Arena is located in a rural area, Middlesex Centre would have a difficult time trying to reduce the carbon emissions of occupant transportation, which is a key part in net-zero carbon certifications.

By sector, energy use in buildings is one of the largest single contributors to the carbon footprint, at roughly 40%. If current buildings were retrofitted to be net-zero energy, and all newly constructed buildings were built to a net-zero carbon standard, the collective carbon footprint of society would be significantly reduced. Therefore, Middlesex Centre plans to aid in reducing its community's carbon footprint by constructing the new Ilderton Arena to a net-zero carbon standard.

Across Canada and the United States, building to zero-energy standards costs 1% to 8% more up-front than traditional buildings built to code, making net-zero buildings more attainable (Hutchinson, 2019). Since net-zero buildings are highly efficient and produce as much energy as it uses, these types of buildings cost less in operating costs compared to traditional buildings. A study by Canadian Architect (2019) found that net-zero buildings saw a 24% increase in annual operating savings and a 91% increase in emissions savings from onsite measures. Buildings in this study were office, multi-unit residential buildings, schools, warehouses, and big-box retail and currently there are not many net-zero carbon recreational facilities.

Proposed Facility Description

The proposed new recreational facility in Ilderton, Ontario is on a flat, rectangular 3.25-hectare site and will allow for the continued operations of the existing arena during construction of the proposal facility. The development proposal is to construct a 5,350 square-meter (sq. m.) recreational facility featuring a regulation size skating rink with fixed tiered seating for 560 spectators and 100 standing room capacity. The 1,400 sq. m. mezzanine level will provide for a two-lane rubberized walking track and a 120 sq. m. lounge overlooking the skating rink. The hockey rink will have six spacious changerooms, each with washroom facilities. A second phase of development will involve the addition of another ice surface with a 900 sq. m. community centre. The site development also provides for a third phase consisting of a four-sheet curling rink and a 500 sq. m. library. This new net-zero carbon ready facility will build on the municipality's strategic priorities of an engaged community and sustainable municipal infrastructure.

The facility will aim to be net-zero carbon ready as it will include features such as solar panels, geothermal heating, rainwater harvesting, heat recovery systems, and electric vehicle charging stations. This report comprises the examination of new and emerging best practices and technologies that may be applied in the context of an arena, including during construction and operation.

2.0 Similar Net-Zero Recreation Facilities

A net-zero carbon arena is an arena where the goal is to offset the carbon emissions from operational energy and occupant transportation with on-site renewable energy exported to the grid, off-site renewable energy, or carbon offsets (Zeile, 2020). Operators of net-zero carbon arenas plan to reduce and offset their entire planet-warming footprint. Two arenas in the United States have been constructed and are considered net-zero carbon. These arenas include the Climate Pledge Arena and the Woodstock Union Arena. This section will examine the construction practices and facility operations of each arena to identify best practices that can be incorporated into the Ilderton Arena.

2.1 Climate Pledge Arena

The Climate Pledge is an interdisciplinary community of worldwide companies and organizations which work jointly on the global fight against climate change. The Climate Pledge has over 300 signatories, with naming partner of Climate Pledge Arena, Amazon.com, being one of the most renown members (Populous, 2021).

Climate Pledge Arena is a multi-purpose arena in Seattle, Washington, United States, located north of Downtown Seattle in the 74-acre entertainment complex (Obando, 2021). From 2018 to 2021, the arena underwent a $1.15 billion redevelopment (Obando, 2021). The renovated venue has a capacity of 17,151 for ice hockey and 18,000 for basketball (Obando, 2021). The arena is currently home to the Seattle Kraken of the National Hockey League (NHL) and the Seattle Storm of the Women's National Basketball Association (WNBA). In June 2020, Amazon bought the naming rights to the arena and dedicated the arena name to bringing attention to climate change and showing the company's commitment to the Climate Pledge (Obando, 2021). The venue is also planned to be the first net-zero carbon arena in the world, powered exclusively by renewable energy rather than the standard use of natural gas found in other arenas (Obando, 2021). The arena is working towards achieving the International Living Future Institute Zero Carbon certification.

2.1.1 Construction

The three-year project saw the redevelopment of the 1960s era Washington State Coliseum with the renovation including interiors and walls but preserving the original roof (Obando, 2021). The window system and curtainwall system were also salvaged, renovated, and reinstalled to help save material and transportation costs as well as send less demolition and construction debris to landfill (Obando, 2021). In order to reuse the original roof, the construction team had to dig underneath the existing structure and support the roof while building a new arena underneath it, as seen in Figure 1 (Obando, 2021). Retaining the existing roof prevented 22,000 tonnes of concrete and steel material from being sent to landfill (Chan, 2022). Additionally, greenhouse gas (GHG) emissions generated by truck trips required to transport the debris away and bring in fabricated roof materials were also eliminated (Chan, 2022). By retaining the original roof, the process to create the additional steel and concrete needed for a new roof structure was avoided, lowering the carbon footprint of the building (Chan, 2022).

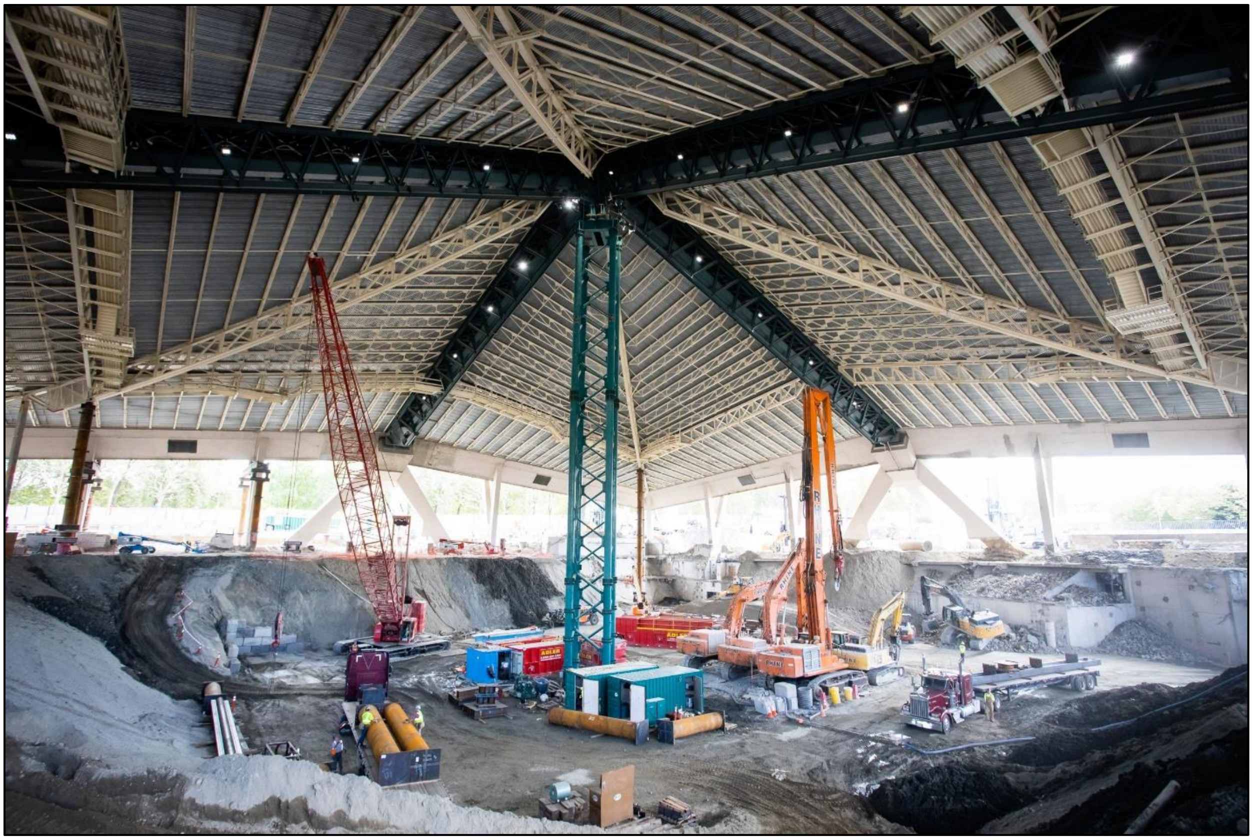


Figure 1: *Original Washington State Coliseum roof being supported while the Climate Pledge Arena is built below it. Source: Obando, 2021*

With the project preserving the original roof, the project team had no choice but to expand the arena underground to increase the footprint. The Climate Pledge Arena features an earth retention system that could support a dig depth of approximately 70 feet (Obando, 2021). The construction team undermined all the foundations of the arena and dug out 600,000 cubic yards (Obando, 2021). The centre of the court went down 15 feet, while the perimeter of the building went down about 55 feet, as seen in Figure 2 (Obando, 2021). Digging downwards for added space doubled the building's floor area to about 860,000 square feet, which allowed the back-of-house, loading areas, concourse, retail, dining, entertainment areas, and other amenities to be expanded (Chan, 2022). The benefits of constructing below ground include being less susceptible to the impact of extreme outdoor air temperatures, requiring less outside maintenance, and the earth surrounding the building provides soundproofing. With construction of the building below ground being less susceptible to the impact of extreme outdoor air temperatures, this will reduce the amount of energy needed to heat and cool the building which will lower operational emissions. Additionally, buildings below ground could potentially cost less to insure as they are better protected against high winds, hailstorms, and natural disasters such as tornadoes and hurricanes. Building the arena below ground also allowed for fewer materials throughout the building, such as using less insulation, since the ground acts as a natural form of insulation which lowered the embodied carbon from construction materials.

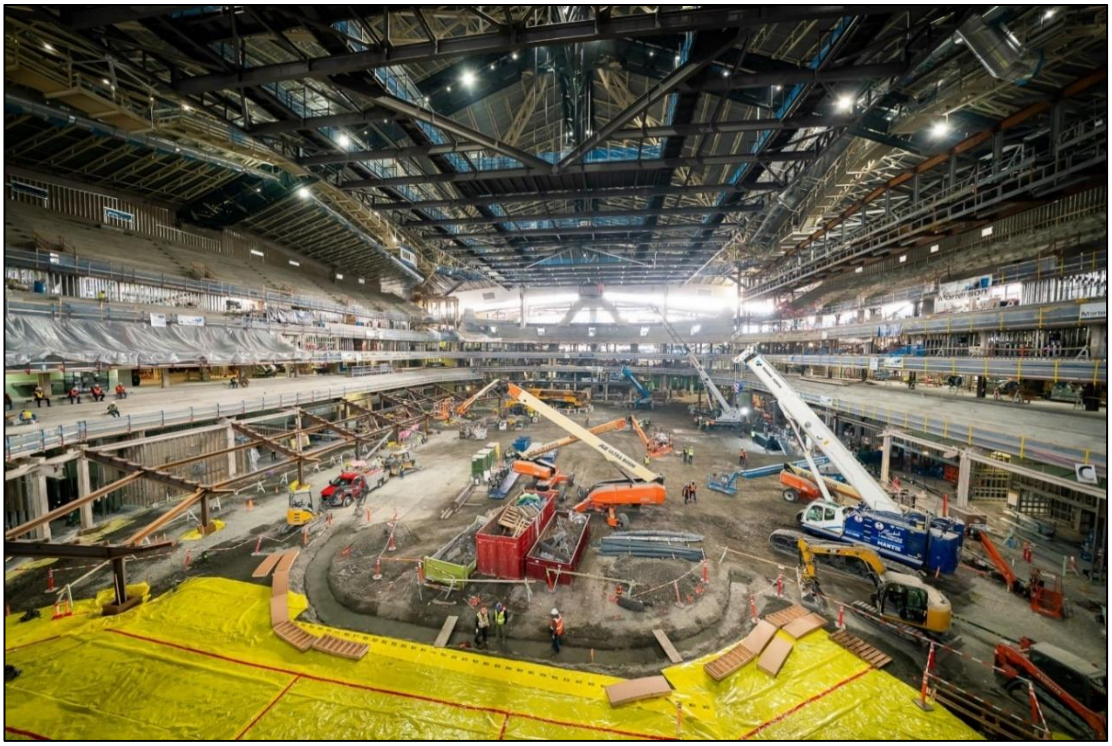


Figure 2: *Climate Pledge Arena being constructed underground to increase the capacity of the original Washington State Coliseum. Source: Obando, 2021*

With the arena being constructed 50 feet below ground and also incorporating a large loading dock to accommodate major concert events, the planners decided to construct a 180-foot tunnel that leads to the loading dock in the arena's deepest basement level (Obando, 2021). The construction team drilled 24-inch steel casings under a nearby brick garage and made the tunnel approximately 30 feet high and 30 feet wide (Obando, 2021).

For buildings interested in constructing below ground several factors need to be considered such as characteristics of the site, location of groundwater, waterproofing, humidity, insulation, and air exchange/ air quality. Materials used must provide a good surface for waterproofing and insulation to withstand the pressure and moisture of the surrounding ground (U.S. Department of Energy, n.d.). Concrete is most commonly used as it is strong, durable, and fire resistant but wood can also be used for interior and light structural work and will also help to sequester carbon (U.S. Department of Energy, n.d.). Insulation and waterproofing materials help to collect and absorb heat generated and retain that heat inside the building's interior which helps to reduce energy consumption and carbon emissions (U.S. Department of Energy, n.d.).

2.1.2 Facility Operations

Seattle's Grid Power

One of the primary reasons that Climate Pledge Arena is certified net-zero is because Seattle's main utility company, Seattle City Light (SCL), is carbon neutral (Smith, 2022). Therefore, there is a greater opportunity for buildings within the city to be powered by sustainable energy sources, rather than non-renewables. There are three very large wind power operations in Washington State, outlined in Table 2, that provide energy to Seattle City Light, which have a combined capacity to produce over 700 megawatts of electricity

– enough to power 165,000 homes per year (Puget Sound Energy, 2015). In total, 90% of the power Seattle receives comes from carbon free sources, therefore the city's buildings have very low operational carbon emissions. These low levels of emissions can be offset by organizations, businesses, and individuals by either purchasing carbon credits, or by private solar energy production to achieve carbon neutrality.

Table 2: *Wind farms that provide electricity to Seattle's utility company, Seattle City Light.*
Source: Puget Sound Energy, 2015

Facility	Location	Number of Turbines	Electricity Production Capacity	Proximity to Seattle
Wild Horse Wind and Solar Farm	Columbia County	149	203 MW	209 km
Hopkins Ridge Wind Facility	Ellensburg	187	156.6 MW	440 km
Lower Snake River Wind Facility	Garfield County	149	342.7 MW	482 km

Climate Pledge Arena's Solar Energy Production

Climate Pledge Arena uses two photovoltaic arrays of solar panels which supplement the building's energy use. One of the arrays is located on the arena's Alaska Airlines Atrium, and the other is located off-site, on top of a parking garage on First Avenue in downtown Seattle, as seen in Figure 3. All together the system is projected to produce 570,000 kilowatt hours (kWh) in 2022 – enough to power 53 American homes (Populous, 2021). The energy produced by these solar panels keeps Climate Pledge Arena's carbon offset expenses low; ultimately allowing the building to operate at net-zero carbon at a lower cost.

Figure 3: *A rendering of the two solar arrays for Climate Pledge Arena which supplement 570,000 kilowatt hours per year located on the First Avenue Parking Garage and Climate Pledge Arena's Alaska Airlines Atrium. Source: Pickerel, 2021*

All-Electric Operations
To operate at net-zero, all traditionally fossil fuel powered systems within industry level arenas were converted to electric, meaning the electrical capacity of the building needed to be drastically increased. Therefore, Seattle City Light provided Climate Pledge Arena with 26 kilovolts (kV) distribution capacity, rather than the originally planned 15 kV (Coliseum, 2022). This ensured enough electricity is able to supply all systems with Climate Pledge Arena's robust operations as an ice hockey rink, multipurpose sports venue, and entertainment facility.

As far as the building's capacity for ice hockey goes; it is the first ever NHL rink to have a fully electric ice refrigeration and dehumidification system (Coliseum, 2022). Energy efficient heat recovery units are paired in tandem with an all-electric boiler system, which alone uses six electrical substations to provide hot water and heat to the entire facility. Climate Pledge Arena also has multiple restaurant and concession locations, therefore traditional gas fired stoves and ovens were replaced with electrical substitutes. Also, the ice re-surfacer, supplied by Zamboni, is fully electric as well.

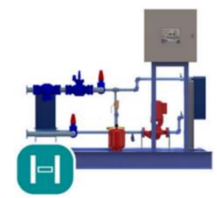
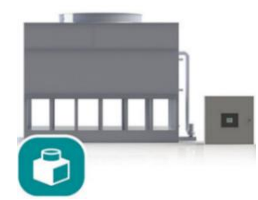
"Rain to Rink" at Climate Pledge Arena
Sunlight is not the only natural resource that Climate Pledge Arena uses sustainably. The roof, which has an elevated, centralized tip at its center allows for easy control of rainwater and is fixed with rainwater ducts along its edges, as seen in Figure 4.

Figure 4: *An arial view of one of the rainwater ducts on Climate Pledge Arena.*
Source: Lam, 2016

These ducts capture the rainfall, which occurs on average 150 days a year in Seattle (Lam, 2016), and lead it to a below grade 15,000-gallon cistern. The captured rainwater is domestically filtered and heated, then pumped into the Zamboni room to be used in ice-resurfacing before and during practices and games. The system dubbed "Rain to Rink" by the Seattle Kraken Sustainability department will save the city of Seattle 50,000 gallons of water annually (Zillgitt, 2021). Rain capture technology is used not for net-zero carbon purposes, however it does contribute to a more sustainable building.

Recreational Arena Net-Zero Mechanical Units: CIMCO Refrigeration
As Climate Pledge Arena is a relatively new project, it became difficult for Green Samaritan Consulting to examine and analyze the exact mechanical units within the facility. However, the Canadian refrigeration company, CIMCO, offers many net-zero ready solutions for recreational ice rinks (Lam, 2016), as these products are powered by electricity rather than traditional fossil fuel. They are outlined in Table 3. Furthermore, Green Samaritan Consulting has provided Middlesex Centre with a full mechanical system quote for a typical net-zero arena, which was completed by CIMCO Refrigeration.

Table 3: *Net-zero ready Heating, Ventilation, and Air Conditioning (HVAC) equipment.*
Source: CIMCO refrigeration, 2021a.

Equipment	Manufacturer	Product Name	Description	Additional Information	Photo
Dehumidification Unit	Climate by Design International	Arid-Ice 2500 E	All-electric, compact desiccant dehumidifier, which effectively removes moisture.	Net-zero ready, built in humidity control, CIMCO smart rink connect.	
Heat Recovery	Alpha Laval	Smart Heat	Industrial desuperheater built specifically for recreational ice rinks	Will provide heat for showers, ice-resurfacer, and other hot water needs.	
Compressor	Mycom	Smart M	A reciprocating compressor that uses less horsepower per ton of refrigeration that comparable units.	Net-zero ready, reports deviations from optimal operation and notifications for upcoming maintenance	
Evaporative Condensing Unit	Evapco	Smart Condense	An evaporative condenser designed for easy maintenance and decreased water and electricity usage.	Calculates waste heat rejection, monitors water consumption, and early detection of part failure.	

2.2 Woodstock Union Arena

The Woodstock Union Arena in Woodstock, Vermont became the first net-zero carbon indoor ice rink in the United States in 2021 after an extensive updating and retrofitting process on the 18-year-old arena (Picard, 2021). It has no net annual energy costs for heating, fuel, and electricity due to its efficient updates and newly installed solar roof (Caduto, n.d.). By making the building's components extremely efficient, adding an on-site renewable energy source, recycling energy, and reducing waste where possible, this building was able to reach an equilibrium of the carbon it emitted and the carbon it captured from the renewable energy source. The goals of this project, championed by the original architect of the building, included lowering energy costs, improving accessibility for the community, and reducing carbon emissions created by the arena (Pendak, 2017). Through a series of public fundraising rounds and no government contributions, the architect was able to integrate necessary safety changes with sustainable goals at an opportune time to achieve the above goals and make the Woodstock Union Arena a sustainable building pillar of the community and United States (Pendak, 2017; Caduto, n.d.). The upgrades managed to reduce energy and fuel costs from $140,000 USD per year to $50,000 USD, with additional savings expected as overproducing solar panels offset costs (Pendak, 2017).

2.2.1 Construction

As this project was a retrofit, there is limited information about the construction materials. Instead, there is information regarding the system changes and new technologies added to support facility operations.

The project was completed in four phases between 2017 to 2021, costing approximately $1.4 million USD in donations from local businesses and individuals (Pendak, 2017). Each phase of the retrofit was completed sequentially and included (1) refrigeration updates, (2) heat recovery system installation, (3) renewable energy and dehumidification system installation, and (4) the integration of systems. Phases one and two totalled approximately $500,000 USD each, while phases three and four represented the remaining $400,000 USD of the budget (Pendak, 2017). Since the original arena, constructed in 2003, needed safety updates and reconstruction and system upgrades, this proposal's timing presented a perfect window of opportunity for the Woodstock community (Picard, 2021).

Phase one of the project totalled $460,000 USD and included a new rooftop cooling tower and motor, new water tank filters, and a rebuilt compressor, as well as other refrigeration updates (Pendak, 2017). The cooling tower, motor, and filter installations used a variable frequency drive (VFD) motor and new treatment system to improve efficiency and reduce wasted energy. Moreover, the refurbished compressor, new sensors, high-volume filters, and cleaned clog lines also have improved the refrigeration system making it more efficient to cool the rink and machinery in the building to avoid energy loss (Caduto, Mayhew & Bishop, 2020).

Heat recovery updates in phase two improved the building's overall HVAC system, regeneration wheels, and added heat recovery equipment to reduce energy waste. This phase costed approximately $410,000 USD. Firstly, an enlarged regeneration wheel was installed to recycle heat 70% more effectively and modulating burners were added (Caduto, Mayhew & Bishop, 2020). Next, high efficiency boilers were installed to produce rink resurfacing and domestic hot water with less waste – supplementing the new water filtration systems for maximum efficiency (Caduto, Mayhew & Bishop, 2020). Finally, heat recovery equipment that detected carbon dioxide (CO_2) levels using a demand sensor and controller was installed to match fresh air needs in the building more accurately – sending fresh, ventilated air to areas that were in higher use (Caduto, Mayhew & Bishop, 2020). This system also included a newly engineered duct network that was reinstalled onsite. All of these retrofits and installations to the building reduced pressure on the cooling tower and lowered overall consumption to the newly efficient cooling system.

Phase three was particularly important for the net-zero construction and included the installation of solar panels. In this phase, 211 400-watt modules and 644 430-watt modules were mounted to the 28-foot awning with the goal of over-generating energy to support surrounding buildings (Whitchurch, 2021). The solar panels' benefits were three-fold in that it powered the arena, overproduced, and offset energy use to power surrounding buildings, and provided a shading effect for the building reducing the load of the refrigeration system in summer months (Caduto, Mayhew & Bishop, 2020). This phase generated enough energy to the facility to grant net-zero status when combined with the previous two phases.

Finally, phase four integrated all systems through smart software and re-engineering electrical phasing to ensure that each system received feedback from one another and worked in tandem for maximum efficiency (Pendak, 2017). By rewiring equipment and electrical devices, the arena improved its overall energy consumption to keep energy costs low (Caduto, Mayhew & Bishop, 2020). Additionally, heat capture and new lighting were added during this phase (Pendak, 2017).

2.2.2 Facility Operations

The building is 30,000 square feet in total, 17,000 square feet of which is designated as open space for changerooms and the lobby area (Caduto, Mayhew & Bishop, 2020). The arena consists of one single ice pad frozen for only seven months of the year and converted to dry land during the summer months (Picard, 2021). Since the Woodstock Union Arena is a designated non-profit organization, the arena receives no public financial support from the municipality to run the facility (Caduto, Mayhew & Bishop, 2020). As a result, bills became very expensive to keep up with. The cost of operating the rink (keeping the ice intact, ventilation, and lighting) was increasing as the use of the rink was declining over the years (Caduto, Mayhew & Bishop, 2020). As a result, the Union Arena staff saw the benefits of becoming a net-zero building, producing their own energy to meet and exceed demand and to lower the operational costs of the building in a short amount of time.

Initially, the arena relied solely on propane for heating and the dehumidifier and electricity from the grid to run the building (Picard, 2021). However, as the price of electricity in Vermont began to rise, the cost of electricity grew too great to operate the building financially. Moreover, the lack of a natural gas hookup on-site did not provide any other energy options for the building (Picard, 2021). Since the retrofit was finished, the arena has relied on propane and self-sustained electricity from solar power generation (Picard, 2021). Although a source of carbon, propane runs high-demand equipment such as refrigeration compressors. Since the arena does not have its own energy storage system for the solar array and the refrigeration units must run consistently, regardless of weather, propane was a low-cost solution. The arena is able to remain net-zero carbon by offsetting the amount of propane used and selling excess solar power to the neighbouring high school and middle school (Whitchurch, 2021). As seen in Figures 5 and 6, the solar array on the roof of the building faces southeast and consists of 855 photovoltaic panels that cover 21,000 square feet (Chester, 2021). In one year, the solar panels generate approximately 392,000 kWh (Chester, 2021). The panels were designed to provide more than enough power to run the arena, and excess energy is fed to the adjacent high school and middle school to help offset their reliance on electricity. Additionally, the solar array on the roof provides more than just energy generation for the building. Due to their extensive coverage, the panels act as shades that absorb solar heat that the metal roof would otherwise absorb. Therefore, they reduce the energy load required of the HVAC and refrigeration systems of the building (Picard, 2021).

Figure 5: *East facing roof of Woodstock Union Arena consisting of 644 430-watt solar panels. Source: Whitchurch, 2021*

Figure 6: *The south-facing roof of Woodstock Union Arena consists of 211 400-watt solar panels angled to optimize solar absorption. Source: Whitchruch, 2021*

The overall operations of the arena are monitored through intense software upgrades by installing a building automation system (BAS) which includes computerized controls for refrigeration, HVAC, and lighting and integrated control management of all mechanical systems (Chester, 2021; Picard, 2021; Caduto, Mayhew & Bishop, 2020). The BAS in particular aids the building in being net-zero carbon as it optimizes the energy use within the building. This ensures no excess power from propane and solar (and therefore any carbon emissions associated with them) is wasted during the operation of the building. All lighting in the building is light-emitting diode (LED) and is set on timers to turn off automatically. Additionally, all the electrical aspects of the building had capacitors installed to make sure the equipment and devices operate more efficiently. Submetering of the entire system was also included in electrical upgrades and VFDs were added to HVAC and compressor motors to increase efficiency (Chester, 2021; Picard, 2021; Caduto, Mayhew & Bishop, 2020).

The operation of HVAC components is mainly regulated through electronic scheduling and monitoring. For example, the furnace demand is controlled by carbon dioxide levels within the space (Wilson & Li, 2020). This means that heating stops when the carbon dioxide passes a threshold value and is only turned on as needed beyond that threshold. This includes when areas have a large number of people, causing natural heat and carbon dioxide levels to rise. Therefore, energy demand on the furnace is reduced as the heating load is reduced, and ventilation can be increased where needed (Wilson & Li, 2020). The Union Arena also had ductwork extended in the ice pad down either side of the boards to improve the air distribution and ventilation of the space (Caduto, Mayhew & Bishop, 2020). Although this may not seem like a pressing issue, air recirculation is often not the standard approach to maintaining ice quality since the ice pad area needs stringent air and temperature controls. However, because of the carbon dioxide sensors, the air distribution is only sent to areas requiring extra heat, and ventilation can be increased to those with too much heat, providing a balanced ice pad environment (Caduto, Mayhew & Bishop, 2020).

A heat recovery system is used to heat most of the building year-round. Waste heat generated from the compressors and dehumidifiers is captured and then recirculated in the building HVAC system rather than venting it outdoors (Picard, 2021; Wilson & Li, 2020). This waste heat is also used to take the heating load off hot water tanks used to heat washroom faucets and shower water and water for resurfacing the ice in the Zambonis (Picard, 2021; Wilson & Li, 2020). Additionally, any extra heat that is not used in warming the building or heating water is then used to aid in the melting of the snow pit, which, once melted, is reused in the building as greywater (Picard, 2021; Wilson & Li, 2020). This heat recovery system also includes three storage tanks (Figure 7) refurbished from the original refrigeration system, thus reducing additional carbon outputs from the retrofitting process.

Figure 7: *Heat recovery system storage tanks refurbished from the original refrigeration system at Woodstock Union Arena. Source: Whitchruch, 2021*

The arena also installed a completely new, high-efficiency refrigeration system. A CIMCO 11-ton indirect ammonia shell tubing system is used to refrigerate the ice pad (Wilson & Li, 2020). Although ammonia is not the safest refrigerant as it is toxic, the cost was cheaper than alternatives and fit within the organization's $1.4 million USD budget and was an upgrade from the previous hydrofluorocarbon (HFC) refrigerant system used pre-retrofit. This new system also included a high-efficiency industrial-level condensing boiler and hot water tanks (Caduto, Mayhew & Bishop, 2020; Picard, 2021). These new elements were built beyond the expected demand of the arena, anticipating potential expansion in the future if enough funds were collected. A new cooling tower was also added that emits a reduced amount of heat into the atmosphere, lowering the energy demand on the building overall (Picard, 2021). The final piece of the refrigeration upgrades included a desiccant dehumidifier system (Wilson & Li, 2020). This system allows the arena to remove humidity in the ice rink and condense the water vapour removed during the process for reuse within the building (Wilson & Li, 2020). However, it must be noted that this dehumidifier continues to run on propane. Since there is no natural gas hookup available and the energy required for constant use would use too much solar-provided energy needed to run the rest of the building, the organization opted for the next cheapest available option. As an offset to using a carbon-based fuel for the dehumidifier, the arena reuses the condensed water as greywater in the washroom faucets, showers, and toilets to keep their carbon usage low (Wilson & Li, 2020). There is a requirement for greywater filtration for this use; however, this information was not available online or through contact with the organization.

The Woodstock Union Arena is relatively similar to phase one of the Ilderton Arena and has many operation aspects that could be scaled to support the new build. For example, the solar array on the roof, heat recovery system, and refrigeration upgrades prove that small-scale arenas can become net-zero facilities by retrofits alone. Since the new Ilderton Arena will be a completely new build, there is ample opportunity to incorporate these technologies and operational habits from scratch. Additionally, the Woodstock Union Arena is an example of over-engineering the original functional design to accommodate future expansions. The new Ilderton Arena would benefit significantly from designing a solar array and refrigeration system that can handle expansion projects with no additional retrofitting in the future. There is also an opportunity for Middlesex Centre to connect with the Woodstock Union Arena organization through Efficiency Vermont. They often hold seminars on net-zero building retrofits and construction and aid municipalities in creating plans toward net-zero futures (Caduto, Mayhew & Bishop, 2020). Green Samaritan Consulting attempted to reach out to this organization for more information on the Woodstock Union Arena, but no reply to the request was received.

3.0 North America Net-Zero Facilities

The mandate for net-zero buildings across the United States and Canada is growing rapidly, according to new data from New Buildings Institute (NBI), a non-profit organization pushing for better performance in buildings. According to NBI's 2020 Getting to Zero Buildings List, the total number of verified and emerging zero energy buildings in North America has grown to nearly 700 – representing a 42% increase since 2018. The total square footage of zero energy buildings has surpassed 62 million, a 39% jump from 2018.

In the United States, where commercial and residential buildings account for 30% of the nation's carbon emissions, transitions to zero energy buildings will contribute significantly to low-carbon economy. Most of zero energy buildings run entirely on electricity and on-site renewable energy generation "proving to be a cost-effective way to reduce carbon emissions, achieve deep energy savings, and improve the indoor air quality of homes and commercial buildings" (New Buildings Institute, 2020).

Even though these building projects are spread across all climate zones, the states which prioritize climate action goals are leading the market such as California, Oregon, New York, and Massachusetts demonstrating substantial growth in zero energy projects over the last two years. The buildings outside these domains also grew by more than 20% over the last two years.

The NBI'S 2020 Getting to Zero Buildings List reflects a similar pattern of growth in both public and private sectors even though private building owners have a larger share in real estate. The public owned properties emerging as net-zero includes educational institutions, libraries, and government buildings. Many corporations in the private sector such as IKEA, Walmart, Google, Apple, and Amazon have accomplished zero energy projects and have committed to setting "science-based emissions reduction targets" (New Buildings Institute, 2020). Some of the facilities are being discussed here that may be of relevance to the proposed arena and achieving net-zero goals with maximum efficiency.

3.1 The Research Support Facility, Colorado

The Research Support Facility (RSF), located on the National Renewable Energy Laboratory's (NREL's) campus in Golden, Colorado, is a ground-breaking standard for energy efficiency and design for commercial buildings around the world. This living laboratory incorporates smart design, load reductions, and innovative applications of existing technologies to achieve net-zero energy on a fixed budget (National Renewable Energy Laboratory, 2012).

The U.S. Green Building Council's Zero Energy Leadership in Energy and Environmental Design (LEED) certification was awarded to the RSFA in February 2020 recognizing its zero energy operations. It is one of the largest Zero Energy LEED Platinum-certified commercial buildings in the world with an area of 362,055 square feet.

The RSF generates an energy use intensity of 35 kilo-British thermal unit (kBTU) per square foot per year and delivers 50% more energy than required by current commercial code. It has many unique features that distinguish it from other facilities including a 2.5-megawatt photovoltaic system that resides on the rooftops of the RSF and campus parking garages. Through the use of evaporative cooling, outside air ventilation, and waste heat capture, the building uses 50% less energy compared to conventional buildings. The facility uses south-facing windows that enhance daylighting by reflecting light to the ceiling and deep into the space with light-reflecting devices. The electrochromic glass on windows help reduce impacts of heat gain in summers. With 19% of the primary energy in the United States consumed by commercial buildings, the RSF is changing the way commercial office buildings are designed and built (National Renewable Energy Laboratory, 2012).

Table 4: *A summary of key findings for the RSF.*
Source: National Renewable Energy Laboratory, 2012

Building Name	**The Research Support Facility (RSF) Golden Colorado**
Building Address	NRELs Flatirons Campus Labs and Offices 19001 W. 119th Ave, Arvoda CO 800007
Building Type	Public
Project Aim	NRELs vision is transform today's energy challenges into tomorrow's solution
About the Building	Building size: 362,055 square feet
Renewable Energy Technologies	Biomass, Solar, Wind
Energy Use and Production	• Office space designed to have an energy use intensity of 35 kBTU per square foot per year • Non-data center space designed to perform 30% better than ASHRAE 90.1 2007 standards • Natural ventilation through operable windows • About 80% of regularly occupied spaces have daylighting • Open office design and a narrow floor plate of 60 feet • LED lights with a lighting control system • Radiant heating and cooling
Building Benefits	• Natural ventilation system, a collaboration between air and earth, moderates temperatures within the atrium as compared to the exterior climate • The atrium pool is used as a heat sink to help balance the overall system and provide passive heating of pool water
Building Challenges	The building was procured through a performance-based design-build delivery. Builders did not have to financially justify individual energy-saving strategies. Rather, they had to hit an aggressive energy target at a firm fixed price.
Costs and Funding	• $259/sq. ft., excluding design costs and photovoltaics (PV) • Cost: $91.4 million (construction cost)
Awards	• 2014 *R&D Magazine* Laboratory of the Year Award • 2014 *R&D Magazine* Editors' Choice Award for the HP Apollo 8000 System • 2014 DOE Sustainability Award • 2014 Finalist for Project Management Institute's Project of the Year Award • 2013 LEED Platinum Award, U.S. Green Buildings Council

	• 2011 LEED Platinum Award, U.S. Green Buildings Council • 2011 ENERGY STAR Certified Building • 2011 DOE Secretary's Achievement Award • 2011 Green Gov Presidential Award Green Innovation, White House Council on Environmental Equality

3.2 Unisphere, Maryland

Unisphere is a 135,000 square foot building that was inaugurated in 2018 in Maryland. It is now being considered as the world's largest commercial net-zero energy building which uses a blend of advanced technologies that make it an energy efficient facility. Despite the challenges of being in a dense urban environment surround by skyscrapers the builders successfully completed this unique piece of modern construction.

Its mechanism includes numerous devices connected to a high-powered computer "nerve center" that tracks energy consumption and coordinates heating, cooling, and other operations. Windows automatically darkens when it's hot outside and open to let fresh air flow in. Air circulates through a quarter mile-long concrete network 12 feet underneath the building, providing passive heating and cooling — the pipe network tends to be cooler than the air outside in the summer and warmer in the winter. A pool in the center of the building's large atrium soaks up excess heat — and can also be used for swimming. There are 52 geo-exchange wells drilled 500 feet into the earth that function like heat pumps. Water-filled pipes buried underground pull heat from the earth in the winter to heat the building and then send heat from the building back into the earth during the summer to cool it. Initially the underground geo-exchange wells were not allowed to be constructed by the county, however once they were convinced the closed loop wells were not meant for drinking water the law was amended and the construction of these wells was allowed. The building has unique features that showcase real time energy use and encourage users to take the stairs rather than use the elevators (Faloon, 2019).

Table 5: *A summary of key findings for the Unisphere.*
Source: Faloon, 2019

Building Name	**Unisphere**
Building Address	1000 Spring Street, Silver Spring, Maryland
Building Type	Commercial
Project Aim	• 120,000 sq. ft. of new office space, 10,000 sq. ft. of retail space, as well as public amenity space for the Silver Spring community. • Earn a LEED Silver rating from the US Green Building Council
About the Building	• 135,000 square feet • World's largest commercial net-zero building • A stylish staircase is meant to entice people to take the stairs instead of taking the elevator • Thermal pool • Its centerpiece is the energy wheel that uses real-time data to illustrate energy use. When its lights shine outward, the building is making energy. When they shine inward, it's using energy.
Renewable Energy Technologies	• Photovoltaic • Geothermal

Energy Use and Production	• 3,000+ high efficiency solar panels. • The photovoltaic system is designed to produce over one megawatt of power over the course od a year to offset the entire annual power consumption. • 52 geothermal wells drilled more than 500 feet into the earth will be used to increase the efficiency of the heating and cooling system between 25-50%.
Building Benefits	• Each successive floor is a little smaller than the floor below it to maximize the solar access for the facade-mounted solar panels. • On the south facade, the solar panels not only generate energy, but also function as shading devices. • Increased insulation, triple paned glazing, and electrochromic tinting glass on windows. The glass changes its level of tint when driven by an electrical signal allowing control over energy consumption and glare. • Intake air into the atrium is routed through an underground concrete labyrinth located beneath the parking garage to pre-heat or pre-cool the air • Natural ventilation will operate in three stages: automatic, manual, and mechanical assist. • A centralized BAS • Photocells on lights throughout the space will automatically adjust lighting levels depending on the amount of daylight available
Building Challenges	• All the renewable energy had to be located on the site, physically connected to the building, and tied into the building's electrical distribution system. • Dense urban environment. Site was surrounded on four sides by buildings that were built to the vertical zoning limit, which creates shadowing. • The county refused initially to build water wells underground but once they were convinced those were not meant to be for drinking water, the law was amended.
Awards	• Achieved LEED Platinum rating • 2020 Community Leader award

3.3 University Town Center, California

The University Town Center is a Sustainable Living and Learning Campus and has multiple revisioning projects in progress. La Jolla Commons is a LEED Gold and Platinum campus comprised of two 13-storey Class-A office towers with an entitled development parcel and two parking structures situated in the renowned University Town Center submarket of San Diego.

The building's exterior is predominately a glass curtainwall system incorporating highly efficient, insulated, double-paned glass with a clear, low-emissivity coating. La Jolla Commons Office Tower is an architectural landmark of crisp modernism with highly efficient floorplates, state-of-the-art operating systems, extensive campus amenities, panoramic office views, and excellent visibility from La Jolla Village Drive and Interstate 805 (WSP, 2022).

Natural ventilation is used through a copper roof that radiates heat from the sun into a ceiling plenum. Fresh outdoor air is pulled through the natural ventilation process into the occupied space from a vented underfloor plenum. Use of low emissive coatings on the windows that reflect invisible long wave infrared heat and simultaneously reduce heat-gain loss. On-site fuel cells used methane for electricity conversion through a non-combustion process.

In the summer months, shading devices are used on all windows. This helps reduce the affect of solar heat gain. The facility uses photo-electric daylight sensors to regulate the lights along with occupancy sensors. This prompted lights to be off 100% during daylight hours. University Center San Diego plans to reach its goal of carbon-neutrality through its green building projects (University of California, San Diego, 2022).

Table 6: *A summary of key findings for the University Town Center.*
Source: University of California, San Diego, 2022

Building Name	**University Town Center**
Building Address	La Jolla Commons San Diego, CA 92121
Building Type	Residential and Public
Project Aim	• To help the City of San Diego assess impacts of climate change. • To identify strategies, policies, and technologies that can prepare for the unavoidable changes of climate change. • University Center San Diego plans to reach its goal of carbon-neutrality through its green building projects.
About the Building	• A glass curtainwall exterior incorporating highly efficient, insulated, double-paned glass with a clear, low-emissivity coating • 415,000 square feet • Two 13-storey Class-A office towers
Renewable Energy Technologies	Biogas
Energy Use and Production	• Natural ventilation is used through a copper roof that radiates heat from the sun into a ceiling plenum. Fresh outdoor air is pulled through the natural ventilation process into the occupied space from a vented underfloor plenum. • Use of low emissive coatings on the windows that reflect invisible long wave infrared heat and simultaneously reduce heat-gain loss. • On-site fuel cells used methane for electricity conversion through a non-combustion process. • In the summer months, to prevent the negative affect of solar heat gain, shading devices are used on all windows. • The center uses photo-electric daylight sensors to control the lights in addition to occupancy sensors. This prompted lights to be off 100% during daylight hours.
Building Benefits	• Helping the City of San Diego assess the likely impacts of climate change • Identifying strategies, policies, and technologies that can prepare for the unavoidable changes of climate change. • Working on finding strategies to reduce or mitigate the projected impacts of climate change, sharing experiences and best practices. • Educational programs for students and civic officials.
Building Challenges	It is a busy and living campus therefore construction with day-to-day activities is a challenge.
Costs and Funding	$1.4 billion USD

Awards	• LEED Gold 2008 • ENERGY STAR 2011

4.0 Europe Net-Zero Facilities

The European Union (EU) is a strategic partner for Canada and shares many common values and policy priorities (Government of Canada, 2022). The EU has created ambitious targets to reduce greenhouse gas emissions and be climate-neutral by 2050. This net-zero objective is driven by the European Green Deal and aligns with the EU's commitment to global climate action under the Paris Agreement (European Commission, 2021). Currently, the EU's building sector accounts for approximately 36% of Europe's GHG emissions. Multiple residential, non-residential, and public service buildings will need to be renovated or retrofitted with green technology in order to meet the pledge of net-zero by 2050. In addition, under the buildings plan, all new constructions will need to be net-zero by 2030 to successfully achieve these targets (Rankin, 2021). The following section outlines and summarizes various sustainable buildings across Europe, including information regarding green construction practices, renewable energy technologies, and building benefits and challenges.

4.1 BedZED Eco-Village

The Beddington Zero Energy Development (BedZED) is the largest sustainable community in the United Kingdom. BedZED was initiated by Bioregional and developed by Peabody Trust in partnership with Bioregional and ZEDfactory architects (Bioregional 2016). The BedZED project was completed in 2002 and was developed on a former brownfield site. BedZED was designed to be a thriving community where people could enjoy high quality living standards, while only utilizing a fair share of earth's natural resources (Bioregional, 2009). In order to create a benchmark for a sustainable lifestyle within the community, ecological and carbon footprinting were used as benchmarks in the design process. The BedZED village is known in Europe for the unique approach of tackling the reduction of overall carbon emissions in not only energy consumption, but also within the materials used in the construction process (Chance, 2009).

Table 7: *A summary of key findings for the BedZED Eco- Village*
Source: Bioregional, 2009; Bioregional, 2016; Chance, 2009.

Building Name	**The Beddington Zero Energy Development (BedZED)**
Building Address	Sandmartin Way, Wallington SM6 7DF, United Kingdom
Building Type	Residential
Project Aim	United Kingdoms first large-scale, mixed-use sustainable community.
About the Building	The BedZED eco-village is comprised of 100 homes, office spaces, a college, and community facilities. The homes range from one to four-bedroom houses. Each home has private outdoor space with greenspace and gardens. **Green Construction Practices** <u>Local Materials:</u> More than half of the construction materials (52% by weight) were sourced within 57 km of the building. <u>Reclaimed Products:</u> Approximately 3,400 tonnes of construction materials (15% of total materials by weight) were reclaimed or recycled products. Almost 100%

	of the steel in the building was refurbished from the Brighton Railway Station nearby. Brownfield Development: The land that BedZED is situated on was recycled. The land was previously used for spreading sludge from nearby sewer works, and was a brownfield site. Exposed Thermal Mass: In the summer, the building produces cooling. In the winter, the building stores passive heat gains until needed. North-South Orientation: The north-facing windows produce good daylight with minimum solar heat gain. The extensive south-facing windows produce good, passive solar heat gain with a glazed buffer sunspace. There is minimum north glazing to maximize daylight, and minimum over-shading by adjacent buildings. **Building service systems** Building Insulation: BedZED homes are heated by the warmth of the sun, and are highly insulated. The distinctive wind cowls helps fresh air circulate within the home and promote ventilation. Water Saving Appliances: BedZED homes use 40% less water than the average home. The homes have dual-flush toilets, aerated flow taps and shower heads, and water-efficient washing machines.
Renewable Energy Technologies	The energy required at BedZED is supplied from renewable technology on-site. • In 2005, there was an issue with the original wood-powered boiler, and BedZED shifted operations to source 80% of the electricity from the national grid. • The roof is composed of 777 m^2 of solar photovoltaic (PV) panels, which provides the building with 20% of the electricity demand. • In 2017, a new biomass boiler was installed along with a green electricity tariff, bringing BedZED back to the net-zero vision. The 130 kW biomass combined heat and power (CHP) unit was intended to utilize fuel from local tree surgery waste. However, there was multiple functionality issues due to tar build up from burning wood gas.
Energy Use and Production	On average, a BedZED household uses 2,579 kWh of electricity per year. This is four times lower than the average household in the region.
Building Benefits	State of the art energy efficiency due to super-insulation, double and triple glazed windows, and high levels of thermal mass.
Building Challenges	**Lessons Learned** Biomass Combined Heat and Power Unit: The choice of a more proven technology as well as establishing a proper management system would have avoided problems with the CHP unit. The heating power plant was unsuccessful due to its small scale.
Awards	In 2001, BedZED won the Housing Design Award for sustainability from the Royal Institute of British Architects.

4.2 Housing +

Housing +, also referred to as BOLIG+ in Danish, is a residential apartment building outside of Copenhagen, Denmark (Realdania, 2022). This building is Denmark's first net-zero energy building, and was constructed in 2015. In addition to the building being energy neutral, it also produces electricity for tenant use. This four-storey apartment building consists of 10 apartments of varying sizes, and features a large green communal outdoor area (Wittchen et al., 2010). The project concept was created during an energy camp in 2005, where various representatives from the construction industry came together to provide a solution to the following question: "How can we develop energy efficient homes for the expanding global population?".

Table 8: *A summary of key findings for Housing+*
Source: Realdania, 2022; Wittchen et al., 2010.

Building Name	**Housing+ (BOLIG+ in Danish)**
Building Address	Søborg Hovedgade 150, 2860 Søborg, Denmark
Building Type	Residential and New
Project Aim	The owner, Realdania, wanted to tackle the challenge of building energy efficient housing through net-zero technology in Denmark.
About the Building	Housing + is a four-storey apartment building comprised of 10 apartment units of various sizes. The energy output from the building comes from PV panels on the roof and building façade in tandem with a VisBlue Vanadium Redox Flow Battery (VRFB) for storage. **Unique Design and Construction** Balcony Facades: The PV panels installed on the roof were only able to produce approximately 50% of the building's energy needs. For additional energy production, PV panels were installed along the building exterior. This created a harmonious design of PV panels, windows, and the enclosed balconies for building aesthetic and efficiency. **Obtaining Energy Neutrality** In order to obtain energy neutrality, the building design was carefully considered and selected to ensure the building could achieve net-zero targets. The building included the following critical features: 1. A compact and well insulated thermal envelope 2. An airtight design 3. Effective decentralized mechanical ventilation 4. Hybrid ventilation in the summer 5. Heat recovery technology from grey wastewater 6. Electricity production from multiple PV panels 7. Connection to the local district heating grid
Renewable Energy Technologies	• Photovoltaic panels on the roof and building exterior • VisBlue Vanadium Redox Flow Battery (VRBF) for storage
Energy Use and Production	In Denmark, there is a large price difference between selling and buying power of electricity from the grid at an approximate rate of 0.27 €/kWh (0.35¢/kWh). In order to improve the operational cost of the building, the experimental VRFB was installed to store the electricity from time of production to time of use.

	The VisBlue VRFB used for energy storage allows for the productivity of the building to increase in energy production anywhere from 25% to 50% daily. Please refer to Section 5.1.1 Battery Energy Production for an in depth analysis of this technology.
Building Benefits	In addition to being energy neutral, Housing+ also produces additional electricity for residential use to power mobile chargers, vacuum cleaners, lighting, and other small appliances.
Building Challenges	The actual energy consumption of the building was higher than initially calculated in the design phase of the project. This is likely due to one of the following reasons: 1. Changes in the building design, construction materials, or installations during the construction phase. 2. Occupational behaviour of the building tenants (i.e. increased room temperatures) 3. Weather differences from the design year used in the calculations

4.3 Sonova Wireless Competence Center

According to the Switzerland Federal Office for the Environment, the building sector is responsible for approximately one quarter of cumulative CO_2 emissions across the country. The Sonova Wireless Competence Center, located in Murten, Switzerland was designed to limit its environmental impact and operate carbon-neutrally while adapting to outside climate conditions (Sonova, 2022). This non-residential office building was completed in April 2021, and was constructed out of renewable and reusable materials to minimize construction related gray energy. The building is composed of a single wythe of cement block which was produced carbon neutral, and can retain energy and moisture (Sonova, 2022). The building is self-regulating by absorbing heat and releasing it when colder outside. The Sonova Wireless Competence Center has an array of photovoltaic panels on the roof, which generate 260,000 kWh of energy per year; this is higher than the energy required to run it. The surplus of energy is fed back into the grid (Les Délires Productions, 2021).

Table 9: *A summary of key findings for Sonova Wireless Competence Center*
Source: Les Délires Productions, 2021; Sonova, 2022.

Building Name	**Sonova Wireless Competence Center**
Building Address	Herrenschwandweg 4, 3280 Murten, Switzerland
Building Type	Commercial
Project Aim	Switzerland's first carbon-neutral office building. Sonova is a zero-energy building that provide employees with a modern and inspiring workspace. In addition, the building plans aligned with Sonova's commitment of continuous reduction of the company's environmental impact.
About the Building	Two-storey building <u>1st floor:</u> reception area, central staircase, open-plan cafeteria, logistics center, research and development laboratories, and test chambers <u>2nd floor:</u> open-plan offices and meeting rooms **Minimal Energy Requirements**

	The building was designed to operate carbon-neutral and adapt to the changing outside climate conditions. The building required minimal building service installations such as heating or ventilation. Pure Lime Putty: The healthy indoor climate and controlled natural ventilation is a result of using pure lime putty on the walls and ceilings. This putty purifies the air inside and regulates the atmospheric humidity. Ventilation Flaps: The air in the building is refreshed by the windows instead of traditional ventilation ducts. There are controllable ventilation flaps on the windows that facilitate fresh air circulation. An ambient temperature of 21°C to 26°C is guaranteed throughout the year. Window Surface Area and Position: The surface area of the windows was precisely sized with respect to the building façade to ensure that the building does not heat excessively with warmer temperatures. The windows were strategically placed high on the façade so that the maximum amount of natural light can be used and artificial light be avoided.
Renewable Energy Technologies	Photovoltaic panels on the roof
Energy Use and Production	The Sonova Wireless Competence Center's PV arrays generate approximately 260,000 kWh of energy per year. This is higher than the amount of electricity that is required to run it. The surplus electricity is fed back into the grid.
Building Benefits	• Minimal energy requirements • Healthy indoor climate • Self-regulating ventilation
Building Challenges	Since the building is only one year old, there have not been any productivity studies released yet to assess operating functionality compared to initial design plans. Typically, reports will be released to investigate functionality of carbon-neutral buildings after one to two years of operation.

4.4 Powerhouse Brattørkaia

Powerhouse Brattørkaia is the largest energy-positive building in Norway, and the world's northernmost energy-positive building (Powerhouse, 2018). It is set to generate more energy in the operational phase than is required for consumption through the production of building materials, construction, operations, and disposal of the building. Powerhouse Brattørkaia was carefully designed so that the combination of solar energy and extremely low energy consumption ensured that the building resulted in net-positive energy production (Mun-Delsalle, 2021). A high level of insulation resulted in the limited requirements for heating and ventilation systems (Powerhouse, 2018).

Table 10: *A summary of key findings for Powerhouse Brattørkaia*
Source: Mun-Delsalle, 2021; Powerhouse, 2018; Snøhetta, 2021

Building Name	**Powerhouse Brattørkaia**
Building Address	Brattørkaia 17, 7010 Trondheim, Norway
Building Type	Commercial
Project Aim	Powerhouse Brattørkaia was designed to be Norway's largest energy-positive building. Powerhouse Brattørkaia aimed to set a new standard for the construction of new buildings to produce more energy than consumed over its lifespan, including construction and demolition.
About the Building	Trondheim, Norway is located 63° N of the Earth's equator and does not have consistent sunlight between seasons. This building demonstrates unique planning and design to harvest and store maximum solar energy under challenging conditions. **Building Design** • This eight-floor building is 18,200 m^2 gross internal area, with 13,500 m^2 above ground. • The building also features a mezzanine and underground parking. • The building location was carefully selected in order to ensure maximum exposure to the sun throughout the day and changing seasons. • The building maximizes solar energy through the skewed pentagonal roof. **Minimal Energy Requirements** <u>Thermal mass:</u> The structural system is composed of thermal mass (low emission concrete) that is exposed through strategic cut-outs in the ceiling. The mass absorbs and retains heat and cold to help regulate the buildings temperature without electricity. <u>Heat Recovery:</u> The building utilizes heat recovery solutions for ventilating air and greywater (from all sources except toilets). The building also uses seawater for heating and cooling. <u>Natural Daylight:</u> The use of artificial light is kept at a minimum due to the building design to maximize daylight. The building includes an illuminated core atrium that functions as a public garden. The horizontal glass windows provide a "well" of daylight to enter the building on every floor from the core of the building.
Renewable Energy Technologies	Powerhouse Brattørkaia maximizes sunlight with a unique sloped and pentagonal roof design that incorporates 2,000 m^2 of photovoltaic solar panels. In addition, there are 500 m^2 of solar panels on the building façade.
Energy Use and Production	• Energy Performance: 458,457 kWh per year • Powerhouse Brattørkaia produces more than twice the amount of electricity it consumes daily. The excess electricity is supplied to neighboring buildings, cars, and boats through a local micro-grid. • Powerhouse Brattørkaia has collaborated with the City of Trondheim to utilize the surplus of electricity to power the city's all electric bus fleet.
Building Benefits	• Energy positive, produces twice the amount of energy it consumes daily

	• Essentially a small power station in the middle of the city
Building Challenges	Rune Grasdal, the Senior Architect and Project Manager for the Powerhouse Brattørkaia project, stated that it is an extremely difficult task to build energy positive buildings. It would almost be impossible to complete such a project without strong teams with exceptional knowledge and experience in building sustainable buildings. Powerhouse Brattørkaia has been able to reach all of its energy goals in the first year of operation except for the lighting system. The LED motion sensor lights consume a lot more energy than originally anticipated, as the switches and occupancy sensors have a high-energy demand even when the lights are off. At night, the lighting energy consumption was half the amount consumed during the day. A simpler control system using more light in the daytime (with little waste to operate sensors and switches), and enabling a full shutdown at night would have been more efficient.
Awards	Powerhouse Brattørkaia has received the BREEAM Outstanding certification. This is the highest ranking by the worlds leading sustainability assessment for an asset's environmental, social, and economic sustainability performance.

4.5 Green Office Meudon

Green Office Meudon is located in Meudon-la- Forêt, France, and is approximately 20 minutes away from the centre of Paris, France. The bioclimatic design of Green Office Meudon utilizes natural ventilation and natural light by taking advantage of the north-south orientation of the building (Green Office, 2022). These features eliminate the need for energy-intensive air conditioning systems and utilize the outside weather to optimise the internal building temperature (Cartier, 2012). In the building design, priority was given to passive systems in order to benefit from the thermal inertia of the concrete structure and automated external sunshades. The net-positive energy building is easily accessible from public transportation networks and offers a pleasant working environment (Green Office, 2022). Green Office Meudon utilizes the SI@GO software application system to measure energy production and consumption in real time (Cartier, 2012).

Table 11: *A summary of key findings for Green Office Meudon*
Source: Cartier, 2012; Green Office, 2022.

Building Name	**Green Office Meudon**
Building Address	11, Avenue Maréchal Juin 92 MEUDON, France
Building Type	Commercial
Project Aim	The project aim was to create a net-positive energy building in Meudon, France.
About the Building	Green Office Meudon has a net floor area of 23,300 m^2 with 1,250 workstations. The building was designed to limit the need of energy requirements for lighting based on the north-south orientation. **Building Features** • Natural ventilation • Optimum use of natural light • Three-metre high ceilings • Seven-storey high green wall and external terraces

	Energy Management System • 100% of offices in direct daylight with dimmable low-energy lighting and presence detectors • Blinds on the facades controlled by hours of sunlight • Heating, automated vents and circulating fans controlled by temperature sensors • Water management with sensor traps in the washrooms
Renewable Energy Technologies	• Approximately 4,200 m^2 of solar photovoltaic panels on the roof, skylight, façades, blinds, and car park shelters. • Green Office Meudon also houses a cogeneration plant that includes an engine and generator unit to supply power and heat simultaneously. It runs off pure rapeseed oil that is locally sourced from farmers in the Paris region. This system covers 100% of the building's heating needs and 55% of its power needs.
Energy Use and Production	Total annual energy production: 490,000 kWh (originally estimated to be 450,000 kWh) Energy Production: 64 kWh/m^2/annually Energy Consumption: 62 kWh/m^2/annually Summary of energy consumption after one year in operation: heating 53%, office equipment 14%, lighting 13%, utilities 3%, lifts 2%, and cooling 1%
Building Benefits	• Net-positive energy production • Bioclimatic design • North-south orientation to optimize lighting • Reports show that this building uses 30% less energy than most energy-efficient high environmental quality buildings currently on the market, which is equivalent to energy savings of 65%
Awards	Green Office Meudon has the following certifications: • NF Bâtiments Tertiaires - Démarche HQE – Passeport HQE Exceptionnel • 2005 BBC-effinergie low-energy certification • BREEAM Excellent in design phase • 2011 Pyramid d'Argent award in the innovation category

4.6 Solaris Énergie Positive

Solaris Énergie Positive building is located in Clamart, France. Solaris has set the goal of exceeding the environment and sustainability initiatives outlined by the Grenelle de l'Environnement to produce an energy positive building (Batiactu, 2009). In order for this project to be a success, the project team addressed the importance of making economically reasonable choices, while using proven techniques that are easy to manage and maintain (Tsialdaridis, 2008). The project team also recognized the importance of reducing the overall energy consumption of the building's features prior to incorporating renewable energy technology. The renewable technology chosen for this office building include the dual use of solar photovoltaic panels and geothermal wells (Batiactu, 2009).

Table 12: *A summary of key findings for Solaris Énergie Positive*
Source: Batiactu, 2009; Tsialdaridis, 2008.

Building Name	**Solaris Énergie Positive**
Building Address	10 Av. Réaumur, 92140 Clamart, France
Building Type	Commercial
Project Aim	The project aim was to build a net-positive energy building in Clamart, France.
About the Building	Solaris Énergie Positive is a 31,000 m^2 building **Low Energy Consumption Features** • North-south orientation and an optimized building shape • Insulation via the outer shell of the building to abolish thermal bridges, combined with energy efficient glazing • The use of thermal mass materials (internal mass) • Night-time over-ventilation and rotary heat exchangers • Sophisticated regulation • Use of geothermal energy • A garden to create a microclimate **Smart Management Features** • Motion sensors and low consumption light bulbs • Smart dimming technology to adapt to exterior lighting levels • Energy stored in the floor using coil networks • Heat generated during daytime use is absorbed in thermal mass • In the winter, 120 geothermal probes tap into the Earth 100 meters underground and inject heat into the building. In the summer, the opposite occurs.
Renewable Energy Technologies	**Earth and Sun Energy** • The roof includes 4,223 m^2 of solar photovoltaic panels which are oriented south at an inclination of 17 degrees in such a way to best match the perpendicularity of the equinoxes for the latitude of France. • 120 geothermal probes, 100 metres deep for a total of 12 km geothermal power The combination of these two renewable energy technologies enables Solaris to offset the total energy requirements of the building while generating a surplus. The value of electricity generated and sold to the French Electricity Utility is estimated to be €291,000 /year (equivalent to approximately $409,500 CAD).
Energy Use and Production	The combination of low energy consumption technologies and smart management features allow for Solaris's energy bill (before solar panel power generation) to be € 7/m^2/ year compared to an equivalent building without these technologies at € 16/m^2/year.
Building Benefits	• Two sources of renewable energy generation (solar and geothermal) • The building produces a surplus of electricity which is equivalent to an annual savings of 320 tonnes of CO_2 emissions per year
Awards	The Solaris building has undertaken the certification procedure for a High Environmental Quality and low consumption building.

5.0 Net-Zero Technologies and Best Practices

5.1 Net-Zero Technologies

Through research of past net-zero arenas, community buildings, and business places, Green Samaritan Consulting has identified several net-zero technologies that represent best practices in the industry and would be beneficial for the new Ilderton Arena. These technologies include:

- battery models,
- eco-friendly refrigerants,
- heat recovery systems,
- energy use simulation software,
- rainwater capture systems, and
- solar panels.

5.1.1 Battery Energy Storage

Energy storage is rapidly becoming one of the key technologies that will help decarbonize society's electricity grid and energy systems (Centrica Business Solutions, 2022). There is also growing interest among the net-zero building industry to implement battery energy storage systems to maximize solar power. Middlesex Centre expressed specific interest in battery technology, therefore, this report incorporates research findings surrounding battery energy storage systems within the sustainable building industry, so that Middlesex Centre can explore the opportunity to store harvested solar power from the net-zero carbon ready arena.

Currently, the consumption of solar energy does not align with the period of solar energy production, resulting in a significant portion of solar power waste if not immediately consumed (VisBlue, 2020). Implementing an energy storage system has many benefits including (Centrica Business Solutions, 2022):

1. Improving energy reliability and resilience;
2. Integrating storage with low-carbon generation sources;
3. Ensuring a more flexible and robust power grid that can accommodate unplanned outages; and
4. Integrating more renewable energy sources to reduce reliance on fossil fuels.

Due to growth in popularity, battery storage technology is predicted to become more affordable for commercial and industrial applications. This will enable more organizations to integrate battery storage technology as part of their energy strategy (Centrica Business Solutions, 2022). Battery storage systems coupled with on-site solar photovoltaic systems will accelerate decarbonization, while ultimately reducing overall energy costs, especially during peak price times (VisBlue, 2020). Figure 8 below outlines what a typical day looks like in terms of solar energy production and consumption of solar power with a battery storage solution. The peak of solar energy produced is harvested and stored in the battery to be used around the clock, when needed.

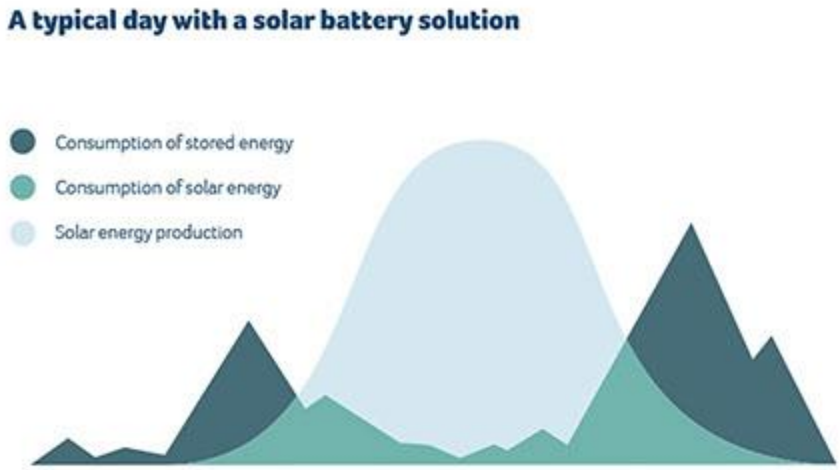


Figure 8: *Solar Production and Consumption - this image represents the ratio of solar energy that is produced and consumed throughout the day. The light green represents the solar power that is consumed during solar energy production, the dark green represents the stored energy consumed from the battery solution. Source: VisBlue, 2020*

Energy storage can be identified as the true bridge to a clean-energy future. The mass deployment of battery storage systems has been proven to overcome one of the biggest obstacles to renewable energy, which is the cycling between oversupply when the sun is shining and the shortage of supply when the sun sets. A battery storage system works by smoothing the imbalances between supply and demand (Katz, 2020). Two types of batteries currently being used for sustainable net-zero energy buildings are (1) Lithium Iron Phosphate batteries and (2) Vanadium Redox Flow batteries. These two battery technologies are described below.

How do Lithium-Ion Batteries Work?

Lithium-Ion batteries work by utilizing lithium-ion as the cathode, and graphite as the anode. Different types of lithium-ion batteries are created by changing the cathode material. Some of the most common lithium-ion batteries include: Lithium Iron Phosphate (LFP), Lithium Cobalt Oxide (LCO), Lithium Manganese Oxide (LMO), Lithium Nickel Cobalt Aluminum Oxide (NCA), and Lithium Nickel Manganese Cobalt Oxide (NMC) (Dragonfly Energy, 2022).

The Lithium Iron Phosphate ($LiFePO_4$) is the most common type of lithium-ion battery that is used for renewable energy storage. This battery uses $LiFePO_4$ as the cathode material to store lithium ions, and the anode material is made of graphite. The electrolyte carries positively charged lithium ions from the anode to the cathode (and vice versa) through the separator. This movement of lithium ions creates free electrons within the anode that creates a charge at the current collector. This chemical composition allows $LiFePO_4$ batteries to have a high current, good thermal stability, and a long lifecycle (Dragonfly Energy, 2022). The schematic diagram of a $LiFePO_4$ battery is shown below in Figure 9. The advantages and disadvantages of $LiFePO_4$ batteries are listed below in Table 13.

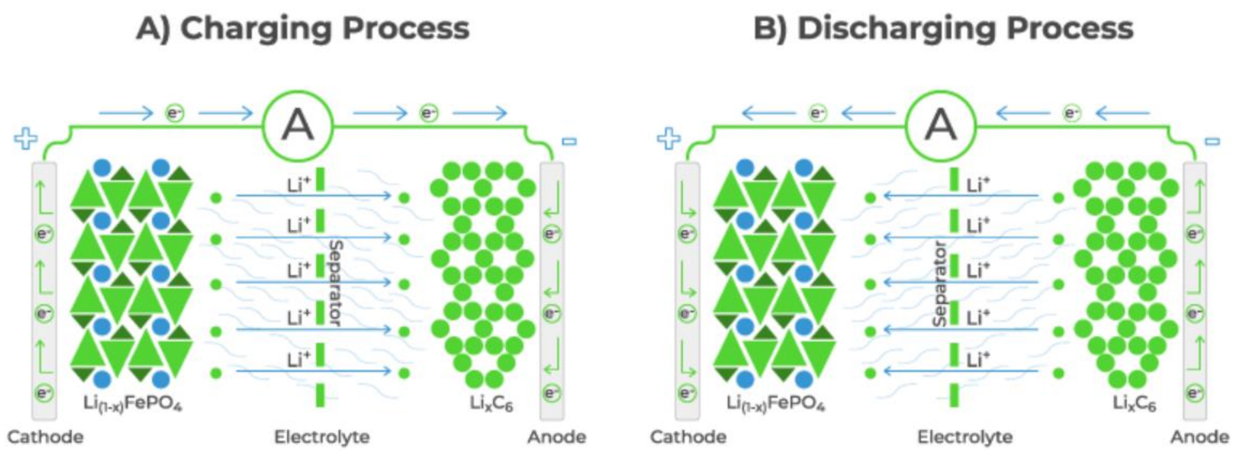


Figure 9: *The schematic diagram of a Lithium Iron Phosphate battery*
Source: Dragonfly Energy, 2022

Table 13: *The advantages and disadvantages of $LiFePO_4$ compared to other batteries on the market*
Source: Luda Battery, 2021

Advantages	Disadvantages
1. Energy Density: $LiFePO_4$ batteries have one of the highest specific power ratings, which means that it can deliver high amounts of current and power without overheating. 2. Lifecycles: $LiFePO_4$ batteries can have approximately 2,000 to 5,000 discharge cycles before showing signs of aging. 3. Compact Size and Lightweight: $LiFePO_4$ batteries have a compact size and a high-power density. 4. Operating Temperatures: $LiFePO_4$ batteries do not enter thermal runway conditions until 270°C. Exceeding this temperature typically results in end-of life for $LiFePO_4$ batteries.	1. Embedded carbon in limited lifecycle batteries. In order to avoid increasing emissions, the energy stored has to be significantly less carbon intensive that the energy displaced. This is especially true for limited lifecycle batteries. 2. Low Specific Energy Rating: $LiFePO_4$ batteries have less storage capacity per weight than other lithium-ion options. This can be minimized by connecting multiple batteries in parallel. 3. Aging: $LiFePO_4$ batteries can age rapidly and have a high self-discharging rate compared to other batteries on the market. 4. Operating Temperatures: $LiFePO_4$ batteries do not perform well at low temperatures and need more protection and care. 5. Low Nominal Voltage: $LiFePO_4$ batteries have a low nominal voltage that reduces energy. 6. Cost: $LiFePO_4$ batteries are expensive due to the materials used to build them.

How do Vanadium Redox Flow Batteries Work?

Vanadium redox flow batteries (VRFB) are often used for grid energy storage (VRB Energy, 2022). A VRFB is a type of rechargeable flow battery that uses the element vanadium and its ions as charge carriers (Cunha et al., 2014). This type of battery utilizes vanadium's ability to exist in four oxidation states, which allows the battery to function off one electroactive chemical element instead of two (Cunha et al., 2014). This battery has two separate tanks, one containing a positive electrolyte and one containing a negative electrolyte. Both electrolytes contain vanadium in different oxidation states dissolved in sulphuric acid.

The electrical current from the solar panels is fed through the cells electrodes where it moves electrons from the positive to negative electrolyte. This process charges the battery as liquid flows back towards the tank. During battery discharge, this process is reversed (VisBlue, 2020). The VRFB schematic diagram of this process is shown in Figure 10. The advantages and disadvantages of VRFBs are outlined in Table 14 (VRB Energy, 2022).

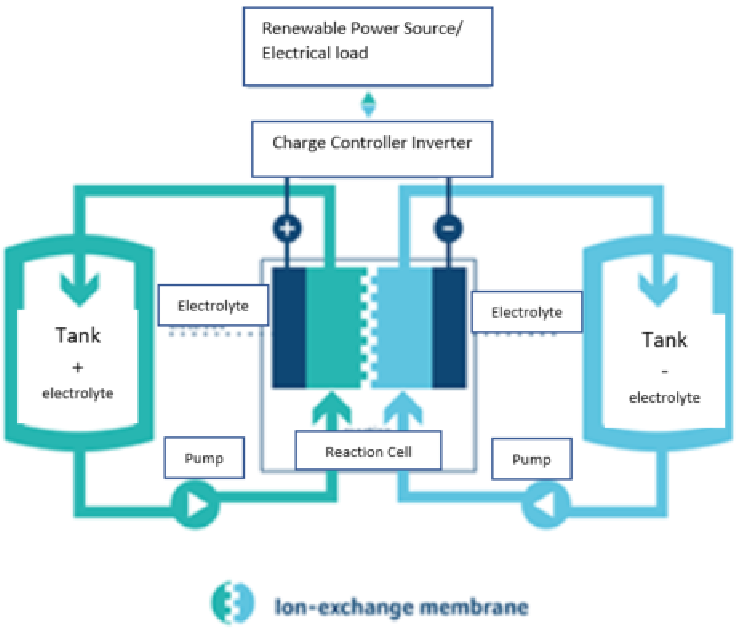


Figure 10: *The schematic diagram of a vanadium redox flow battery*
Source: VisBlue, 2020

Table 14: *The advantages and disadvantages of VRFBs compared to other batteries on the market*
Source: VRB Energy, 2022

Advantages	Disadvantages
1. No limitations of energy capacity 2. Can remain fully discharged indefinitely with no damage 3. Safe, non-flammable aqueous electrolyte 4. Wide operating temperature range, including passive cooling 5. Long charge-discharge cycle life (approximately 15,000-20,000 cycles) 6. Relatively low cost	1. Relatively poor energy-to volume ratio in comparison to storage batteries 2. Relatively poor round-trip efficiency 3. High weight of aqueous electrolytes 4. Relatively high amount of vanadium oxides 5. Embedded carbon from battery cells can increase emissions

VisBlue Vanadium Redox Flow Battery
VisBlue is a Danish and Portuguese company that commercializes green energy storage with a patented VRFB technology. The VisBlue battery solution has a lifespan of more than 25 years, and provides a safe and eco-friendly battery solution that enables organizations to better utilize the energy produced from renewable sources. With this battery installed, organizations are able to use sustainable power, use green energy at night, monitor usage throughout the day, and buy power when rates are low. The additional benefits of VisBlue Vanadium Redox Flow Battery are described below (VisBlue, 2020):

1. Innovative Technology: The VisBlue battery is an energy storage solution that enables a higher utilization rate of energy generated from renewable energy sources and store it for use around the clock.
2. Scalability: The VisBlue battery is scalable as the electrical power and storage power can be scaled independently so this type of battery can be tailored to specific needs.
3. Ecofriendly: The separated major operating components (tanks, electrolyte, pumps, electrode stack, etc.) are either recyclable or reusable in different ways.
4. Cost: The relative cost of this battery compared to others over the lifetime is low, which makes it a profitable investment.
5. Payback period: When considering feed-in tariffs and electricity costs, the average payback period for a standard VisBlue battery is less than 10 years.
6. Customisable and upgradable: The VisBlue battery is easy to disassemble and upgrade if electricity pattern or energy needs change.

5.1.2 Refrigeration

The refrigeration process in an ice hockey rink is a closed loop system in which heat is extracted from the concrete pad below the ice surface and either released to the external air or used elsewhere in the facility. Refrigerants are substances which expand and cool from gaseous to liquid states that allow refrigeration to take place – these substances remove from heat one area, then move it to another. (The Explained Channel, 2016).

Traditionally, refrigerants were man-made, synthetic compounds and commonly fell into one of two categories: chlorofluorocarbons (CFCs) and hydrochlorofluorocarbons (HCFCs) (K-J Thomas Mechanical, 2022). If exposed to the atmosphere, synthetic CFCs had the capacity to deplete the ozone layer and drastically warm the earth's climate. For example, CFC R-12 – known as Freon-12 – has a Global Warming Potential (GWP) of 10,200, meaning it has over 10,000 times the atmospheric warming effect of carbon dioxide (K-J Thomas Mechanical, 2022). Synthetic HCFCs were introduced shortly after as they are not as detrimental to the ozone layer, however studies have shown they still posses a very high GWP. Freon-22 (R-22), an HCFC commonly used in industrial refrigeration systems, ice rinks, and air treatment, has a GWP of 1,760 – almost 2,000 times that of CO_2 (K-J Thomas Mechanical, 2022).

Research and development have come a long way since the days of synthetic refrigerants. Modern systems have the capacity to operate on natural refrigerants which are a better alternative as they possess a much lower or no GWP (Discovery Designs Refrigeration, n.d.). For example, ammonia, which is a naturally occurring substance on earth and has a GWP of 0, has proven to be a very effective alternative to synthetic refrigerants. Ammonia systems which do not warm the climate, also cost less to implement and operate anywhere from 3% to 10% more efficiently than those using CFCs (CIMCO Refrigeration, 2021b; Goodway, 2022). The Canadian Recreation Facilities Council conducted a census and found that 65% of ice arenas use ammonia as a refrigerant, 25% use HCFCs mainly as R-22, and 10% have natural ice (Courchesne, 2013). CO_2 is proving to be another viable natural solution in industrial refrigeration. It is a non-toxic, non-flammable refrigerant that provides the optimum balance between performance, efficiency, and safety (CIMCO Refrigeration, 2021b). CO_2 refrigerant is also non-corrosive with most materials and is a good replacement option for freon refrigerants such as R-22 (CIMCO Refrigeration, 2021b). Ammonia and CO_2 are cost-effective, efficient alternatives to CFCs and HCFCs that is also safer for the environment (Goodway, 2022).

Another alternative to freon refrigerants is a new synthetic refrigerant replacement called Opteon. Opteon is an A2L refrigerant class that has lower global warming potential, low flammability, and lower toxicity levels (Opteon, 2022). Opteon's safer chemical makeup reduced health and safety concerns during installation and use, while also requiring lower pressure – meaning lower strength, more efficient, compressors can be used when including it in the ice rink refrigeration system (Opteon, 2022).

Table 15: *Summary of different refrigerants*
Source: K-J Thomas Mechanical, 2021; Goodway, 2022; Opteon, 2022

Refrigerant	Ozone Depleting Potential	Global Warming Potential	Type
CO_2	0	1	Natural
Ammonia	0	0	Natural
Opteon (R513A)	0	573	Synthetic
R134A	0	1,300	Synthetic

5.1.3 Heat Recovery

Heat recovery is a term used to define the recovery of heat-energy or waste-heat energy that is released from building processes which would otherwise be unused and dissipate into the immediate environment. Heat loss typically occurs due to three main mechanisms: electromagnetic radiation, convection, and conduction. Thermal-heat-recovery technologies utilize one or a combination of these three mechanisms in order to recover waste-heat. Thermal heat recovery has been identified as a potential application in sustainable buildings to drastically reduce fossil-fuel consumption. In order to determine a given building's feasibility for implementing heat recovery systems, two crucial factors must be considered: the temperature of the waste heat and the quantity of heat produced. Generally speaking, the higher the temperature and quantity of waste, the more suitable the system is for generating electricity. (McKenna, n.d.).

In sustainable buildings, heat recovery systems are most effective when several components are integrated to conserve energy and output fresh ventilated air as needed instead of on a scheduled basis. The high efficiency equipment can be integrated at several levels to maximize energy savings and reduce energy consumption. For instance, utilizing waste-heat recovery from refrigeration components is a great way to recover heat from the equipment required to run the facility (Arena Guide, n.d.-c). Heat savings are estimated to be approximately 75% using this method and can make both refrigeration and heating ventilated air more efficient processes (Arena Guide, n.d.-c). In addition to recovering heat waste from refrigeration components, the following heat recovery technologies are great options to reduce overall energy consumption and maximize energy savings:

- Boiler Flue Economisers,
- Heat Recovery Wheel,
- Plate Heat Recuperator Technology, and
- Underground Thermal Energy Storage.

Boiler Flue Economisers

A slightly newer heat recovery technology includes the boiler flue economisers. Economisers can be fitted to most boiler models to capture heat vapour that can be reused to improve boiler efficiency (Renewable Energy Hub, 2018). Waste heat from flue gas in boilers would normally be expelled through the roof or ventilation of the building. However, condensing economisers reclaim this heated gas and use its latent heat to warm water inside the boiler while condensing the gas to resume the heating process (Natural Resources Canada, 2016). When paired with integrated smart systems that can adjust heating levels based on outdoor temperatures, economisers allow for more waste heat to be put to use and reduce the energy demand on the building in colder temperatures. This recovered heat from the boiler via water to air heat exchange also can preheat incoming air and thus requires less energy from furnaces to warm the building. Therefore, boiler flue economisers have the potential to use waste heat to preheat both water and air needed to run the building, creating significantly less energy demand However, condensing economiser boilers also come with a higher upfront cost (Furnace Compare, 2020). This increased cost does have a smaller payback period as the nearly 90% efficiency rate results in more cost-saving over time, lower emissions, and does not require extensive ductwork for exhaust air to exit the building (Furnace Compare, 2020).

Heat Recovery Wheel

One of the most common heat recovery systems used in commercial settings is the heat recovery wheel, also referred to as the heat regeneration wheel. Heat recovery wheels have the largest air recovery efficiency of all ventilation systems and tend to be much bigger compared to other technologies, meaning they can move a larger recovered heat mass (Renewable Energy Hub, 2018). Two large wheels are aligned in a “honeycomb” fashion where one will draw warm exhaust air and heat from the refrigeration system, while the other draws in fresh outdoor air (Renewable Energy Hub, 2018). The wheels also rotate in opposite directions so that energy from the warm exhaust air can be transferred to incoming air, heating it up (Renewable Energy Hub, 2018). The schematic diagram of a typical heat-recovery wheel is demonstrated in Figure 12. The benefits of heat recovery wheel technology is that it aids in cost savings for the HVAC system (Jasir, 2020). Since the wheel system exchanges fresh and “contaminated” air, the heat exchange that occurs preheats the fresh air, reducing the energy demand on the building heating system (Jasir, 2020). Additionally, as the heat recovery wheel system is driven by speed of wheel rotation, the amount of energy transferred from exhaust air to fresh air can be controlled to raise or lower the temperature of air being fed back into the building (Renewable Energy Hub, 2018).

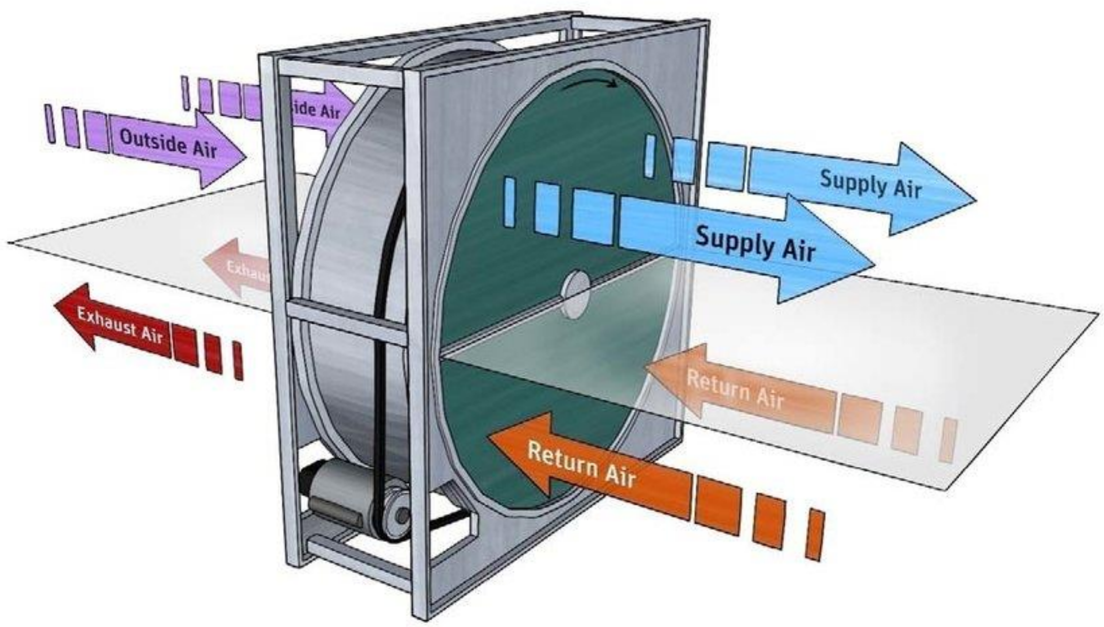


Figure 11: *The schematic diagram of a typical heat recovery wheel system*
Source: Softah & Gawad, 2014

Plate Heat Recuperator Technology

Smaller scale heat recovery can be done by utilizing a series of plates. A single box with parallel metal or plastic plates allows for extracted warm air to pass between them transferring energy to incoming air (Renewable Energy Hub, 2018). The two separate air streams do not touch one another during this process but utilize the heat capacity of the plates to transfer energy from recovered air to fresh air (Renewable Energy Hub, 2018). Plate heat recuperation technology also had the ability to be used with fluids as well in areas where hot and cold energy vessels (air or fluid) are exposed (Christodoulides et al., 2022). Due to this large area of exposure, there is a greater amount of heat transfer that can occur (Christodoulides et al., 2022). The schematic diagram of a plate heat exchanger is shown below in Figure 13. There are three different forms of plate heat recuperation technology, all of which can be arranged in single or multi-pass systems to maximize heat recovery (Jouhara et al., 2018). Overall, plate heat recuperation systems tend to have approximately 70% efficiency when inspected and maintained on a regular basis.

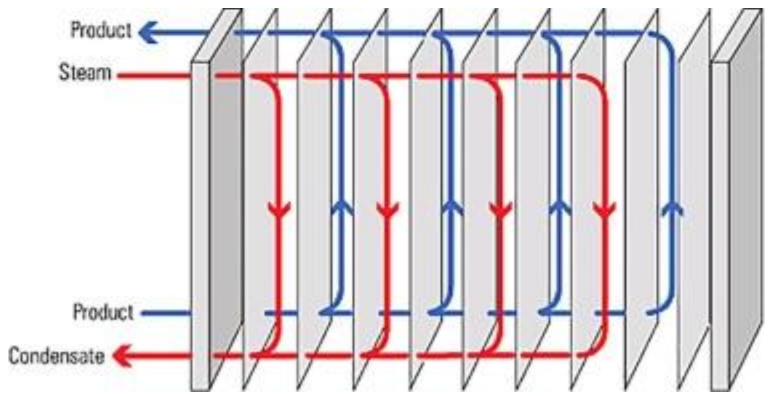


Figure 12: *The schematic diagram of a typical plate-heat exchanger*
Source: Jouhara et al., 2018

Underground Thermal Energy Storage

Underground thermal energy storage (UTES) is a form of natural energy storage that provides large-scale seasonal storage of heat and cold in underground sites (Lim, 2013). UTES can be coupled with heat recovery by taking excess heat from the building that would otherwise be expelled into the atmosphere and instead pump it into the ground to be stored. Utilizing underground as thermal energy storage is suitable because of its high thermal inertia (Lim, 2013). Ground temperature is weakly affected by climate variations above ground at depths of 10 to 15 metres, allowing for stable temperatures (Lim, 2013). The large storage capacity of natural underground sites makes UTES a form of long-term and seasonal storage (Lim, 2013). UTES can efficiently store thermal energy from various sources including solar energy and by-product waste heat underground for a long period of time (Lim, 2013). Underground thermal energy storage systems can be coupled to ground source heat pump systems and can be realized with or without heat pumps or reversed heat pumps (Laloui & Rotta Loria, 2020).

There are three common types of underground thermal energy storage systems, depending on the location of the site. These systems include aquifer thermal energy storage, borehole thermal energy storage, and rock cavern thermal energy storage. These systems are outlined below in Table 16.

Table 16: *Different types of underground thermal energy storage systems*
Source: Lim, 2013

Aquifer Thermal Energy Storage	Borehole Thermal Energy Storage	Cavern Thermal Energy Storage
• Open-loop energy storage system that stores thermal energy in the groundwater and porous matrix • Consists of a set of cold and warm wells, coupled through hydraulic pumps and heat exchangers • Multiple wells can increase the energy storage capacity • Favourable for large-scale energy storage	• Thermal energy is stored underground for extraction during demand periods • Closed-loop system that stores thermal energy in the bedrock underground • Borehole heat exchangers are installed to penetrate into the storage medium • Suitable for both small- and large-scale energy applications	• High construction cost and not very common • Uses underground rock caverns including abandoned mines and oil reserves to store hot water underground • Provides a high loading and unloading power simply by pumping water into and out of caverns faster

5.1.4 CO_2 Detection Sensors

High indoor air quality of a building is achieved by obtaining the perfect balance between ventilation and productivity levels. The CO_2 concentration in a building varies day-to-day depending on the occupancy. A CO_2 sensor is used to monitor the building's CO_2 levels; when the levels are elevated to a fixed degree, the sensor sends a signal to the ventilator, which then triggers the ventilation system to react by adjusting the level of ventilation in the room, as needed. The application of a CO_2 sensor reduces energy consumption as the room fans will only operate for the required time to stabilize CO_2 levels, and shut-off again (Senseair, 2022).

A study on buildings utilizing demand-controlled ventilation systems with an incorporated CO_2 sensor show that energy costs are reduced by approximately 30%. This results in a return on investment in approximately one year (Senseair, 2022). CO_2 sensor technology can be utilized to monitor rink use, output fresh air as needed, while aiding in the adjustment of overall temperatures. This technology can also help lower energy use and prolong the life of compressor equipment – as seen in the Woodstock Union Arena retrofit (Arena Guide, n.d.-a). Figure 11 below, demonstrates the energy saving capacity with the incorporation of CO_2 control mechanisms compared to other types of controls (fixed and motion detection).

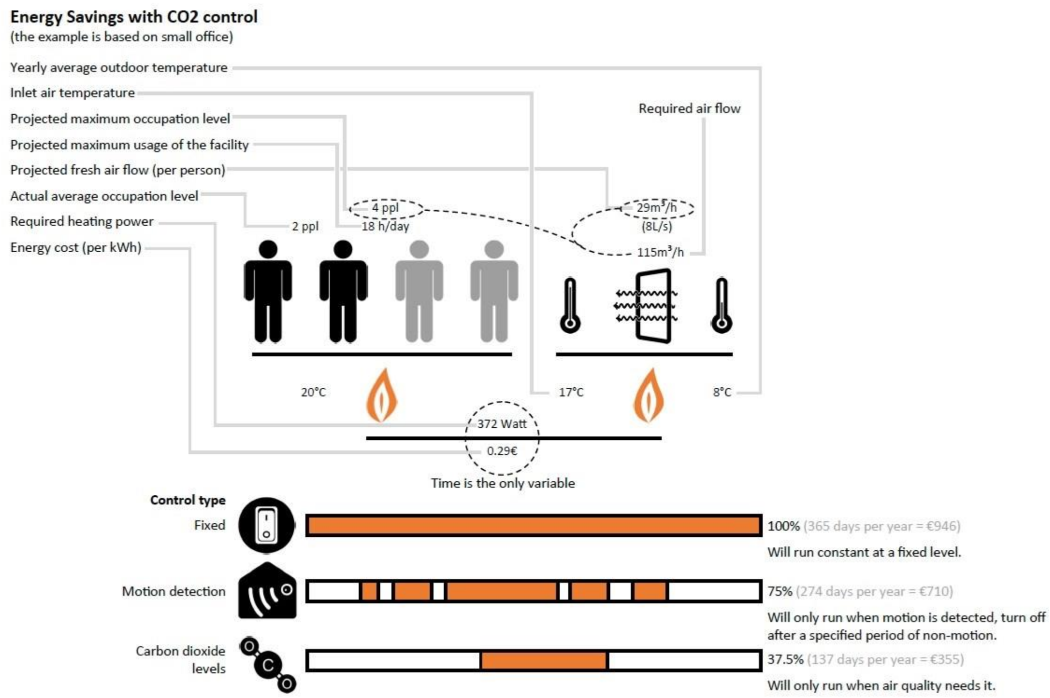


Figure 13: *Potential energy savings with CO_2 control systems*
Source: Senseair, 2022

5.1.5 Energy Use Simulation Software

To further plan for estimated energy output, three-dimensional (3D) building energy simulation tools can be integrated into the planning stages to avoid energy sinks in the current design. Energy simulations are computer-based analyses that provide estimated energy use projections based on the current technology used in the building and the expected traffic (Wulfinghoff et al., 2010). Most software also includes climate in the surrounding area to provide highly accurate predictions on the amount of energy the building will need to run. These simulations provide information on heat and energy loss, building components, system sizing, and recommendations to technology that works best with one another to optimize the building's design. There are several 3D building energy simulation softwares including Green Building Studio, Energy Plus, and IESVE. The IES software with VE (IESVE) is specifically designed for retrofitting, while IESiSCAN is best for optimizing building operations of a new build (Integrated Environmental Solutions Ltd., 2021). The IES program provides some of the best add-ons for a new build and would be an ideal software for this project's energy projections.

5.1.6 Rainwater Harvesting

Reusing natural resources through rainwater harvesting systems is another way to save on energy costs by integrating systems that take advantage of the rain and snow in Southwestern Ontario. Water and wastewater systems use approximately 38% of municipal government energy consumption in Canada, however, it is not typically considered in net-zero accounting during these types of builds since there is little data on the actual water-related emissions (Shapiro, 2021). While the United Kingdom is one of the countries moving toward making government water systems net-zero, this is not the case in Canada (Shapiro, 2021). With that being said, rainwater harvesting and reducing water intake is still a best practice. Rainwater harvesting through non-pressurized dry systems such as inexpensive barrel and duct collection systems are the first step in collecting non-potable water for landscaping, toilet, and ice rink resurfacing (Ogale, 2014). Dry systems are less costly compared to wet systems, which typically involve pressurized pipe systems and multiple inlets (Ogale, 2014). Diverting potentially contaminated rainwater is also a primary stormwater management tool to improve the environmental well-being of the area by reducing toxins, decreasing demand on the local water supply, and avoiding excess drilling for wells (Arena Guide, n.d.-b). Water can be harvested from rooftop collection, melted snow, and condensation from dehumidifiers and compressors before being filtered and used. A combination of filters can be stacked to reach varying purity levels and reducing costs where possible. Simple physical filters can be used to remove large impurities for outdoor water use, while five-micron and ultraviolet-light filters should be integrated for toilet water and rink resurfacing (O'Shea, 2017). At this purification level the ice freezes more quickly and the quality of the rink may be closer to pond skating (O'Shea, 2017).

5.1.7 On-site Solar Power Generation

Another technology that is widely incorporated into net-zero buildings is on-site renewable energy production. Producing energy on-site using renewable technologies like solar and geothermal aid in reducing operational costs of the building while simultaneously improving the efficiency (Galland, 2012). Particularly, solar power provides the most long-term, abundant sustainable source of electricity for building operations (Galland, 2012). Additionally, solar power has other benefits than simply generating power for a building. By using solar power to electrify a building, it allows for enhanced financing capabilities for new projects (National Renewable Energy Laboratory, 2018). Since the cost of running a solar-powered building is reduced and slightly more predictable over time, any cost savings can be applied to future green projects on the property or for other projects an organization may be financing (National Renewable Energy Laboratory, 2018). Although studies have not occurred within Canada to prove this fact, on-site solar power generation has allowed projects in similar climates of the United States to divert excess funds that would have been spent to run a single building on multiple other projects that required financial aid (green projects or otherwise) (National Renewable Energy Laboratory, 2018).

Solar arrays are often placed on underutilized building spaces like roofs and wall faces but can also be built as free-standing structures near the building (Graphic Products, n.d.). Typically, each solar array (whether affixed to the building or otherwise) should be aligned to the same height and positioned to maximize sunlight directed onto the panel (Graphic Products, n.d.). By placing solar panels in a south-facing direction, more electricity is produced year-round as it captures more sunlight during all seasons (Graphic Products, n.d.). However, studies have shown that in North American climates, peak demand for energy occurs from mid-afternoon to evening. Therefore, incorporating west-facing panels as well allows for more power generation than south-facing panels during peak hours (Graphic Products, n.d.).

The energy output of solar panels also relies upon how they are attached to a building. Most solar arrays have the option to be attached or ballasted (National Renewable Energy Laboratory, 2018). Although both options are feasible for any solar array, ballasted systems can only be installed on flat or low sloped surfaces and angled less than 20 degrees to reduce wind loads on the panels (National Renewable Energy Laboratory, 2018). Ballasted systems also tend to have slightly reduced annual energy output but more kilowatts per square foot of surface, meaning more energy production in summer months compared to attached systems (National Renewable Energy Laboratory, 2018). As such, buildings with higher operating costs in the summer months may benefit from ballasted systems to alleviate the energy demand during high peak seasons.

The cells used to construct solar arrays are primarily available in two forms: crystalline silicon cells and thin-film cells (Galland, 2012). Crystalline silicon cells account for approximately 87% of the available market and the other 14% are thin-film cells (Galland, 2012). Although thin-film cells are less expensive to make, they lack the efficiency of crystalline cells. As a result, crystalline silicon cells are often used in renewable building projects as their rigid structure fits easily in commercial building design and is more readily available for purchase (Galland, 2012). However, one thing to consider is using high concentrated photovoltaic (CPV) cells when possible (Surple, n.d.). These CPV cells are traditional crystalline silicon-based but focus sunlight onto more efficient cells. While traditional photovoltaic cells available on the market only have a 22% efficiency, CPV cells have a 46% efficiency (Surple, n.d.). CPV cells are about four times more expensive than traditional crystalline silicon cells, but when combined with energy management software and a BAS can result in energy and cost savings of about 20% annually (Surple, n.d.).

The total cost of installing a solar array is entirely dependent on the surface size they are installed on (National Renewable Energy Laboratory, 2018). In other words, larger surfaces result in a higher cost per unit for each array (National Renewable Energy Laboratory, 2018). For example, a building that has a 9,000-kWh demand for electricity that has space to install a 7,500-watt array would cost approximately $19,000 to $22,000 (Deco Management, 2021). Generally, every square foot of roof space has the potential to generate about 15 watts of solar energy (Deco Management, 2021). Therefore, with the approximate roof space of the proposed Ilderton Arena (taking into account space between panels and other roof fixtures) being 56,000 square feet, a minimum of 840 kilowatts of potential solar energy could be generated. Most power generation will occur during mid-peak and peak hours as designated by the Ontario Energy Board (OEB); the most expensive time to use energy (Deco Management, 2021). Since energy rates are constantly changing, at a minimum solar power generation would reduce the amount of "expensive" grid energy needed from local utilities even in small systems, thus reducing the cost of building operations (Deco Management, 2021). Moreover, the price of solar panels is decreasing over time and becoming more affordable and available to the public and programs are available for those producing excess energy. For example, in Ontario, solar array systems of 500 kilowatts or less can use the Net-Metering System to apply a credit to individual utility bills when excess energy is supplied to the grid (Deco Management, 2021). Overall, the cost of installing on-site solar power generation is a long-term investment where the benefits far outweigh the increased upfront cost. Although the initial cost is higher than traditional buildings, self-sufficient energy production aids in reducing the monthly electricity bills from local utility companies (Surple, n.d.).

5.2 Net-Zero Best Practices

Zero carbon standards for buildings requires 100% of the operational energy use associated with the facility to be offset by on- or off-site renewable energy and 100% of the embodied carbon emissions associated with the construction and materials of the project to be disclosed and offset (Populous, 2021). Zero carbon buildings typically operate efficiently, phasing out combustion sources and utilizing renewables which ultimately boost the resiliency of the building (Populous, 2021). The following net-zero building best practices encompass construction best practices as well as facility operations best practices that can be incorporated at the Ilderton Arena.

5.2.1 Construction

To succeed as a net-zero building, the planning and construction of the building must be meticulously thought out. However, when it comes to industry best practices for constructing net-zero buildings, there is no consensus on how it should be done (Rockwool, 2020). Currently, there is no formal building code or building standards specifically addressing the structural necessities of a net-zero carbon building, and as such, the standard Ontario Building Code dictates all construction aspects (Rockwool, 2020). However, guiding principles are to include low embodied carbon materials and incorporate net-zero operational energy standards as both are components of net-zero carbon designations.

The Canada Green Building Council has a zero-carbon building standard that is used to officially give the net-zero designation to buildings in Canada (Canada Green Building Council, 2021). To be considered net-zero, the council defines it as the sum of the embodied and operational carbon of the building minus the amount of emissions avoided through offsets of green energy generation (Canada Green Building Council, 2021). However, there is no right or wrong way to achieve this goal. Instead, the Canada Green Building Council offers practices that could help achieve net-zero during the construction process by creating a tight building envelope, minimizing upfront embodied carbon, and maximizing insulation to reduce the energy load of the building (Canada Green Building Council, 2021; Rockwool, 2020). As such, the new Ilderton Arena should focus on building the arena with good insulation for the walls, windows, roof, and foundation to maximize building efficiency.

Insulation of Walls

An airtight, highly insulated building envelope is key to achieving a net-zero building system (Rockwool, 2020). A thermal boundary must be built for the entire building; this includes the below-grade areas. The typical best practice is to use insulation materials with higher R-values to ensure maximum heat retention of the building (Rockwool, 2020). This would stop any unnecessary energy loss and increase overall building efficiency. Typically, in North American climates, wall insulation R-values will vary between R-20 to R-60, ceilings will vary from R-30 to R-80, and floors from R-20 to R-60 (Zero Energy Project, 2022a).

There are a few options for wall structures that optimize building insulation through advanced framing techniques (Zero Energy Project, 2022a). These framing techniques reduce the amount of wood material used and waste generated during the construction process while improving energy efficiency (Barricade Building Products, 2018). Advanced framing replaces some wood beams with insulation, maximizing the insulated wall space and increasing the overall wall R-value (Barricade Building Products, 2018). Three wall methods use advanced framing techniques: rigid exterior insulation; single plate, double-stud walls; or double plate walls.

Exterior rigid insulation requires standard single-frame walls to be built and exterior building insulation to be added (Zero Energy Project, 2022a). One-inch-thick exterior rigid insulation is generally used to achieve sufficient insulation without needing additional support for the trim (Zero Energy Project, 2022a). However, if more than one-inch-thick insulation is required to suit the climate, more wood will be needed to hold the insulation in place. Although relatively low-cost when using traditional materials, this option does have issues concerning global warming potential (GWP) (Zero Energy Project, 2022a). Since another goal of a net-zero building involves lowering embodied carbon and lessening environmental impacts, the options presented in Table 17 must be carefully selected. For example, typical "pinkboard" rigid insulation has a GWP of 1,430, while expanded polystyrene has a GWP of only 7 and a higher R-value (Zero Energy Project, 2020a).

Table 17: *Global warming potential (GWP) of rigid exterior insulation options*
Source: Zero Energy Project, 2020

Rigid Insulation Name	Insulation Material	R-value per inch	GWP
“Blueboard” (Dow Styrofoam)	HFC-134a	R-5	1,430
“Pinkboard” (Owens Corning Foamular)	HFC-134a	R-5	1,430
Expanded polystyrene	Blown pentane	R-3.9	7
Polyisocyanurate foam board	Blown pentane	R-6	7

Single plate, double-stud walls use 2x8 or 2x10 wall plates with studs aligned in a 2x4 or 2x6 staggered layout (Zero Energy Project, 2022a). Double plate walls require two 2x4 walls to be built and placed five inches apart to form a 12-inch cavity, allowing more insulation to be blown in (Zero Energy Project, 2022a). As shown in Table 18, the two options vary by price, with double plate walls being more expensive overall by $234 per 100-foot wall (Arena, 2016). However, paying more in lumber and labour means the building will be better insulated and have a higher overall R-value (Arena, 2016; Dodge & Thompson, 2016). Many of these extra framing costs can be managed by good building design and careful planning to favour more right-angled walls to minimize waste, labour, time, and overall cost (Arena, 2016).

Table 18: *Cost of wall framing options that do not require external insulation*
Source: Arena, 2016

Framing Type	Length of 8-ft. Wall	Framing Factor	Framing Needed	Framing Cost per Floor	Framing Cost
Single Plate, Double-stud	100 ft.	20%	1,280 ft.	$0.61	$781
Double Plate	100 ft.	20%	2,560 ft.	$0.40	$1,024
				Net Increase for Double Plate Wall	**$243**

In addition to various wall structure types, there are also multiple options for insulation materials within those walls. Interior insulation has numerous options: traditional spray foam, low GWP spray foam, water blown, bio-based and loose fill, and batt options (Zero Energy Project, 2020; Zero Energy Project, 2022a). Price and embodied carbon vary for each insulation option, although insulation properties for each remain in the R-30 to R-60 range when appropriately applied (Zero Energy Project, 2020; Zero Energy Project, 2022a).

Traditional spray foam insulation consists of gases used to expand cells of plastic foam into a wall or ceiling cavity (Zero Energy Project, 2020; Zero Energy Project, 2022a). Over time, the gases used in the blowing process migrate out of the plastic foam and into the atmosphere (Zero Energy Project, 2020; Zero Energy Project, 2022a). The blowing agents of these spray foams tend to have high GWPs; therefore, although a cost-effective option, it increases the embodied carbon of the building and it can potentially contribute to global warming. However, spray foam insulation costs range from $0.50 to $2 per board foot, making it the most economical and budget-friendly choice (HomeAdvisor, 2022).

Low GWP spray foams are among the most commonly used insulations in new buildings. Low GWP insulation generally has a GWP less than 5 and has two universally available options in North America (Zero Energy Project, 2020). Both Insulthane Extreme™ from Elastochem and Wall-Tite ECO™ by BASF are slightly more expensive than traditional spray foam insulation but have more cost savings and net-climate savings over 20 years, as seen in Table 19. Although the Elastochem product is slightly more expensive, it uses Solstice blown foam with a slightly higher R-value, resulting in less foam needed to insulate the building (Zero Energy Project, 2020).

Table 19: *Comparison of Insulthane Extreme™ by Elastochem and Wall-Tite ECO™ by BASF low GWP spray foam insulation in terms of cost and environmental savings*
Source: Zero Energy Project, 2020

	Insulthane Extreme™	**Wall-Tile ECO™**
GWP	1	1000
Climate benefit by energy savings (tonnes CO_2 per year)	3.2	3.2
Environmental payback time	8 months	8 years
Net climate savings over 20 years (tonnes of CO_2 equivalent)	62	38
Cost to install	$3,700	$3,600
Energy savings over 20 years	$19,000	$19,900

Water-blown spray foam is available in open and closed cell foams that can be found on the market (Zero Energy Project, 2020). Water-blown foams react with the water to produce carbon dioxide and heat to expand the foam, making them one of the lowest GWP insulation foams with a GWP of only 1 (Zero Energy Project, 2020). The typical R-values of water-blown insulation is R-4.9 per inch. However, it is 25% lower in thermal insulation performance over time than other blown-in methods and yields about 25% higher application costs than low GWP and traditional insulations (Zero Energy Project, 2020). This technology is still new and costly; therefore, despite its low GWP and overall embodied carbon, the loss of insulation properties and higher cost make it unfit for the Ilderton Arena project.

Bio-based spray foams are another alternative to low GWP spray foams. Typically, bio-based spray foams contain either soy or castor oil and have a GWP of about 1 (Zero Energy Project, 2020). However, it must be noted that "bio-based" really means "bio-containing" in this regard. Biological or recycled material in this insulation type only ranges from 7% to 20% (Zero Energy Project, 2020). Moreover, due to the low market availability and market demand, these products are significantly more expensive to obtain (Zero Energy Project, 2020). They also may not be suitable for varying seasonal climates that southern Ontario experiences.

Loose-fill and batt insulation options contain no petrochemicals and have the lowest GWP of any insulation type (Zero Energy Project, 2020). Materials for this insulation type include straw bales, fibreglass batt, dense-packed cellulose, or mineral wool batt (Zero Energy Project, 2020). Table 20 shows the amount of embodied carbon between multiple insulation types. It indicates that loose-fill and batting insulation such as straw bales and denim batt have lower embodied carbon than traditional polystyrene foam and would overall minimize the embodied carbon of the building (Zero Energy Project, 2020). On a net-zero basis, loose-fill and batting insulation using recycled materials is an excellent choice in the construction process to reduce carbon; however, the labour costs are incredibly high (Zero Energy Project, 2020). Of the loose-fill options, straw bales have the highest potential for insulation. As a result, they should be considered for the Ilderton Arena project because it would lower embodied carbon, can be sourced locally, and the benefit outweighs the added labour costs of installation.

Table 20: *Embodied carbon of multiple insulation materials compared equally at a value of R-28*
Source: Zero Energy Project, 2020

Material	Embodied Carbon by Weight (kg CO_2e/kg)	Embodied Carbon for 4x8 Wall at R-28 (kg CO_2e/kg)
Straw bales	0.06	8.00
Mineral wool batt	1.28	21.75
Fibreglass batt	1.35	17.60
Denim batt	1.50	22.45
Dense packed cellulose	0.63	41.30
Extruded polystyrene foam	3.42	38.50
Expanded polystyrene foam	3.29	37.25

Overall, the Ilderton Arena project should incorporate high R-value insulation throughout the entire building. In particular, because of cost and the desire to reduce embodied carbon, low GWP spray foam insulation and fibreglass batt insulation optimize building energy efficiency, reduce embodied carbon, and keep costs within the budget provided.

Window Options

While still wanting to include as much natural passive lighting into the building to reduce energy costs, heat retention of windows is often relatively low. To optimize net-zero building efficiency, windows must be constructed to keep in mind their orientation, window glazing type, and shading mechanism (Zero Energy Project, 2022b).

The most accepted practice for passive solar lighting through windows is to place 50% to 60% of the window area facing south (Zero Energy Project, 2022b). Most of the activity intense rooms should be planned on the south-facing side of the building to use passive solar energy (Zero Energy Project, 2022b). By having most windows facing south, the building can maximize the heat and light from the sun in the winter months while simultaneously being built to limit excess solar energy in the summer months with the help of overhangs (Rosenbaum, 2014). Ideally, south-facing windows should have a higher solar heat gain coefficient in the winter months but low solar gain in the summer months in the northern hemisphere. Optimizing this seasonal shift in solar gains allows for the exclusion of heat in the summer and retention in the winter (Zero Energy Project, 2022b).

Window technology is improving quite quickly for net-zero buildings. Industry-standard suggests selecting windows with a heat loss rate of U-0.25 or lower to construct a tighter building envelope (Zero Energy Project, 2022b). A heat loss rate of U-0.25 or lower means that buildings now have the option between advanced double-glazed windows and triple-glazed windows (Zero Energy Project, 2022b). Both double- and triple-glazed windows allow the building to capitalize on the natural heat that reaches the windows (Rehau, n.d.). Figure 14 examines the major differences between double-glazed and triple-glazed windows. Overall, the more glazing of a window, the better the building insulation (EcoLine Windows, 2022). Triple-glazed windows tend to have an R-value of R-7 or R-8, while double-glazed windows have a maximum R-value of R-3.8 (EcoLine Windows, 2022).

Double-Glazed Windows

- ✓ Lower cost
- ✓ Can reduce up to 50% heat loss
- ✓ Weighs less
- ✓ More popular and available
- ✓ Performs best with fibreglass frame
- ✗ Less energy efficient
- ✗ The industry standard in Canada
- ✗ Less durable

Triple-Glazed Windows

- ✓ The most energy efficient glazing
- ✓ Lower U-factor
- ✓ High performance when used in combination with fibreglass frame
- ✓ Safer
- ✓ Extremely durable
- ✓ Stronger and longer lasting
- ✗ More expensive
- ✗ Can be subject to overcharging by contractors

Figure 14: *Comparison of double glazed and triple glazed window options*
Source: Fligg, 2014

Triple-glazed windows have a U-factor of U-0.2, while double-glazed windows only have U-0.26 (Ecoline Windows, 2022). By having triple-glazed windows, less heat escapes the building, overall reducing energy costs needed to heat the building year-round. However, the drawback is that triple-glazed windows are typically 10% to 15% more expensive than double-glazed options (EcoLine Windows, 2022). The return on investment of triple-glazed windows is saving 2% to 3% of the annual energy bill for the entire building (EcoLine Windows, 2022). Therefore, when designing net-zero buildings, the industry standard is starting to lean toward triple-glazed window units. Although slightly most expensive upfront, installing triple-glazed windows reduces the energy needed to run the building over time, making net-zero operation more achievable.

Another popular addition to windows in net-zero buildings is solar window films. Solar window films are lightweight vinyl adhesive that is professionally applied in commercial buildings (Carroll, 2018). These films block out ultraviolet rays and help regulate the heat loss and gains of the window year-round (Carroll, 2018). Installing solar films is generally low cost and professional adhesive films only cost on average $3 CAD more than residential self-installed non-adhesive films (Carroll, 2018). However, one thing to consider when installing solar films on double- or triple-glazed windows is that it may void any warranty associated with the window (Carroll, 2018). Although uncommon, some films are designed to absorb all solar heat and can transfer more heat to the window than it is capable of holding and breaking the insulation seal of the window (Carroll, 2018). Therefore, it becomes important to meticulously choose the right film for each window. Shinier window films appear invisible from the inside and reflect ultraviolet light thus increasing passive solar lighting but minimizing heat gains (Carroll, 2018). Dark window films block ultraviolet light by absorbing the energy, making the room darker but also transferring absorbed heat into the room (Carroll, 2018). Solar films can be welcome additions to south-facing windows in order to minimize solar gains in the summer months but will continue to reflect heat in winter months. Therefore, although they have great benefits to window efficiency, careful consideration is needed if optimizing summer and winter passive solar energy is desired.

The final construction aspect of windows includes shading devices for each window. Shading devices' proper placement and design can allow direct solar radiation to be blocked during certain times of the year (Charron, 2006). Fixed overhangs can be added to capitalize on the south-facing orientation and natural solar cycles during the building construction. It is suggested that if fixed overhangs are to be used, they must not shade the window at all on December 21st but shade 50% to 100% of the windows on June 21st (Charron, 2006). Additionally, it is suggested that these overhangs be combined with other shading mechanisms to account for solar loads on windows facing different directions in spring and fall. For example, the best practice for east-facing windows suggests having fixed overhangs of 12 to 18 inches and moveable shading mechanisms like awnings, sunscreens, or tall outdoor vegetation (Zero Energy Project, 2022b).

However, a new shading mechanism has become increasingly popular in the net-zero community. When triple-glazed or high-performance double-glazed windows are not within budget or available, insulated shades have been used as a cost-effective alternative (Zero Energy Project, 2022b). Insulated shades are lined curtains designed to keep warm air from leaving or entering the building through windows, decreasing the amount of wasted energy used for heating (Abbess, n.d.). They have been available on the market as home furnishing for years, but their use in commercial buildings other than hotels has increased dramatically in the past decade due to their energy-saving capabilities (Abbess, n.d.).

Green Roofs

Green roofs, which are roofs that contain living vegetation on their exterior, are a great way to offset operational carbon emissions and can act as additional insulation for protection against heat loss. A green roofing system, which is an extension of an already existing roof, have at minimum a waterproofing membrane, root expulsion system, drainage capacity, filter cloths, a fertilized growing medium, and plants, as seen in Figure 15 (Green Roofs for Healthy Cities, n.d.).

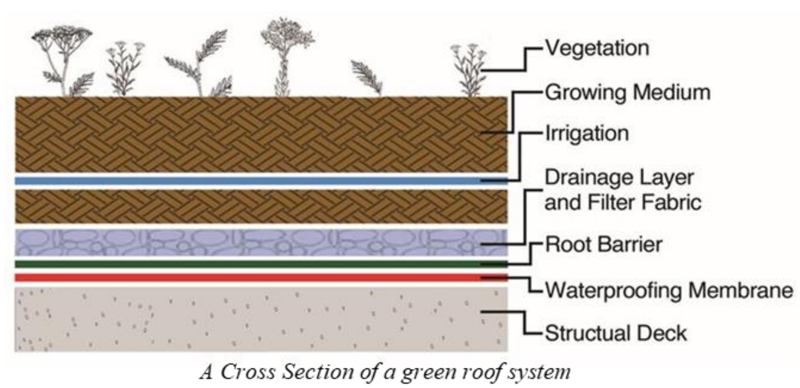


Figure 15: *The layers of a green roof*
Source: Green Roofs for Healthy Cities, n.d.

Green roofs offer many more private and public benefits such as (Green Roofs for Healthy Cities, n.d.):

<u>Private Benefits</u>

- Energy Efficiency
  - In recreational buildings, the roof is where the most substantial heat loss occurs during winter months, and where temperature gain is greatest in the summer months. Green roofs offer greater insulation to protect against these factors, ultimately leading to more energy efficient HVAC systems (Green Roofs for Healthy Cities, n.d.).
  - Research found in the National Research Council of Canada states that extensive green roofs result in a 75% decrease in energy demand for air conditioning units (Green Roofs for Healthy Cities, n.d.).
  - Carefully planned solar arrays can also be paired with green roofs in order to maximize the building's capacity to achieve net-zero carbon.
- Elongation of roofing membrane life
  - Green roofs cover most of exterior facing water proofing membrane. This shields the membrane from extensive precipitation, freezing and thawing, and drastic temperature changes which can all lead to tearing in its surface.
- Fire Retardant
  - Green roofs carry a much lower burning heat load than their traditional counterparts (Green Roofs for Healthy Cities, n.d.) – less heat is generated when they are burned which keeps the structural integrity of the facility safer in a fire emergency.
- Marketing
  - Green roofs have been shown to increase revenue, sales, property value, and employee retention (Green Roofs for Healthy Cities, n.d.).

<u>Public Benefits</u>

- Stormwater Management
  - Green roofs limit the amount local runoff precipitation, as rainwater and moisture are absorbed in the membrane level. The vegetation, through transpiration, takes which is then released back into the atmosphere through evaporation (Green Roofs for Healthy Cities, n.d.).
  - This can also be seen as a private benefit, as this process reduces the likelihood of on-site flooding events during excess precipitation.
- Moderation of Urban Heat Island Effect
  - Sunlight absorbed is by flat, barren, horizontally oriented surfaces and radiated as heat energy. That is why cities are much hotter than rural areas – this is know as the Urban Heat Island effect (UHI) (Green Roofs for Healthy Cities, n.d.),
  - Plants on green roofs absorb the suns energy, rather than reflect it, thus mitigating the building's contribution to the UHI (Green Roofs for Healthy Cities, n.d.).
- Air Quality Improvements
  - Plants increase oxygen levels, while decreasing the amount of carbon dioxide in the atmosphere.
  - Vegetation can also capture airborne pollutants and filter noxious gases (Green Roofs for Healthy Cities, n.d.).

White or Alternative Coloured Roofing

New studies have shown that changing the color of a facility's roof will make a very large difference in its operational efficiency. In a report published by the Energy and Buildings Journal, white roofs are three times more effective in fighting against the global warming effect than darker shades (Sika Sarnafil, n.d.).

This is because they reflect the sunlight's ultraviolet rays, rather that absorbing it, then radiating heat as infrared energy. Ultraviolet radiation is not trapped as easily by greenhouse gases; therefore, it is emitted back into space rather than trapped in the atmosphere (Sika Sarnafil, n.d.).

In 1998 Dr. Jeff Luvall and Dr. Dale Quattrochi of NASA studied aspects of cities which contributed to the urban heat island effect. Their team fixed planes with thermal and infrared cameras to aerially document areas of Salt Lake City, Utah (Sika Sarnafil, n.d.). RC Wiley is an American home furnishing company that has an 850,000 square foot facility in the heart of the city. This facility is equipped with a reflective white roofing membrane which is manufactured by Sika Sarnafil, one of the leading American manufacturers in polyvinyl chloride (PVC) and roofing systems. The distribution facility is depicted to emit much less heat than other buildings in the area, all of which had black or darker shaded roofing in the area. The manufacturer also offers roofing membrane in tan, reflective grey, and light green hues.

5.2.2 Facility Operations

There are three components to attaining and maintaining net-zero usage including energy efficiency, onsite renewable energy production, and renewable energy purchased from the grid (Linnean Solutions, 2022). The facility manager can play a large role in taking smart steps to achieving and maintaining net-zero for a building (Linnean Solutions, 2022). According to Linnean Solutions, for projects seeking to be net-zero, efficiency should be a high priority and is also the most cost-effective measure. Some measures that can be incorporated into a net-zero building to increase efficiency and reduce energy use intensity are presented in Table 21.

Table 21: *Net-Zero Building Facility Operations Strategies*
Source: Linnean Solutions, 2022

Area	Measure	Explanation
Load Reduction	Plug load management – use schedule-controlled power strips and outlets and low plug load equipment.	Schedule-controlled power strips help to reduce phantom power by turning off after a scheduled amount of time.
	Install ENERGY STAR or DesignLight Consortium (DLC) approved LED lighting lamps and ballasts.	ENERGY STAR and DLC approved lighting have been tested and shown to consume less energy than those that are not approved.
	Install occupancy and dimming ballast sensors for lighting.	Occupancy sensors and vacancy sensors help to reduce energy consumption by automatically deactivating after a set amount of time.
	Install daylight/photocell sensors on lighting near clerestory windows or skylights and exterior lighting.	Daylight/photocell sensors help to reduce energy consumption by activating and deactivating lighting based on natural lighting levels.
	Lower domestic hot water temperatures.	Lowering domestic hot water temperatures allows for less energy to be consumed to heat the water.
	Install sub-meters on major equipment and use software and dashboards to monitor and track energy consumption.	Sub-meters measure the energy consumption of specific areas or equipment. Metering major mechanical equipment will reveal how often it runs and how much energy it consumes during operation, as well as identify when equipment drifts away from set points.

	Prompt behavioural change – engage occupants through campaigns, signage, etc.	Increasing building occupant awareness and engagement in environmental and sustainable practices can have a significant positive impact on the performance of the building.
Passive Strategies	Install shading devices – permanent overhangs on south facing windows and operable shades on east and west facing windows are very effective at reducing solar heat gain.	Overhangs and shades help to reduce solar heat gain during the summer months and help to reduce the cooling load of the building. Operable shades or window blinds allows for controlling the amount of light entering a space on cloudy and sunny days.
	Maximize opportunities to utilize daylight in spaces.	Installing many windows and skylights will allow for daylighting which will reduce the amount of artificial lighting needed and will help reduce energy consumption.
	Explore ways to use natural ventilation.	Natural ventilation will reduce the use of mechanical equipment to bring in fresh air to the building and will reduce energy consumption.
	Maximize envelope performance to reduce HVAC system demands.	Proper insulation and airtightness of the building envelope reduces air loss through the building and helps to reduce energy consumption since the HVAC equipment does not need to work as hard to heat and cool the building.
Efficient Systems	Ensure that systems such as lighting and HVAC remain optimally sized.	Having optimally sized lighting and HVAC equipment will ensure greater comfort for building occupants and lower building operating costs.
	Use the most efficient equipment and appliances.	Premium efficiency motors consume less energy. Higher efficiency boilers, with a combustion efficiency of 85% or greater, consume less fuel than lower efficiency units. If rooftop units are installed, look for ones with an Energy Efficiency Ratio (EER) of 11.5 or greater. If chillers are needed, look for ones with a Coefficient of Performance (COP) of 2.8 or greater for air-cooled systems or 5.1 or greater for water cooled systems. For domestic hot water storage tanks, install ones that are ENERGY STAR or Air-Conditioning, Heating, and Refrigeration Institute (AHRI) certified.
	Use automated night setbacks to turn down heating and lighting.	Reducing the set point during the heating season and increasing the set point during the cooling season when the space is unoccupied will help to reduce energy consumption as the equipment will not need to be running at higher levels to heat and cool the building.
Energy Recovery	Evaluate the possibility of using heat exchangers and air re-circulators.	Heat exchangers help reduce utility consumption by conserving water, electricity, and steam.

		Recirculation eliminates forcing heat out of the building and offers substantial protection from changing outside temperatures which leads to fuel savings.

Once measures have been implemented to allow the building to operate more efficiently, it is important to complete commissioning to ensure that new equipment and systems are installed properly and functioning as designed. Commissioning of equipment is vital to the entire system's operation to ensure everything is functioning as designed and failure to commission new equipment could result in less-than-optimal performance. It is also important to ensure performance continues to be reassessed and improved upon wherever possible. This can be completed through re- or retro-commissioning. Periodic recommissioning is a systematic approach for the re-optimization of previously commissioned equipment and systems. Equipment and systems are reviewed on a regular basis to identify and adjust less-than-optimal performance in the facility's equipment, lighting, and control systems. Failure to complete recommissioning equipment can lead to reduced efficiency, improper fluid flows and temperatures, and premature decommissioning/replacement. Periodic recommissioning examines equipment performance through a different lens than preventative maintenance and is performed to ensure the system continues to operate as designed.

Additionally, building energy use can be reduced by putting in place control strategies such as reducing the operating time of a piece of equipment or using equipment during off-peak hours. Strategies can be applied using the BAS to control mechanical units or by using stand-alone controls. Controls that could be implemented include:

- *Unoccupied setback:* reducing the set point during the heating season and increasing the set point during the cooling season when the space is unoccupied.
- *Outdoor air temperature reset:* adjusting the heating water and/or chiller water supply temperature based on the outdoor air temperature.
- *Demand control ventilation:* adjusting the outdoor air rate based on the internal air quality (i.e. increasing ventilation based on carbon dioxide levels).
- *Scheduling:* setting a time to activate the HVAC equipment to maintain space temperature; commonly based on the average occupancy hours.
- *Economizer control:* using outdoor air when the outdoor air temperature allows for cooling of the building instead of using mechanical cooling.
- *Peak shedding:* a strategy through which peak energy demand can be reduced and this can be done through staging – where equipment activation is staggered so that instantaneous demand does not skyrocket, or by using thermal storage so peak energy load can be reduced at certain points of the day when demand is high.

A building can also purchase low-impact electricity, renewable energy certificates (RECs), or high-quality carbon offsets to displace or offset the carbon footprint and energy consumption associated with energy use in the building. For low-impact electricity or RECs, it is recommended to be purchased through a credible vendor (e.g. generator, aggregator, distributor, etc.) certified under the EcoLogo or Green-e Energy National Standard. Carbon offsets should be purchased from a high-quality carbon offset project developed to meet an approved voluntary or regulatory industry standard. Voluntary offset standards include Verra, Gold Standard, Plan Vivo, Climate Action Reserve, UK Woodland Carbon Code, UN Clean Development Mechanism, and Green-e Certified Carbon Offsets. Compliance market offset standards include European Emission Trading Scheme, British Columbia Carbon Registry, and Western Climate Initiative.

As an added sustainable building feature to help reduce water consumption, a building can install high-efficiency washroom fixtures which uses less water than standard fixtures while still performing its function. Low flow fixtures are increasingly becoming more available and range from toilets to showerheads. Low flow fixtures expel half the gallons per minute than their standard counterparts and are specifically designed to limit water waste (O'Leary Plumbing & Heating Inc., 2019). Additionally, with faucets and showerheads, with the less water used, the less amount of energy is needed to heat the water which will lower both energy and water consumption, contributing to a building becoming net-zero (O'Leary Plumbing & Heating Inc., 2019). Table 22 outlines the recommended flush and flow rates for high efficiency washroom fixtures.

Table 22: *Recommended high efficiency washroom fixtures flow rates*
Source: BOMA BEST 3.0

Fixture	Litres	Gallons
Toilet	4.8 L/flush or less	1.28 G/flush or less
Urinal	1.9 L/flush or less	0.5 G/flush or less
Faucet	5.7 L/min or less	1.5 G/min or less
Showerhead	7.6 L/min or less	2 G/min or less

As well, waterless urinals can be installed to further reduce water consumption. Waterless urinals don't use water to help dispose of waste. In 7,000 uses an old inefficient urinal could use approximately 35,000 gallons of water, a conventional urinal could use approximately 7,000 gallons of water, a highly efficient urinal could use approximately 3,500 gallons of water, but a waterless urinal may use as little as five or six gallons of water for maintenance purposes (Grainger Inc., 2021).

To further reduce water consumption, toilets and urinals can include proximity detectors to enable automatic, censored flushing systems and faucets can include automatic, hands-free mechanisms with mixing valves and proximity detectors to produce tempered water at the tap. Automatic systems create a healthier environment as there are less touch points for people to contract viruses and bacteria and have increased efficiency as they are programmed to provide the correct amount of water at the appropriate time rather than remaining on for as long as the visitor chooses.

6.0 Recommendations

Technologies

On-site Energy Production Using Solar & Geothermal Energy

The fundamental approach to a facility achieving operational net-zero emissions is striving to run it on as much sustainable energy as possible. One way to do this would be to generate energy on-site through solar panel arrays and geothermal welling. This report discussed many examples of entities around the world which have successfully supplemented large amounts of their operational energy use from on-site, non-carbon emitting energy production. In in some cases, buildings have shown to be completely powered by on-site energy generation without the need to purchase energy from local utility companies.

Battery Storage Systems for Clean Energy

One of the largest problems with sustainable energy production methods is that they are intermittent, for example solar power is not a viable solution when the sun isn't shining. Therefore, energy storage is proving to be a key technological aspect to decarbonizing modern day society. In many cases periods of solar energy production do not coincide with periods when energy is needed, resulting in significant portions of solar power waste. Energy storage systems offer many benefits such as improving energy reliability and resilience, integrating storage with low carbon generating sources, ensuring a more flexible and robust power grid that can accommodate unplanned outages, and integrating more renewable energy resources to reduce resilience on fossil fuels.

Implement Rainwater Harvesting System

An effective rainwater harvesting system can have multiple benefits to the facility, water table, and local community. First off, collecting rainwater aids the cost of water bills – to which funds can be located elsewhere in facility operations. Furthermore, harvesting rain can help with stormwater runoff, which can reduce flooding around the facility during extreme precipitation events – that are increasing rapidly. It will also ease stress on the local community as running a hockey rink uses enormous amounts of water; more clean drinking water will be available for the families of Middlesex Centre.

Construction

Installing Triple-Paned Windows

Net-zero building best practice recommends installing double- or triple-paned windows with a minimum R-value of 8. Panes with glazing with center-of-glass R-values of 8 or higher are widely available and use sophisticated low-emissivity coatings and low-conductivity argon or krypton in the gaps between tiles helps lower embodied carbon levels. Furthermore, window technology is improving quite quickly for net-zero buildings; industry-standard suggests selecting windows with a heat loss rate of U-0.25 or lower to construct a tighter building envelope. Constructing a building with multi-paned windows allows a tighter building envelope, thus increasing operational efficiency and reducing costs.

Build a Super Insulated, Thermal-Bridge-Free Envelope

Net-zero buildings must have a complete thermal boundary, including below-grade areas. Slab-on-grade, basement slab, and foundational wall insulation values ranging from R-20 to as high as R-60 based on location is best practice. Insulation, which comes in various forms such as loose fill, water-blown, and spray foam are traditionally composed of materials that have high GWP; meaning the production of these materials cause high levels of greenhouse gases to be released into the atmosphere. Using low GWP spray foam insulation during construction can drastically lower the embodied carbon emissions within buildings, and should be considered for the new Ilderton Arena project.

Maximize the Use of South Facing Windows and Install Overhangs or Shades on East and West Facing Windows

Daylighting can be used to create a pleasant, healthy space for the community rather than merely using it to conserve energy. The most accepted practice for passive solar lighting is to place 50% to 60% of window surface area facing the south. Installing a large percentage of windows toward the south will maximize heat from sunlight in the winter, while limiting the warming effect of sunlight during the summer months. South-facing windows should have a higher solar heat gain coefficient, allowing for the exclusion of heat in the summer and retention in the winter. Furthermore, on east and west facing windows, the installation of overhangs and shades can allow building operations staff to limit sunlight during warmer months. Thus, aiding the building's cooling system to maximize efficiency.

Building Operations

Implementing a Heat Recovery System

In a traditional HVAC system, the waste heat generated from the refrigeration process was released outdoors through externally facing vents. A heat recovery system takes advantage of this waste heat that is generated from compressors and dehumidifiers by capturing and storing it to be used in other parts of the building. This can take the heating load off the general building heating system and hot water tanks used for faucet, shower, and ice re-surfacer water. In the example of Woodstock Arena, waste heat is also used to melt the snow pit generated from the ice cleaning process – which can then be used throughout the building as greywater. For the Ilderton Arena, it is recommended that a heat recovery system be installed to make use of the waste heat produced during the refrigeration process. Heat recovery systems (like heat recovery wheels and CO_2 sensors) can then be used to heat the air of the building, aid in melting snow in the snow pit, or reduce energy demand by preheating water. It is also recommended to look further into underground thermal storage of waste heat so that it can be stored for future energy demands of the building.

Commissioning and Recommissioning Equipment

Periodic recommissioning is a systematic approach to facility maintenance which ensures the re-optimization of previously commissioned equipment and systems. It is a best practice for mechanical equipment, lighting, and control systems to be reviewed every three to five years to identify less than optimal performance and adjust if necessary. Failure to complete recommissioning processes can lead to drastically lower efficiency, improper fluid flows, and in the worst cases, premature retiring or decommissioning of equipment. Periodic recommissioning examines building equipment and system performance through a different lens than preventative maintenance however it is carried out to ensure the facility can operate efficiently, and as designed.

Installing a Building Automation System

A Building Automation System (BAS) is a network of automated controls which serve to automate and optimize certain functions and systems within a building. BAS's can be implemented for temperature control; automatically decrease setpoints during heating seasons and increase the setpoint during the cooling season or when space is unoccupied. They can also be used to increase ventilation cycles based on internal air quality, use outdoor air when external air temperature allows for cooling or heating, and cost optimization through peak shedding – when equipment start up is staggered so energy use does not skyrocket. Automating these processes can allow building operators to focus their time on less mundane manual tasks, ultimately increasing employee productivity and saving capital.

Use Efficient Lighting and Lighting Controls – ENERGY STAR or DLC Approved LED Lighting

The progress in LED lighting has been breathtaking. In net-zero energy homes, LEDs have been making a big dent in the niche formerly occupied by compact fluorescents, primarily due to light quality rather than straight-up energy savings. Controls that keep lighting off when spaces are unoccupied and dim lights when daylight is available are the norm. Net-zero energy buildings are being lit with 0.7 watt per square foot or even less, and actual peak lighting loads are lower still. Also, you can install occupancy sensors and photocell lighting controls to help reduce energy consumption.

Install Low Flow Washroom Appliances

Low flow washroom fixtures, which include shower heads, faucets, urinals, and toilets, expel half the volume of water per minute in comparison to their standard counterparts. Installing these fixtures in a building not only limits water waste, but also optimizes energy efficiency of a building; less energy is needed to heat hot water because its use is cut in half. Therefore, low flow washroom appliances can reduce costs in water and energy usage, while also decreasing carbon emissions if water is heated using fossil fuel combustion.

7.0 Conclusion

The Canadian Government has enacted the *Canadian Net-Zero Emissions Accountability Act* of 2021. This act outlines Canada's legislative commitment to achieve net-zero emissions by 2050. In order to reach this goal, emitters of greenhouse gases will be required to either eliminate or offset carbon emissions. The proposed idea of a net-zero hockey arena will allow the opportunity for the Municipality of Middlesex Centre to contribute to achieving Canada's net-zero targets and sustainable development goals. This will be accomplished by utilizing new building technologies and best industry practices involved in the construction and operation of net-zero buildings.

Although building to zero-energy standards costs approximately 1% to 8% more up-front than traditional buildings, net-zero buildings are highly efficient and produce as much energy, if not more than it uses. Net-zero buildings therefore cost less in terms of operational costs compared to traditional buildings (Hutchinson, 2019). Zero-carbon building standards require 100% of the operational energy use associated with the facility to be offset by on- or off-site renewable energy, and 100% of the embodied carbon emissions associated with the construction and materials of the project to be disclosed and offset (Populous, 2021). The new Ilderton Arena in Middlesex Centre will aim to be net-zero carbon ready as it will strive to include features such as solar panels, geothermal heating, rainwater harvesting, heat recovery systems, and electric vehicle charging stations.

Green Samaritan Consulting has outlined various new and emerging best practices and technologies that may be applied in the context of an arena. Similar buildings, such as the Climate Pledge Arena in Seattle, Washington and the Woodstock Union Arena in Woodstock, Vermont were studied in depth to better understand the project details regarding construction materials and facility operations. In addition, the scope of research was expanded further to include unique and cutting-edge net-zero facilities within North America and Europe. To name a few, this includes the Unisphere in Silver Spring, Maryland, USA; the Housing + residential building in Søborg, Denmark; and Powerhouse Brattørkaia in Trondheim, Norway.

From the extensive net-zero buildings research, a series of key findings for best technology, best practices, and best operations strategies were identified. The best net-zero technologies include efficient energy storage systems such as the VisBlue vanadium redox flow battery, refrigerants, heat recovery systems, rainwater harvesting systems, solar panels, and software to monitor building energy-use. The best net-zero construction practices include the incorporation of a highly insulated building envelope, triple-glazed windows, shading devices, and green roofs. The best net-zero facility operations strategies include load reduction, passive strategies such as maximizing daylight and natural ventilation, efficient systems such as optimally sized HVAC systems, and energy recovery using heat exchangers and air re-circulators.

A series of recommendations were presented which includes items such as renewable energy production and storage, construction materials, and building operations for the new Ilderton Net-Zero Arena in Middlesex Centre. The overall recommendations are summarized in Table 23.

Table 23: *Summary of recommendations*

Technologies	• On-site energy production using solar and geothermal energy • Battery storage systems for clean energy • Implement rainwater harvesting system
Construction	• Installing double- or triple-paned windows • Build a super insulated, thermal-bridge-free envelope • Maximize the use of south facing windows and install overhangs or shades on east and west facing windows
Building Operations	• Implementing a heat recovery system • Commissioning and recommissioning equipment • Installing a building automation system • Use efficient lighting and lighting controls – ENERGY STAR or DLC approved LED lighting • Install low flow washroom appliances

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