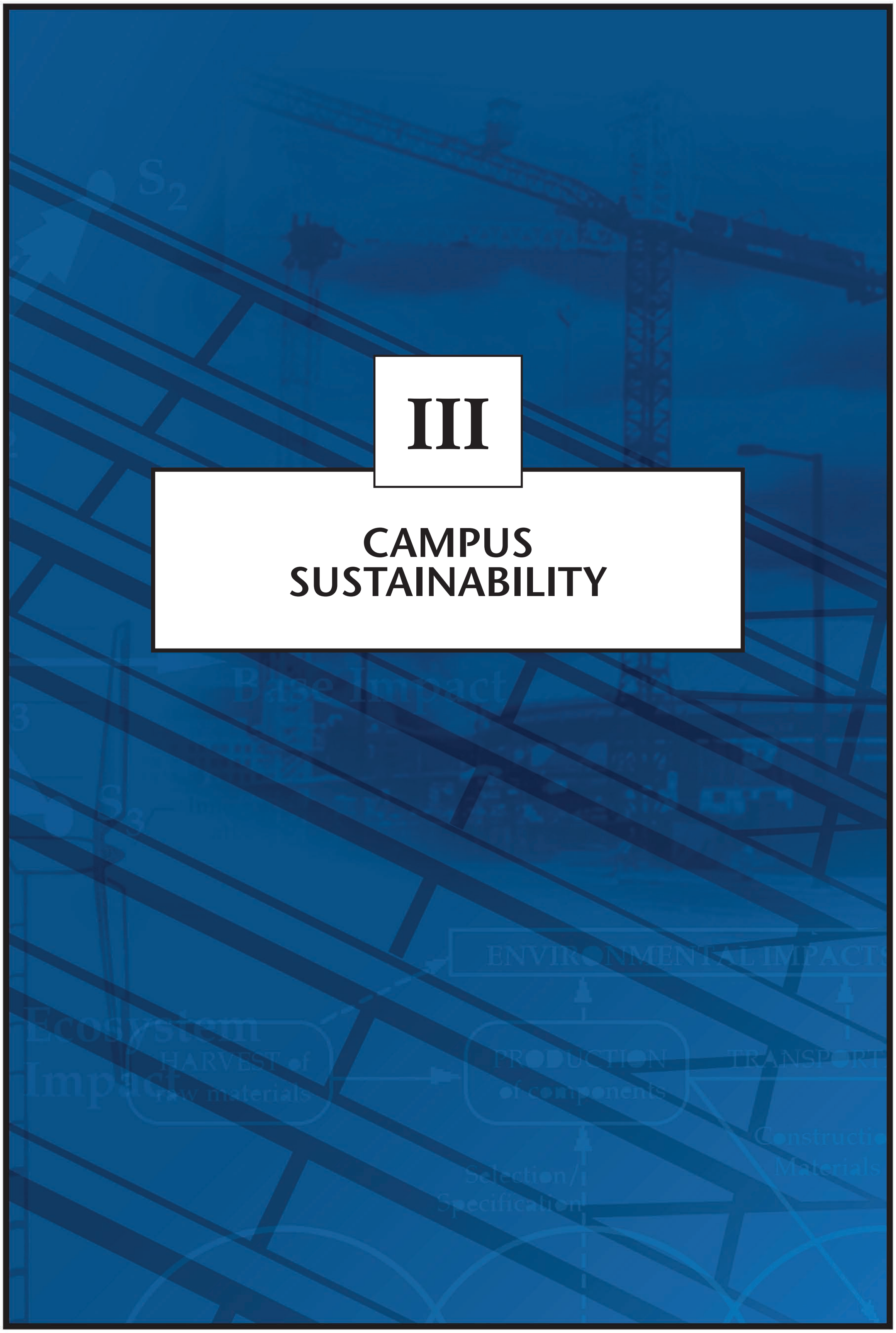


III

CAMPUS SUSTAINABILITY

MOHAWK COLLEGE'S NET ZERO ENERGY AND ZERO CARBON BUILDING—A LIVING LAB FOR HIGH EFFICIENCY AND RENEWABLE ENERGY TECHNOLOGIES IN BUILDINGS

Rutul Bhavsar[1], Anthony Cupido[2], Mariano Arriaga[3]

INTRODUCTION

In recent years, large high efficiency and Net-Zero Energy Buildings (NZEB) are becoming a reality that are setting construction and energy benchmarks for the industry. As part of this significant effort, in 2018, Mohawk College opened the 8,981 m^2 (96,670 ft^2) Joyce Centre for Partnership and Innovation (JCPI) building in Hamilton, Ontario; becoming Canada's largest NZEB and zero-carbon institutional facility. The building integrated a high-efficiency design, construction materials, and technologies; as well as renewable energy technologies to significantly reduce its annual energy consumption and greenhouse gas emissions. Furthermore, the JCPI building was also designed as a living lab where students, faculty, researchers and industry are able to monitor and validate the performance of this state-of-the-art facility. The building was designed to have an energy use intensity of 73 kWh/m^2·year (0.26 GJ/m^2·year); hence, potentially consuming approximately 80% less energy than the average educational service building in Ontario. This paper gives an overview of the design criteria and technologies that were considered to achieve this innovative building.

KEYWORDS

energy efficiency, energy use intensity, greenhouse gas emissions, net zero energy building, renewable energy, zero carbon building.

1 ENERGY & GREENHOUSE GAS EMISSIONS IN BUILDINGS

1.1 Energy & Environmental Impacts

Global energy demand will continue to increase in the foreseeable future. The International Energy Agency estimates that with the increasing demand from emerging economies, the global energy demand will increase by 30% by 2040 if no steps are taken to mitigate the current trend;

1. Student, Energy and Power Innovation Centre, Mohawk College, Hamilton Ontario, Canada, rutul-bhadreshkumar.bhavsar@mohawkcollege.ca

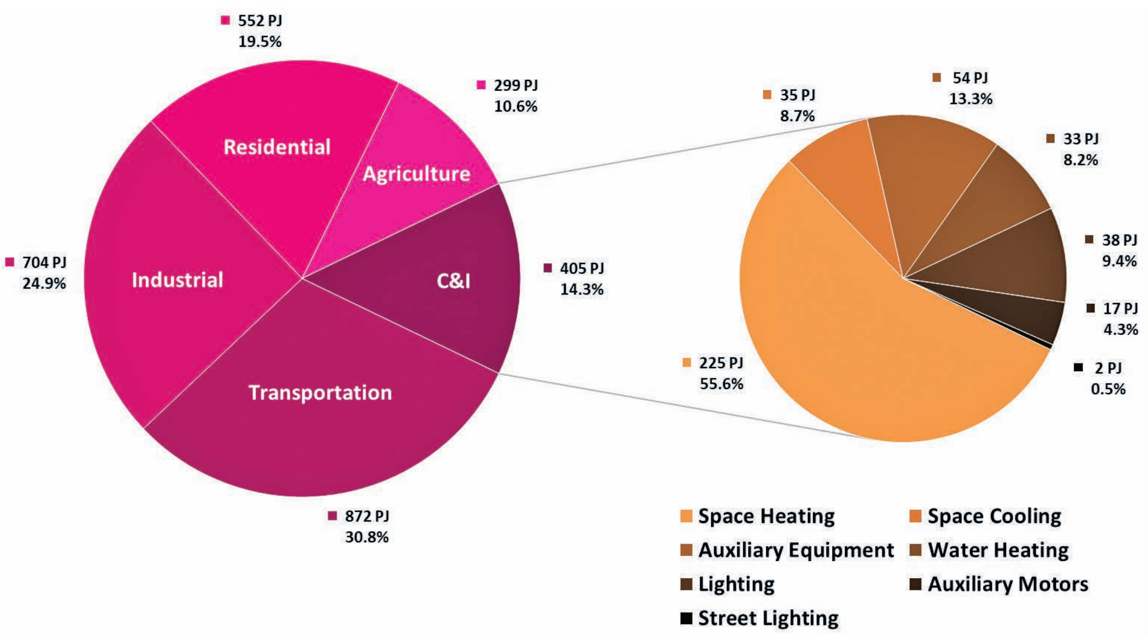
2. Sustainability Research Chair, Mohawk College, Hamilton Ontario, Canada, tony.cupido@mohawkcollege.ca

3. General Manager & corresponding author, Energy and Power Innovation Centre, Mohawk College, Hamilton Ontario, Canada, mariano.arriaga@mohawkcollege.ca

however, the contribution and rationale for this trend varies among countries (International Energy Agency, 2016). For example, Canada's primary energy production increased by 5.4% from 2015 to 2016 (total: 19,709 petajoules), with a 2.6% increase in energy exports (12,507 petajoules); while the country's energy demand decreased by 2.5% (7,953 petajoules) (Statistics Canada, 2019). Partially, the reason behind the national energy demands is due to energy efficiency measures implemented nationwide over several years; including programs and/or standards to reduce energy consumption of equipment and buildings (Natural Resources Canada, 2019).

In Canada, buildings typically require a significant amount of energy due to substantial heating and cooling loads over the year; hence, they represent a considerable portion of the country's energy demand. In 2016, buildings represented 30.8% of the total secondary energy use in the country (2,455 petajoules). Residential and Commercial & Institutional (C&I) buildings accounted for 18.3% and 12.5% (1,458 petajoules and 997 petajoules), respectively. In the case of the province of Ontario, the total energy consumption for buildings accounted for 956 petajoules, representing 36.8% of the total provincial energy demand in the same year. The energy demand contribution of the residential and C&I building sector was 21.2% and 15.6%, respectively (National Resources Canada, 2015). Figure 1 (a) shows the total energy demand in the province of Ontario broken down by sector; where it can be easily seen that approximately one third of the energy demand is due to buildings. Additionally, Figure 1 (b) expands on the energy end-use for the C&I buildings; highlighting that space heating represents the single highest end-use, accounting for approximately 55% of the total use. As further discussed in this paper, this split will be significantly reshaped when considering recent and upcoming high-energy efficient buildings.

FIGURE 1. (a) Annual energy consumption in Ontario by sector, (b) End-use breakdown for C&I buildings (Natural Resources Canada, 2019).



(a) (b)

1.1.1 Environmental Impacts

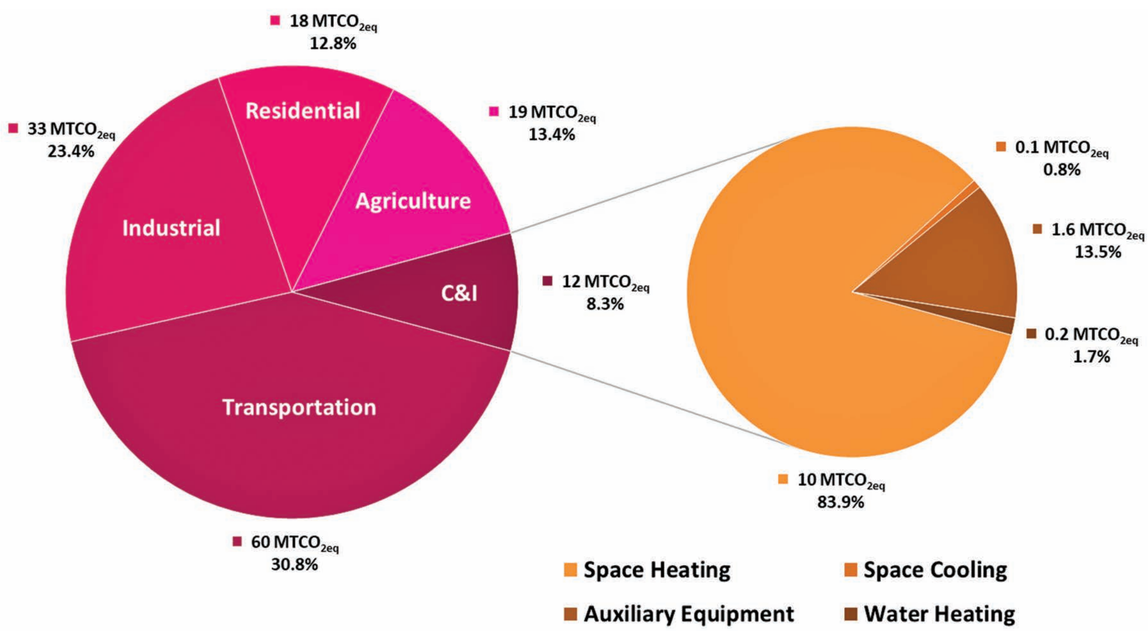
Over the last decades, energy generation has been increasingly linked to its associated environmental impacts and global warming effects (European Environment Agency, 2017). Between 1986 and 2016, the average global temperature has increased by approximately 0.7°C and there is a growing global concern about reducing the human activity associated with such increase (USGCRP, 2017). Currently, 78% of the global Greenhouse Gas (GHG) emissions are due to primary energy production, which in the case of Canada, represents 81% of the total associated GHG emissions (Natural Resource Canada, 2018). Furthermore, GHG emissions in Canada have increased by 20.8% in the period from 1990 to 2016 (Natural Resource Canada, 2018).

Canada's total GHG emissions in 2016 were estimated at 704 megatons of carbon dioxide equivalent (Mt CO_2eq); with the province of Alberta and Ontario having the largest GHG contribution; 37% and 23%, respectively (Government of Canada, 2018). In the case of Ontario, the residential and C&I sector account for 21.1% of the GHG emissions. Figure 2 (a) shows the total GHG emissions for the province of Ontario broken down by sector; where the residential and C&I sector account for approximately one fifth of the total emissions. In addition, Figure 2 (b) expands on the GHG emissions associated with the end-use for the C&I buildings. Similarly, as with the energy breakdown, space heating is the single highest end-use cause of GHG emissions, accounting for nearly 84%.

1.1.2 GHG Emissions and Energy Consumption Reduction Trends

Global concerns about climate change and associated GHG emissions have resulted in countries setting up national level emission reduction targets, such as the Kyoto protocol and the Paris agreement (United Nations Climate Change, n.d.). Under the latter, Canada has committed to reduce GHG emissions by 30% below 2005 levels by 2030. Efforts to achieve such a target

FIGURE 2. (a) Annual GHG emissions in Ontario by sector, (b) End-use breakdown for C&I buildings (Natural Resources Canada, 2019).



(a) (b)

require specific activities in multiple areas and sectors, such as green infrastructure, clean energy technologies, energy efficiency and fuel switching. In the case of the building sector, GHG reduction targets have permeated into the development of energy efficiency measures enforced by building codes and rating systems (United Nations Climate Change, 2016).

In Canada, previous and on-going efforts to reduce GHG emissions have resulted in a 3.1% reduction while still having an economic growth of 12.9% from 2005 to 2013 (United Nations Climate Change, 2016). This is a direct result of a sector-by-sector regulatory approach particularly in the electricity and transportation sector (United Nations Climate Change, 2016). For example, Ontario phased-out coal-fired electricity generation and set more stringent GHG emissions standards for automobiles, light trucks, and heavy-duty vehicles in the last decade (United Nations Climate Change, 2016). As a result, mainly due to the coal phased-out, GHG emissions in the province dropped by 22% in 2016 when compared to 2005 levels (Environment and Climate Change Canada, 2018). Additionally, Ontario has taken further steps to reduce and/or adapt to the effects of climate change. Since 2014, the provincial government has invested approximately $4 billion to finance projects that promote green infrastructure in areas such as clean transportation, energy efficiency and conservation, and clean energy technologies (Ontario Financing Authority, 2019; Ontario Financing Authority, 2019).

1.2 Energy & Carbon Footprint for Buildings in Canada

As previously mentioned, residential and C&I buildings represent a considerable 33.8% share of the total secondary end-use energy in Canada. This percentage is likely to be maintained or even increased since on average buildings have increased their floor space and hence their energy demand has also risen, despite the significant efforts in energy conservation and efficiency. In the period from 1990 to 2015, the total floor space has increased by 65.2% to reach 1,996 million m^2 and by 46.6% to reach 747.5 million m^2 for the residential and C&I building sector, respectively (Natural Resources Canada, 2018). Correspondingly, the energy demand for the building sector has increased by a total of 43.8% from 1990 to 2015; which represents an 8.8% and 35.0% energy increase for the residential and C&I sector, respectively (Natural Resources Canada, 2018).

Despite the overall energy demand increase for the building sector, the associated GHG emissions have been reduced by a slight 1% (from 113.8 to 112.6 Mt CO_2eq) from 1990 and 2015 (Natural Resources Canada, 2018). This is the result of a GHG emission cancelling effect between the emission reduction in the residential and an increase in the C&I sector. Specifically, the GHG emissions in the residential sector decreased by 8.0% (from 72.8 Mt CO_2eq to 66.8 Mt CO_2eq), while GHG emissions in the C&I sector increased by 11.7% (from 41.0 Mt CO_2eq to 45.8 Mt CO_2eq) (Natural Resources Canada, 2018).

1.2.1 Energy Use Intensity

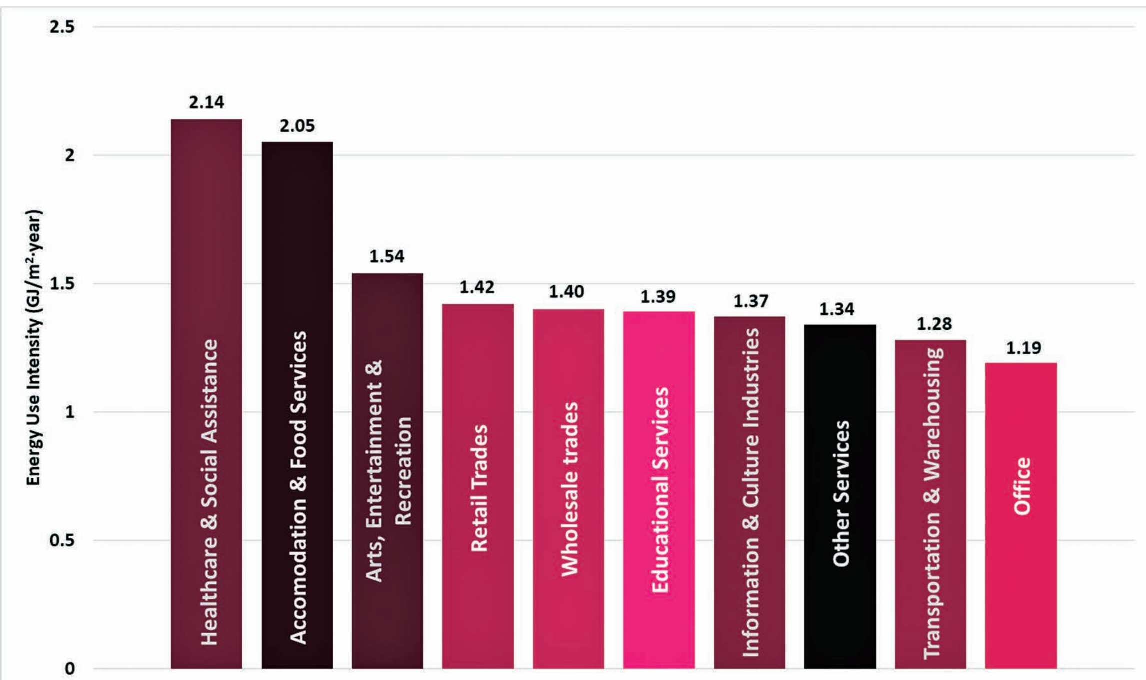
The relationship between a building footprint and its energy consumption is essential to benchmark its energy consumption with other buildings. The Energy Use Intensity (EUI) metric, usually expressed in kWh/ m^2·year units, is the energy consumption to building area ratio widely used to compare building energy performance regardless of their different energy sources or footprint (Energy Star, 2017). Evidently, EUI building benchmarking considers classifications to account for factors such as building use, construction year, and geographical location. Figure 3 shows the EUI benchmarks for the Ontario region for buildings with different end-uses and built between 1990 and 2016 (Natural Resources Canada, 2018). Note that healthcare and social assistance, as well as the accommodation and food services, have the highest EUI presented due to amount of people and level of services they require. In contrast, there is a certain level of uniformity among the remaining categories which potentially indicates that the type of service offered is not as relevant as the energy required for the building operation itself. High energy efficient buildings can drastically decrease this base EUI value as it is further discussed in this paper in Section 5.

1.3 Mohawk College's Sustainability Goals

Mohawk College is committed to positively impact the people, the environment and the economy, while enhancing knowledge of sustainability and developing sustainability habits in the workplace and the community. From an environmental perspective, the College has a 30% GHG emission reduction target by 2020 from the 2007 level (13,722 tCO_2eq) by implementing energy conservation, efficiency and fuel-switching initiatives (Mohawk College, 2014). The types of initiatives range from building improvements and monitoring, reduction of single-occupant vehicle use, increase of on-site Renewable Energy (RE) generation and switch to low-emission energy sources for its heating requirements (Mohawk College, 2014). Some of these initiatives are still being implemented; yet the College is still on track to meet its 2020 GHG emission reduction target. By 2017, the College already reached a 25% GHG emission reduction (10,303 tCO_2eq) (Wilhelm, Haviland, & Robitaille, 2018).

To further reduce its carbon footprint, showcase environmental & sustainability leadership while increasing its educational services, Mohawk College opened a Net-Zero Energy Building (NZEB) in September 2018. The Joyce Centre for Partnership & Innovation (JCPI) building is an 8,981 m^2 space, making it the largest institutional NZEB in Canada (Canada Green

FIGURE 3. 2016 EUI benchmark by building/service type in Ontario (Natural Resources Canada, 2018).



Building Council, 2018). Since the early building design stage, several energy efficiencies and RE sources were considered to demonstrate the College's commitment towards GHG emission reduction and sustainability.

The rest of this report provides details of the design considerations and technologies used for the JCPI building construction. Section 2 gives a brief review of Zero-Carbon and NZEBs concepts, different design criteria for sustainable buildings and some of the related certifications available to validate their energy efficiency at the design and operational level. Section 3 describes the general sustainability design and specific energy targets for the JCPI building. Section 4 provides sustainability target details including the living lab concept, water conservation and embodied carbon. Section 5 presents the energy-related efficiency and generation considerations for the building; including the design EUI breakdown, passive energy considerations and the RE technologies used for electricity, heating and cooling services. Finally, Section 6 describes the forthcoming activities and opportunities that Mohawk College will engage in to validate the energy performance of the building, as well as creating projects involving industry partners, research staff, faculty and students.

2. SUSTAINABLE BUILDING CONCEPTS AND TECHNOLOGIES

High-efficiency and NZEB have gone from small proof-of-concept projects to large endeavors that not only make environmental but also economic sense (New Building Institute, 2018). In 2018, the educational building sector in the USA & Canada, reported a growth of 37% in zero energy buildings (New Building Institute, 2018). More recently, the concept of Net-Zero Carbon Buildings (NZCB) has also started gain momentum to acknowledge the total life-cycle carbon footprint of buildings. Advances in material sciences and energy generation technologies, as well as sustainability awareness, have played a critical role in such development. Certifications have been established to acknowledge the effort and commitment in building design and operation.

2.1 Net-Zero Energy and Carbon Building Definitions

There is no unanimous consensus for the definition of a NZEB; however, a commonly used one is "a building with greatly reduced energy needs through efficiency gains such that the balance of energy needs can be supplied with renewable technologies" (Torcellini, Pless, Deru, & Crawley, 2006). Thus, this definition is subject to different interpretations on how to achieve a NZEB status. For example, is the net-zero status based on, RE generation (on- or off-site), energy cost recovery and/or GHG emission-free energy generation to cover at least the building's annual energy consumption? Some buildings can comply with all the above but depending on the specific building design and constraints, it might only be able to fulfill some of these above concepts. Regardless of the type of energy and/or environmental savings expected, there is a growing trend of net-zero homes and C&I buildings in Canada. In 2012, the New Building Institute (NBI) reported 60 commercial and multi-family buildings or projects verified, or working towards, zero energy status. By 2018, NBI reported 67 zero energy verified projects and 415 in progress (New Building Institute, 2018). For example, by 2016 there were already 23 net-zero homes in three different provinces as well as larger NZEB such as the Evolv1 project in Waterloo, Ontario; the Cure-Paquin Elementary school in Saint-Eustache, Quebec; and recently, the JCPI building described in this paper (The Cora Group, 2018; Natural Resources Canada, 2019; Canada Green Building Council, 2018).

The Canada Green Building Council (CaGBC) has been promoting a Net Zero-Carbon Building (NZCB) designation to emphasize the need to further reduce carbon emissions associated not only with the building operation but also with its construction phase (Canada Green Building Council, 2017). This concept acknowledges that, during the construction phase, there are embodied carbon emissions due to the manufacturing, transportation and installation process of building materials. This initiative aims to create awareness and potentially set an embodied carbon benchmark for buildings.

2.2 Building Sustainability Considerations

The overarching goal of a NZEB or NZCB is to create a substantial sustainability awareness level in the organization and community where buildings are located. Thus, such buildings have not only high energy-efficiency performance goals but also sustainability ones; such as minimizing the use of non-renewable resources, reducing solid & liquid waste, improving recycling strategies, as well as improving user comfort levels in terms of air quality, temperature control, lighting, acoustic/noise, and visual aspects. Hence, a high-performance building needs to consider design, construction and operation aspects that can ensure that the building sustainability goals are also met (ASHRAE, 2010). The following is a list of design, modeling, and technological aspects that can help achieve such sustainability goals:

2.2.1 Designing and Modeling Aspects

- **Envelope performance and thermal mass transfer:** It is critical for a NZEB to identify the main heat gains and losses through analyzing the thermal performance of the building envelope. Like the building energy budget, it is necessary to choose a specific R-value target for different locations in the building to minimize overall heat loss. The R-value can be defined as the capacity of an insulating material to decrease conductive heat losses. For example, solar radiation is, in most cases, a critical factor to use or mitigate depending on the building location, orientation and weather conditions. In cold climates, high solar heat gains will reduce energy consumption associated with heating in colder months; while this gain will be counterproductive in hotter months. In addition, the layout, orientation, and envelope materials play a significant role in estimating the heating gains and losses. One example of a high-performance building envelope is the Evolv1 project (The Cora Group, 2018).
- **Energy use intensity breakdown:** Setting an EUI goal and breaking this down by end-use is an essential aspect to achieve a high energy performance building. The concept of this exercise is combining the target EUI for such type of buildings (Figure 3) and itemize it by end-use such as heating, cooling, auxiliary equipment, lighting, etc. (Figure 1). This process is mostly based on historical information and experience; as more hard-data and more statically valid information is available, this process will significantly help to match design and operation values.
- **Lighting systems:** Lighting represents on average 10% of the total energy consumption in a building; hence the importance of implementing energy efficient lighting (e.g., LED lighting) but most important are the relationships between lighting and savings associated with daylight and occupancy levels. Automated lighting controls that take into consideration such factors can significantly reduce energy consumption due to lighting (Lutkemeyer, et al., 2010).

- **Energy efficient equipment:** Due to programs such as ENERGY STAR®, the energy efficiency of Heating, Ventilation, and Air Conditioning (HVAC)-related equipment has increased significantly. However, high performance buildings aim to also take advantage of "free" energy sources such as air- and ground-heat pumps as well as heat recovery systems (Lutkemeyer, et al., 2010).

2.2.2 Technology Aspects

- **Solar PV systems:** Solar Photovoltaic (PV) systems are typically a low-Operation and Maintenance (O&M) cost solution to fully or partially generate energy onsite. A technical and economic feasibility assessment is required to quantify the benefits; however, some jurisdictions have policies that encourage these installations such as an energy innovation program & net-metering program (Natural Resource Canada, 2019; Government of Ontario, 2019). In addition, a consideration for large buildings is the available roof footprint for solar panel installation. In most cases, the actual roof footprint of the building is not likely enough to generate the annual energy required.
- **Ground source heat pumps:** A Ground Source Heat Pump (GSHP) extracts the absorbed heat in the upper layer of the earth which can be used for space heating and cooling. In summer, the heat energy gained by the building envelope is rejected into the ground using heat pumps, where it is stored for use in winter (National Renewable Energy Laboratory, 1998). Unlike a typical heating/cooling system which uses electricity or natural gas to generate all the heating and/or cooling required for the building, GHSP takes advantage of the temperature below ground surface to decrease the thermal energy generation requirements. The thermal energy from the ground is distributed throughout the building by using conventional circulating pump thus reducing energy consumption and emissions as they only require electricity for its operation. The most cost-effective applications for GSHP are typically larger buildings such as, office buildings, institutional buildings or retail shopping malls, where the GSHP units are able to provide heating as well as cooling services (Natural Resources Canada, 2002). GSHPs capital costs vary depending on the site characteristics; however, they can be up to twice the cost of conventional systems (Natural Resource Canada, 2017). Yet, the typical energy efficiency for such systems is equivalent to 500%, since only one part of energy is required to move five parts of heat from ground (Fredin, 2009). For example, two elementary schools in Lincoln, Nebraska, installed with geothermal heat pump systems, reported total energy cost savings of 57% with reduction in electrical demand of about 42% (National Renewable Energy Laboratory, 1998). As an additional example, a warehouse GSHP demonstration project in Kalispell, Montana, resulted in 66% energy savings (Liu, Malhotra, Walburger, & Habibzadeh, 2014)
- **Solar thermal systems:** Solar thermal energy systems also known as active solar heating systems are now a mature modular technology that can complement a heating and cooling building system (United States Department of Energy, 2017). Like solar PV, the capital costs are high; yet O&M costs can be negligible depending on the facility size. Solar thermal systems are an intermittent resource that in most cases requires certain thermal storage capacity, as well as appropriate control systems to optimize the total HVAC system in the building.

- **Variable refrigerant flow systems:** A Variable Refrigerant Flow (VRF) system can regulate and operate a building HVAC system according to the space load conditions or where zoning is required. VRF systems can effectively provide occupant comfort and installation, while saving in electricity cost (Carrier Corporation, 2013). A VRF system can consist of several indoor evaporators connected to an outdoor or indoor condensing unit, interconnected using a refrigerant piping system and controlled using thermostats (Carrier Corporation, 2013).

  In general, VRF has two types of multi-split systems heat pump and heat recovery systems. The heat pump system can only provide either heating or cooling because the outdoor unit controls and considers all the indoor units as one, so if the mode on any indoor unit is changed, it goes to standby until the mode on the outdoor unit is changed (Casey, 2012). In contrast, a heat recovery system can provide heating and cooling by transferring the thermal energy among different zones. VRF systems are easily modifiable and best fit C&I buildings with multiple small indoor units where air transfer between rooms is feasible. However, VRF systems are not recommended for locations where outdoor ventilation is a priority.
- **Rain water harvesting:** Rain Water Harvesting (RWH) is a simple and mature technology that has been used for thousands of years (ASHRAE, 2010).The water harvested can be used for irrigation, cooling, and toilet flushing; thus, reducing the demand and cost of water coming from the municipal supply. The system consists of a catchment area, related piping and in most cases, a water storage and treatment system. In general, RWH systems are simple but require significant O&M costs for regular tank cleaning and equipment servicing for backflow prevention, as well as regular water quality tests (ASHRAE, 2010).

2.3 Examples of Net-Zero Energy and Carbon Certifications

Several organizations have created certifications for high performance buildings to acknowledge and promote best practices, as well as create a relevant building benchmark. The following is a sample list of the most widely used related certifications:

- **ENERGY STAR® certification for buildings:** The ENERGY STAR program has been become a recognized and widely adopted certification for energy efficient products. Furthermore, ENERGY STAR now also includes certification for not only buildings but also industrial facilities. In the case of buildings, there is a 0–100 scale for certification with a minimum eligibility requirement of 75 points and requires an annual record submission (Energy Star, n.d.). The program tracks energy performance of about 40% more building area than LEED-certified in US commercial buildings. Currently, the certification focuses on energy performance and does not include associated carbon footprint (Yudelson, 2016).
- **LEED® Certification:** The Leadership in Energy and Environmental Design (LEED) certification is an internationally recognized program that sets standards for the design, construction, and maintenance of environmentally sustainable buildings and infrastructure. LEED has a tier-based rating system based on building performance. The rating system is accepted across over 160 countries and has more than 5,000+ LEED certified and registered projects in Canada (Canada Green Building Council, 2019). In

addition to energy efficiency parameters, LEED also considers environmental aspects such as improvements in indoor air quality and reductions associated with environmental impacts. Yet, LEED is not a net-zero certification; hence, there is no requirement to have on-site RE generation, although it is encouraged.

- **BREEAM Certification:** The Building Research Establishment Environmental Assessment Method (BREEAM) is one of the largest globally recognized sustainability assessment methods that classifies buildings based on their performance under multiple sustainability schemes. The BREEAM assessment is an arduous process requiring third-party assessment and further validation from the Building Research Establishment (BRE) centre (BREEAM, 2018). The BREEAM certification is widely used in Europe and has been applied in buildings in the United States; however, this certification does not have a current presence in Canada.
- **World Green Building Council:** To date, the World Green Building Council (WGBC) has certified 2.65 billion m^2 as green building spaces around the world and is forecasting additional growth in coming years (World Green Building Council, 2018). In 2017, the CaGBC, member of the WGBC, launched the zero-carbon building standard to consider carbon emissions as a key indicator for building performance. An NZCB is an energy efficient building which generates or procures most of its energy from carbon-free RE to balance its annual carbon emissions associated with operations of the building (Canada Green Building Council, 2017). CaGBC is currently running a pilot program including 15 of Canada's most sustainable building projects, with four identified as zero carbon design certified buildings and, as it is discussed in detail here, the JCPI building being one of them (Canada Green Building Council, 2019).

3. SETTING NET ZERO-ENERGY AND CARBON CONCEPTS FOR JCPI

A key factor to build and operate at net zero energy and/or zero carbon building is to set sustainability concepts and both technical & organizational targets at the design stage (Brostrom & Howell, 2008). In the case of the JCPI building, these concepts included sustainability and educational components, as well as specific energy efficiency and generation that aimed to achieve a high-performance building. The following is a list of the major concepts taken into consideration as part of the design and construction phase:

- **Sustainability and education concepts:**
  - **Living lab and educational component:** Mohawk College aims to enhance student learning experiences by continuously providing further hands-on and experiential learning opportunities; thus, extending learning opportunities outside the typical classroom and lab environment. The JCPI building was designed with the experiential learning concept in mind by providing safe supervised access for students to the mechanical and electrical rooms, as well the RE generation systems. The learning targets will be expanded to data access, curriculum development, and potential re-creation of the building performance for students to operate under real-life scenarios.
  - **Water conservation and recovery:** Water conversation and recovery awareness is also a key aspect of the JCPI design. Due to the end-use of the building, there is no significant use of water as it mostly consists of labs and some classes in the building. Most of the areas used in this five-storey building are on the two bottom floors

which consists of theater and common area; however, the building can showcase and demonstrate related technologies that students, partners and the general public can implement outside Mohawk College.

- **Embodied carbon:** Embodied carbon is defined as "the emissions associated with the production, transportation, assembly, use and eventual decommissioning of materials used in a building's construction (Canada Green Building Council, 2017). The initial building design did not include such a concept; however, as part of a net-zero energy building goal, there is an implicit/explicit effort to reduce or eliminate carbon emissions in its operation. The embodied carbon metric elevated this target to consider the carbon emissions associated with building construction; i.e. material manufacturing, delivery and installation. This effort is being piloted as part of the CaGBC program described in the previous section.

- **Energy efficiency and generation concepts:**
  - **On-site Renewable Energy Generation Target:** Producing all the energy required for the building's energy demand on-site was the main target for making JCPI a net-zero building—inclusive of the energy required for all electrical loads, space heating and cooling. It was a challenge to generate all the energy required for the building within the building footprint and site constraints due to the amount of energy required to supply the whole building.
  - **Energy Efficiency and Conservation Target:** The fundamental building energy target was to achieve a NZEB, which requires a high efficiency building design as a prerequisite. Thus, a low energy consumption building requires less RE generation, and in principle, it results in a more cost-effective alternative. However, a high energy efficient building still has to ensure a comfortable environment for the occupants.

4. SUSTAINABILITY AND EDUCATION CONCEPTS

The JCPI design expresses the mutually interdependent sustainability and education goals, while drawing occupants into an interconnected social space with classrooms, meeting rooms, informal learning spaces, lounge areas and a cafe. Furthermore, the design embraces the technical challenges of NZEB performance while considering sound aesthetics that enhance campus life (Figure 4).

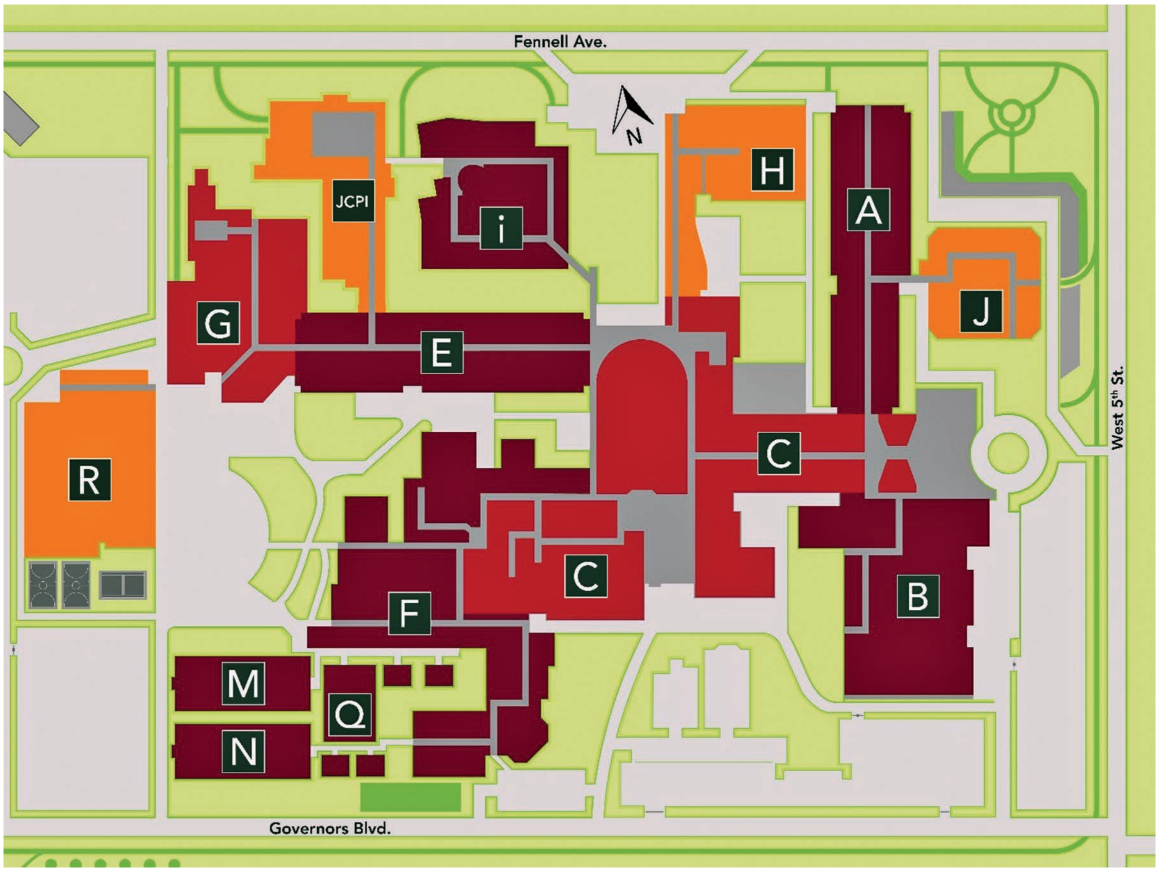
The JCPI building design had the additional challenge of integrating the building to the current Fennell campus. The five storeys design was required to fit between two pre-existing buildings (G- and I-Wing) while directly connecting to all four levels of the E-Wing building (Figure 5); all mechanical, electrical rooms, and access to the solar PV are located on the top floor of the JCPI building. From an architectural perspective, the tight in-fill site for the facility meant that the form of the JCPI building needed to integrate to other adjacent buildings. The transparent, light-filled atrium, as well as the "L" shape design, avoids occluding adjacent buildings.

4.1 Living Lab and Educational Components

The JCPI building is a living learning lab and a demonstration site to showcase the possibilities around NZEBs. In addition to the existing classrooms, students will be provided supervised access to the mechanical, electrical rooms and safely access the rooftop where the solar PV panels are installed. It will be an on-going process to engage faculty, staff and students on

FIGURE 4. The Joyce Centre for Partnership and Innovation building at Mohawk College.

FIGURE 5. JCPI building campus location.



developing related projects, as well as updating curriculum for related courses taking advantage of the project's results, facilities and equipment access. In addition, further experiential learning opportunities will be provided to students through the ability to simulate the operation of the facility and they can be graded on their performance, for example.

4.2 Water Conservation and Recovery

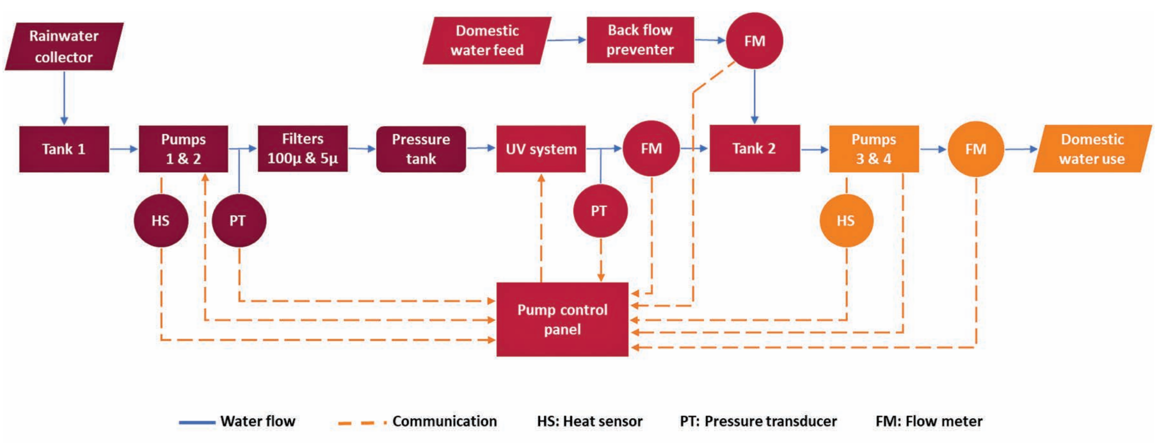
Water conservation and recovery was one of the key sustainability objectives for the JCPI building design. An RWH system was designed to reduce the use of service water from the municipal system for the building, which included additional such as low-flush urinals and toilets and low flow faucets. Typically, Mohawk College does not irrigate its lawns; however, the green areas around the JCPI building will likely require irrigation to establish growth and plantings as required under municipal site-plan control for the first years of operation.

The schematic for the RWH system is shown in Figure 6. The 228,000 litres cistern (Tank 1) is designed to store approximately one month of the typical non-potable water use. The rainwater is primarily harvested from the building roofs, with a minor RWH supplement from perimeter foundation tiles. The cistern water is then filtered, disinfected via ultraviolet treatment and subsequently stored in a 1,100- litre hydro-pneumatic tank (Tank 2) to facilitate distribution into the building end-uses. Provincial guidelines require that the RWH system be installed with back flow preventers to avoid the collected water from reaching the municipal water pipes. Even though the RWH design aims to cover the building non-potable demand, the municipal water line is the backup for the system. Finally, the full RWH system is integrated to the Building Automation System (BAS); hence, detailed information about water and related-energy consumption will be available for building operators, research staff and students to improve the building performance and potentially propose related projects.

4.3 Embodied Carbon

There is a growing awareness for the NZCB standard to address embodied carbon and other GHG emissions associated with building materials (Canada Green Building Council, 2017). Emissions associated with the manufacturing, transport, and installation of building components currently represent a relatively low proportion of an average building's total carbon

FIGURE 6. JCPI building rainwater harvesting system.



footprint, but for a low-energy building, such emissions grow in importance since the operational GHG footprint is reduced.

A cradle-to-grave Life Cycle Assessment (LCA) of the JCPI project was conducted utilizing the Athena Impact Estimator for Buildings to estimate the embodied as well as the operational GHG emission footprint (Athena Sustainable Materials Institute, 2018). The LCA considered a 60 year building service life and included the multiple stages of the construction phase such as resource extraction, product manufacturing and transportation, building construction, product maintenance and replacement, and building demolition/deconstruction/ disposal. In the case of embodied carbon, the results of the LCA showed that steel and concrete contributed with the largest proportion of GHG emissions. The embodied carbon impact was reduced by using steel with highly recyclable contents and the concrete was mixed with more than normal Supplementary Cementing Material (SCM), such as slag. Overall, the LCA shows that the JCPI embodied carbon in the building structure is about 4,330 tCO_2eq which is significantly higher than the expected net-operational GHG emission footprint, refer to Section 5.2 (Athena Sustainable Materials Institute, 2018). Other buildings have been using similar approaches to reduce their embodied carbon footprint. The YMCA community center in Toronto used a concrete mix of Portland-limestone cement with a high amount of SCM and the performance of the concrete remained fairly unaffected while the embodied carbon impact was reduced by 10% (Mantle, 2017). A similar GHG reduction is anticipated for the JCPI building and will be verified.

5. ENERGY-RELATED STRATEGIES

Energy-related strategies for the JCPI building can be broadly divided in three areas: (1) estimating energy consumption, (2) considering energy efficiency measures, and (3) calculating required on-site energy generation. There was an iterative nature to the planning process starting from considering an energy budget and how the different energy efficient and renewable energy technologies will impact the final NZEB goal. In this section, some of the main energy-related considerations are discussed, including the estimated energy consumption and patterns, building envelope technologies, daylight and lighting considerations, as well as the considered renewable energy technologies.

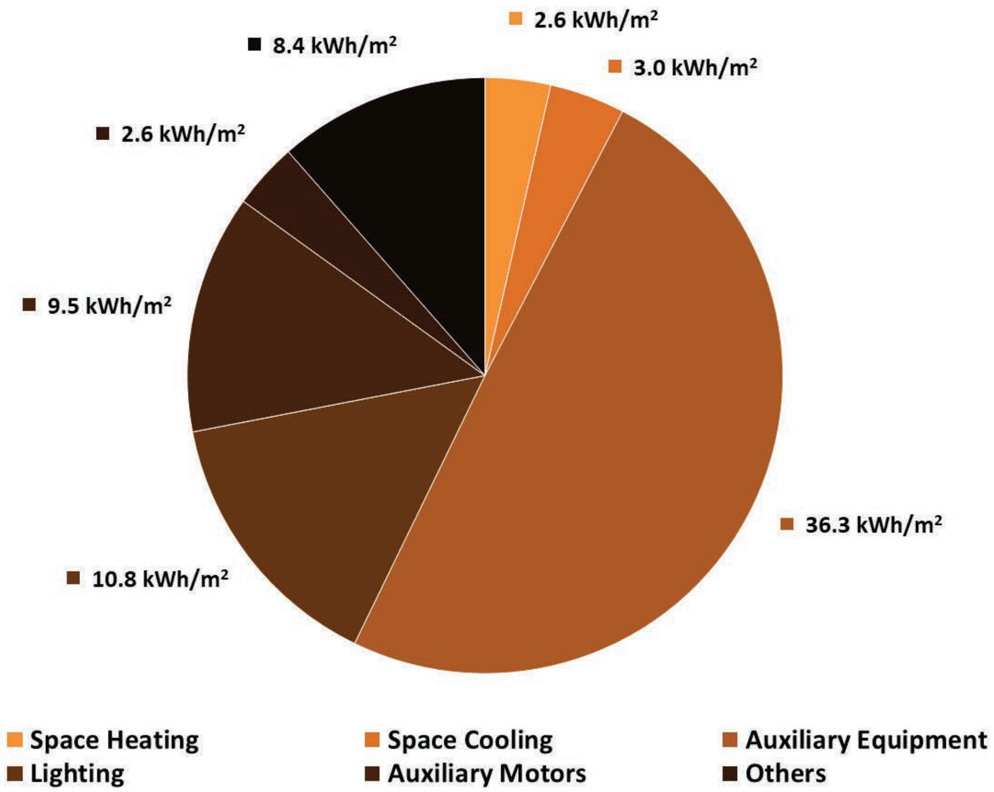
5.1 JCPI Energy Conservation and Efficiency Considerations

5.1.1 Energy Building Performance

With regards to the JCPI's energy performance, a critical aspect to achieve a NZEB was to establish an appropriate energy budget at the preliminary design stage. The energy budget considers the energy consumption of the building based on the building end-use, its mechanical & electrical systems and energy requirements of the auxiliary equipment and ancillary services. In the case of the JCPI building the end-use of the rooms are primarily classroom space, teaching laboratories, and collaborative learning spaces.

The energy budget for the building was calculated based on defining the EUI breakdown of the different energy consumption activities/equipment. The use of EUI for calculations makes the process easy to scale the energy requirement regardless of the final building construction area. Furthermore, the EUI calculation is/can be used as a benchmark to compare the JCPI building design to other related buildings, as further described in this section.

FIGURE 7. JCPI building estimated annual EUI breakdown.



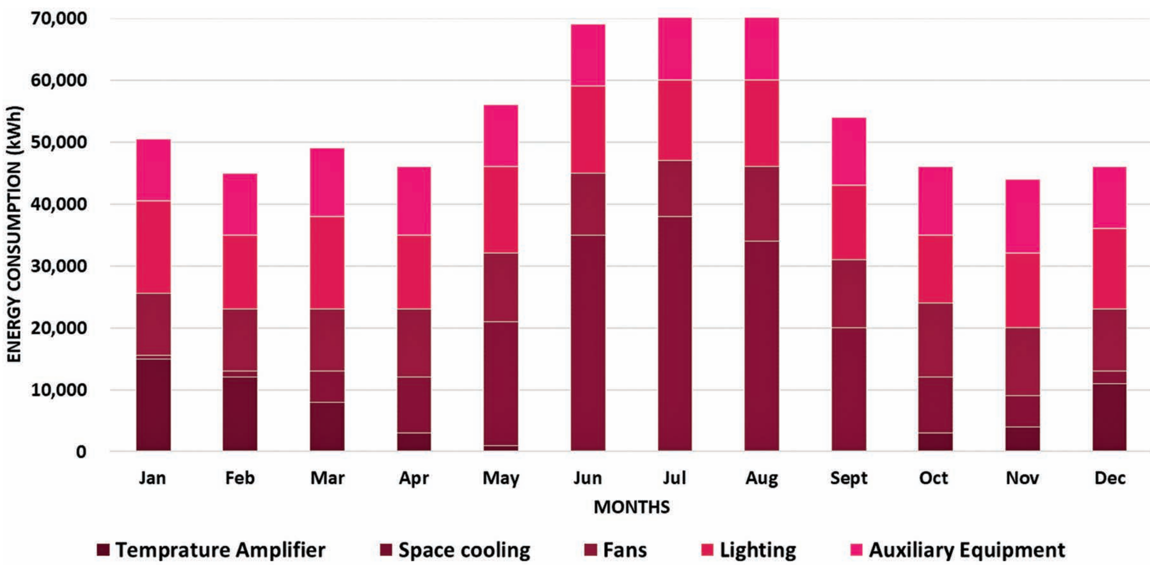
The design EUI target for the JCPI building was estimated to be 73 ekWh/ m^2·year (0.26 GJ/m^2·year)[4], considering the total end-use in the building and the fact that the selected geothermal system significantly reduced the heating/cooling energy requirement. Figure 7 shows the breakdown of the building design EUI estimates. The EUI target was estimated considering interior and exterior lighting, ventilation, auxiliary equipment, occupancy levels, solar energy received and conduction heat gains and losses. It is expected that auxiliary equipment (i.e. plug-loads) represent approximately 50% of the building consumption (Mohawk College; McCallum Sather; B+H Architects, 2017). Given the varied end-use of the building, there is uncertainty around how additional plug loads will affect the building's energy consumption. For example, a technology lab requiring specialized equipment with high energy consumption can potentially have a major impact on the NZEB performance. The remaining 50% of the EUI budget encompasses lighting, pumps, fans, space cooling, the VRF and Domestic Hot Water (DHW) systems. As further explained in this section, the EUI inventory was calculated considering a geothermal system for heating and cooling. Thus, considering that the total gross area of the JCPI building is 8,981 m^2, the estimated annual energy demand was modeled to be 655,613 kWh per year.

The EUI budget was calculated based on previous construction experience and calculations including monthly energy requirements as well as estimating the overall heating and gains and

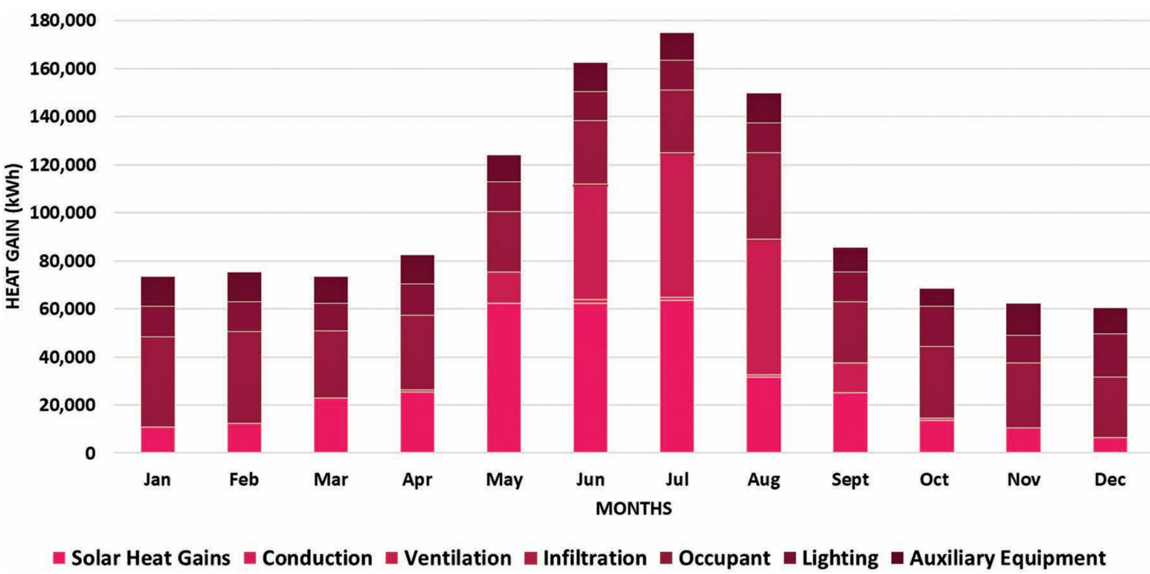
4. 73 ekWh/m^2·year refers to equivalent kWh. The rest of the document refers to this unit just as kWh.

losses in the building through the year. Figure 8 (a) shows the JCPI building monthly consumption estimates to give a better understanding of the energy consumption breakdown. The winter consumption variation is mostly due to the use of the VRF units, part of the geothermal system, as temperature changes through the season. For the summer months, the relatively high energy increase is due to using the VRF system plus the energy required by the central air conditioning system, to meet the cooling requirements of the building. In addition, Figure 8 (b) and (c) show heat gain and losses respectively that are taken into account to determine the monthly energy

FIGURE 8. JCPI building monthly energy estimates (a) consumption (b) heating gains and (c) heating losses (Mohawk College; mcCallum Sather; B+H Architects, 2017).

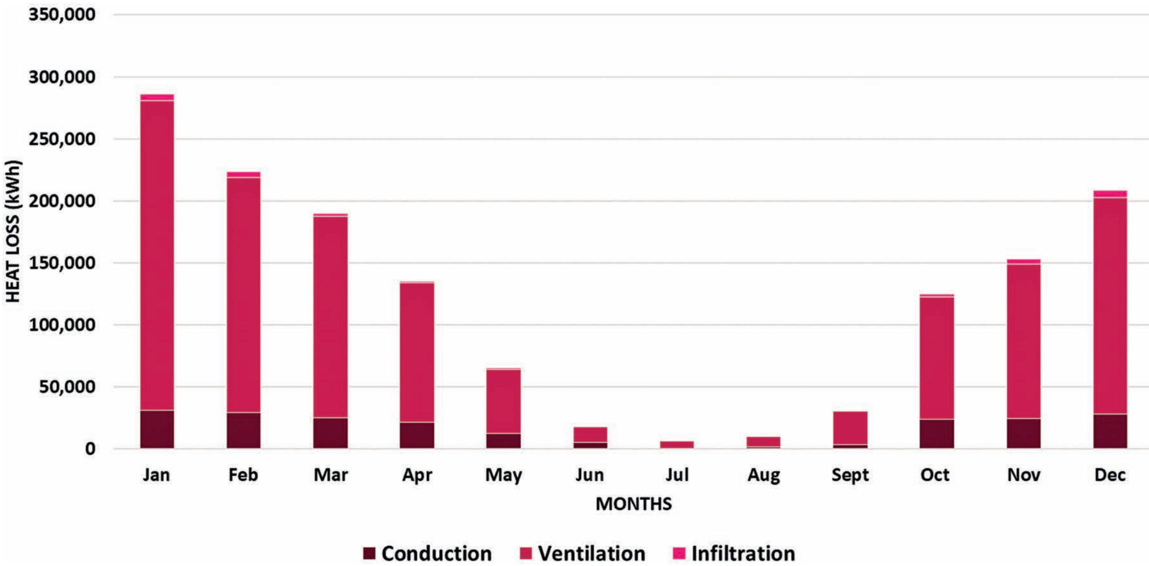


(a) Estimated monthly energy consumption



(b) Estimated monthly heat gains

FIGURE 8. *(Continued)*



(c) Estimated monthly heat losses

consumption for the building. Note that heating losses due to ventilation are considerable as the building uses outdoor air to maintain the air quality in the building.

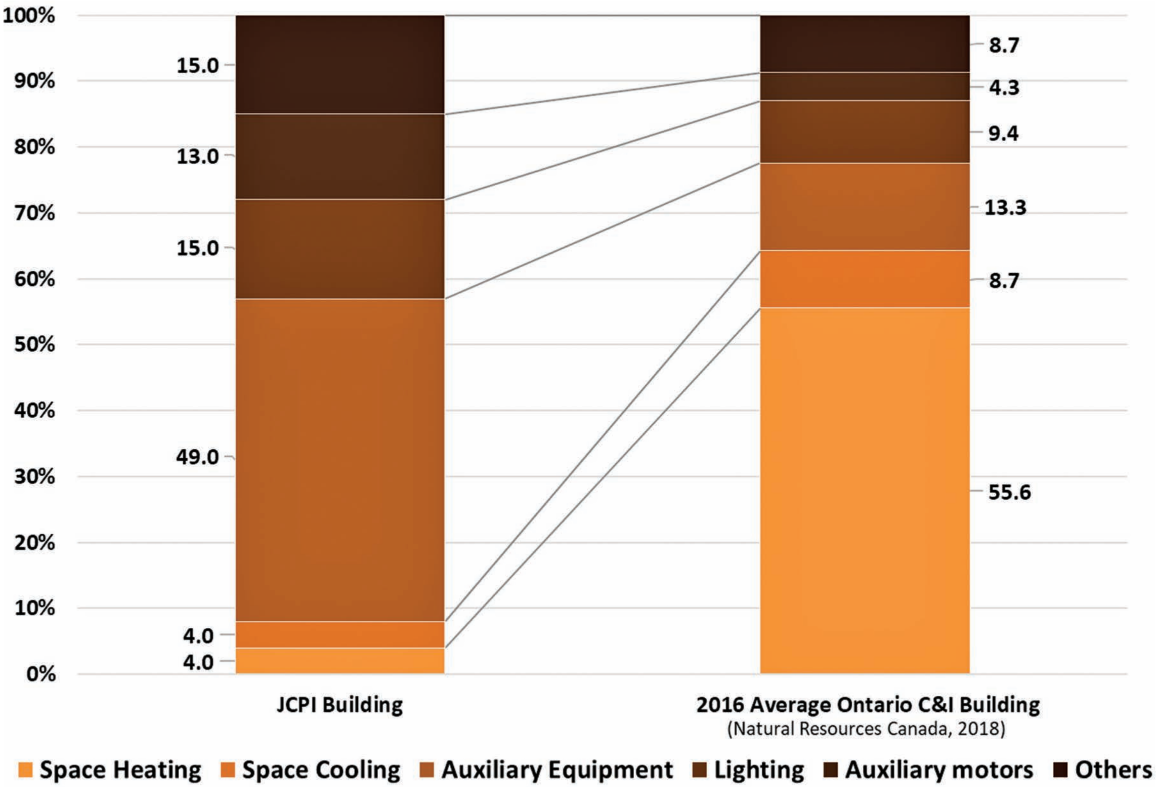
5.1.2 Energy End-Use Comparison

An interesting aspect of average and high-energy efficiency buildings is the breakdown proportion of the energy end-use. Average buildings with conventional technologies require a considerable amount of energy to heat the building, while a tight building envelope would require significantly less energy for the same task. Figure 9 shows the energy end-use breakdown for (a) the JCPI building and (b) an average C&I based on the national energy use database (Natural Resources Canada, 2018). For an average C&I building, 56% of the energy demand is used for space heating followed by auxiliary equipment and lighting. In contrast, the high end-use at JCPI building is auxiliary equipment (e.g. plug loads) with 49%, while space heating represents only 4% of the design consideration. This low space heating energy requirement is due to the VRF system part of the GSHP solution; in summer, the heat gained by the building is dissipated into the ground and the inverse process is done during the winter months. VRF systems combined with GSHP units can decrease energy consumption by 32–40% (Karr, 2011).

5.1.3 Energy Use Intensity Comparison

As previously described, the JCPI building has a design EUI target of 73 kWh/ m^2·year (0.26 GJ/m^2·year), which makes it a noticeably high energy efficient building. As summarized in Section 1.2.1, there are EUI benchmarks for different types of building depending on their end use (National Resources Canada, 2015). Figure 10 shows the relevant building types benchmark for educational services and office buildings and compares them to the design EUI target. Approximately, the JCPI building is expected to consume only 20% of the energy required for an average educational or office building in the region. Hence, the combination of energy

FIGURE 9. Energy End-Use percentage (a) JCPI building estimate (b) 2016 Average C&I building in Ontario.



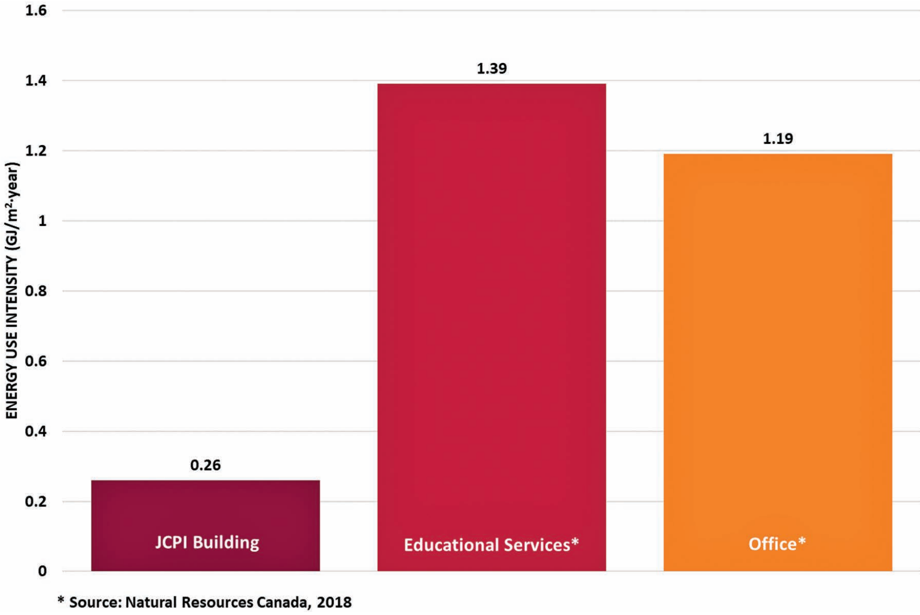
efficiency technologies and the use of RE resources can significantly reduce the operational energy and cost of buildings.

5.1.4 Specific energy models

The target EUI set for the JCPI building required the use of energy efficient technologies related to a high-performance building enclosure, as well as daylighting management and efficient artificial lighting design. However, an upcoming challenge of such buildings is the energy demand of auxiliary equipment or plug loads that can represent approximately half of the building energy consumption. In any new design or mixed-used building, such as the JCPI, there is a certain level of uncertainty on the actual energy demand requirement of such loads. The following is a brief description of the JCPI building considerations with respect to these considerations:

Building Envelope Performance: Walls are a major component of the building envelope and it is expected that they provide acoustic and thermal comfort without compromising the building aesthetic. To achieve thermal comfort as well as low energy consumption, the thermal resistance of the building envelope requires high R-values and becomes increasingly important as the ratio between wall and total envelope area increases (e.g., high-rises) (Sadineni, Madala, & Boehm, 2011). In the case of the JCPI building, a comprehensive approach to wall and window design was taken which considers an effective average R-10 value, including roofs, walls and windows.

FIGURE 10. EUI comparison among JCPI building and related 2016 Ontario C&I building sub-sectors benchmark.



The JCPI building roofs were designed to have an R-40 thermal resistance which is higher than the respective provincial requirement of R-29 set in the Ontario Building Code (OBC) (Ministry of Municipal Affairs, 2016). The roof assembly comprises a 2-ply Styrene-Butadiene-Styrene (SBS) modified bitumen membrane, a polyisocyanurate insulation board, a vapour barrier mounted on a sloped structure and a local tapered insulation board.

The walls were designed to have an effective R-30 value which is also above the OBC minimum requirement of R-26 (Ministry of Municipal Affairs, 2016). The wall assembly consists of two major components, a rainscreen laminated glass system (R-10) and an insulated opaque assembly (R-20). The rainscreen system not only improves the aesthetics of a building but also protects the building from water infiltration into the structure (Said, 2015). The insulated opaque assembly has three layers. The exterior layer is an air and vapour barrier sheath. The middle layer is the structural frame of the building with compressed polystyrene insulation boards and the cavity is filled with spray foam. Finally, the internal layer consists of a wall board (Mohawk College; McCallum Sather; B+H Architects, 2017).

The selected window system consists of two layers, the rainscreen described above and a triple pane glass, which is expected to have an R-6.6 value. Windows represent 35% of the total vertical walls of the JCPI building which aims to balance between the occupant's comfort level and the energy requirements throughout the year; for example, ensuring minimum operation time of the HVAC systems while effectively controlling the overall solar gains and reducing cooling loads.

Daylight & lighting system: The JCPI building design estimated that lighting will be approximately 15% of the annual energy consumption which is the 2^{nd} largest end-use throughout the building. The 15% design was accomplished by considering natural lighting as a major source of lighting and an input to the artificial lighting considerations. Natural light studies were performed to assess the shadowing effect of the building orientation and design throughout the year. Figure 11 shows an example of the shadow analysis performed for the JCPI building at the early stages of design to determine the amount of lighting that each section of the building and solar PV canopy will receive. Furthermore, this shadow analysis was used to estimate the level of artificial lighting required on each of the building sections.

A foot-candle analysis relating natural and artificial light throughout the different seasons of the year was also performed. Figure 12 shows an example of this analysis for a specific time and day (June 21st at 9:00am) which helped determine the appropriate level of artificial lightening in different rooms by considering the lowest and highest natural lighting levels and relating them to the required foot-candle standards for the building activities. The indoor lighting systems were designed to utilize natural lighting as the primary source of illumination and to reduce the requirement of artificial lighting. Furthermore, the lighting system is controlled to allow for daylight-, time- and occupancy-based settings, as well as manual lighting control. The lighting equipment used throughout the building is ENERGY STAR© certified and follows the Illuminating Engineering Society recommendations for an educational facility. Additionally, the outdoor lighting is controlled by daylight sensors and time-based settings.

Occupancy Levels and Auxiliary Equipment: The number of users and types of activities performed in the JCPI building will have a significant impact on the total energy demand. As an educational institution, the number of users will vary based on the academic cycle and scheduled classes. As an example, Figure 13 shows the expected occupancy level for a typical weekday throughout the academic fall and winter terms. The building is expected to hold classes and applied research activities during the day, as well as some undergraduate and continuing education classes in the evening. This occupancy curve was used as a baseline to estimate the hourly energy load of the building (e.g., lighting, auxiliary equipment, HVAC).

FIGURE 11. Preliminary JCPI building shadow analysis.

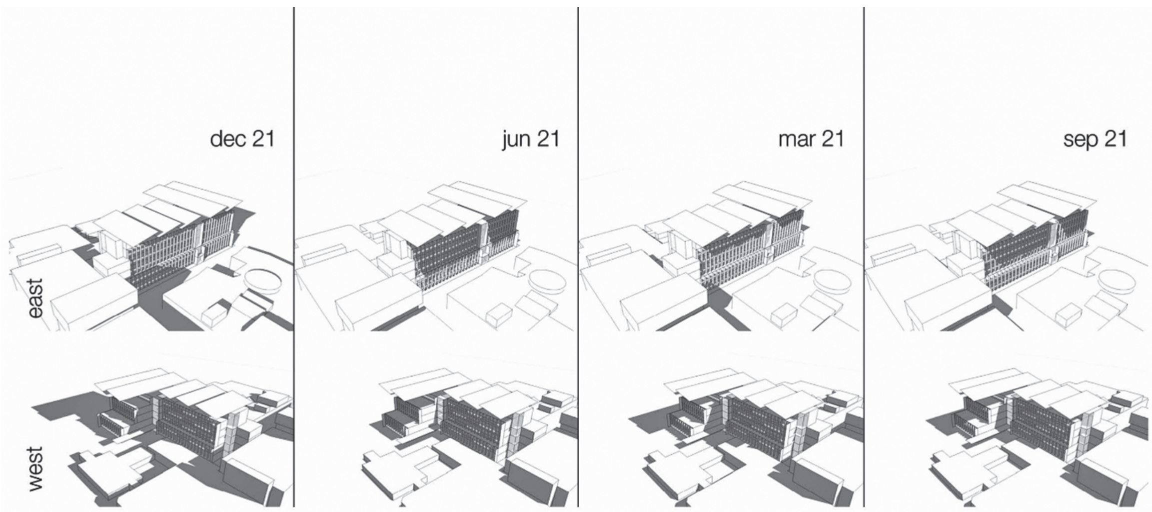
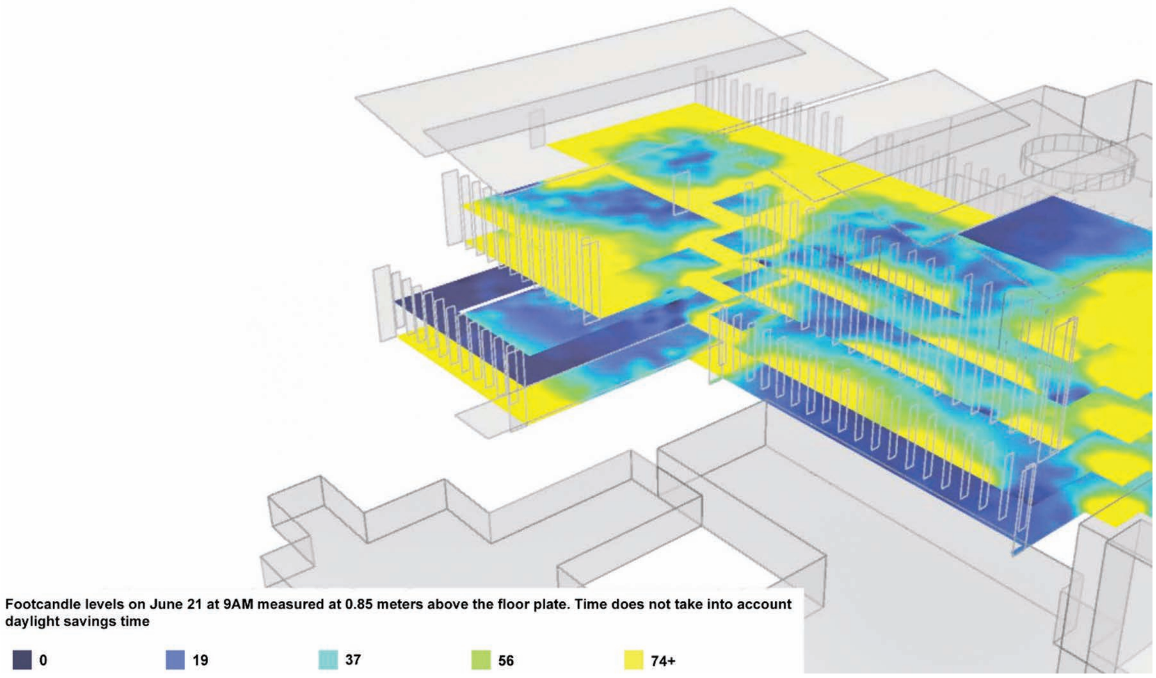


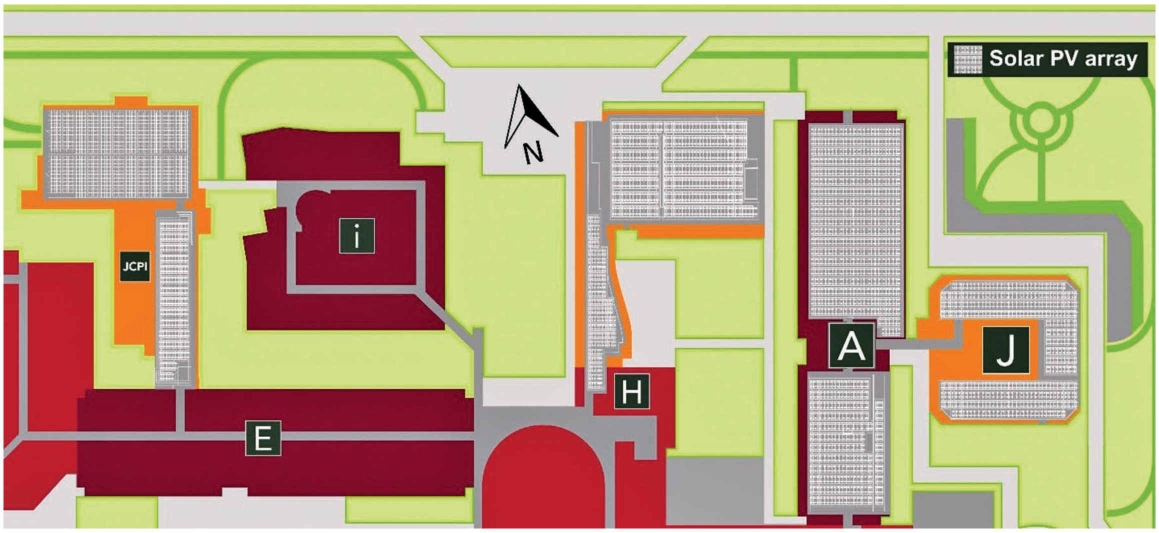
FIGURE 12. Preliminary JCPI building foot-candle analysis.



The building's energy consumption is expected to be highly dependent on auxiliary equipment, such as process and receptacle loads. These loads are driven by the type of users (e.g., students, faculty, and staff) and the equipment required for their activities, including regular loads such as computing devices, but also larger equipment installed at the laboratories. However, understanding the actual impact of user-dependent loads on the overall building energy performance will be an on-going challenge. Over the next few years, the level of occupancy and the types of activities will vary and understanding the relationship will help assure the balance of energy demand versus generation.

FIGURE 13. JCPI building estimated weekday hourly occupancy profile.

FIGURE 14. Solar PV arrays used for JCPI net-zero energy goal located on different building rooftops throughout Mohawk College campus.



5.2 On-site Renewable Energy Generation

As discussed in Section 5.1.1, the estimated annual energy demand for the JCPI building is 655,613 kWh; hence, as part of the NZEB target set for this building, it is required to generate at least this amount with on-site RE technologies. This energy demand includes all building end-uses such as electrical and thermal loads. Due to the building location and space availability, the RE technologies selected were a solar PV system for electricity generation, a geothermal system for heating and cooling, and a solar thermal system for DHW use.

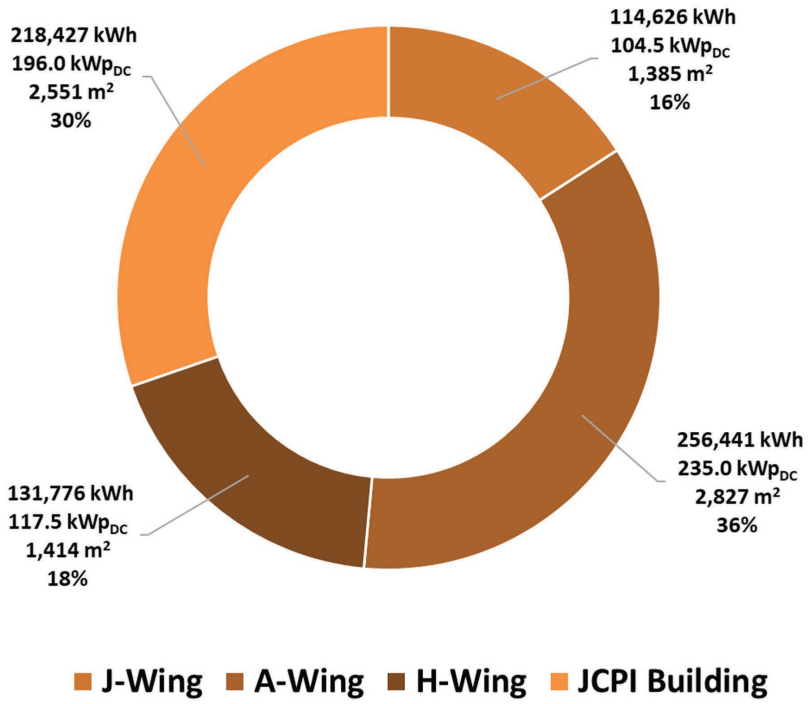
5.2.1 Solar Photovoltaic Systems

The on-site electrical supply for the building is through solar PV panels installed on the JCPI building roof and on adjacent buildings which are interconnected to the campus grid. The objective of the solar PV system is to offset, or potentially surpass, the annual energy consumption of the JCPI building to achieve a net zero energy status. The solar PV system was sized to generate approximately 10% more energy than the estimated JCPI building annual energy consumption as well as complying with the provincial regulation regarding net metering connection limit set at 500 kW (Government of Ontario, 2017).Thus, the installed solar PV capacity is 499.6 kW_p AC which is estimated to provide 721,269 kWh annually.[5] Furthermore, the total installed solar PV array capacity is higher than the AC capacity, 653.4 kW_p DC, which is a typical design practice to account for system losses, reduced solar panel performance due to environmental factors and economic factors (U.S. Energy Information Administration, 2018).

The space required for the complete solar PV system is approximately 8,177 m^2; however, the total roof area at the JCPI building is approximately 2,550 m^2. Hence, only approximately 30% of the solar PV system was installed on the JCPI rooftop and the remaining solar PV arrays were installed on adjacent Mohawk College buildings (Figure 14). In addition, Figure 15

5. The solar PV energy calculation considered 10% losses and a 16.5% capacity factor which refers to "the ratio of the net electricity generated, for the time considered, to the energy that could have been generated at continuous full-power operation during the same period" (United States Nuclear Regulatory Commission, 2019).

FIGURE 15. Solar PV system estimated annual energy generation, installed capacity and area.



shows the estimated annual energy generation, the DC solar PV installed capacity, the roof area required for installation and the percentage of the installed capacity for each of the buildings used (e.g., JCPI building and H-, A-, J-wing).

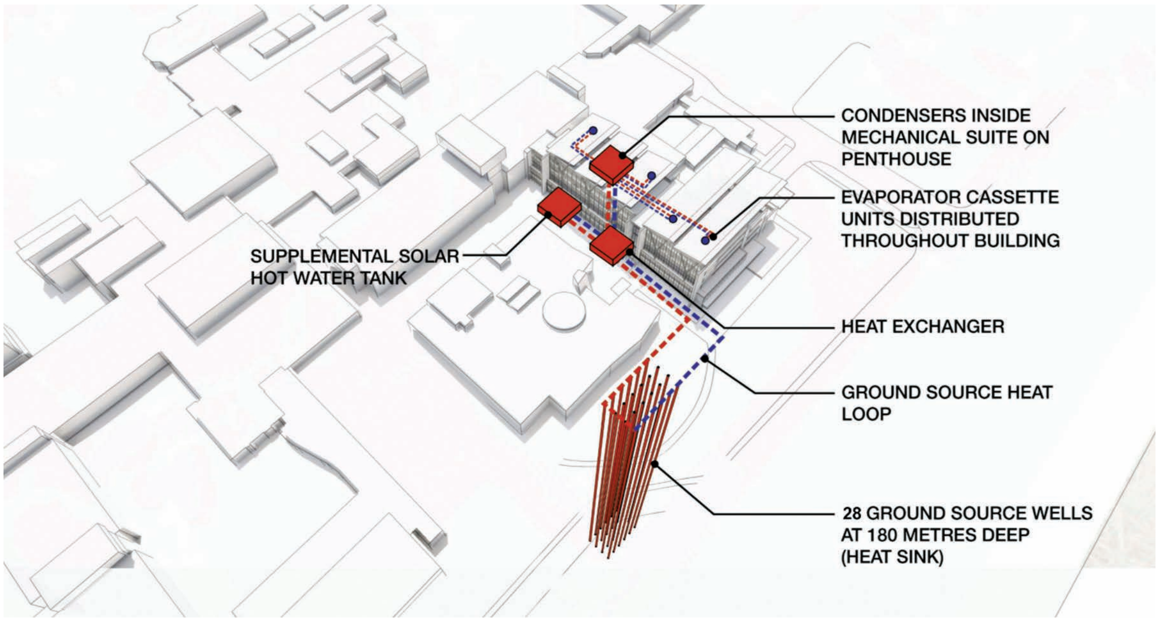
5.2.2 Geothermal System

As described in Section 2.2.2, GSHP are significantly more energy efficient than conventional HVAC systems since they take advantage of the ground as a natural thermal source and sink. In the case of the JCPI building, the GSHP was designed to supply the energy demand for the heating and cooling requirements for the whole year, considering that:

- A GSHP will reduce on-site energy consumption and eliminate the need to use fossil fuel for heating purposes in the building.
- Ability to set and control temperature set-point of individual rooms and transfer heat among them to reduce heating and cooling demand.
- The system will first aim to reach individual room set-points using existing thermal energy in the building. If the set-points cannot be reached, then the GSHP will supply the remaining energy balance from the ground.

The geothermal system for the JCPI building consists of a set of heat pumps coupled to 28 geo-exchange wells, each 180 meters deep (Figure 16). The wells are approximately spaced 4 meters apart and the well field covers approximately a 1,000 m^2 area. On an annual basis, the well field will be able to use the ground as a heat sink during the summer months and as a heat source during the winter months, since underground temperatures are more stable than atmosphere temperatures.

FIGURE 16. JCPI building preliminary design-phase geothermal system.



The GSHP was designed to provide the heating requirements for the full year. However, the building was designed with a backup system to cope with peak thermal heating requirements. As a heating backup, there is an electrical temperature amplifier (templifier) system that can provide a temperature boost if the set-points cannot be achieved by only the geothermal system. To avoid oversizing the system, the templifier was sized to boost the temperature for only the building vestibules. The templifier also serves as a backup for DHW consumption in the building.

5.2.3 Solar Thermal System

The JCPI building design includes a solar thermal system to offset the DHW energy cost of the building. The system consists of five flat plate solar thermal collector panels with two 450 litre tanks; one serving as a pre-heating system connected to the solar thermal system and a secondary tank which supplies the DHW for the building. The solar thermal systems operate when there is a temperature difference of at least 10°C between the pre-heat tank and the solar collector temperature. Furthermore, when the pre-heating tank reaches a specified set-point, a recirculating pump turns on to equalize the temperature between the pre-heating and the secondary tank.

It is expected that most of the DHW load is supplied by the solar thermal system, which will be validated in the coming years. Yet, similar to the geothermal system, the solar thermal system requires a backup alternative to supply DHW to the building. The templifier system supports DHW demand when the solar thermal system cannot meet the temperature set-points required for the secondary tank. Since the system was designed with a solar pre-heating tank, the secondary tank will already be at a higher temperature than the main water supply; thus, the templifier only needs to supply the temperature difference with the predetermined DHW supply set-point.

6. FORTHCOMING ACTIVITIES AND OPPORTUNITIES

The JCPI building represents a distinct opportunity to advance and enhance concepts and knowledge around NZEB and NZCB technologies at regional, provincial and potentially a national level. Thus, Mohawk College is currently engaged in the following activities:

- **CaGBC performance certification:** Mohawk College is currently recording and analysing the information collected from its renewable energy technologies in order to obtain CaGBC performance certification.
- **Renewable energy technologies performance analysis and validation:** In collaboration with industry, facilities and students, the Energy and Power Innovation Centre at Mohawk College has begun to analyze the different technologies installed in the building to provide feedback on their performance and potentially identifying current challenges.
- **Analysis of occupancy vs. energy consumption:** In collaboration with collaboration with industry, Mohawk College is currently undergoing a study to analyze in detail the relationship between energy consumption and occupancy in specific areas of the building.

In the near future, Mohawk College expects to further collaborate with industry, such as construction, contracting, and architectural firms, to provide feedback and lessons learned that can be used in the design of future high efficiency and/or NZEBs. In addition, the building information and analysis will be used to develop case studies in collaboration with facilities, researchers, faculty and students. This case study will help as experiential learning opportunities for students, as well as support curriculum development activities.

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