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PERFORMANCE ASSESSMENT OF THE HARMLESS HOME

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Abstract: Construction is a significant contributor to environmental problems and climate change across various issues, such as resource consumption, energy demand, and waste generation. Research into sustainable building materials and their performance is required to minimize construction's environmental impact. The Harmless Home project aims to reduce this environmental harm through a holistic, sustainable approach with materials, water, electric, and septic systems, including solar panels to generate energy, water capture systems, and a new sustainable block material called Just BioFiber (JBF). This study analyzed subjective and objective measurements of four critical Key Performance Indicators: Energy and Emissions, Water, Indoor Environmental Quality, and Cost. The project was evaluated using Post-Occupancy Evaluation (POE) approaches. The International Initiative for a Sustainable Built Environment (iiSBE) protocol was followed to investigate and analyze the results.

1 INTRODUCTION

Construction has been accused of provoking environmental problems from an unnecessary consumption of global supplies in construction and building service to the pollution of the surrounding environment. The building sector accounted for almost 1/4 of the total energy consumption and Green House Gas (GHG) emissions in Canada in 2018 (NRCan, 2020). Further, energy used in buildings for heating, cooling, and lighting comprises up to 40% of the carbon emissions of developed countries (Pérez-Lombard, Ortiz, & Pout, 2008). Buildings are a sector with immense potential and relatively low cost for carbon reductions (IPCC, 2007).

The construction sector has the prospects to attenuate climate change due to its tremendous contribution to carbon dioxide (CO_2) emission worldwide (UNEP, 2020). Moreover, governments worldwide are inquiring about improvement and transparency in building performance assessment to guarantee that buildings make significantly less GHG emissions to the environment. In Canada, several sustainable agendas and policies were inspired by reducing GHG emissions while creating a better occupants' experience, such as the Energy Step Code in British Columbia and the Build Smart strategy at a federal level. (Ministry of Energy, Mines and Low Carbon Innovation, 2019) (NRCan, 2017)

There are widely used commercial benchmark tools for green building rating systems such as Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Methodology (BREEAM), WELL Building Standard (WELL), High Quality of Environment Certification (HQE), and others. Most of these abovementioned benchmarks have optimized energy and resource efficiency in building performance (UN-Habitat, 2017). Doing things more efficiently to save energy and carbon has been a current technical challenge and an economic payback depending on the construction. However, green buildings must not only use natural resources within profitable means; they also support occupants' health and wellbeing to contribute to the building's sustainability.

Housing have evolved into a unique and different product, which requires consideration for consumers' needs and desires. Repetitive failures of housing projects arise, in part, from the absence of feedback and lessons-learned from the end-user's or occupants' perspectives (Jiboye, 2012). These failures could drive an enormous loss of investment made in the housing development; besides, it could lead to lethal injuries or even death.

Hence, it is necessary to discover a methodical feedback method to obtain lessons from the occupants and ensure quality and value for their money (Preiser, 1995). Meir, Garb, Jiao, & Cicelsky (2009) recommend that conducting post-occupancy evaluation becomes necessary to achieve a sustainable result. Since the 1960s, post-occupancy evaluations were notably used to register building evaluations, either success or failure. The purpose of a post-occupancy assessment is to obtain information for effective management of the current housing stock and feedforward to enhance the further project in the following areas: planning, design, and construction (Amole, 2009). Li, Froese, & Brager (2018) confirmed that more than 140 POE projects are available worldwide. However, POEs of residential housing has just attained significant recognition in the latest two decades (Leaman, Stevenson, & Bordass, 2010).

The current research aims to carry out a performance assessment in a house constructed in Victoria, British Columbia, called Harmless Home. This research aims to present an overview of the literature to help as a background and source of reference for ongoing study in housing evaluation research and its related subfields. This research covers a summary of POE, including its methods and procedures. It presents an overview of the performance elements and approach for the holistic assessment of building housing. As Harmless Home aims not to harm the environment, this research considers the indoor environmental quality (IEQ), which has received tremendous attention in the latest years. Moreover, the whole sustainable water/electric/septic system includes solar panels to generate energy and recycling water systems and a new sustainable brick material called Just BioFiber (JBF).

2 BUILDING AND MATERIAL DESCRIPTION

- Project type: New construction
- Location, East Sooke, BC
- Climate Conditions: Moderate oceanic climate with dry summer months and rainy, humid, and cool winters
- Project Owner: Confidential
- Construction Period: May 2017 – Dec 2018
- Budget: C$1,500,000.00 construction
- Net Floor Area: 441.66 m^2
- Water: Low-flow fixtures, rainwater harvesting system, and stormwater run-off system.
- Materials: Just BioFiber (Modified Hempcrete), Insulated Concrete Forms (ICF), dimensional lumber, and plywood.

The Harmless Home is located in East Sooke, BC (shown in Figure 1). According to its designer, Jack Anderson from Greenplan, it was designed not to harm the environment, targeting low CO2 emission, low toxicities, self-energy sufficiency, long lifetime, and limited food production. After several exterior walls analyses by the owner, architect, and builder. Solar panels were used to generate electricity in an on-grid system, generating more energy than required to operate, consequently saving CO2. Achieving water self-sufficiency was one of the design intents of the Harmless Home. Harmless Home was designed to depend entirely on rainwater for all the different water-required activities within the building through a rainwater harvesting system and stormwater run-off system.

Figure 1: Harmless Home

JBF was selected by various factors like durability and strength, fire resistance, improved air quality, no mould or insect problems, positive environmental impact, absorbing CO2 from the ecosystem, and competitive price. JBF is a block comprised of 3 key components: 1 - hemp hurd as an inner core, 2 - lime binder that absorbs atmospheric CO2 as it strengthens and 3 - structural frame engineered for high wind, earthquakes and tall wall assemblies. Figure 2 shows the step-by-step wall design construction usgin the JBF, which consists in the following steps from the company's instruction (JBF, 2022)**:**

1. The Bottom Strip (composite) is laid down and tied into the foundation
2. Flax-Lime Mortar is applied to the bottom strip to reduce thermal transfer
3. Glue is applied to the Bottom Strip to lock onto the blocks
4. Blocks are placed onto the Bottom Strip
5. Flax-Lime Mortar and Glue are applied to each block
6. Blocks are placed onto each other in an interlocking pattern
7. When all courses (rows) of the wall are assembled, the top interlocking caps are cut off
8. The Top Strip is laid over the block wall and tied into the wall using bolts

Besides the benefits of the JBF block, it cannot be used below-grade because of the nature of the hemp hurd decomposing in soil; therefore, ICF was used below-grade and JBF above-grade for all exterior walls as show in Figure 3 in the initial construction phase.

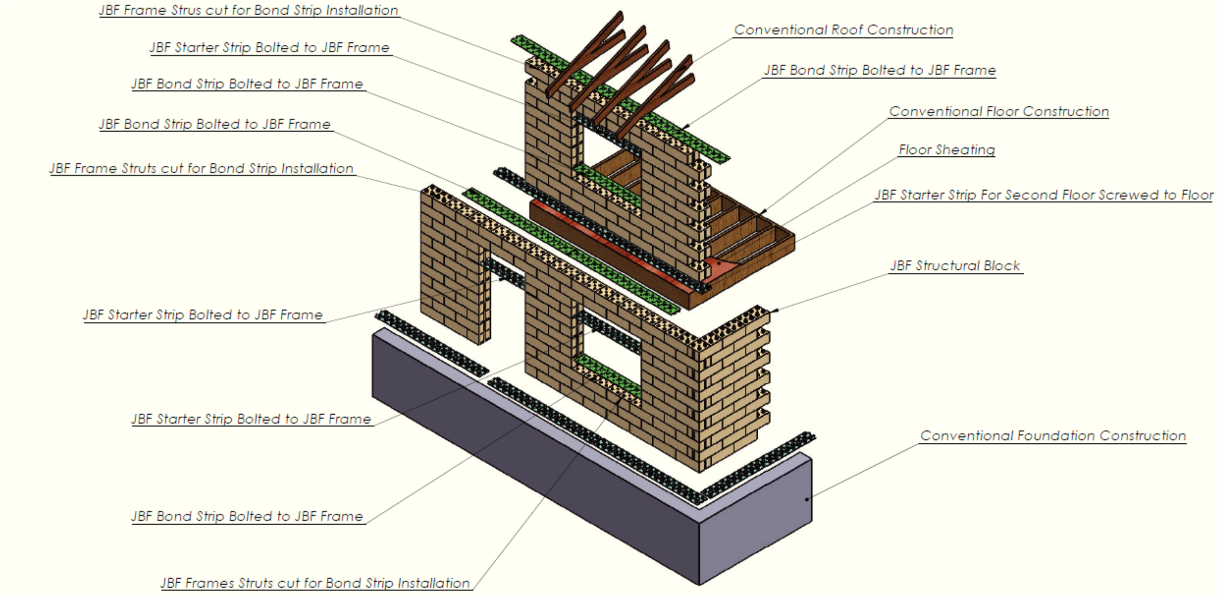

Figure 2: Wall Design and Construction Details

Figure 3: ICF vs JBF

3 MATERIALS AND METHODS

This research is about the post-occupancy evaluation (POE) of a green building house called Harmless Home located in East Sooke, BC. POE is a method of studying occupants of buildings through occupants' feedback and/or measurements of building performance, which covers energy and water assessment, Indoor Environment Quality (IEQ), physical assessment, occupant survey questionnaires, visual records, and technical measurement of a building structure (Sanni-Anibire, Hassanain, & Al-Hammad, 2016). This study focused on following the iiSBE Protocol to assess the building performance evaluation of the Harmless Home. Some of the goals for benchmarking include the following categories of performance:

1. Occupancy Issues
2. Energy and Emissions
3. Water Use
4. Economic Factors
5. Indoor Environmental Quality
6. Site Issues
7. Materials Issues

The Key Performance Indicators (KPI) for the abovementioned categories were defined and collected for:

- Building performance at least for six months of operation for thermal comfort and at least two years of operation for other KPIs;
- Predicted performance at the design stage; and (based on building energy modelling and green building certification submissions); and
- Reference values for similar buildings in the exact location.

The work required to collect both quantitative and qualitative data from various sources:

- Metered data for energy and water use should be collected from utility bills or sub-meters. However, due to the specific project with solar panels and rainwater harvesting system, energy was calculated by the Tesla Solar App and water empirically for average annual human consumption per year. The energy use intensity (EUI) and water use intensity were calculated in kWh/m²/year and m³/m²/year. The energy information was compared to the predicted energy modelling and water with similar typical buildings of the same type in the region. Greenhouse Gas (GHG) emissions were calculated using The Ministry of Environment and Climate Change Strategy carbon intensity factors.
- Spot measurements for indoor environment quality were taken using The Thermal Efficiency Monitoring (TEM) Kit from SMT Research that provides an assessment of the thermal performance of existing structures (SMT Research, 2013). The sensors were installed in the north and south walls to measure the thermal flow through the Just BioFiber, as shown in Figure 2.

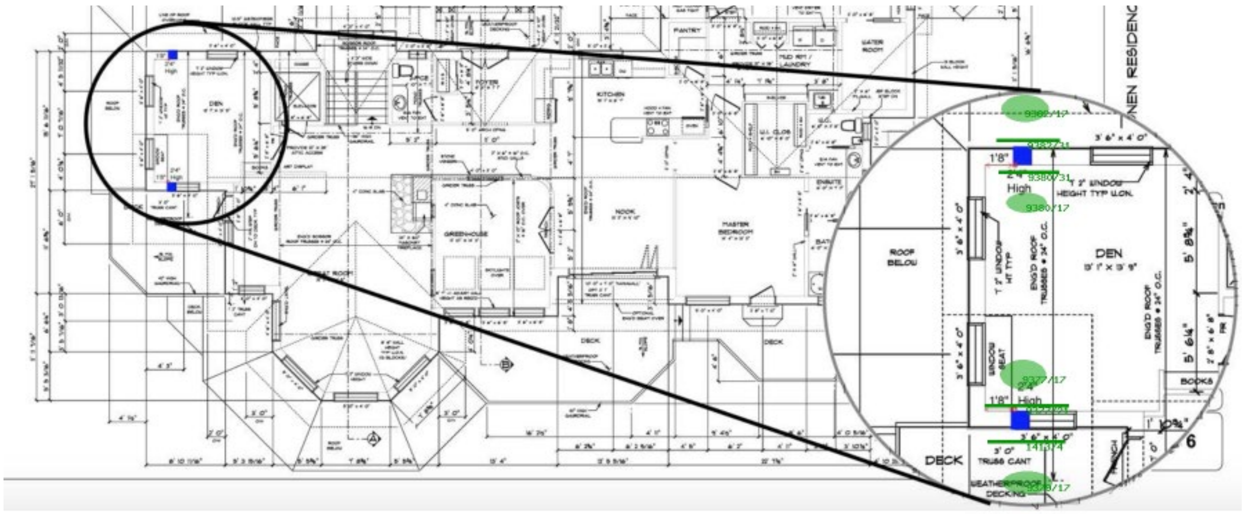

Figure 2: TEM Kit Installed Localization

- Documentation from the design phase was used to identify predicted performance at the design stage, including drawings, specifications, and energy modelling.
- Standardized calculation methodologies using the Common Carbon Metrics were used to convert energy into carbon emissions, aligning with the provincial GHG conversion factors.

Finally, to understand the Harmless home building performance, the lessons learned and identified problems or concerns that needed to be addressed, the abovementioned data was compared to commercial benchmarks like Building Owners and Managers Association of Canada (BOMA), LEED, and BREEAM, besides standards code like the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).

4 RESULTS AND DISCUSSIONS

4.1 Occupancy

The occupancy of the Harmless Home is as predicted in the design phase, two people. The typical occupation of the building is almost the whole day based on two retired people. Sporadically, they leave the building for their outside activities and personal gatherings. Sometimes, they receive visitors that were not considered for this study. Therefore, although the calculated number indicates similar occupancy predicted, there is uncertainty about the number of guests frequency and time using the building, as it is not tracked.

4.2 Energy and Emissions

While using energy from the grid at certain times, since the solar panels do not always overproduce power, Harmless Home can generate more energy than it requires to operate as a whole; therefore, it can be considered to a net-zero house (or more accurately, a net-positive house). The key performance indicator for energy use intensity is equal -10.26 kWh/m²/year, values significantly lower than the Passive House Standard and BOMA Best certification required for 15 kWh/m2/year and 29.9 kWh/ft2/year, respectively (BOMA, 2020) (Passive House Canada, 2022).

The net usage shown in Table 1 in Megawatt-Hour since 2019 is -13.60 MWh, according to the table and information exported from the Tesla Solar App:

Table 1: Exported Energy Consumption from Tesla Solar App

Year	From Grid (MWh)	To Grid (MWh)	Net Usage (MWh)
2019	11.36	-16.24	-4.88
2020	12.88	-16.49	-3.61
2021	10.77	-15.88	-5.11
		Total	-13.60

Regarding emissions, The Ministry of Environment and Climate Change Strategy publishes a set of greenhouse gas (GHG) emission intensity factors for electricity use annually. The latest report published in 2020 set a GHG emission intensity factor of 40.1 tCO2e/GWh (Ministry of Environment and Climate Change Strategy, 2020). Hence, this -13.60 MWh in three years is equivalent to a saving of 5.45 tons of CO2 based on the factor given from the Ministry of Environment and Climate Change Strategy report.

4.3 Water

The harmless houe uses no off-site water and a direct measure of the water used from the on-site system could not be done. Calculating the average water use per person in a household in Canada based on McGill University study that is 329 L/person/day (McGill, 2022), the necessary amount of water for the two occupants per year should be 240.17 m³/year or approximately 0,54 m³/m²/year. Since 2012, water use intensity at BOMA BEST certified office properties has been relatively constant, between 0.6 m³/m² and 0.7 m³/m² each year. Nevertheless, in the BOMA's last report, the average water use intensity was 0,67 m³/m²/ year. Consequently, Harmless Home uses around 19.40% less water than buildings certified by BOMA (BOMA, 2020). However, these are theoretical numbers to understand the average consumption in traditional houses with no water filter system, contrary to the Harmless Home; therefore, the KPI for water intensity use is considered 0.0 m³/m²/year.

4.4 Cost

The construction cost of the Harmless Home was around C$1,500,000.00, excluding land, which means the construction cost is equivalent to C$315.52/ft². According to Altus Group, in their last report, the average price of a custom-built single-family home is between C$450/ft² to C$1,135/ft² (Altus Group, 2022). Although Harmless Home used an innovative material from Alberta, the price was slightly lower than conventional construction costs in the region.

Commissioning cost was considered all-included in the agreement based on the contract between the owner and builder, and because of confidentiality, data was not provided.

Annual Operating Water Cost reflects only the variable costs for the building. Since Harmless Home was designed to use reclaimed water and recycle all the greywater, the predicted price is $0.00.

Annual Operating Energy Cost reflects only the variable costs for the building, and since Harmless Home was designed to use solar panel energy, the predicted price is listed as $0.00.

4.5 IEQ – Thermal

Figure 3 shows the temperature value daily from August 30th, 2018, to April 08th, 2019, recorded by the TEM Kit from SMT Research. The values are plotted according to the model described by ASHRAE 55. ASHRAE standard 55 defines the acceptable range a building should be maintained. From the below chart borrowed from ASHRAE standard 55, the permissible content is for the winter 20-24 and the summer ~22-26. With a good humidity range between ~30-70% (ASHRAE, 2020).

According to the ASHRAE 55 thermal comfort standard, 41.73% of occupant spaces should be within the zones specified on the standard.

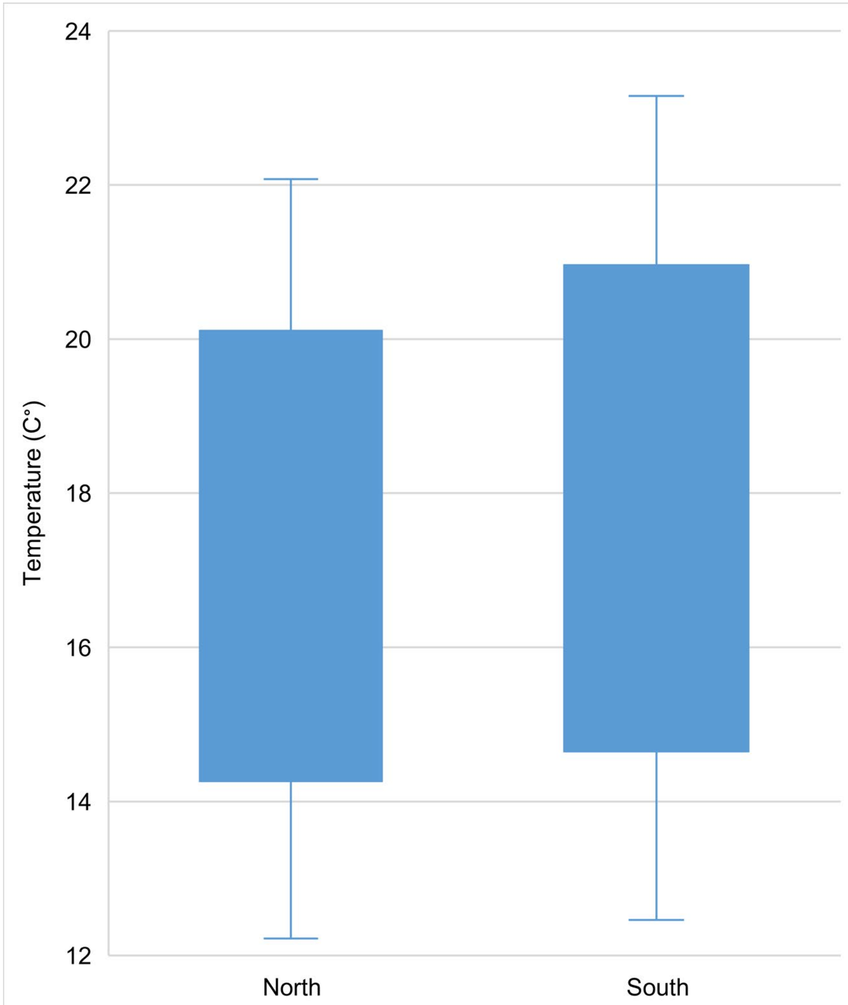

Figure 3: Indoor temperature values from August 30th, 2018, to April 08th, 2019

4.6 Site

4.6.1 Protected Habitat

Significant landform modification was necessary to develop viable access to the property so that cisterns could be excavated and a home site made accessible. This negatively impacted about 20% of the natural environment of the site. The land was subsequently marketed and purchased by the owners of the Harmless Home. During the building time of their house and external services, they have been most protective of the remaining natural ecosystem. According to the architect, the project impacted less than 10% of the land; therefore, approximately 70% of the site was protected.

4.6.2 Heat Island Effect

The siting of the Harmless Home was done to retain the trees to the east, offering morning shade, but the Home is fully exposed to the sun for the remainder of the sun path (be it winter or summer) in the south and west aspects. The site is also exposed to a rock outcropping and is thus prone to steady breezes that limit heat accumulation around the building perimeter. The primary roofline is also intentionally south orientated to accommodate the anticipated central solar panels array requested by the owners in the search for energy independence. The variety takes up about 75% of the south-facing rooflines, which ensures solar energy is captured in solar panels for electrical generation and potentially offset thermal accumulation.

4.6.3 Storm Water Sent Off

Upon building the Home, all the rain that falls around the Home's perimeter likely continues its natural journey off-site, but by design, much of the water that lands on the Home's roof is captured as rainwater cisterns. The architect estimates that around 90% of all rainfall would be sent off-site via the various trenches and drainage courses created on the hillside.

4.7 Materials

No measurement was taken to calculate the amount of materials waste and reuse/recycle.

5 CONCLUSION

Below is an overview of some critical lessons identified from the Harmless Home performance assessment according to the iiSBE Protocol. This project is ongoing; consequently, these are initial findings , and further measurements and occupants' surveys will be run. These results will be further studied in other papers:

1. Hours of operation and occupation load in current building occupancy can be challenging to quantify accurately without monitoring sensors or recording on a continued basis. These are critical aspects of managing futures POEs to have a precise occupancy analysis.

2. Even though two retired people occupy the Harmless Home, their social life welcoming people in their Home, especially to promote the JBF and their findings of the house, this can impact the original design assumptions momentarily, increasing the energy and water use.

3. Surprisingly, the Harmless Home consumed less energy than predicted in the Building Energy Modelling (BEM). However, the BEM considered that JBF had an R-value equal to 21.84, but the study from SMT Research about the JBF's R-value determined that the actual R-value was 40.15. Besides, solar panels currently produce energy in the Harmless Home that needs to be considered in the BEM model, and these changes are vital and need to be considered in further BEM analysis.

4. Actual building performance can be directly impacted by how the building is managed. The thermal sensors are located below a window in a den that hardly ever is used, affecting the thermal comfort measurement having a below-average for a high-performance building.

5. The thermal comfort results are below expected for a high-performance house. However, the den is rarely used, so setting up a high temperature is unnecessary.

6. Even though the ASHRAE 55 states that the minimum temperature for indoor comfort is 20°C, the occupants report that they both feel comfortable in temperature from 17°C to 20°C, which should be considered in the IEQ - Thermal results, not only ASHRAE 55.

7. A lack of sub-metering, sensor or data acquisition was a significant barrier in water and indoor environmental quality performance assessment.

References

Altus Group. (2022). *2022 Canadian Cost Guide.* Vancouver: Altus Group.

Amole, D. (2009). Residential satisfaction in students' housing. *Journal of Environmental Psychology*, 76-85.

ASHRAE. (2020). *ASHRAE standard thermal environmental conditions for human occupancy.* Atlanta: The Society.

BOMA. (2020). *Building on Sustainability: 2020 National Green Building Report.* Toronto: BOMA.

IPCC. (2007). *Climate Change: Synthesis Report.* Geneva: Intergovernmental Panel on Climate Change.

JBF. (2022). *FAQ*. Retrieved from Just BioFiber: Structural Solutions: https://justbiofiber.com/products/faq/

Jiboye, A. D. (2012). Post-occupancy evaluation of residential satisfaction in Lagos, Nigeria: Feedback for residential improvement. *Frontiers of Architectural Research*, 236-243.

Leaman, A., Stevenson, F., & Bordass, B. (2010). Building Evaluation: Practice and Principles. *Building Research & Information*, 564-577.

Li, P., Froese, T., & Brager, G. (2018). Post-occupancy evaluation: State-of-the-art analysis and state-of-the-practice review. *Building and Environment*, 187-202.

McGill. (2022). *How much are we using?* Retrieved from McGill Water is Life!: https://www.mcgill.ca/waterislife/waterathome/how-much-are-we-using#:~:text=If%20we%20look%20at%20how,L%20of%20water%20per%20person.

Meir, I. A., Garb, Y., Jiao, D., & Cicelsky, A. (2009). Post-Occupancy Evaluation: An Inevitable Step. *Advances in Building Energy Research*, 189-219.

Ministry of Energy, Mines and Low Carbon Innovation. (2019). *BC Energy Step Code: A Best Practices for Local Governments.* Victoria: Energy Step Code Council and the Building and Safety Standards Branch.

Ministry of Environment and Climate Change Strategy. (2020). *Electricity Emission Intensity Factors for Grid-Connected Entities*. Retrieved from Government of British Columbia: https://www2.gov.bc.ca/gov/content/environment/climate-change/industry/reporting/quantify/electricity

NRCan. (2017). *Build Smart Canada's Buildings Strategy: A Key Driver of the Pan-Canadian Framework on Clean Growth and Climate Change.* St. Andrews by-the-Sea: Natural Resources Canada.

NRCan. (2020). *Canada's GHG Emissions by Sector, End Use and Subsector*. Retrieved from Natural Resources Canada: https://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/showTable.cfm?type=HB&sector=aaa&juris=ca&rn=3&page=0

Passive House Canada. (2022). *Passive House (Passivhaus) is considered to be the most rigorous voluntary energy-based standard in the design and construction industry today.* Retrieved from

Passive House Canada: https://www.passivehousecanada.com/about-passive-house/#:~:text=Buildings%20consume%20up%20to%2040,cooling%20energy%20than%20conventional%20buildings.

Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information. *Energy and Buildings*, 394-398.

Preiser, W. F. (1995). Post-Occupancy Evaluation: How to Make Buildings Work Better. *Facilities*, 19-28.

Sanni-Anibire, M. O., Hassanain, M. A., & Al-Hammad, A. M. (2016). Post-Occupancy Evaluation of Housing Facilities: Overview and Summary of Methods. *Journal of Performance of Constructed Facilities*.

SMT Research. (2013). *Thermal Efficiency Monitoring (TEM) Kit*. Retrieved from SMT Research: https://www.smtresearch.ca/thermal-efficiency-monitoring-kit

UNEP. (2020). *Global Status Report for Buildings and Construction: Towards a Zero-Emissions, Efficient and Resilient Buildings and Construction Sector.* Nairobi: United Nations Environment Programme.

UN-Habitat. (2017). *Building Sustainability Assessment and Benchmarking - An Introduction.* Nairobi: United Nations Settlements Programme (UN-Habitat).