EFFECT OF DIFFERENT CLIMATES ON A SHIPPING CONTAINER PASSIVE HOUSE IN CANADA

Wesley Bowley,[1] Phalguni Mukhopadhyaya[2]*

ABSTRACT

Passive House buildings with an annual energy demand of less than 15 kWh/m^{2}a (i.e. kWh/m^2 per annum) can help Canada and other countries achieve thermal comfort with minimum energy use and carbon footprint through meticulous design and selection of highly efficient building envelope elements and appliances. Shipping container based passive houses can reduce the cost of passive house construction and also promote recycling. In this paper, a passive house built using shipping containers, originally designed for Victoria, BC, Canada, is analyzed using Passive House Planning Package (PHPP) software in different climactic zones of Canada. The locations under consideration are: Halifax (Cool–Temperate), Toronto (Cold–Temperate), Edmonton (Cold), and Yellowknife (Arctic–Climate). This paper critically examines the energy demand changes in various climate zones and make necessary modifications to the design to achieve passive house energy performance requirements in selected climates. Results show that with modified designs shipping container passive houses can meet passive house requirements, except in the Arctic–Climate of Yellowknife.

KEYWORDS

shipping container, passive house, energy efficiency, cold climate, passive house certification

INTRODUCTION

The Passive House Standard (PHS), developed by the Passivehaus Institute, provides design and construction guidelines for ultra-low energy buildings and up to 90% less energy consumption than conventional new buildings [1]. This is achieved namely through large amounts of insulation, airtightness, limiting thermal bridging and heat recovery ventilation (HRV). By decreasing the required heating demand to a low enough value, significant savings can be made by not requiring large dedicated Heating, Ventilation, and Air Conditioning (HVAC) systems [2].

Passive house buildings are mostly constructed in central Europe, where it was first introduced, but as passive house gains more recognition, they are now being built globally, especially in North America [3–5]. Investigation on the performance of passive houses in different climates

1. Graduate Student, Department of Civil Engineering, University of Victoria, BC, Canada
2. Associate Professor, Department of Civil Engineering, University of Victoria, BC, Canada; *Corresponding Author, phalguni@uvic.ca, 250-472-4546

has been reported in the literature [6]. Usually, significant changes to the design are needed for different climates to meet passive house requirements. While most of the studies on passive houses are conducted in the Northern Hemisphere, a study has been reported where the feasibility of the passive house concept is examined in the Southern Hemisphere [7].

There exist a few studies on buildings with shipping containers [8–12] but no study on a container house built to passive house standard has been reported, except the recent one published by the authors [13] for a shipping container house in Victoria, British Columbia, Canada. This paper goes further to demonstrate that through appropriate analysis and design it is possible to create a container passive house in most climatic zones of Canada. Apart from Victoria in British Columbia, additional locations considered were Halifax in Nova Scotia, Toronto in Ontario, Edmonton in Alberta, and Yellowknife in Northwest Territories, located in Cool–Temperate, Cold–Temperate, Cold, and Arctic climatic zones [14], respectively. The concept of building passive houses with shipping containers can address various issues related to sustainability, recycling and affordable energy-efficient housing.

METHODOLOGY

The software tool that was chosen for the design is the Passive House Planning Package (PHPP), version PHPP_V9.6a_EN, which is the standard modeling package used by passive house designers, developed by the Passive House Institute [15]. This tool calculates the heating and cooling loads, ventilation requirements, energy use of plug loads as well as energy generated from renewables such as solar panels and solar hot water heaters. Based on the inputs provided to the software by the designer, it will then determine whether or not the design meets passive house requirements.

The structure that will be used in this analysis is a design that uses shipping containers as the main structural elements. The building is designed in such a way so that it is capable of being off-grid and self-sufficient in the cool–temperate climate of Victoria, British Columbia, Canada, while meeting the energy requirements of a passive house. Some of the benefits of container houses include a robust and weather-proof structural element that is self-supporting and inexpensive to acquire in port cities. Design challenges include limited interior space, lack of insulation and extreme thermal bridging due to a steel exterior, thus requiring either structural modifications to introduce thermal breaks, or encapsulation of the interior or exterior with insulation. In some cases, depending on climate and local building codes, the thermal bridging is often ignored. However due to the high performance requirements of passive house, this is not an option.

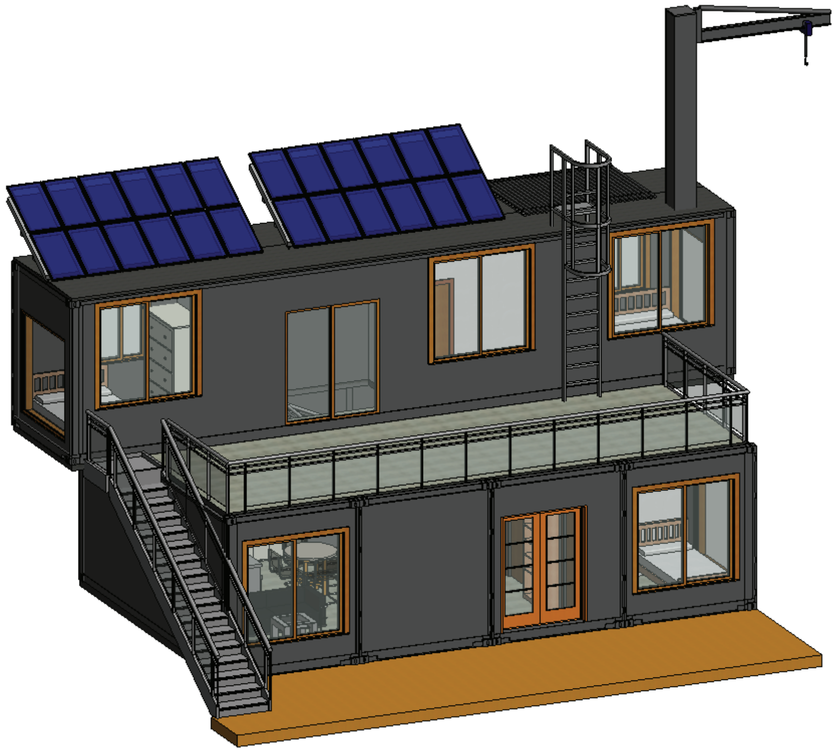
BASE CASE—CONTAINER PASSIVE HOUSE

The base case container passive house design has been done for the climate conditions of Victoria, British Columbia, and essential aspects of the design are outlined below.

Construction

The design is based on four twenty-foot long high cube containers (20 ft. length × 8 ft. width × 9.5 ft. height) or (6100mm length × 2440mm width × 2900mm height) and one forty-foot long high cube container (40 ft. length × 8 ft. width × 9.5 ft. height) or (12200mm length × 2440mm width × 2900mm height). The twenty-foot containers are positioned side by side along the long dimension and make up the ground floor. The forty-foot container is then

FIGURE 1. 3D Model of Passive Container House.



positioned rotated 90 degrees with the long face facing the ends of the twenty-foot containers below them. It is located at the back end of the floor below so that the top of the twenty-foot containers form a deck, accessed by stairs and French doors on the forty-foot container. A three-dimensional model of the construction is shown in Figure 1.

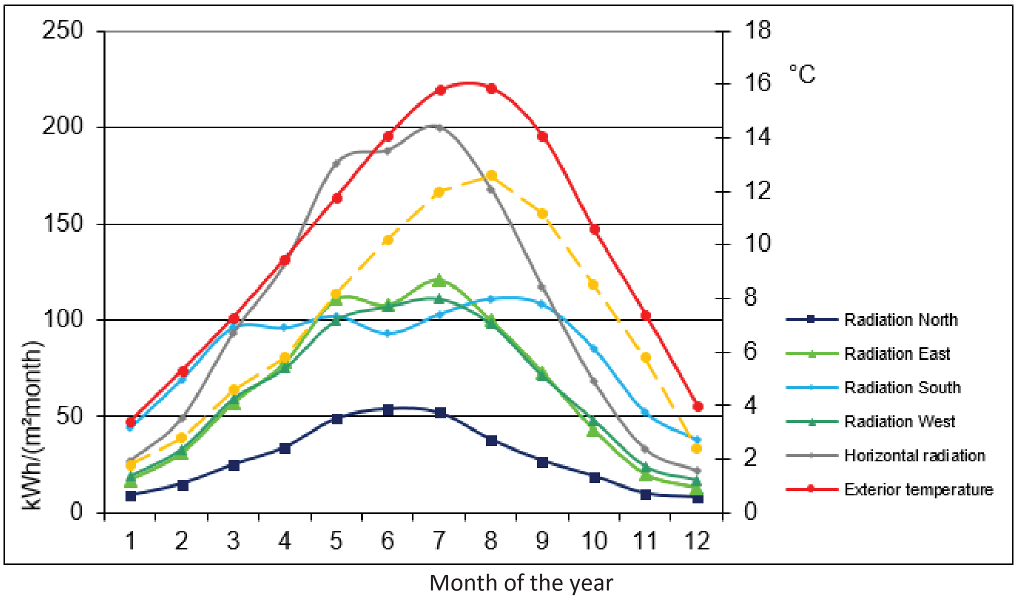
The wall cross section is made up of the container wall with all insulation on the interior surface. The insulation layer is made up of a 24mm vacuum insulation panel (VIP) (thermal resistance = 8.8 m^2.K/W), sandwiched between two 12.5mm extruded polystyrene (XPS) foam boards for a nominal combined thermal resistance of around 9.7 m^2.K/W. 2 × 4 (38mm × 89mm) framing could then be added on the interior in order to have a surface which drywall and other components could be mounted on without damaging the VIP.

The goal of the design is to be compact in size (just under 90m^2 treated floor area) and off-grid, with solar panels providing all power and rainwater harvesting from the roof and deck to provide drinking water. The layout of the containers is optimized such that there is sufficient area to collect the required volume of water. This means that the volume to surface area ratio is not optimized for energy efficiency but is enough to meet passive house standard.

Thermal Bridge

All walls of the containers are insulated from inside. Hence, the main thermal bridges are window and door frames, and interior doorframes that are cut through containers walls with narrow thickness that makes it difficult to insulate with VIPs. Another source of thermal bridging would be the attachment points for the wood framing if it makes direct contact with the container walls.

FIGURE 2. External temperatures and solar radiation values for each cardinal direction (Victoria).



Climate

Exterior temperature strongly influences energy consumption characteristics of buildings. Figure 2 shows a typical graph obtained from the average monthly temperatures and directional solar radiations for Victoria, British Columbia. Similar data are available in PHPP software (Version PHPP_V9.6a_EN) for other locations considered in this study.

Energy Conservation Measures

Thermal characteristics of the materials used for construction of the building envelope and related construction details together determine the overall thermal transmittance capacity (U-value) of the assembly. Table 1 shows the materials used in the exterior envelope, and their respective U-values, and the U-value for the combined wall. The calculated total U-value for the exterior wall is 0.105 W/(m^2K). Apart from insulating the exterior walls, other energy conservation measures considered for this passive house design exercise are: windows, doors, and HRV system. These building components were taken from the passive house certified database that comes with the software. The list includes all of their operating parameters, and it allows designers to vary different components and compare the results. Table 2 is a list of the components used for base case design. Table 3 compiles window information, such as thermal transmittance (U) and solar heat gain coefficient (g) values, and window and glazing areas in each cardinal direction. There are three different U-values in Table 3 due to the different sizing of the windows on each face and the ratio of glass area to window frame area that creates minor differences in the total U value for the window.

Energy Efficiency

The internal temperature is set to 21 degrees Celsius and the number of occupants is the standard residential occupancy rate default in the PHPP. The air replacement rate is 140 m^3/h, with

TABLE 1. Thermal properties of exterior wall assembly.

External Wall Layer	Thermal Conductivity [W/(m.K)]	Thickness [mm]
Steel	42.7	2
Rigid Polyurethane Foam	0.025	13
Vacuum Insulation Panel	0.003	24
Rigid Polyurethane Foam	0.025	13
Drywall	0.250	13
Total U value [W/(m^2K)] = 0.105		

TABLE 2. Component list for base case design.

Component	Name*
Glazing	AGC–iplus Advanced 1.0 (4:/12/4/12/:4 Kr 90%)
Window Frames	ENERGATE® / Ludwig Häußler GmbH–EN1042+ –HKKF
Door	Pazen Fenster+Technik–ENERslide (Schiebeelement)–SWISSP. Ultimate PU
HRV	Airflow UK–DV80 Adroit

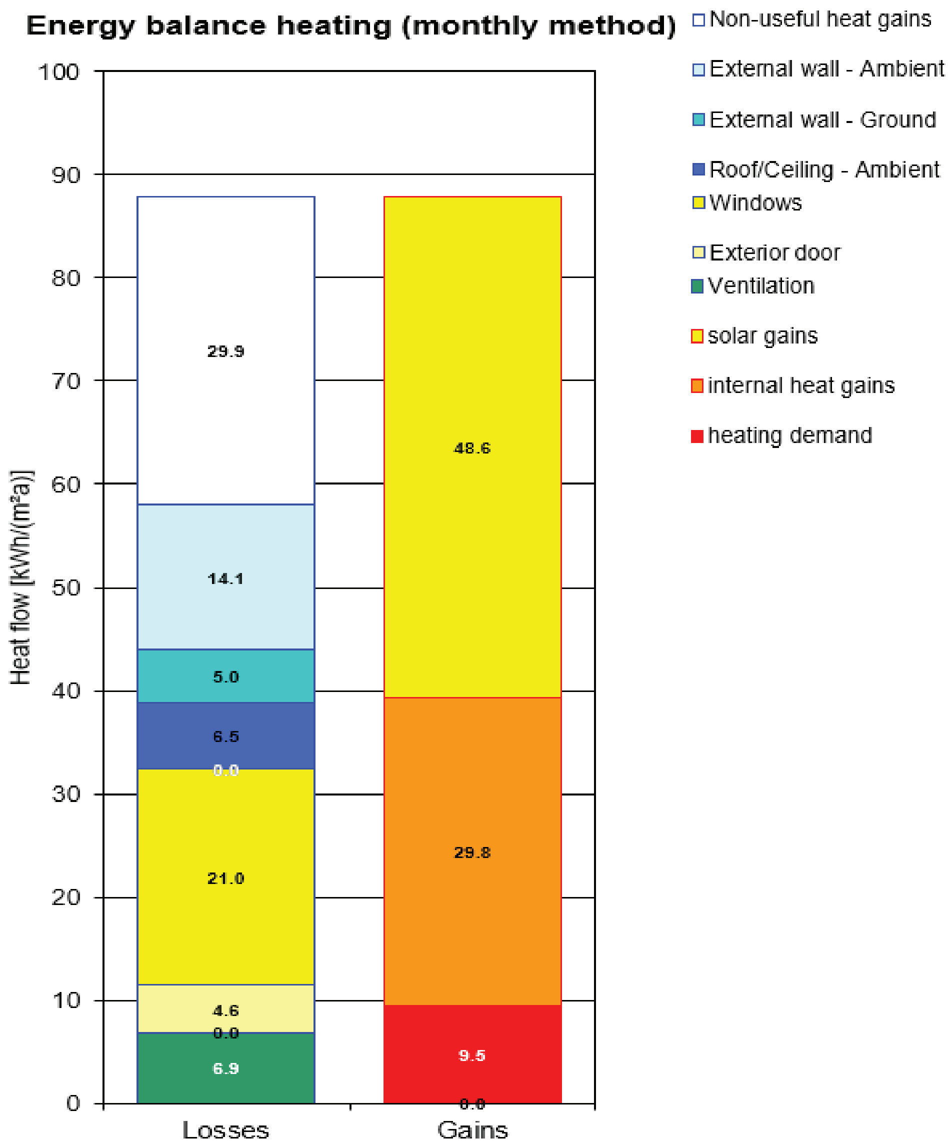
* As in Passive House Institute Database

TABLE 3. Window summary for base case.

Direction	g-Value	Window Area [m^2]	Window U Value [W/(m^2K)]	Glazing Area [m^2]
North	0.42	5.04	0.79	2.96
East	0.42	8.72	0.65	6.62
South	0.42	16.00	0.62	12.53
West	0.42	4.00	0.62	3.13
Total or Average Value for All Windows	0.42	33.76	0.67	25.25

an infiltration rate of 7 m^3/h. Other relevant parameters used in the PHPP are program defaults. According to the passive house design strategy, there is no need for a dedicated cooling system. Night time ventilation can be used to lower the air temperature overnight, if needed. Using these design principles, the Passive House Planning Package (PHPP) calculated the annual energy use per square meter for the base case in Victoria to be 9.5 kW/m^2a. This is well below the passive house requirement of 15 kW/m^2a. The energy balance showing heat losses through envelope and heating demand for the base case in Victoria are shown in Figure 3.

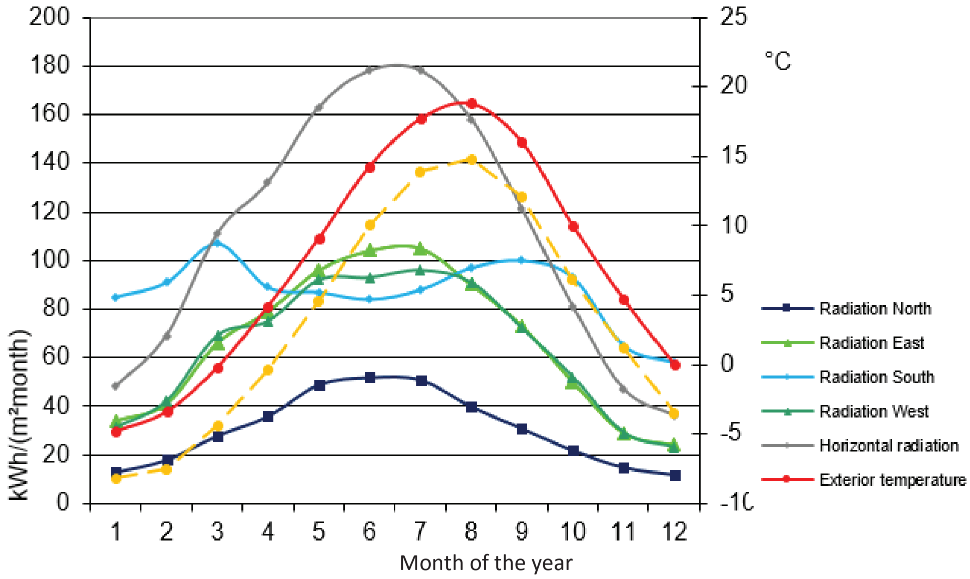
FIGURE 3. Energy balance showing heat losses through envelope and heating demand for the base case in Victoria.



CONTAINER PASSIVE HOUSE IN OTHER CITIES

The purpose of this analysis is to assess the energy performance of the aforementioned base case structure in different climatic zones of Canada. Thereafter, if energy performance does not meet the passive house design requirement, changes will be made to the design so that it meets the requirement. Ideally, this could be done by changing building components or adding more insulation. However, in the case of the arctic climate zone, an alternate design has been developed in addition to the original design in an attempt to meet the requirement in such a challenging climate.

FIGURE 4. External temperatures and solar radiation values for each cardinal direction (Halifax).



Halifax

The climate zone for Halifax is cool–temperate, which is the same as Victoria. So only a few changes are required, however, this location is chosen because of the much harsher winters that Atlantic Canada experiences when compared to the Pacific Coast. Climate characteristics are shown in Figure 4 and Figure 5 presenting the energy balance for the base case in Halifax climate.

The only change that needs to be made in the base case design was to replace the solid doors with windowed French doors, thereby increasing solar thermal gains. The list of components that are used in the modified building is shown in Table 4. Window information is summarized in Table 5.

Using the above components, the PHPP calculated the annual energy use per square meter to be 12.5 kW/m^{2}a (Figure 6). This is below the passive house requirement of 15 kW/m^{2}a.

TABLE 4. Component list for Halifax.

Component	Name*
Glazing	AGC–iplus Top 1.1 (4:/12/4/12/:4 Kr 90%)
Window Frames	ENERGATE® / Ludwig Häußler GmbH–EN1042+–HKKF
Door	Pazen Fenster+Technik–ENERslide (Schiebeelement)–SWISSP. Ultimate PU
HRV	Wernig–G90-160 Enthalpie

* As in Passive House Institute Database

FIGURE 5. Energy balance showing heat losses through envelope and heating demand for base case in Halifax.

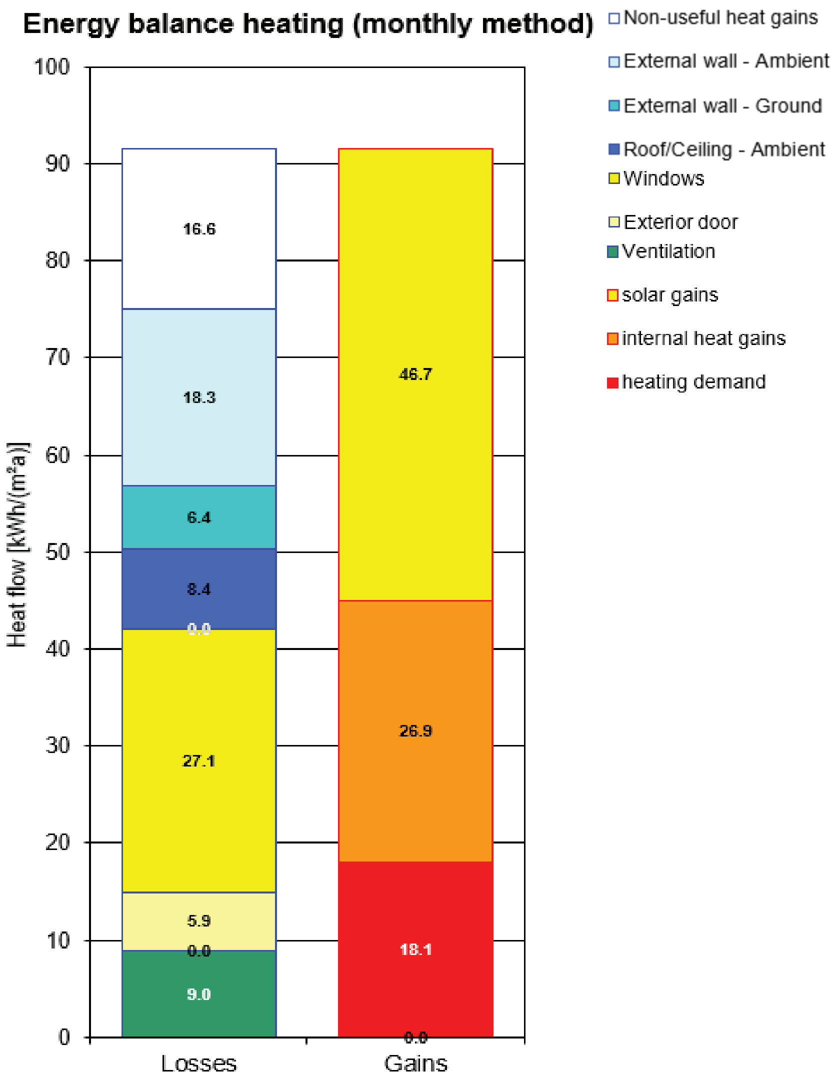
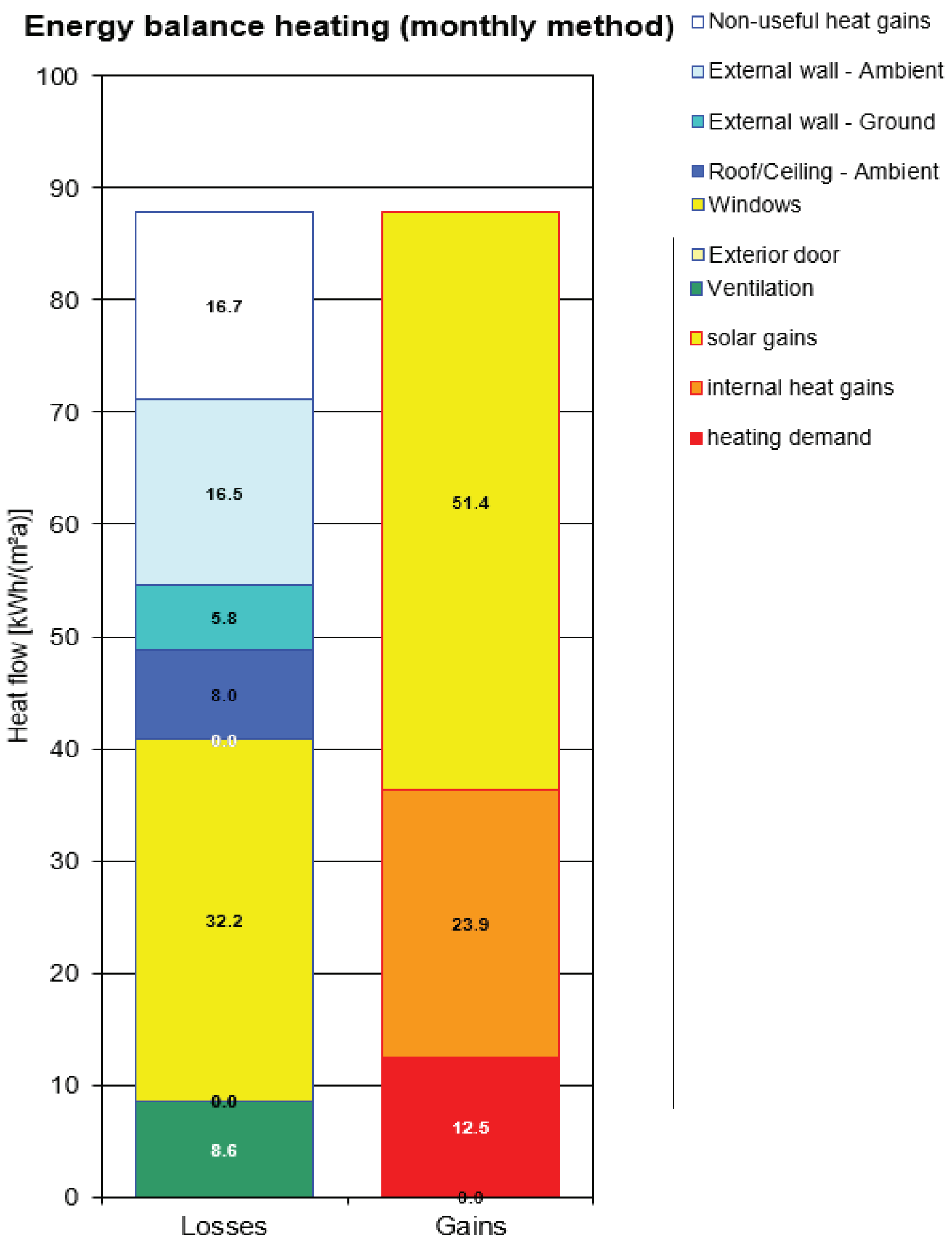


TABLE 5. Window summary for Halifax.

Direction	g-Value	Window Area [m²]	Window U Value [W/(m²K)]	Glazing Area [m²]
North	0.42	5.04	0.79	2.96
East	0.42	8.72	0.65	6.62
South	0.42	24.00	0.64	18.59
West	0.42	4.00	0.62	3.13
Total or Average Value for All Windows	0.42	41.76	0.68	31.31

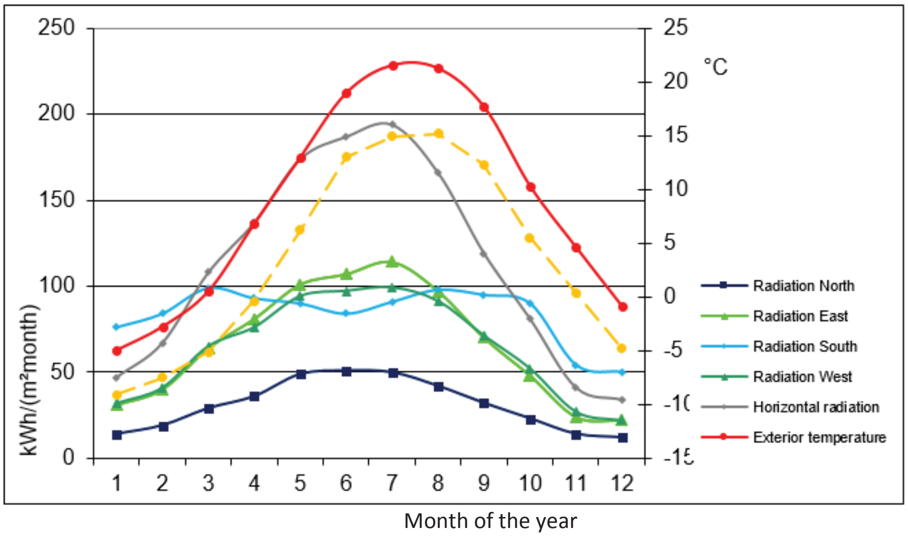
FIGURE 6. Energy balance showing heat losses through envelope and heating demand for modified design in Halifax.



Toronto

Toronto is in a cold–temperate climate zone in the PHPP, which is only one step colder than the cool–temperate Victoria. As a result, less extensive modifications are needed to reach the requirements. Toronto's climate data can be seen in Figure 7. Figure 8 shows the energy balance for the base case in this climate with no modifications. The heating load requirements could be met in this location just by upgrading the building components to more efficient models. A more efficient HRV with humidity recovery is chosen, as well as upgrading the glazing of the windows. The solid panel doors have been replaced with windowed French doors to increase

FIGURE 7. External temperatures and solar radiation values for each cardinal direction for Toronto.



solar thermal gains. No changes are made to window sizes, however, glazing area is increased due to the windows in the French doors. Table 6 contains a component list, and a summary of window information is shown in Table 7. The energy balance for the modified Toronto case is shown in Figure 9. This design meets passive house requirements for heating demand at 14.8 kW/m^{2}a. This has been achieved simply by swapping out components for more energy efficient models. A further increase could be achieved by reducing north facing window size.

Edmonton

According to the PHPP, Edmonton is in the cold climatic zone, which is the second coldest zone after the Arctic. As a result, there are more changes to the components, especially window sizing. Figure 10 shows the average monthly temperature and solar radiation levels throughout the year. Figure 11 depicts the energy balance, not meeting the passive house requirement, for the base case in this climate with no modifications.

TABLE 6. Component list for Toronto.

Component	Name*
Glazing	AGC–iplus Top 1.1 (4:/12/4/12/:4 Kr 90%)
Window Frames	ENERGATE® / Ludwig Häußler GmbH–EN1042+–HKKF
Door	Pazen Fenster+Technik–ENERslide (Schiebeelement)–SWISSP. Ultimate PU
HRV	Wernig–G90-160 Enthalpie

* As in Passive House Institute Database

FIGURE 8. Energy balance showing heat losses through envelope and heating demand for base case in Toronto.

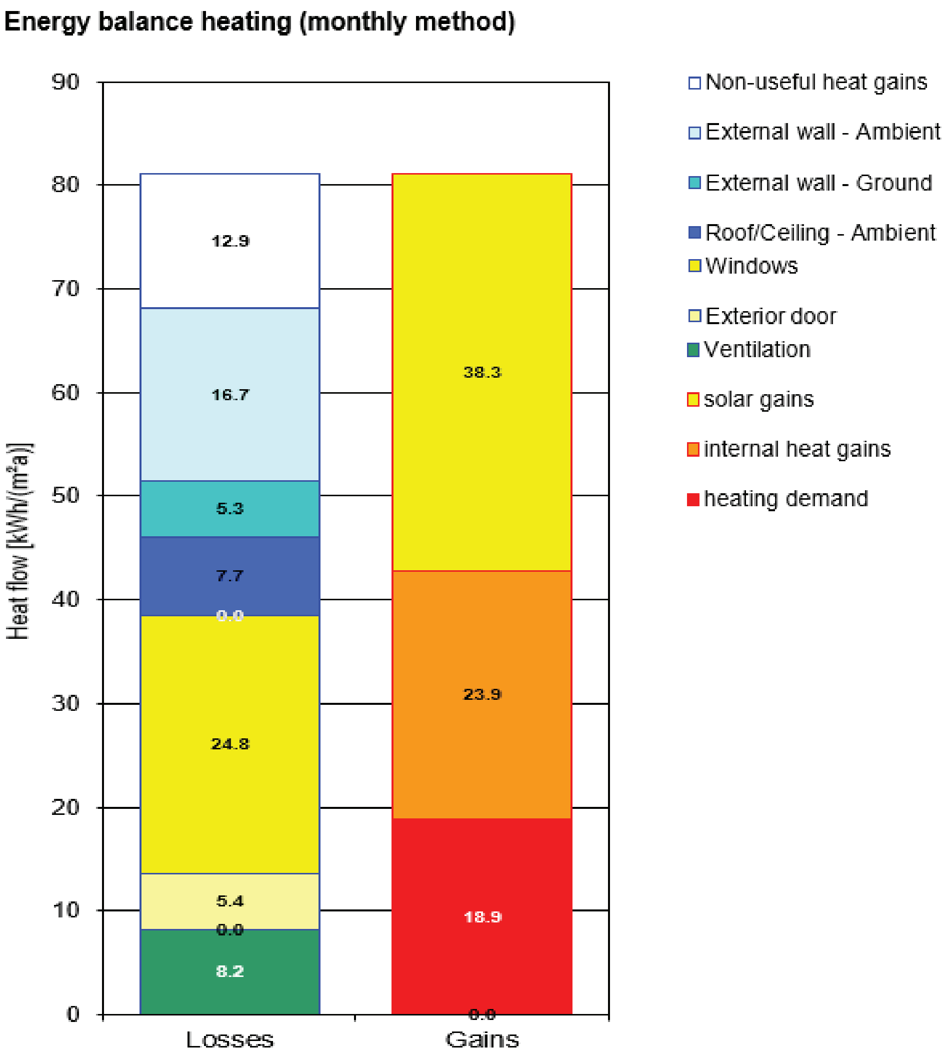
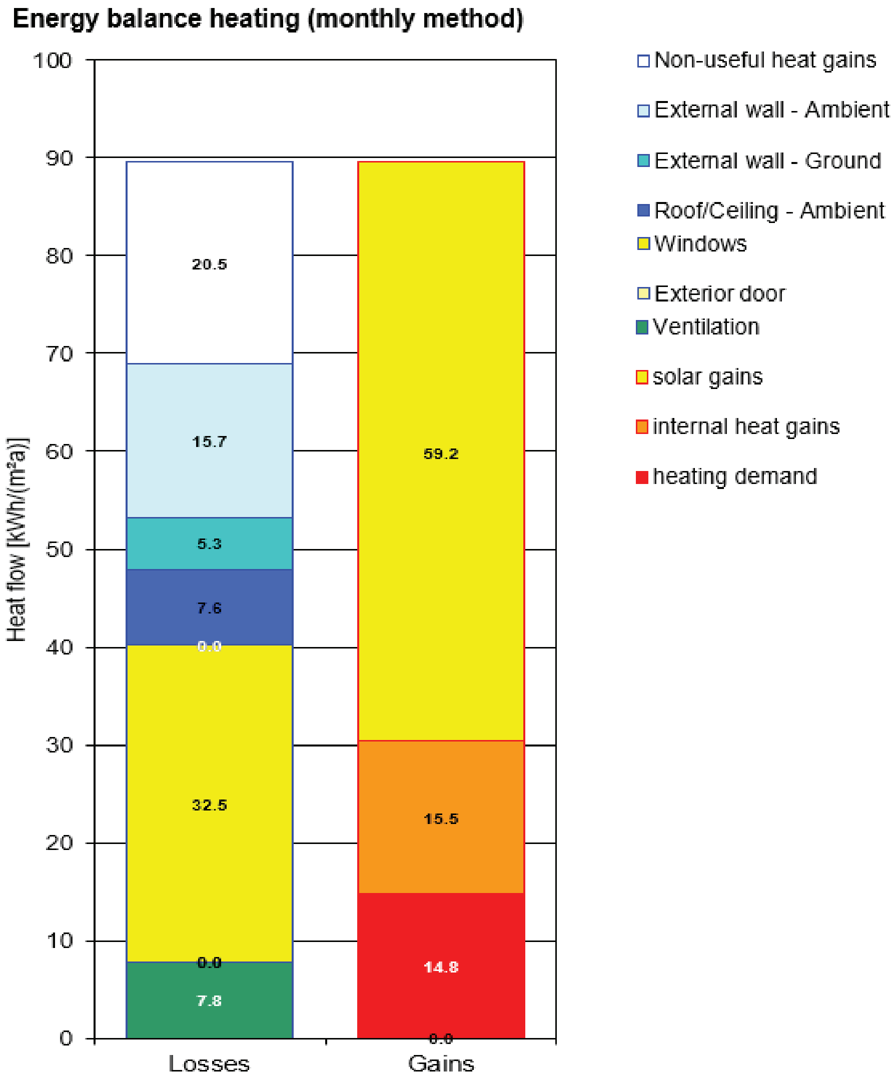


TABLE 7. Window summary for Toronto.

Direction	g-Value	Window Area [m^2]	Window U Value [$W/(m^2K)$]	Glazing Area [m^2]
North	0.51	5.04	0.82	2.96
East	0.51	8.72	0.68	6.62
South	0.51	24.00	0.68	18.59
West	0.51	4.00	0.66	3.13
Total or Average Value for All Windows	0.51	41.76	0.71	31.31

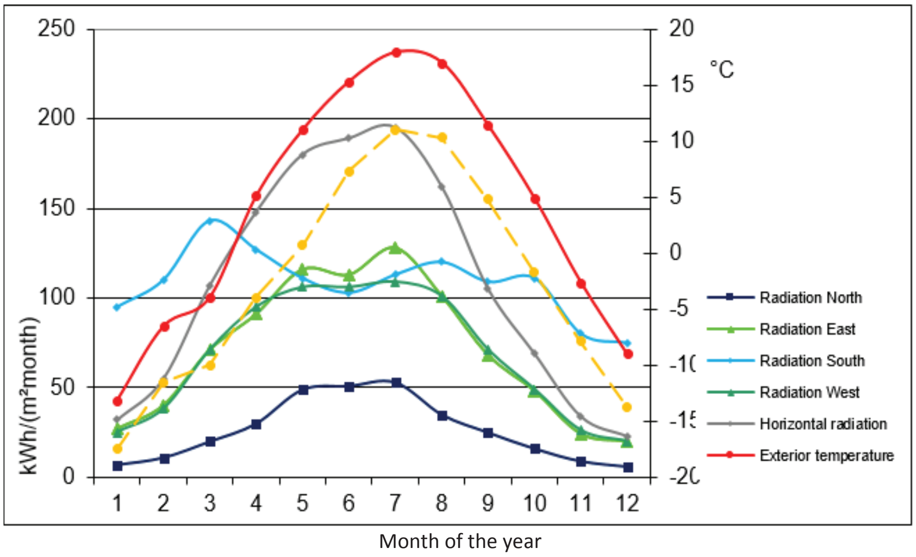
FIGURE 9. Energy balance showing heat losses through envelope and heating demand for the modified design in Toronto.



Several changes were incorporated to meet the passive house energy efficiency target. These changes were chosen in the order of least invasive to most invasive. The first preference was given to swapping out components such as HRV, windows and doors, with better performance rating. The next option considered was increased wall insulation, since it is relatively simple to add more foam. Lastly, window dimensions and locations were altered which would require more invasive construction changes.

A more efficient HRV model was chosen which increased the amount of heat recovered from the exhaust air. The thickness of the foam insulation in the walls was doubled from two 13mm thick layers to two 24mm thick layers. All north facing windows were removed, and the window dimensions for all non-south facing windows were halved with the addition of the east and west bedroom windows having a further height decrease from 1.0m to 0.7m. Insulated glass French doors were used instead of a south facing solid panel door to increase solar gains. Table

FIGURE 10. External temperatures and solar radiation values for each cardinal direction for Edmonton.



8 contains a component list, and a summary of window information is shown in Table 9. The energy balance for the modified Edmonton case is shown in Figure 12. With the changes to the base case mentioned above, this design now has a heating demand of 12.7 kW/m^{2}a, which is below that of the requirement of 15 kW/m^{2}a.

Yellowknife

Yellowknife is in the Arctic climate zone according to the PHPP, and as expected it is a much harsher climate than the rest of Canada. Figure 13 shows the average monthly temperature and solar radiation levels throughout the year. The original container house design was for Victoria, British Columbia, so it was not as critical that it be optimized for energy efficiency. In addition, the layout of the containers was made in such a way as to maximize the roof area for a rainwater harvesting system with enough collection area to supply the residence with drinking water year-round. This means that the layout is not optimized in terms of the interior volume to surface area ratio. This makes a significant difference when external temperatures are as cold as the Arctic. Hence, preliminary assessment indicated that substantial design modifications would be required. Consequently, a new container layout is modeled consisting of two floors made up of three twenty-foot containers (total six) joined together on the twenty-foot faces. This significantly decreases the volume to surface area ratio and results in reduced heat transfer through surfaces. It also means that the floor of the second floor, and the ceiling of the first floor are facing each other and not exposed to the outside directly. However, thermal bridging effects will dictate the temperature of the floor/ceiling. Hence, further modifications are done by cutting out these container faces (floor/ceiling) and rebuild it in wood, introducing a thermal break between floor/ceiling and the steel walls. The modified design has the same south facing window area as the original design, with the exception of the French door on the second floor that lead to the deck because the new layout lacks a deck. The thermal characteristics of the external wall and its components are shown in Table 10. Table 11 contains a building component list, and a summary of window information is shown in Table 12.

FIGURE 11. Energy balance showing heat losses through envelope and heating demand for base case in Edmonton.

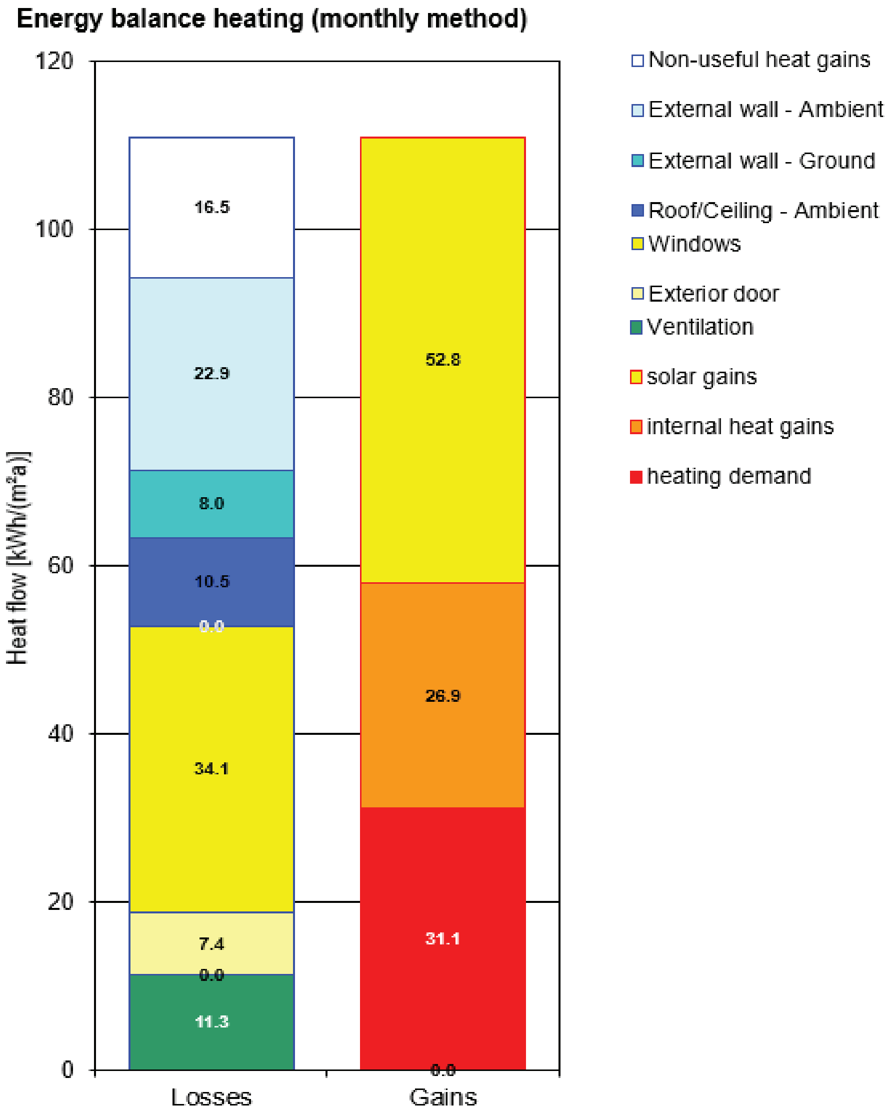


TABLE 8. Component list for Edmonton.

Component	Name*
Glazing	AGC–iplus Top 1.1 (4:/12/4/12/:4 Kr 90%)
Window Frames	ENERGATE® / Ludwig Häußler GmbH–EN1042+–HKKF
Door	Pazen Fenster+Technik–ENERslide (Schiebeelement)–SWISSP. Ultimate PU
HRV	Wernig–G90-160 Enthalpie

* As in Passive House Institute Database

TABLE 9. Window summary for Edmonton.

Direction	g-Value	Window Area [m²]	Window U Value [W/(m²K)]	Glazing Area [m²]
North	0	0.00	0.00	0.00
East	0.51	1.58	0.92	0.75
South	0.51	24.00	0.68	18.59
West	0.51	0.70	0.88	0.36
Total or Average Value for All Windows	0.51	26.28	0.83	19.71

FIGURE 12. Energy balance showing heat losses through envelope and heating demand for the modified design in Edmonton.

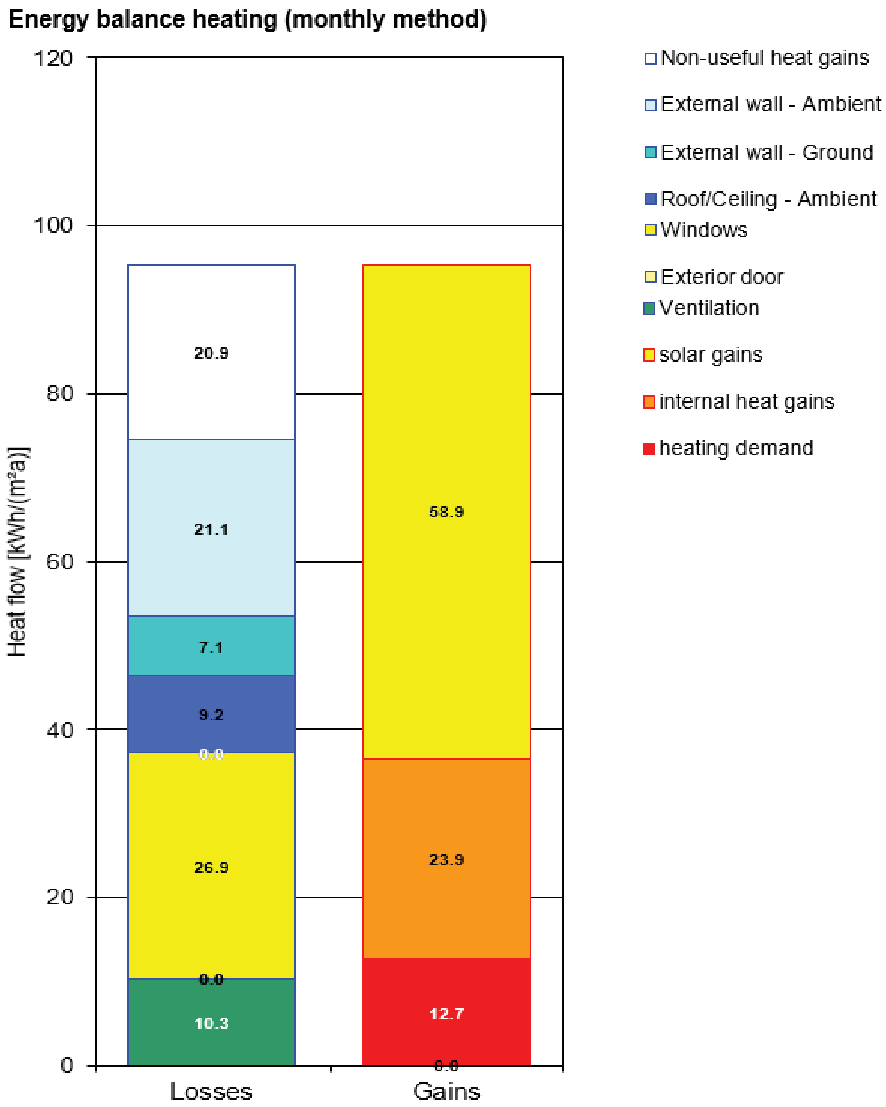


FIGURE 13. External temperatures and solar radiation values for each cardinal direction for Yellowknife.

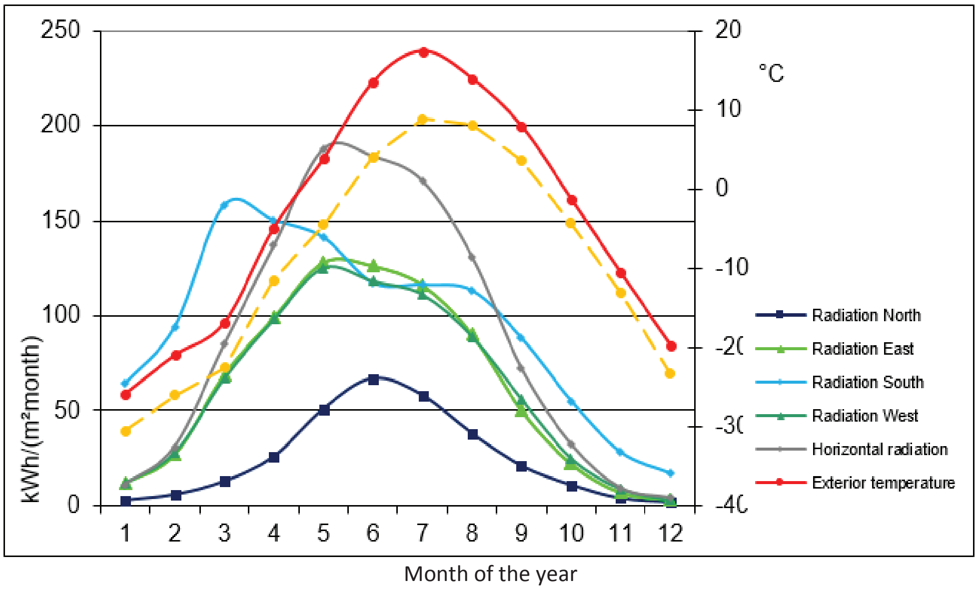


TABLE 10. Thermal properties of exterior wall assembly.

External Wall Layer	Thermal Conductivity [W/(m.K)]	Thickness [mm]
Steel	42.7	2
Rigid Polyurethane Foam	0.025	24
Vacuum Insulated Panel	0.003	24
Rigid Polyurethane Foam	0.025	96
Drywall	0.250	13
Total U value [W/(m2K)] = 0.075		

TABLE 11. Component list for Yellowknife.

Component	Name*
Glazing	Guardian–ClimaGuard nrG (4:/12/4/12/:4 Kr 90%)
Window Frames	ENERGATE® / Ludwig Häußler GmbH–EN1042+–HKKF
Door	Pazen Fenster+Technik–ENERslide (Schiebeelement)–SWISSP. Ultimate PU
HRV	Dantherm–Dantherm HCC 2 Effective Heat Recovery Efficiency [%]: 93 Electric Efficiency [Wh/m^3]: 0.37

* As in Passive House Institute Database

TABLE 12. Window summary for Yellowknife.

Direction	g-Value	Window Area [m^2]	Window U Value [$W/(m^2K)$]	Glazing Area [m^2]
North	0	0.00	0.00	0.00
East	0	0.00	0.00	0.00
South	0.62	17.00	0.77	13.02
West	0	0.00	0.00	0.00
Total or Average Value for All Windows	0.62	17.00	0.77	13.02

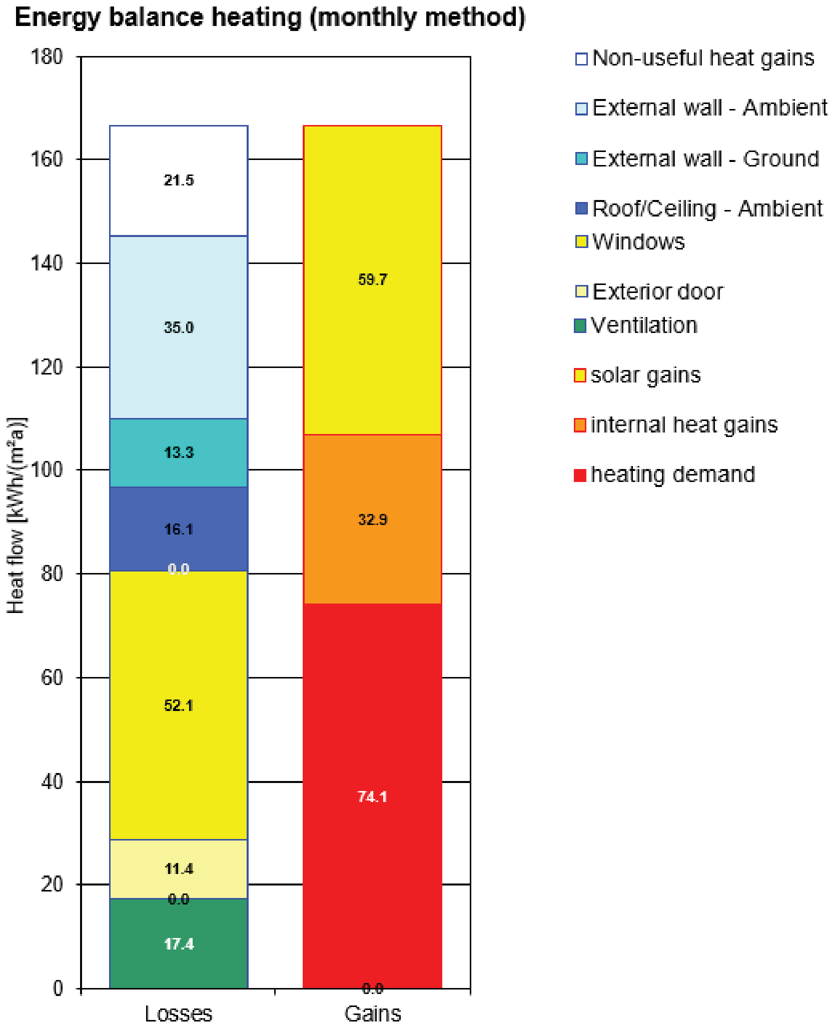
Figures 14 and 15 depict the energy balance for the base case in this climate without and with modifications, respectively. Figure 15 indicates that the proposed design modifications are not enough to meet the passive house energy efficiency requirement.

Another design option that would significantly improve the energy performance is insulating shutters, either external or internal. These shutters would be closed at night to temporarily increase the U value of the windows, while being open in the day to allow maximum solar gains. In addition, since there is much less sun during the winter due to being so far north, it may be more beneficial to have them closed most of the day instead of getting solar gains that are not enough to make up for the losses through the window. Again, the problem is that in PHPP it is not possible to modify the U values of components over time according to a prescribed schedule. In an attempt to improve energy efficiency, an approximate estimate of the effect of having insulating shutters is calculated by changing the U-value of the glazing. The U-value of the window glazing and a two-inch (50mm) foam panel is considered approximately as R12 or 2.11 RSI. To account for the inability to assign a schedule for the insulating shutters, a constant value of half the U-value of the foam is added. This aims to approximate the real situation where the full U-value will be applied half the time (during the night and not during the day) by having half the U-value applied at all times. By this method, as indicated by PHPP, 4.9 kW/m^2a energy savings in the heating demand can be achieved. Furthermore, the same calculation has also been carried out using vacuum insulation panels (VIPs) which were used in the walls (R50 or 8.8RSI) [16–18]. This achieved an energy savings of 8.8 kW/m^2a, though at a significant cost increase. With these extremely non-conventional measures, the heating demand can be lowered from 26.5 to 21.6 and 17.7 kW/m^2a by using the foam panels and VIP panels, respectively, yet still be short of passive house requirement 15 kW/m^2a.

RESULTS AND DISCUSSION

The results show that designing a passive house using shipping containers in different Canadian climates is possible but more challenging in an extreme cold climate. Figure 16 shows the heating demand of the base case design and the modified designs of all five locations considered in this study. Except in Arctic climate of Yellowknife, the passive house performance requirement (i.e. 15 kW/m^2a) was met in all other locations.

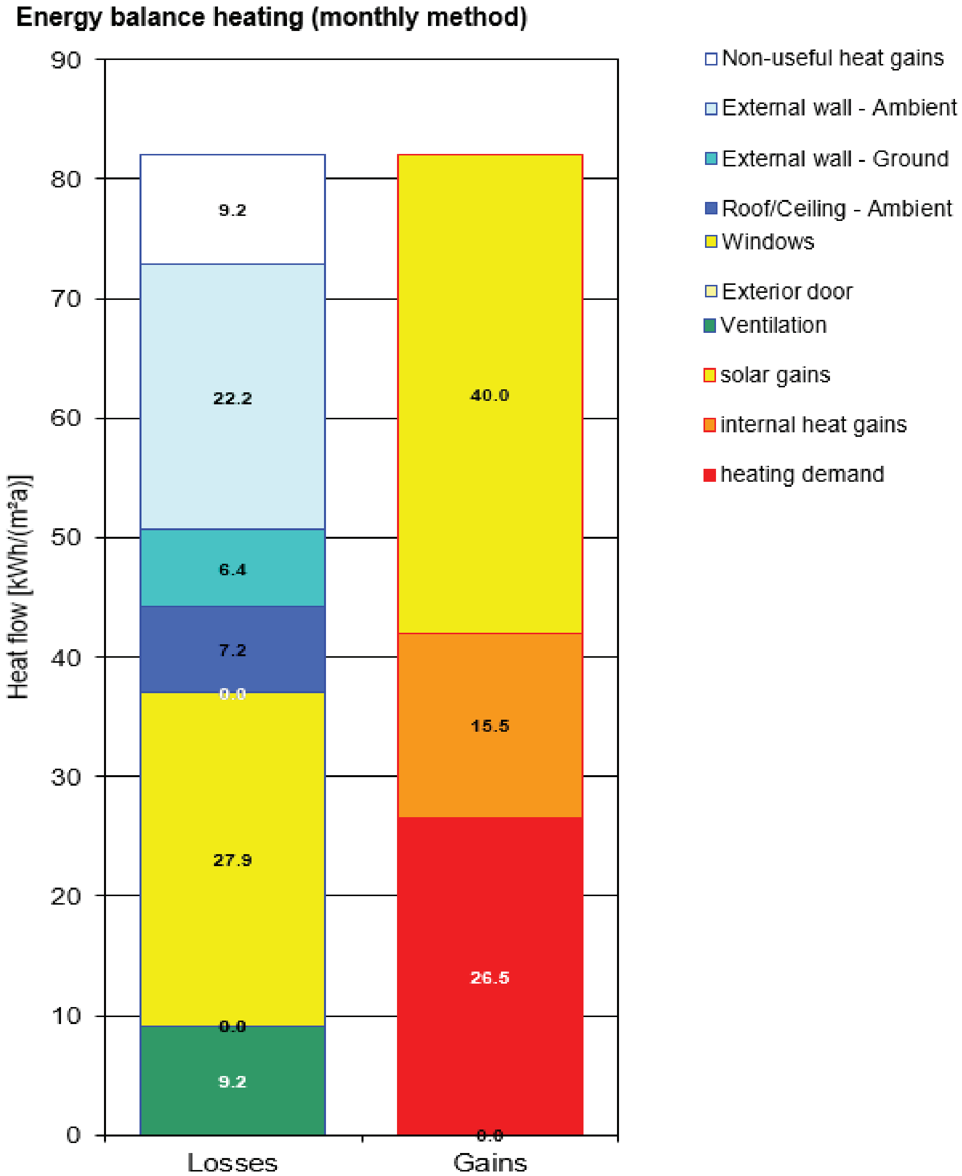
FIGURE 14. Energy balance showing heat losses through envelope and heating demand for base case in Yellowknife.



Despite Halifax having the same climate as Victoria according to Passive House Planning Package (PHPP), the heating demand is nearly double. The base model heating demand for Halifax and Toronto are such that the passive house requirements could be met by simply swapping some of the building components to more efficient versions, although this would increase costs. Edmonton requires additional reduction of non-south facing windows and increasing the area of south facing windows.

The base model in Yellowknife has more than double the heating demand of Edmonton, and more than the heating demand of all the other locations combined. The heating demand was high enough that a new alternate design was made once it became clear that simply modifying the original design would not be sufficient. The alternate design was more rectangular, with a higher volume to surface area ratio. Through measures such as removing all non-south facing windows and using the most efficient components in the PHPP database, the heating demand was cut by 64%. However, this was still not enough to meet the requirements.

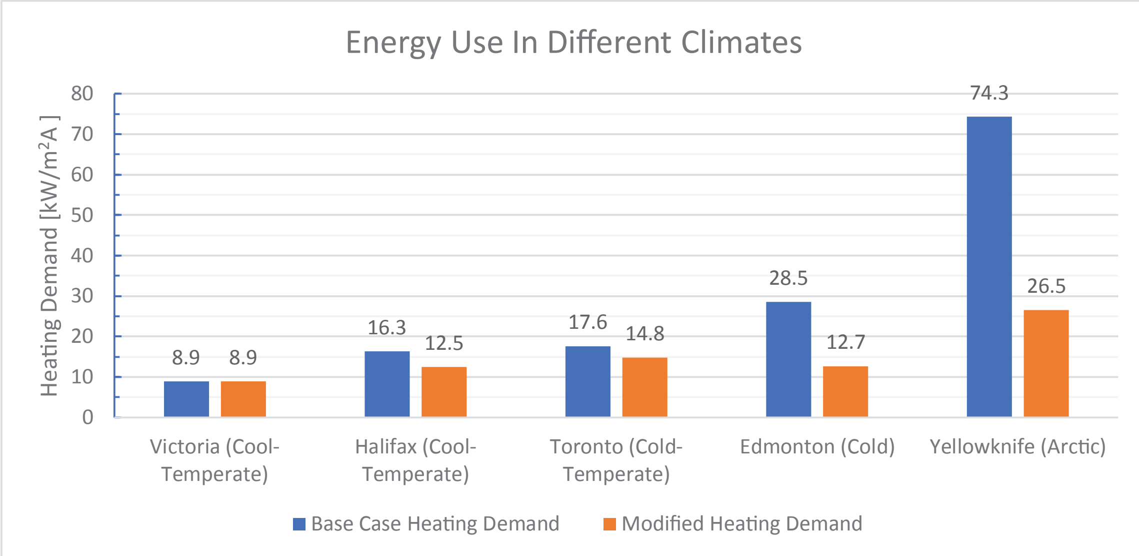
FIGURE 15. Energy balance showing heat losses through envelope and heating demand for the modified design in Yellowknife.



It is possible to reduce the heating demand further by introducing insulating shutters or panels to cover the windows at night to reduce energy transfer through them, while being removed during the day to make use of solar thermal gains. Using two-inch foam panels resulted in an estimated reduction of 4.9 kW/m^{2}a, and using the same vacuum insulation panels (VIPs) as the walls reduced the demand by 8.8 kW/m^{2}a.

One measure that could be taken to further reduce the heat loss through external walls is to make use of snow, much like igloos. The weather resistant nature of the shipping containers, coupled with having all windows and openings on the south facing side of the building makes this possible. Snow cleared from the solar panels (if used), driveway, and other areas of the

FIGURE 16. Comparison of heating demand in different climates for base cases and modified cases.



property if needed can be blown on top of the roof and against the walls. However, load calculations need to carried out for checking the safe snow load carrying capacity of the container structure. The cold temperatures of much of the year mean that there is only approximately one month a year where there is no naturally deposited snow on the ground. The snow that is piled on the building will be there for the majority of the year. Dry snow has an R-value of around one per inch; for example, having around two feet of snow would give about R24 (4.22 RSI) to the exterior. However, the PHPP software does not allow for the U-values of surfaces to change during different times of the year. As a result, a constant value would have to be selected that averages out through the year. Due to this and the variability of the snowfall and melting rates, this option was not modeled, but it could be done.

SUMMARY AND CONCLUSIONS

Passive houses are buildings with high performance envelopes that minimize heat flows and ensure thermal comfort and energy efficiency. Building a passive house with shipping containers in five different Canadian climate zones, is a new concept that has been explored in this study. Challenges to achieve required energy efficiency have been addressed through the use of appropriate building materials, components and design changes. The Passive House Planning Package (PHPP) has been used to design and calculate the energy balance in the shipping container passive houses. A comparison of energy performance of shipping container passive house in each of the five Canadian climate zones shows that with appropriate minimal design modifications shipping container passive house performs well in Cool–Temperate, and Cold–Temperate climates of Halifax and Toronto, respectively. Only moderate modifications are required for Cold climates such as Edmonton. It is found that even with an alternate design with extensive modifications, the proposed design does not meet passive house requirements in Yellowknife, which has an arctic climate.

REFERENCES

1. Schnieders, J., and Hermelink, A., 'CEPHEUS results: measurements and occupants' satisfaction provide evidence for Passive Houses being an option for sustainable building'. Energy Policy, 34, 2006, pp. 151–171.
2. Passive House Knowledge Database, Passive House Institute, https://passipedia.org/, retrieved March 2017.
3. Schiano-Phan, Rosa, Brian Ford, Mark Gillott, and Lucelia Rodrigues. "432: The Passivhaus Standard in the UK: Is It Desirable? Is It Achievable ?," January 1, 2008.
4. Brew, James Scott. "Achieving Passivhaus Standard in North America: Lessons Learned." ASHRAE Transactions 117, no. 2 (July 2011): 51-.
5. "Projects Archive." Passive House Canada | Maison Passive Canada. Accessed December 17, 2018. https://www.passivehousecanada.com/projects/.
6. Schnieders, J., Feist, W. and Rongen. L., Passive houses for different climate zones, Energy & Buildings, 105, 2015, pp. 71–87. DOI: 10.1016/j.enbuild.2015.07.032.
7. Badescu, Viorel, Nicolae Rotar, and Ioana Udrea. "Considerations Concerning the Feasibility of the German Passivhaus Concept in Southern Hemisphere." Energy Efficiency 8, no. 5 (October 2015): 919–49. https://doi.org/10.1007/s12053-015-9332-8.
8. Prisco, J., 'Starburst' container residence to rise in California desert', CNN, December 2017, https://www.cnn.com/style/article/joshua-tree-container-house/index.html.
9. Harrison, K. L. 'Shipping Container Homes Could Help Solve the Housing Crisis in Puerto Rico', Inc., 2018, https://www.inc.com/kate-l-harrison/puerto-rico-should-rebuild-with-shipping-container-homes.html.
10. "Container City I—Projects—Container City." Accessed December 17, 2018. http://www.containercity.com/projects/container-city-I.
11. Insider, Clinton Nguyen, Business. "This Shopping Mall in Seoul Is Made Entirely of Shipping Containers." Business Insider. Accessed December 17, 2018. https://www.businessinsider.com/this-mall-in-seoul-is-made-of-recycled-shipping-containers-2016-7.
12. August 2, Bruce Constantineau Updated:, and 2013. "Vancouver Social Housing Built from Shipping Containers | Ottawa Citizen," August 1, 2013. https://www.ottawacitizen.com/news/canada/vancouver-social-housing-built-from-shipping-containers.
13. Bowley, W. and Mukhopadhyaya, P. 'A Sustainable Design for an Off-Grid Passive Container House', Journal of International Review of Applied Sciences and Engineering, Volume 8, Issue 2, 2017, pp. 145–152.
14. 'Active for more comfort: Passive House, Information for property developers, contractors and clients', International Passive House Association, Rheinstraße 44 | 46, 64283 Darmstadt, Germany, 2014, http://www.passivehousecanada.com/downloads/iPHA_Brochure.pdf.
15. Feist, W. (Ed.), Passive House Planning Package, Passive House Institute, Darmstadt (1998–2015).
16. THRESHHOLD™, R 50 is The Next Step in vacuum insulation, Available: www.thermalvisions.com/Theshhold_page.html.
17. Mukhopadhyaya, P., Molleti, S. and van Reenen, D. "Vacuum Insulation Panel (VIP): An Historic Opportunity for the Building Construction Industry," Interface, Technical Journal of RCI, August 2014.
18. Mukhopadhyaya, P., MacLean, D., Korn, J., van Reenen, D., and Molleti. S. "Building application and thermal performance of vacuum insulation panels (VIPs) in Canadian subarctic climate', Energy and Buildings, Volume 85, Dec 2014, pp. 672–680.