Building to the Passivhaus Standard for New Construction Commercial & Institutional Buildings

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March 17, 2015

Status: Final
Revision: 02

Authorization

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Acknowledgments

This study has received the whole-hearted support of many individuals. A special thanks to Alexandre Hebert and Jennie Moore from the BCIT School of Construction, for providing direction and full support for this study.

Gratitude also goes to Vanesa Alzate Respeto and the Factor Four team for their valuable contributions. Also appreciated is the reliable information and subject matter expertise provided for this study. In particular, thanks goes to Mark Bernhardt from Bernhardt Contracting, Elise Woestyn from HCMA Architects, Sarah Rohler from RHPD, Guido Wimmers from Building Evolution, and Heidi Grantner from Synergy Enterprises. Without their willingness to assist, this study would not have been at all possible.

Executive Summary

With 47,000 students enrolled annually, BCIT is the largest post-secondary institution in British Columbia. BCIT's vision is to be integral to the economic, social, and environmental prosperity of British Columbia. The School of Construction and the Environment (SoCE) is one of BCIT's six schools. It offers construction trades as well as construction sciences, environmental sciences and technology programs. The scientific community has called for a 75% (Factor Four) reduction in global levels of energy and material consumption to achieve ecological sustainability. This target has often been perceived as "unrealistic", and the goal of BCIT SoCE's Factor Four initiative is to explore, with the help of BCIT's community (Students, Faculty and Researchers), how these reductions are possible and whether they can be achieved without compromising service levels.

In 2013, BCIT's Factor Four Team investigated Energy Conservation Measures (ECM) to improve the energy performance of Building NE1, a 20,000 m^2 Trades & Technology and mix-use educational building within the Factor Four area located at the Burnaby main campus. ECMs were identified that would reduce total energy consumption to reach the set intensity target, while improving air quality and thermal comfort; however, based on surveys done to evaluate seismic risk and deferred maintenance value, reports showed that demolishing and rebuilding Building NE1 as a new construction was more economical than proceeding with a major renovation. Further, Sandra Rohler of RPHD (Rohler Passivhaus Design) was contracted and released a preliminary building analysis report on Building NE1. This work defined a set of recommendations that included researching and understanding the implications of rebuilding NE1 to the meet the Passivhaus Standard while also achieving LEED Gold Certification, as a means to reach the energy intensity target set for NE1 in the Factor Four energy plan.

The objectives of this study are to build upon the recommendation of RPHD and assess the Passivhaus standard as it relates to new construction of Commercial and Institutional (C&I) buildings at BCIT, while studying the differences in building science, design and construction with LEED, and identify priority actions and recommendations to further develop the business case for the Passivhaus standard. Specifically, the following research questions will be investigated:

- What is a Passivhaus building and why pursue the standard?
- What are the implications of committing to building a Passivhaus building at BCIT while meeting the LEED Gold requirement for all new construction and major renovation projects at BCIT?
- Are there real-world examples that can be used for comparison and evaluation?

The study was conducted through primary and secondary research. The approach taken to ensure currency of the information was to conduct in-person and electronic interviews with industry stakeholders and utilize the results of a 3rd party general survey to synthesize appropriate recommendations and priority actions. This report will therefore present an overview of the LEED rating system and a focused review on the Passivhaus Standard for C&I buildings. Findings will be considered to inform BCIT stakeholders of the critical considerations

to meet the Passivhaus standard for new construction development. The report is presented in the following sections:

Section 1: Introduction
Section 2: Canadian Construction Industry: A Primer
Section 3: Leadership in Energy and Environmental Design (LEED)
Section 4: Passivhaus Standard
Section 5: Analysis and Assessment
Section 6: Recommendations & Priority Actions

Results of the study indicate that the Passivhaus standard is achievable in not only residential but commercial and institutional buildings, as evidenced by the 17 certified and registered Passivhaus institutional buildings throughout the world. Although there are currently no certified Passivhaus institutional buildings in Canada, the principles of the standard remain the same; however, design criteria needs to be adapted for the specific climatic conditions in order to meet the standard. The commercial availability of Passivhaus-quality components and materials are difficult to procure in North America; however, locally sourced and high quality components/materials are available and could most likely meet the stringent requirements of the standard. The LEED rating system and the Passivhaus Standard cannot be compared like for like as each has a different focus, e.g., the primary focus of Passivhaus is on energy efficiency whereas LEED focuses on broader sustainable development categories, including energy efficiency. In terms of energy performance, the Passivhaus's energy performance requirement can award most of the points (35%) available in the Energy and Atmosphere category to help achieve LEED Gold certification.

The overall conclusion is that LEED and Passivhaus are complementary. If the stringent energy performance requirement of the Passivhaus standard is met in the building design, this achievement would help reach LEED Gold Certification or higher, while the broad categories of LEED would allow a continued pursuit of other sustainable development and design. A Passivhaus building at BCIT would be the first of its kind in Canada and would be the final piece of the Factor Four puzzle, allowing the SoCE to officially operate on 25% of its historical energy consumption. BCIT's School of Construction and Environment (SoCE) is ideally positioned to lead and pursue the Passivhaus standard, as they have the opportunity, capacity and established framework to benefit from the knowledge and experience gained through constructing a Passivhaus building. However, lack of knowledge and experience of the Passivhaus standard is a top barrier towards adoption.

A summary of the recommendations generated from this study are as follows.

1. BCIT could consider replacing NE1 with a LEED GOLD certified building while meeting the Passivhaus standard. Next steps could include:

    a) Perform a detailed costs and benefits analysis, or Lifecycle cost (LCC) study of building to the Passivhaus standard.

    b) Perform cost and compatibility comparison in the context of Canadian Regulation and prospective market incentives between a Passivhaus building and conventional building.

c) Conduct an in-depth analysis on the challenges/barriers faced by developers building to LEED certification while meeting the Passivhaus standard.

d) Initiate conversation with BC Hydro regarding the New Construction incentive program to adopt PHPP as a recognized tool for energy modelling.

2. BCIT could further explore what it would mean to position BCIT as an educational leader in Passivhaus design and construction:

    a) BCIT could create a PassivHaus implementation guide.

    b) BCIT could engage in study tours to interact with experts and visits to relevant sites.

    c) BCIT could educate in the form of curriculum development through the SEMAC program or architecture or construction programs.

    d) BCIT could develop/offer a formal program on Passivhaus Design and Construction for those who aim to become a Certified Passivhaus Designer/Consultant.

    e) BCIT could develop/offer a formal program on Passivhaus Trades Person training.

    f) BCIT could consider becoming a Passivhaus accredited building certifier and/or resource hub in North America.

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List of Acronyms

A/V	Surface area to interior volume ratio
ACH	Air Changes per Hour
C&I	Commercial and Institutional
CaGBC	Canadian Green Building Council
CanPHI	Canadian Passivhaus Institute
HRV	Heat Recovery Ventilator
iPHI	International Passivhaus Institute
kW	kilowatt
kWh	kilowatt hours
LEED	Leadership in Energy and Environmental Design
Low-e	Low emissivity
MVHR	Mechanical Ventilation with Heat Recovery
O&M	Operations and Maintenance
PHPP	Passivhaus Planning Package
SoCE	School of Construction and Environment
USGBC	US Green Building Council

Revision History

Rev	Description	Revised by	Date
D01	Initial draft	C.Lum	Dec 24, 2014
D02	Draft of Final Report	C.Lum	Feb 24, 2015
R01	Completed final draft report with feedback from reviewer	C.Lum	Feb 26, 2015
R02	Final document release	C.Lum	Mar 17, 2015

Introduction

Background

With 47,000 students enrolled annually, BCIT is the largest post-secondary institution in British Columbia. BCIT's vision is to be integral to the economic, social, and environmental prosperity of British Columbia. BCIT's foundation is comprised of certificates, diplomas, and both undergraduate and graduate degrees: the entry-to-practice credentials that lead to rewarding careers. These are enhanced by programs and courses that are aligned with career development and growth, and include industry services, advanced studies, and continuing education. BCIT offers experiential and contextual teaching and learning with interdisciplinary experiences that model the evolving work environment. Finally, BCIT conducts applied research to enhance the learner experience and advance the state of practice.

The School of Construction and the Environment (SoCE) is one of BCIT's six schools. It offers construction trades as well as construction sciences and technology programs. It is also home to BCIT's environmental sciences certificate, diploma and degrees. Having both the School of Construction and the School of the Environment under one roof, SoCE is concerned with the built environment, the natural environment and the relationship between them. Tackling energy / climate change challenges associated with buildings is in SoCE's DNA.

The scientific community has called for a 75% (factor four) reduction in global levels of energy and material consumption to achieve ecological sustainability. This target has often been perceived as "unrealistic", and the goal of BCIT SoCE's Factor Four initiative is to explore, with the help of BCIT's community (Students, Faculty and Researchers), how these reductions are possible and whether they can be achieved without compromising service levels. The Factor Four area is located on the north end of BCIT's main campus (located in Burnaby) and is comprised of seven buildings (NE1 to NE8) where SoCE delivers most of its construction programs.

The focus of this study is on Building NE1 (also known as the J.W Inglis Building), a 20,000 m^2 Trades & Technology mix-use educational building within the Factor Four area. Currently, the following vocational programs and services are offered within NE1:

- Architectural Science
- Architectural and Building Engineering Technology
- Architectural and Structural CADD and Graphics Technician
- Building Construction Technology
- Building Design and Architectural CAD
- Building Engineering/Building Science (Master of Applied Science)
- Building Science (Master of Engineering)
- Civil Engineering
- Construction Management
- Interior Design

- HVAC Refrigeration
- Millwright
- Electronics Technician
- Food Services (Tim Hortons, Convenience Store, Austin Grill Café)

The size of the building and the diversity of programs & services offered are reflective of its energy consumption. The baseline energy consumption and energy use intensity for NE1 is:

- **4,853,000 kWh/year** for all sources of energy (measured at building level, i.e.: not primary energy)
- **242 kWh/m^2/year** for all sources of energy (measured at building level, i.e.: not primary energy)

In 2013, BCIT's Factor Four Team investigated Energy Conservation Measures (ECM) to improve the energy performance of Building NE1. ECMs were identified that would reduce total energy consumption to reach the set energy intensity target, while improving air quality and thermal comfort; however, based on surveys done to evaluate seismic risk and deferred maintenance value, reports showed that demolishing and rebuilding Building NE1 as a new construction was more economical than proceeding with a major renovation. Further, Sandra Rohler of RPHD (Rohler Passivhaus Design) was contracted and released a preliminary building analysis report on Building NE1. This work defined a set of recommendations that included researching and understanding the implications of rebuilding NE1 to the meet the Passivhaus Standard while also achieving LEED Gold Certification, as a means to reach the energy intensity target set for NE1 in the Factor Four energy plan.

Report Objectives

The objectives of this study are to build upon the recommendation of RPHD and assess the Passivhaus standard as it relates to new construction of Commercial and Institutional (C&I) buildings at BCIT, while studying the differences in building science, design and construction with LEED, and identify priority actions and recommendations to further develop the business case for the Passivhaus standard.

Specifically, the following research questions will be investigated:

- What is a Passivhaus building and why pursue the standard?
- What are the implications of committing to building a Passivhaus building at BCIT while meeting the LEED Gold requirement for all new construction and major renovation projects at BCIT?
- Are there real-world examples that can be used for comparison and evaluation?

The study aims to inform BCIT stakeholders about decisions around building to the Passivhaus standard and how it may be realized for new construction opportunities at BCIT.

Study Scope and Methodology

The broad objectives of this study were focused on the Passivhaus standard as it relates to New Construction building opportunities at BCIT. The study was conducted through primary and secondary research. The approach taken to ensure currency of the information was to conduct in-person and electronic (i.e. email) interviews with industry stakeholders and utilize the results of a 3rd party general survey to synthesize appropriate recommendations and priority actions.

This report will therefore present an overview of the LEED rating system and a focused review on the Passivhaus Standard for C&I buildings. Findings will be considered to inform BCIT stakeholders of the critical considerations to meet the Passivhaus standard for new construction development.

The report is presented in the following sections:

Section 1: Introduction
This section serves as a background to outline the study objectives, scope and methodology as it relates the goals and objectives of BCIT's School of Construction Factor Four Initiative.

Section 2: The Canadian Construction Industry
Provides an introduction to the current Canadian Construction Industry and context for the environment and Green Buildings.

Section 3: Leadership in Energy and Environmental Design (LEED)
Presents an overview of Leadership in Energy and Environmental Design (LEED), outlining the different rating systems, credit categories and certification.

Section 4: Passivhaus Standard
Presents a focused review of the Passivhaus Standard with a Commercial & Institutional (C&I) context, while introducing the Passivhaus Planning Package (PHPP), Passivhaus building design principles, occupant benefits, followed by discussion on Operations & Maintenance and Education & Training and Certification.

Section 5: Analysis & Assessment
Presents the special considerations for building non-domestic Passivhaus buildings, while discussing through a Canadian context, the technology availability, capital and operational cost considerations, followed by a discussion on how the Passivhaus standard could help satisfy LEED Gold Certification as well as presenting real-world examples of Passivhaus C&I buildings that are certified around the world.

Section 6: Recommendations and Priority Actions
Summarizes the outcomes of the study and makes recommendations to further develop the business case for building to the Passivhaus standard at BCIT.

The Canadian Construction Industry: A primer

Canada's Construction Industry

The construction industry in Canada is one of the largest industries/sectors and a key economic driver for the country. The Canadian Construction Industry employs more than 1.22 million Canadians, and accounts for $72 billion in economic activity or 7 percent of Canada's annual Gross Domestic Product (GDP). With aging national infrastructure, and the global demand for natural resources, Canada's construction market is the 5th largest in the world (Canadian Construction Association, 2015).

Construction and Environment

The construction industry is responsible for the infrastructure that supports life, the economy and protection of assets from the external environment. Specifically, this industry is responsible for the building and maintenance of buildings and homes, roads and highways, bridges, rail lines and airport infrastructure.

However, the construction industry has a significant and detrimental impact on our planet, and in Canada, heating and cooling energy alone represents 75-85% of the environmental impact of a building over its total lifecycle. In British Columbia alone, existing buildings account for 12% of total GHG emissions, and 48% if processes involved to construct buildings is taken into account (Pacific Institute for Climate Solutions, 2008).

This increase in infrastructure demand has opened up a job market requiring ethically responsible skilled trades and construction professionals and practitioners whom each have a unique responsibility to the environment to choose sustainable best practices and materials to reduce their carbon footprint on New Construction and Major Renovation construction projects.

Green Buildings

With the context of the construction industry, a Green Building refers to a structure that is constructed or renovated using a process that is environmentally responsible, utilizing resources more efficiently and providing a healthy indoor environment. The act of building and constructing is inevitably going to impact the environment and consume resources, so a green building's focus is on restoring or protecting the environment to reduce their overall footprint and impact on the environment ("Green Building Rating Systems", 2014).

Green Buildings are often described as being open and welcoming, and often considered 'modern' and 'state of the art'. Not only must a green building minimize environmental impacts, but it should also provide a healthy and comfortable indoor environment benefiting occupants, operators and owners with increased productivity, reduced operating costs, and a higher real estate market value.

Through New Construction and Major Renovation projects, an increasing number of buildings are incorporating green features such as green roofs, recycled materials and rainwater collection systems. This adoption shows an explosive growth of the green building movement demonstrating the growing consensus about the worldwide imperative to building "Green" buildings.

The definition of a "Green" Building is ever evolving and is essentially arbitrary. Consequently, various green building rating systems have been developed by industry stakeholders and building professionals. One of them is Leadership in Energy and Environmental Design (LEED), which is North America's leading green building standard.

Leadership in Energy and Environmental Design (LEED)

Overview

In Canada, the Canadian Green Building Council (CaGBC) administers the LEED (Leadership in Energy & Environmental Design) ratings system which is an internationally recognized certification program that was developed by the US Green Building Council (USGBC) and it consists of a comprehensive system of interrelated standards covering all aspects of the design, construction and maintenance of green homes and buildings, while encouraging sustainable building design and renewable energy solutions.

LEED has been widely accepted as the leading green building standard in North America. LEED addresses a broad range of sustainability and environmental concerns impacting the North American construction industry like energy efficiency, toxicity of materials used, promoting renewable materials, water conservation, storm water management, waste reduction, access to alternative transportation and applications of renewable technologies. The broad categories of LEED focus on sustainable building features that can be easily showcased to the general public. With occupants who are concerned about being environmentally responsible, LEED certification is ideal for communities that aim to live a sustainable lifestyle.

LEED certification is achieved through one of the 5 rating system for Commercial and Institutional buildings:

- LEED-NC (New Construction and Major Renovation)
- LEED-EBOM (Existing Buildings: Operations & Maintenance)
- LEED-CS (Core & Shell Development)
- Commercial Interiors (LEED-CI)
- Neighbourhood Development (LEED-ND)

Each ratings system assigns points to generate a score based on the implementation of green building design and construction solutions. Points can be awarded based on 5 main LEED Credit categories.

LEED Credit Categories

Each category has prerequisites that must be met to achieve certification. It is important to note that LEED does not prescribe, and not every project must meet identical requirements to qualify. There are five main credit categories assessed in LEED that result in points accumulation toward certification:

1) **Water efficiency**
   Indoor/outdoor water conservation plan to reduce the burden on the municipal water supply, including low flow, rainwater capture and water efficiency measures
2) **Sustainable Sites and development**
   LEED allocates points for choosing to build on a site that is accessible by public transportation, within proximity of existing infrastructure and amenities.
3) **Materials and resources**
   A construction management program is necessary for LEED certification. Finding creative ways to reuse material, or incorporate waste materials into new material is encouraged. In addition, LEED recommends the use of locally sourced materials to reduce the environmental impact of transporting goods.
4) **Indoor environmental quality**
   To quality for LEED points for indoor environmental quality, the building must focus on occupancy comfort. Factors include indoor air quality, ventilation, thermal comfort, and natural lighting are considered for certification.
5) **Energy and atmosphere**
   Energy efficiency is an integral part of LEED certification. Selecting and commissioning of energy efficient lighting, heating systems, energy performance and refrigerant management with a focus on mitigating use of refrigerants such as Chlorofluorocarbon (CFC).

Levels of Certification

The certification level is awarded based on points achieved (total possible score of 100). Four (4) certification levels that can be achieved: **Certified, Silver, Gold, Platinum**

Table 1: List of LEED certification levels

Certification Level	Points Range
Certified	40 - 49 points
Silver	50 -59 points
Gold	60 -79 points
Platinum	80 + points

LEED Gold requirement for New Construction Public Buildings

As of 2007, The Government of British Columbia set out to mitigate the direct consequences related to global warming by passing the Greenhouse Gas Reductions Target into legislation. The legislation called for improving transportation and transit to reducing GHG emissions and building green communities. In particular, this mandated that all publicly-owned new construction and major renovation building projects in BC over 600 m^2 in British Columbia must achieve a minimum LEED Gold certification. Thus, if the proposed rebuilding of Building NE1 (20,000 m^2) were to achieve the Passivhaus standard, it would also have to achieve LEED Gold certification.

Passivhaus Standard

Overview

The Passivhaus Standard is one of Europe's most recognized green building standard that provides the most rigorous framework for energy efficiency that is widely proven and fairly affordable (Passive House Institute, 2012). The standard was developed by the Passivhaus Institute (PHI) by Dr. Wolfgang Feist and Dr. Bo Adamson, after studying nascent green buildings built in the 1970s, particularly Canada's Saskatchewan Conservation House and other similar green buildings looking to, "calculate a balance point below which the installation of more insulation provided a measurable return on investment, and above which more insulation returned no economic benefit." (Paulsen, M., 2013). This economic "sweet spot" is what defines the Passivhaus standard and the key to its financial feasibility, resulting in a short return on investment for the cost of additional energy saving features.

The term "Passivhaus" has commonly been anglicized to "Passive House". The German word "haus" translates to "building" and not "house", which has caused confusion and thus the standard can be realized for any type of building, not just residential buildings (i.e. houses). The Passivhaus standard was developed on the premise that these green buildings would use no traditional active heating or cooling systems (i.e. passive systems) and would deliver real and significant reductions in energy consumption through detailed energy efficient design, services and construction.

Buildings built to the Passivhaus standard have seen reduced heating and cooling energy consumption by 80-90% compared to conventional structures (Passivhaus Institute, 2012) using high R-value insulation, thermally efficient windows, weather stripping, energy efficient appliances and a Heat Recovery ventilation (HRV) system. These proven techniques have also received widespread attention from the European Union, whom have legislated all new construction must be "near zero energy" by 2020, and many feel the Passivhaus standard is the best way to achieve that target (UK Passivhaus Trust, 2011).

The Passivhaus is an extremely insulated building that minimizes thermal losses with superinsulation and high performance windows, while maximizing passive gains through solar orientation, and heat gains from occupant body heat, existing appliances and building operations. The key mechanical feature of the Passivhaus is the air-to-air heat exchanger, that constantly brings in pre-heated fresh air to regulate temperature, CO_2, humidity and oxygen levels.

It is important to note that PassivHaus certified buildings are not to be confused with 'Passive Solar Houses'. The term Passivhaus relates to a well defined energy efficiency standard, whereas a Passive Solar House typically relates to a house with passive solar design features. While Passive Solar Houses are designed to collect heat from the sun through insulation, thermal mass materials and extensive south-facing glazing, the Passivhaus standard places more importance on airtight envelope construction, energy efficient windows, and an efficient ventilation with heat recovery system to pre-heat fresh incoming air.

According to the International Passivhaus Association (2015), there are now more than 50,000 Passivhaus-type buildings, and over 5500 certified according to the strict Passivhaus Institute certification criteria. Based on the Passivhaus Institute project database, Canada currently has 4 certified buildings, but the greatest numbers are in Germany and Austria, while numbers in Belgium and the UK are quickly on the rise. The Passive House standard can be realized in residential, commercial and institutional (C&I) buildings; this study will focus upon new construction Passivhaus buildings in a C&I context. To be termed a Passivhaus, the building must meet a set of main criteria set forth by the Passivhaus Institute.

Main Criteria for the Passivhaus Standard

A Passivhaus building primarily focuses on reducing the long term energy demand of the building, by reducing the heating and cooling demands to a near zero level. According to Building Evolution (2015), "roughly 85% of the environmental impact of a building over its lifetime is caused by its energy consumption; therefore reducing the energy consumption is becoming priority number one". The Passivhaus construction method focuses on the quality of the building envelope to be as airtight as possible and eliminating any thermal bridges through quality workmanship and construction. The most interesting aspect of the Passivhaus standard may be that it has relatively few mandatory requirements, thereby allowing design flexibility and a focus on energy consumption.

The Passivhaus standard has four (4) key requirements for certification*:

1. **Pressurization Test:**
   Every Passivhaus building must pass a blower door test to ensure a standard level of airtightness (maximum 0.6 ACH @ 50 Pascals over-pressurization and under-pressurization testing).

   A guideline to performing a blower door test for Passivhaus buildings can be found in http://www.greenbuild.ie/PassiveHouseBlowerDoorTesting.pdf

2. **Heating:**
   The building must not consume more than 15 kWh/m^2/yr in heating energy.
   Or alternatively, the building should have a peak heating load of 10 W/m^2 or less.

3. **Cooling Demand **:**
   The building must not consume more than 15 kWh/m^2/yr in cooling energy

   When active cooling is needed, the space cooling demand requirement roughly matches the heat demand requirements above, with a slight additional allowance for dehumidification. The criteria for cooling is applied provisionally; these requirements are applicable for each building and are calculated automatically in PHPP.

4. **Primary Energy:**
   Primary Energy to remain under 120 kWh/m^2/yr.

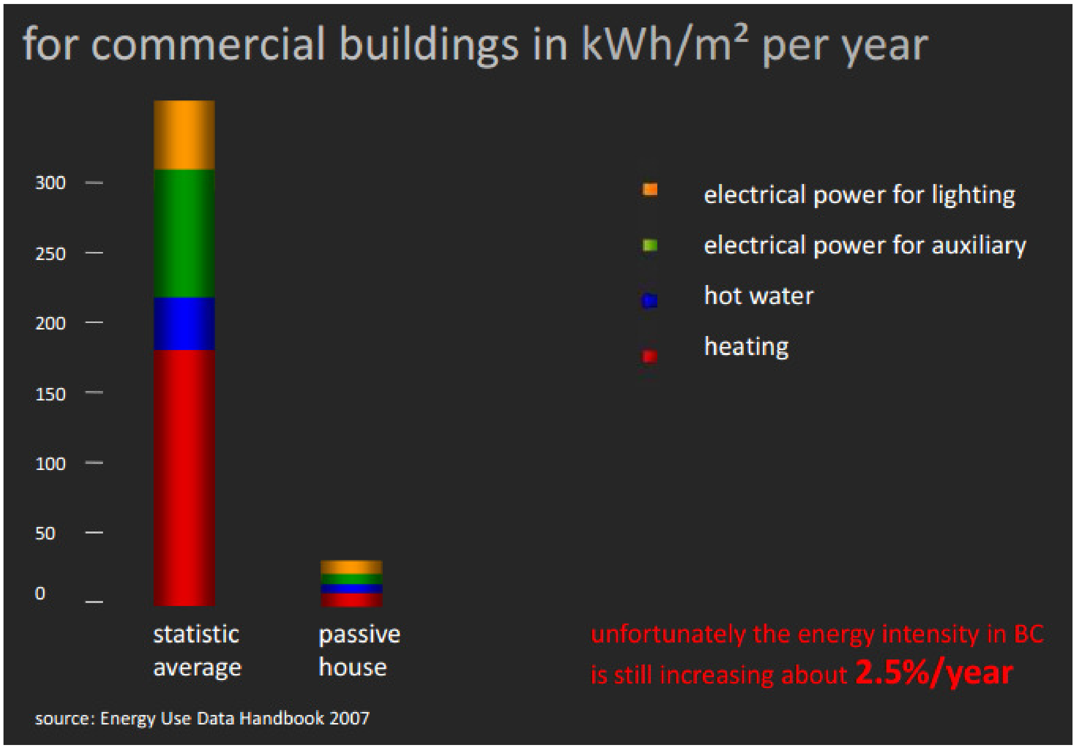
   It is important to note that Primary Energy refers to the source energy required to produce and deliver energy to the building site. Depending on the energy source (electricity or natural gas), a Primary Energy Factor is used to account for nation-wide grid and conversion losses. Therefore the 120kWh/m^2 energy intensity requirement includes energy consumption for heating, appliances and Domestic Hot Water (DHW) plus grid and conversion losses. For example, assuming electricity is the main energy source for a Passivhaus building and assuming a Primary Energy Factor of 2.3 (Canadian average), that equates to 52kWh/m^2 (i.e. 120 kWh/m^2 divided by 2.3) remains for energy consumption for heating, appliances and DHW.

* According to the Passivhaus Institute, Criteria for non-residential Passivhaus buildings, “these criteria are specifically adapted to conditions prevailing in cool, temperate climate and may need to be reviewed for starkly different climates.” All heating and cooling calculations are based on the treated net usable floor area of the building.

**According to the Passivhaus Institute, criteria for non-residential Passivhaus buildings, “The primary energy demand includes the energy demand for heating, cooling, hot water, ventilation, auxiliary electricity, lighting and all other uses of electricity. The limits set above for the specific useful cooling demand and the primary energy demand apply for schools and buildings with similar utilisation patterns. These values are to be used as a basis but may need to be adjusted according to building use. In individual cases where very high internal heat loads occur, these values may also be exceeded.” Ultimately, the metric that must be met is the 120 kWh/m^2/yr limit for primary energy. It would be acceptable to have cooling loads above 15 kWh/m^2/yr if the overall 120 kWh/m^2/yr limit for primary energy is met. To see detailed criteria requirements, go to:
http://passiv.de/downloads/03_certfication_criteria_nonresidential_en.pdf

Figure 1 shows the energy use breakdown of commercial buildings, providing a side by side comparison between a typical Passivhaus building and a conventional building.

Figure 1: Energy Use breakdown of Commercial buildings



Building Science/Construction

The building science behind the Passivhaus Standard looks at improving the interior living environment while providing robust construction and reducing total energy consumption for all building types from residential homes and commercial offices to schools and hospitals. In order to achieve the standard, energy modelling is done through the Passivhaus Planning Package (PHPP) to achieve key building design principles which include strategies to maximize passive solar heat gains and mitigating heat loss through the building envelope. Figure 2 shows a typical schematic of a Passivhaus building.

Figure 2: Passivhaus Building Schematic

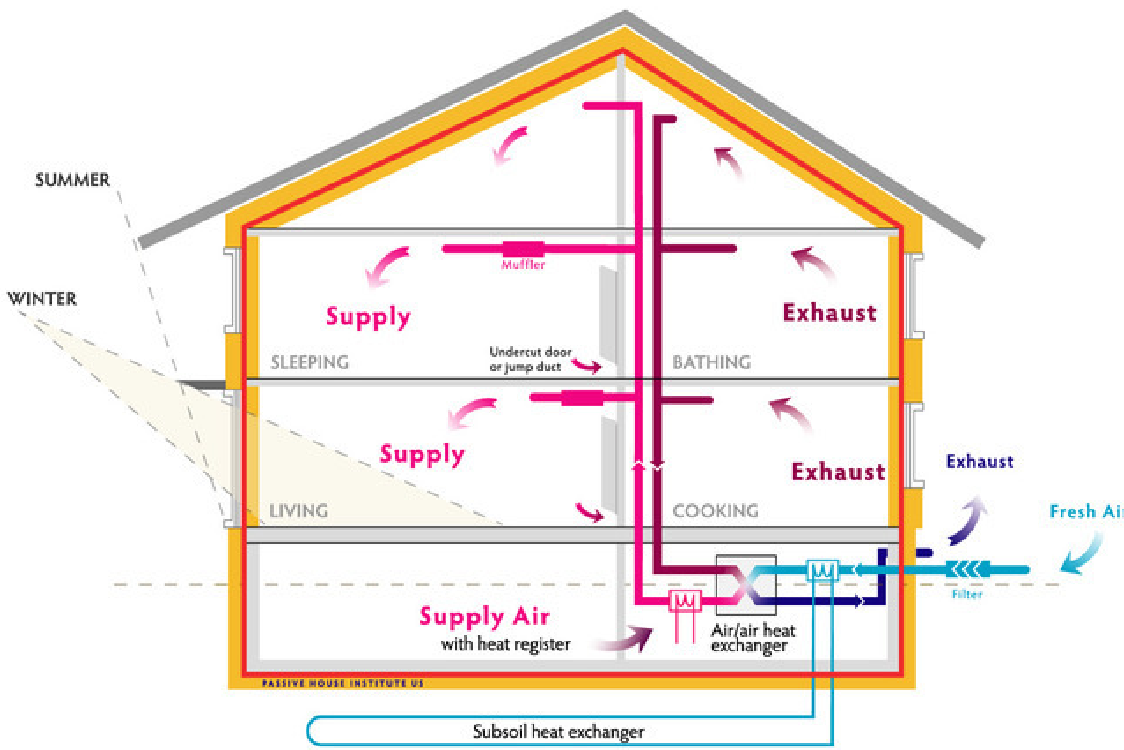


*Image Courtesy of PHIUS

Passivhaus Planning Package (PHPP)

The Passivhaus Institute (PHI) provides a list of steps covering how to achieve the requirements of the Passivhaus standard. In particular, PHI developed the Passivhaus Planning Package (PHPP), a macro-embedded Excel spreadsheet used to model the performance of the proposed Passivhaus building, and to verify and assess that Passivhaus criteria has been met.

PHPP is a tool that provides reliable calculation of performance characteristics and serves as a communication tool that can be used between stakeholders. The tool will allow any building designer or architect to effectively communicate and specify the building components and systems required to meet the Passivhaus standard in the respective climate zone, allowing for example, heating and cooling systems to be confidently sized, insulation thickness to be specified, lighting and appliance analysis, detailed shading and even specify scientifically validated and certified Passivhaus components (Passivhaus Institute, 2012).

Within PHPP, there are a series of tools designed specifically to model the energy performance of a building including:

- Energy balance and attribute calculations
- U-Values calculations
- Heating, cooling, primary energy demand calculations
- Summertime overheating risk
- Sizing appropriate ventilation systems
- Localized climate data
- Addressing thermal bridges within the building envelope

All calculations in PHPP are based strictly on the laws of physics and where possible, on current international standards. The calculations are instantaneous where after changing a variable, the user can see immediately the effect on the energy balance of the building. This makes it possible to compare components of varying quality to optimize the design. The results of PHPP calculations are displayed on a Verification sheet within PHPP. Figure 3 shows a section of PHPP's "Verification" sheet with the results of sample detached house.

Figure 3: Verification sheet from PHPP

Specific building demands with reference to the treated floor area

				Requirements	Fulfilled?*
	Treated floor area	156,0	m^2		
Space heating	Heating demand	14	$kWh/(m^2a)$	15 kWh/(m²a)	yes
	Heating load	10	W/m^2	10 W/m²	yes
Space cooling	Overall specif. space cooling demand		$kWh/(m^2a)$	-	-
	Cooling load		W/m^2	-	-
	Frequency of overheating (> 25 °C)	1,6	%	-	-
Primary energy	Heating, cooling, dehumidification, DHW, auxiliary electricity, lighting, electrical appliances	60	$kWh/(m^2a)$	120 kWh/(m²a)	yes
	DHW, space heating and auxiliary electricity	33	$kWh/(m^2a)$	-	-
	Specific primary energy reduction through solar electricity	25	$kWh/(m^2a)$	-	-
Airtightness	Pressurization test result n_{50}	0,2	1/h	0,6 1/h	yes

* empty field: data missing; '-': no requirement

Although PHPP was originally designed for Passivhaus buildings, it is a design tool that can be used for other buildings. For example, PHPP has a modelling tool that can be used to address thermal bridges and can be applied in the LEED modelling process, thus helping deliver on promised building performance (Passivhaus Institute, 2012).

PHPP's current Version 8.5 (2014) is available for purchase for a nominal fee.

Passivhaus Building Principles

Efficient Building Structure

Heat loss and heat gain through any building's envelope can affect energy use and energy costs. The buildings heat loss and/or natural heat gain from any building envelope is proportional to the area of the surface exposed to the outside environment. The Passivhaus standard calls for a minimized building surface area to achieve exceptional energy efficiency; however, no particular design aesthetic or architectural style is required. Passivhaus designers use a "Shape Factor", which describes the ratio of the building envelope's surface area over the building volume (i.e. A/V). In addition, effective external shading strategies are employed whenever possible. All construction methods can be used for Passivhaus and have been proven successfully: masonry, construction, lightweight construction, prefabricated elements, insulating concrete formwork construction, steel construction and/or a combination of the materials listed.

Building Orientation and Solar Exposure

In a certified Passivhaus building, building orientation and solar exposure is an important consideration that is addressed early in the design stage. Proper assessment of heat gains in the summer and winter are accounted for as occupants, appliances and the solar heat gain are sources to passively heat the home. To effectively take advantage of the solar heat gain in the winter, southernly building orientation with glazed windows is crucial. As with any highly insulated building, overheating in the summer is addressed through effective shading strategies which include utilizing seasonal deciduous trees, fixed or mechanical sun shades, and operable and smart windows. The Passivhaus Institute (2012) states that: "window area and orientation be optimized for passive solar gain, the institute's engineers have concluded, based on computer modeling and field monitoring, that passive solar details are far less important than airtightness and insulation R-value."

Superinsulation

To prevent heat loss and heat gain in the various seasons and in order to achieve the main criteria for Passivhaus certification, all components of the exterior shell employs a continuous high performance insulation that performs 3 to 7 times better than what is specified by national and provincial building codes. i.e. R-20 2×6 wall (effectively an R-12 wall due to thermal bridging through framing members, a value which degrades over time). Most passivhaus buildings have wall and roof R-values ranging from R38 to R60 (Holloday, M., 2009).

Thermal bridge free implementation should be strived for as much as possible, especially in colder climate regions. A thermal bridge is found whenever walls and windows meet, or where floors and roofs meet. All edges, corners, and penetrations should be planned, designed and implemented carefully to avoid thermal bridges within the construction of the building. If this is not possible, thermal bridges should be minimized and the corresponding losses should be taken into account in PHPP. Figure 4 shows a thermograph of a Passivhaus home.

Figure 4: Thermograph of a Passivhaus building

Image courtesy: Simmonds Mills / Thermal Inspections Ltd.

Energy-efficient window glazing and frames

Heat loss through conventional windows and frames contributes up to 50% of heat loss through the building envelope. It is the thermally weakest part of the building envelope and Passivhaus designers looks at the utilization of triple glazed windows, 2 low-emissivity (low-e) coatings with inert gas fill (either krypton or Argon), as well as insulated spacers and frames. Windows (glazing and frames combined) should have U-Values not exceeding 0.80 W/m^2/K, with solar heat-gain coefficients around 50%. Two benefits of triple glazing: first, the surface temperature of the windows is similar to that of the surrounding internal surfaces, reducing any discomfort an occupant may experience when sitting next to the window; second, triple glazing reduces sound transmission from the outside environment.

Airtightness

In order to achieve the high levels of energy efficiency, Passivhaus buildings are extremely airtight and must meet higher than expected air tightness performance standards than conventional Canadian construction building standards (Rosenbaum, 2014). An airtight building envelope will minimize heat loss and draughts, accidental air leakage (or infiltration), and reduce the chance of mold since moisture is less likely to enter and become trapped in cavities within the building envelope.

Through a blower-door pressure air test, the Passivhaus design standard demands for a maximum airtightness level of 0.6 Air changes per hour (ACH) with respect to the building's volume at a pressure difference of 50 Pascals (Pa), a measure of how many times the air within a defined space is replaced. In this case, it is under the test conditions at the standardized 50 Pa pressure difference between inside and outside. The lower the number of air changes means less energy is required to keep that air at a comfortable temperature, resulting in potentially smaller heating and cooling equipment, which reduce both the initial investment and construction costs. Therefore, achieving this level of airtightness requires careful application of appropriate membranes, grommets, tapes and vapour membranes to form a continuous airtight barrier. To put into perspective the high level of airtightness required, a typical code-built

Vancouver home requires a minimum airtightness of 3.5 ACH which makes the Passivhaus standard roughly 6 times more airtight.

Mechanical Ventilation with Heat Recovery (MVHR)

With Passivhaus's airtight construction, relying on infiltration or air leakage alone to provide an acceptable level of indoor air quality is inadequate. Passivhaus designers therefore necessitate that a Passivhaus building must be equipped with an efficient Mechanical Ventilation with Heat Recovery (MVHR) system that provides excellent indoor air quality and highly efficient heat recovery performance (heat recovery of at least 75% or greater). The high quality MVHR required for Passivhaus certification also runs at lower speeds and therefore runs more quietly. Unlike air conditioning systems which condition and recycle air, MVHRs provide a continuous supply of fresh air into areas within the building, while exhausting odors, carbon dioxide and excess moisture out of the building. The MVHR will then extract the heat from the exhaust to preheat the incoming outside air used for ventilating the building.

A correctly sized and installed MVHR allows for the opportunity to heat the building by heating the supply air while isolating fresh incoming air and exhaust air. Since the space heating demand is low (15 kWh/m^2/yr), space heating can usually be met with an air-to-air heat exchanger with the MVHR to preheat incoming ventilation air. An alternative solution is incorporating a geo-exchange heat exchanger with the MVHR, where fresh air is brought into the building through underground ducts that exchange heat with the soil in the ground.

Energy-Saving Equipment and Plug Loads

Energy efficient equipment and plug loads such as computers and lab equipment are recommended to ensure total Primary Energy demand does not exceed 120 kWh/m^2/yr.

Benefits for Occupants

Aside from providing significantly reduced energy savings, the Passivhaus design strategy is carefully modelled to keep the building at a comfortable indoor temperature by relying on the shape and orientation of a building, a high performance heat recovery ventilation system, energy efficient windows, insulation and an airtight envelope. Although the Passivhaus standard is focused on energy efficiency, thermal comfort and indoor air quality is what attracts many to the Passivhaus standard.

Providing comfort is the fundamental purpose of a building. Buildings as a shelter seperate the outdoor environment from the living environment to provide shelter, living space, security and privacy. According to the Passivhaus Institute US (2015), "Passive houses and buildings are extremely comfortable in all seasons. That's because there are no draughts, temperature variance is extremely narrow (even near doors and windows), and because of active, balanced ventilation, indoor air quality is superb."

Indoor Air Quality

Passivhaus buildings are designed to constantly provide continuous fresh filtered air into the building through the MVHR. This insures: low CO_2 and pollutant levels, optimized air supply by room, and maintenance of healthy humidity and moisture levels. This in turn can impact occupant health and well-being in positive ways, allowing for occupants to recover from the stress of daily life, to performing physical activity and increasing productivity.

Thermal Comfort

According to the ANSI/ASHRAE Standard 55-2010, thermal comfort is defined as "that condition of mind which expresses satisfaction with the thermal environment and is assessed by subjective evaluation." (ASHRAE, 2010). Thermal comfort is often difficult to model and measure since a range of factors (i.e. temperature and humidity) must be taken into account on deciding what makes occupants feel comfortable.

Energy efficient buildings are only effective if the occupants of the buildings are comfortable. If the level of comfort is unsatisfactory, occupants will look towards alternative means of heating or cooling a space that could be substantially less energy efficient than typical HVAC systems.

Based on the fact that there is virtually no air leakage in a Passivhaus building, there is essentially no "stack effect", precluding the possibility of indoor drafts and indoor surface temperature differences throughout the building. In the summer, overheating is addressed through opening windows, using automated solar shading, and night time air circulation.

Quiet Indoor Environment

The superinsulation of the Passivhaus building envelope provides excellent sound insulation, effectively mitigating background and outdoor noise. From the insulation of the walls and roof to the triple-pane efficient windows and doors, a Passivhaus building offers a quiet indoor environment. Furthermore, the building design typically results in a smaller MVHR operating more quietly while making the building feel both comfortable in terms of sound and feel.

Net Zero Ready

The extremely low energy requirements of a Passivhaus building provides a strong foundation towards Net-Zero energy consumption, since less renewable energy is required to replace energy that would otherwise come from burning fossil fuels or other energy resources. At the current moment, it is generally more cost effective to save energy through the building envelope than it is to generate energy onsite through solar PV panels; the standard is a conservation-first approach to construction. As renewable technologies become more cost effective, the path towards Net-Zero is a target that can be realized when total energy consumption demand has been minimized. Although the Passivhaus standard does not require renewable technologies such as solar panels as part of certification, it is important to note that any solar panels added to the Passivhaus cannot be used to offset reduced standards of energy efficiency.

Operations & Maintenance (O&M)

By design, a certified Passivhaus building results in reduced heating/cooling loads, and smaller mechanical systems with reduced fan speed and capacity. This is achieved through the selection of high quality components and materials, and detailed workmanship in the design and construction, resulting in a robust and durable building. Smaller and minimal mechanical systems can make a Passivhaus building cheaper to maintain and operate than a building with a much larger conventional, and sometimes complex, mechanical system. Passivhaus's quality control and advanced design would account for the MVHR to be appropriately sized based on the building they are installed in, and the ducting system is carefully designed to provide an equal volume of air to all areas of the building.

The typical building services of a Passivhaus building that require regular and/or as-needed maintenance over the lifetime of the building include:

- Boiler for DHW (Electric or Gas)
- MVHR unit fan
- MVHR filter
- MVHR heat exchanger
- Supply and extract valves
- Duct work

Education & Training

There is a wide variety of Passivhaus trainings available ranging from short introductory Passivhaus lectures to 1-day Passivhaus Basics courses up to professional multi-day Passivhaus Designer courses and Trainer programs. Below is an overview of trainings offered worldwide:

University Programs
Some universities have incorporated Passivhaus topics into their curriculum. For example, UBC has a Passivhaus Design and Construction program for those who aim to become Certified Passivhaus Designer/Consultants.

Certified Passivhaus Designer/Consultant Program
Advanced training through seminars, training courses or private study followed by a written exam. The certificate holder demonstrates the acquired knowledge and experience needed to successfully design, plan and build Passivhaus buildings. 6-day courses offered through CanPHI in Ottawa ON, Toronto ON, and Calgary AB.

Certified Passivhaus Tradesperson Program
A training program designed for Tradesman looking to build Passivhaus buildings. The certificate holder demonstrates the acquired knowledge and experience to successfully construct and build Passivhaus buildings. Courses offered through Oklahoma State University.

Passivhaus Basics
A 1-day introductory, English-language, Passivhaus workshop for participants looking to refresh their knowledge of the Passivhaus standard as well as a modelling exercise focusing on the most important elements using PHPP. Courses offered through CanPHI in Ottawa, ON

Train the Trainer Program

A 2-day course for participants looking to become Certified Passivhaus Design Trainers. Trainers have both the technical knowledge and practical experience to help prepare others to take the Passivhaus Designer/Consultant Exam. Courses offered through PHIUS in San Diego, CA

Accredited Building Certifier Program

The Passivhaus Institute has developed a training course towards becoming an accredited building certifier. The certificate holder demonstrates an expertise in the use and application of PHPP, as this is used to evaluate the building's energy performance. Courses offered through PHIUS in San Diego, CA

Certification

Certified Passivhaus buildings must meet stringent requirements in both their design and construction, where certification is based on a pass/fail performance basis. With clearly defined targets, this uncompromising measure holds designers and builders accountable, mitigating the performance gap that is common in the construction industry. Certification is awarded on the basis of "as-built" rather than "as-designed" performance, and is conducted onsite by an Accredited Building Certifier that provides quality assurance and accountability of the final design and construction.

There are multiple ways to register and certify a Passivhaus project:

1. Original Passivhaus Institute (PHI) in Germany
2. Canadian Passivhaus Institute (CanPHI) in Canada
3. Any other participating partner

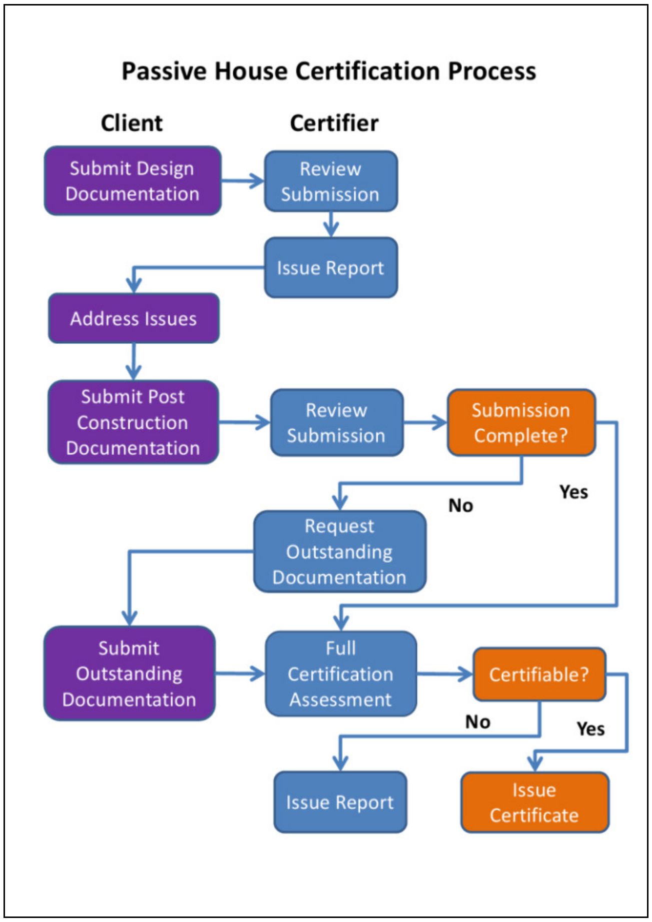
In Canada, one organization has been approved to assess and issue the Quality Assured Passivhaus certificate. Passivhaus trust members and partners in Canada who can provide certification include: Peel Passive House Consulting (www.peelpassivehouse.ca).

There are two (2) approaches that can be taken to obtain certification:

Approach 1: Design Review & Certification:

Before a building permit application is submitted, a design review is performed evaluating all drawing, specifications, and calculations of the proposed Passivhaus building. A report is issued to identify any issues with the design. The intent is to identify issues early on to mitigate deficiencies that could impact certification approval and costly changes post construction. When the building is constructed and commissioned, the as-built drawings are reviewed to verify the project meets all requirements before a certificate can be issued. Non-conformance's are addressed and if rectified, the project can be resubmitted for another assessment. It is worth mentioning that post-construction energy performance verification is not conducted; however, airtightness of the building must be proven by means of the 'blower door' airtightness test. This is often conducted before and after the interior walls are installed. Figure 5 below describes the typical certification process:

Figure 5: Passivhaus Certification flow chart



Approach 2: Streamlined Certification

This approach is meant for experienced practitioners/builders who are familiar with the design process, where only a post construction review of the project is conducted. This approach is a fast track method to reduce certification costs.

Analysis & Assessment

Non-domestic PassivHaus buildings

In 1991, the first-ever Passivhaus project was a four row terraced residential building in Darmstadt, Germany. Since that inaugural project, many Passivhaus homes have been built to the standard. It is often confused that the Passivhaus Standard only applies to individual houses, or multi-unit residences. It is true that the Passivhaus Standard was originally developed for houses but the standard has rapidly expanded to include non-domestic building types such as schools, apartments and commercial buildings.

Non-domestic Passivhaus projects such as schools and other large-scale projects are ideal candidates for Passivhaus design and construction due to their ideal geometry. Since building heat loss is proportional to the area of the surface exposed, larger buildings generally have a lower surface area to interior volume (A/V) ratio, therefore, it's comparatively easier to minimize heat gain and heat loss.

The design of non-domestic Passivhaus projects typically follows many of the principles used for single family residential dwellings. However, some considerable differences and considerations arise in the detailed design of Commercial & Institutional (C&I) buildings when compared to residential building as detailed below.

Treated Net Floor Area

The Treated Net Floor Area of a Commercial & Institutional building can be substantially greater than a residential building. The treated net floor area refers to the sections of the building that are thermally isolated which form the boundary of the certified Passivhaus building; this means that entrance lobbies, basements and stair wells which might not require heating can be excluded from the treated net floor area (BRE, 2014). In addition, a mix-use technology and trades building may have non-traditional processes that have the potential to be energy intensive. These processes must be accounted for (i.e.: this is allowed as part of the certification process) and isolated from the treated net floor area, otherwise meeting the primary energy requirement of the standard will be difficult to achieve. This practice makes the Passivhaus measurements more conservative than most other standards.

Internal Heat Gains

Due to the inherent purpose of the building, C&I buildings can experience increased internal heat gains from occupants, computers, and lab equipment and often require thermal mass in the building construction to reduce fluctuating internal temperatures.

Ventilation Requirements

Requirements for ventilation, exhaust and balanced air flows for appropriate pressure can be challenging due to the large treated floor area, varying classroom sizes, occupancy patterns, and mix-use purpose of the building. Schools may need separate ventilation systems, especially for mix-use buildings according to different room functions.

Occupancy Patterns

Non-domestic Passivhaus buildings such as Institutional buildings can experience fluctuating occupancy due to varying hours of operation and semester terms. Resulting internal heat gains from occupants (to provide heat to the building year round) can fluctuate and can be potentially insufficient; however, the advantage presented by the scheduling of rooms such as classrooms is such that occupancy is typically predictable.

Building Regulations

Provincial Building Regulations sets the minimum basic requirements that must meet satisfactory standards to ensure public health, fire safety and protection, structural sufficiency, and accessibility to all occupants including those with disabilities. These constraints can make the design of the building more challenging and requires more effort in the rigorous Integrated Design Process.

Lobbies and common areas

With a large amount of people entering and leaving the building, main entrance lobby doors are constantly opening and closing with resultant heat losses. These areas might not require heating and thus would need to be thermally isolated from occupied spaces.

Passivhaus in different climate zones

The Passivhaus Standard was developed in Central Europe where the design requirements have been optimized for a temperate climate. In other words, the details that specify the insulation, windows and ventilation are specific to Central Europe's climate (i.e. design temperatures of only -15 degrees C). In colder climates (i.e. falling below -20 or -30 degrees C), this necessitates a more stringent design and that these details may need to be adapted for the country and climatic conditions that the buildings are located in. That being said, the principles of the standard remain regardless of climate and it has been proven the Passivhaus Standard can be achieved in a variety of climates both hot and cold, extreme and mild. Figure 6 shows the different climate regions around the world.

Figure 6: Climates around the world

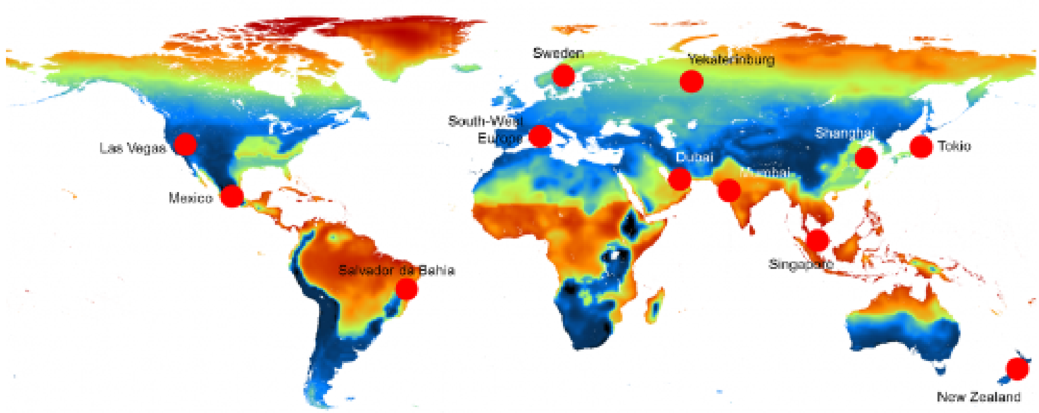


Illustration © Passive House Institute

One of the main criteria for a Passivhaus is that it must not consume more than $10W/m^2$ of peak heating load. In some climates, this can be easily achieved; however, in some colder climates this may be more difficult. In colder climates, the perception is that it is too expensive and uneconomical to have thick, rigid foam under the concrete foundation slab, and thick, high R-Value insulation for the walls and roof which may never be recovered in any possible energy savings. However, the investment in superinsulation and windows can result in a reduced heating and cooling load, and thus, investment in a full-size furnace or HVAC system is no longer required. This capital cost savings can be put towards the extra insulation and other high performance components that are required to meet the standard.

Vancouver Climate Characteristics

In order to successfully implement the Passivhaus standard it is important to understand and evaluate the local climatic conditions of where the building is located, as this guides the selection of appropriate passive design and construction strategies as well as the mechanical ventilation needed to maintain interior comfort.

Vancouver, BC is primarily a heating-dominated city where heating accounts for a significant share of the energy consumed by conventional buildings. Vancouver's climate is similar to Central Europe's where Vancouver's moderate oceanic climate has mild summers and winters and humidity levels are moderate year round. Being on the Pacific Northwest coast, Vancouver inherently has a high level of precipitation, particularly in the months between November – March (a period when homes require heating the most). Consequently, Vancouver receives modest solar insolation in these months and is challenged to benefit from significant passive solar heat gains to passively heat the interior space. The Passivhaus design would then recommend a high performance MVHR system coupled with a geo-exchange ground source heat exchange system as a viable option even though this is not a requirement of the standard.

According to CanPHI's database, which tracks completed projects in BC, there are currently four (4) certified Passivhaus buildings in Victoria, Whistler, and Nelson, ranging from single family detached homes, apartments, to a recreation center. Although mainly residential, these projects demonstrate that Passivhaus buildings and their rigorous standards can be realized in BC's climate.

Commercial Status in North America

Technology Availability

According to CanPHI, sourcing Certified Passivhaus building components locally in Canada is relatively difficult compared to in Europe since there are much fewer suppliers locally that produce these high performance products. Nevertheless, the standard is increasingly being recognized in Canada as an achievable energy efficiency standard helping propel the green building movement while bringing in suppliers that provide higher performance products to the market.

Furthermore, the Passivhaus standard does not demand the use of specific brands or products; however, it is easier to design a Passivhaus building using assemblies that have been modelled and certified to meet the Passivhaus standard; many North American products are available that can help achieve the rigorous standard. The availability of critical components will be discussed below.

SuperInsulation

High quality components such as high R-value Stone wool, cellulose and foam insulation can be sourced locally in BC. Walls built to code are typically 8-9 inches, whereas a typical Passivhaus building will have 14-17 inch walls (Paulsen, 2013). Without sourcing custom made insulation, insulation batts can be layered together to achieve the desired effective R-value.

Triple Glazed Windows

The Passivhaus certification standard for windows is one of the most specific and demanding requirement since the comfort, energy efficiency and cost of high performance buildings can hinge entirely on the windows. The Passivhaus standard demands that window units to be triple glazed, low-emissivity with a U-Value of 0.8 W/m^2K (0.85W/m^2K installed). Ideally, Passivhaus-certified windows should be sourced. Without triple glazing the heat loss is substantially too high, and would risk meeting the rigorous requirements. Most windows sold in Canada meet few, if any, of these requirements. If a lower performing window is selected, it’s important to model and account for the lower performance in PHPP. To see a list of Passivhaus-certified component suppliers in North America, see Appendix A.

Insulated Doors

Just like windows, the doors of a Passivhaus must provide excellent thermal protection of the façade through appropriate insulation. Currently, there are potentially no Passivhaus-certified commercial style door manufacturers in North America. However, there are distribution channels to European manufacturers who provide a large selection of brands and models. North American products are available that could provide a sufficient level of insulation; however, if a lower performing door is selected, it’s important to model and account for the lower performance in PHPP.

MVHR

The Passivhaus standard calls for a Mechanical Ventilation with Heat Recovery efficiency greater than 75% and also specifies a low specific fan power to achieve the very low specific heating requirement of 15 kWh/m^2. Ideally, a PHI certified unit should be specified; however, an efficient North American product would be sufficient and are readily available.

Cost Considerations

The economic feasibility of building to the Passivhaus standard must consider the initial capital expenditure, the total operational and maintenance costs, and the potential energy savings based on current and future energy rates, which are summed over the lifetime of the building.

In general, building to the Passivhaus standard in North America can cost more to build; approximately 10-15% more than a conventional building (Canadian Passivhaus Institute West, 2015). However, this can vary depending on the builder/designer and the features and building services that are chosen. The additional costs are attributed to investing in higher quality building components and extra insulation as well as the scarcity of Passivhaus suitable components in North America. For example, the Passivhaus standard demands usage of superior insulation and air tight construction, coupled with a mechanical ventilation with heat recovery system, all of which cost extra and can potentially increase build costs. The extra investment can be justified for those with a long-term interest in the building if lifetime costs are considered. For comparison, Passivhaus buildings built in Europe see an approximate 7-8 % cost premium but with more experienced practitioners, the cost premium can drop to as low as 1 - 3%. Again, the abundance of European suppliers offering Passivhaus quality components probably allows for a minimal incremental cost.

As stated above, the economic feasibility cannot be based entirely on the upfront capital outlay but one must look at the entire lifetime costs of the building. Thus, it cannot be expected that the costs of a component or the entire building structure will payback the cost of the building by only its energy savings.

Reduced Operational Costs

The Passivhaus standard looks to reduce energy consumption by 80-90% from conventional buildings built to code. Current Canadian electricity costs (~$0.06 - 0.10/kWh) are relatively low compared to other countries such as Germany (~$0.35/kWh), so the energy savings of building to the Passivhaus standard in Canada may not have the same payback period as for a country with high energy rates. The following example will provide an idea of the energy savings one might expect when building to the Passivhaus standard. In 2012, a study was conducted on a Passivhaus-certified building in Whistler, BC called the Rainbow House. It was determined that this building had an annual energy bill of approximately $280. Assuming that the average annual energy bill of a conventional building is about $3000/year, consider the cost of owning this particular Passivhaus home compared to a conventional Canadian home over a 40 year period as seen in Figure 7.

Figure 7: Energy costs of Whistler Passivhaus vs Conventional

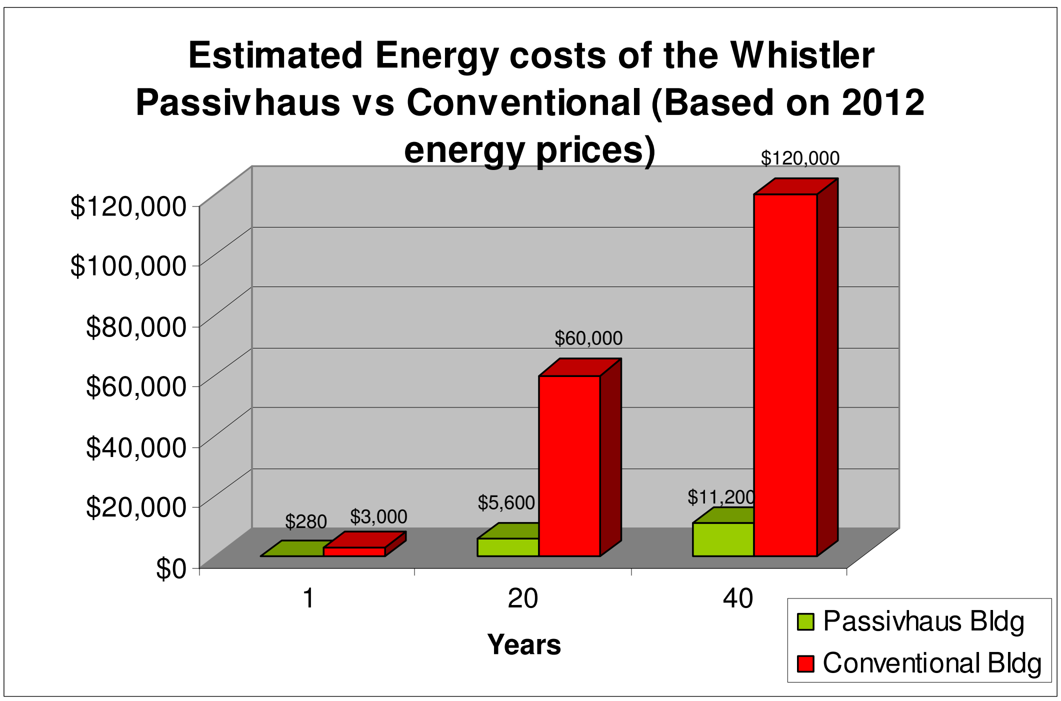
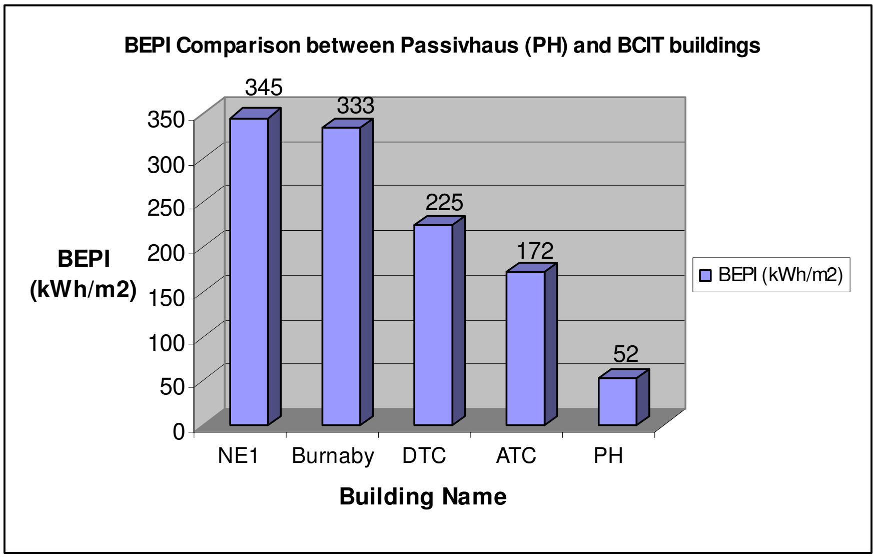


Figure 7 demonstrates low energy consumption compared to standard conventional buildings over a 40 year lifetime of the building. A 90% reduction of energy is projected to be saved, assuming energy rates remain the same as 2012 levels.

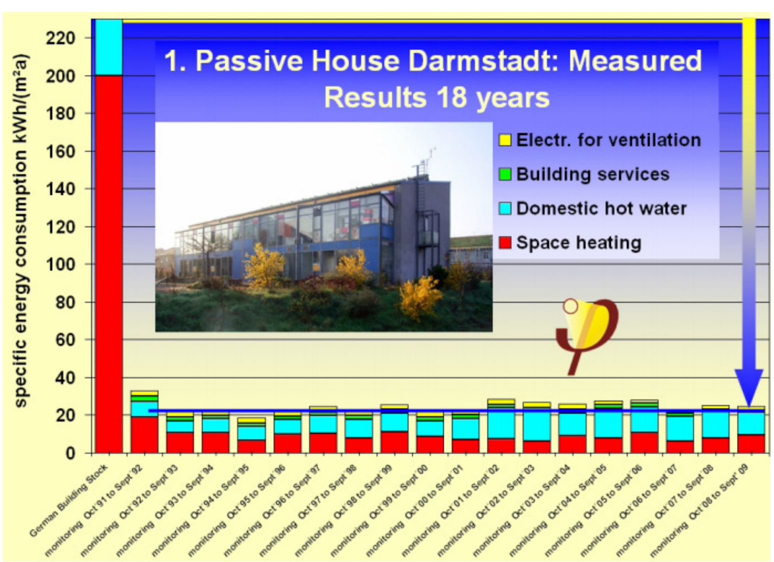
Figure 8 compares the Building Energy Performance Index (BEPI) between an all-electric Canadian Passivhaus building against BCIT buildings and campuses using traditional energy processes and loads. Building NE1 currently performs at 240 – 270 kWh/m^2; however, these energy numbers reflect the reality that NE1 is not a comfortable building. If operated to meet the ASHRAE 62.1 and ASHRAE 55 Standard for air quality and comfort, the “real” energy consumption is estimated at 345 kWh/m^2. The average BEPI for the Burnaby campus is 333 kWh/m^2, where as the Downtown campus (DTC) and Aerospace Technology Campus (ATC) performs at 225 kWh/m^2 and 172 kWh/m^2, respectively. Assuming an all-electric Canadian Passivhaus performs at 52 kWh/m^2 (using Canada's Primary Energy Factor of 2.3 for electricity and excluding all non-traditional processes), demonstrates an 85% reduction in energy consumption compared to Building NE1.

Figure 8: BEPI Comparison



To demonstrate the long-term energy savings of a Passivhaus building, the Passivhaus Institute collected the measured energy consumption per square meter of the very first Passivhaus building located in Darmstadt, Germany over the last 18 years it has been occupied. Figure 9 shows the building demonstrates a consistently low energy intensity year-over-year averaging 20 kWh/m^2. Thus, this low energy demand can be viewed as a reliable hedge against rising energy prices.

Figure 9: Passivhaus Darmstadt: Measured results 18 years



Building NE1 as New Construction

If we look at new construction Passivhaus buildings with the context of BCIT's Building NE1, to rebuild as a new construction would be approximately $150 million. Assuming a 10 – 15% additional cost to build to the Passivhaus standard, this results in a $15 million to $22.5 million additional capital outlay. The Passivhaus standard is becoming increasingly recognized in North America, and as the number of Passivhaus suitable components becomes more available, economies of scales are expected to drive down costs. Financial incentives for the construction of new buildings can further make it more affordable. BC Hydro's PowerSmart team offers the 'Whole Building Design' incentive program which offers incentives for reducing energy consumption through new building construction projects. This incentive offers up to 100% funding for the energy modelling fees charged by the certified designer. At the current moment, Passivhaus's PHPP software is not a recognized modelling tool by BC Hydro's PowerSmart team; however, the magnitude of potential energy savings could be significant enough to influence BC Hydro to adapt PHPP as a recognized modelling tool for their 'Whole Building Design' incentive.

Satisfying the LEED Gold requirement

Passivhaus's basic premise is to lower heating and cooling loads through airtight construction and high efficiency windows with the goal of reducing total energy consumption. It is an energy performance standard that delivers high levels of energy efficiency; LEED is a ratings-based system which addresses a broad range of categories in sustainability, energy efficiency and environmental issues that can be easily showcased to the general public.

Which is better?

The two standards cannot be compared like for like as each has a different focus. For example, the Passivhaus standard is solely concerned about measuring and minimizing primary energy use, and although LEED does address energy efficiency (to a lesser extent), it also addresses broader categories in sustainability and environmental issues impacting the North American construction industry.

Criticism

The Passivhaus Institute has been criticized for only addressing energy efficiency performance in their standard and not the wider sustainability design goals such as overall carbon footprint of construction, water conservation, impacts of specified materials, or site development and waste management concerns that LEED covers with their rating systems.

LEED buildings have been criticized for looking at energy considerations in the design, but then does not test the building's actual energy performance; LEED does not require public disclosure of energy consumption data. LEED does not have a mandatory energy performance requirement which has also been a contentious issue. LEED buildings show on average they use 18-39% less energy than conventional buildings but almost 1 in 3 used more energy (Scofield, 2009). Because LEED is based on "points received" through a check list of items to achieve a certain level of certification, LEED could favour a certain aspect over another and focus heavily on, for example, popular public eye-catching choices such sustainable locations, rather than focusing on the energy performance of the building.

Based on the aforementioned paragraphs, a building's biggest impact on the environment is its energy usage, and when compared to a standard conventional building, LEED buildings typically reduce overall energy consumption by 18-39%. Passivhaus looks to reduce by 80-90% (Passive House Institute, 2012).

The Passivhaus standard's primary focus on energy efficiency means it doesn't compare directly to the broad sustainability categories of LEED but neither are they competitors. Both standards can complement each other; LEED certification can be obtained simultaneously while meeting the Passivhaus standard. If the stringent energy performance requirement of the Passivhaus standard is met in the building design, this achievement would help reach LEED Gold Certification or higher by awarding most of the points (35%) available in the Energy and Atmosphere category, while the broad categories of LEED would allow a continued pursuit of other sustainable development and design.

Impact in Canada

What does it mean for BCIT to have a Passivhaus certified building?

As part of the BCIT Factor Four Initiative, the construction of a Passivhaus building at BCIT would serve three main purposes:

1. Used as an educational tool for educating staff, students, home builders and the public on the Passivhaus standard and its Integrated Design Process
2. Further promote and demonstrate a leading energy efficient construction standard in Canada that has been proven and refined over the last 20 years.
3. Deliver on the final piece of the Factor Four puzzle, allowing the SoCE to officially operate on 25% of its historical energy consumption.

According to the Passivhaus Deutschland database (www.passivhausprojekte.de), currently there are 26 recorded entries for certified school/campus/university buildings, located in Germany, Austria, UK and the US. A Passivhaus institutional building at BCIT would be the first of its kind in Canada and would demonstrate a continual commitment to BCIT's Factor Four Initiative by promoting a stringent energy efficiency construction standard with its undoubted benefits that has been demonstrated for the last 20 years.

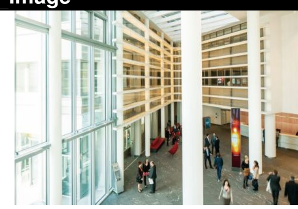
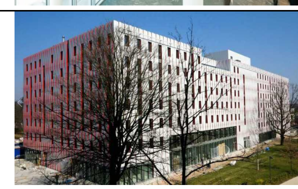
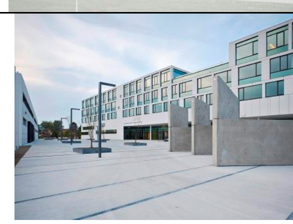
What are the Benefits to Students, Faculties and Facilities?

Since Passivhaus buildings typically use an efficient MVHR it creates a well ventilated and quiet learning environment that also supports the occupant's health, alertness and productivity. This also ensures that the school is kept free of mould or fungus growth, benefiting facilities and operations staff through minimal and focused maintenance activities as the result of less complex technology systems.

Examples of Certified Passivhaus Commercial and Institutional buildings

The Passivhaus standard is increasingly being recognized as a leading international energy efficiency standard for new construction buildings. While the majority of certified Passivhaus buildings are in Europe, many other countries have attempted and succeeded in building to the standard. Table 2 below provides some examples of certified Passivhaus Commercial and Institutional buildings. This list is not comprehensive, but represents examples of projects that have been identified as particularly relevant to this study.

Table 2: Examples of certified C&I Passivhaus buildings

Location	Year Built	Treated Floor Area (m2)	Build	Building Type	Project Description	Image
Wien, Austria	2012	20,984	New Construction	Office Building	Office tower focused on minimizing energy consumption best use of the site resources.	
Hessen, Germany	2014	15,391	New Construction	Office Building	Office building with a bright seven-story lobby with main auditorium and open courtyard	
Hessen, Germany	2013	12,625	New Construction	School	School building with gymnasium	
Niederösterreich, Austria	2012	12,442	New Construction	Office Building	A justice office and administration building	
Baden-Württemberg, Germany	2008	10,836	New Construction	School	A high school with spacious entrance and wing areas	

Recommendations & Priority Actions

In consideration of the LEED review, the Passivhaus review and associated assessments presented in this report, the overall conclusions of this study which are the basis of the recommendations provided are highlighted below:

- The detailed study and assessments presented in this report show no reason not to further develop the business case around building to the Passivhaus standard at BCIT, specifically for rebuilding Building NE1.

- LEED and Passivhaus are not competing standards - they can complement each other to develop a truly "Green" building, one that focuses both on significant energy reduction and sustainable design and development.

- There is a growing movement towards the Passivhaus Standard in North America, as architects and building developers are recognizing the tangible and intangible benefits the Passivhaus standard can offer; however, there are reservations towards adoption within North America. According to a general Passivhaus survey conducted by Synergy Enterprises (2014) which polled general interest categories on the Passivhaus standard: 12 of 34 (35%) respondents said 'Lack of knowledge and experience' was the top barrier within the building industry as a whole. Based on this information, there's seems to be a need for more education and awareness on the Passivhaus Standard. Also, there's a need for more experienced practitioners and real-world examples that can be used as case studies for further assessment and evaluation.

- BCIT's School of Construction and Environment (SoCE) is ideally positioned to lead and pursue the Passivhaus standard, as they have the opportunity, capacity and established framework to benefit from the knowledge and experience gained through constructing a Passivhaus building.

Based on these conclusions, the following recommendations serve to provide guidance to BCIT and industry stakeholders on where to focus their efforts and are intended to highlight priority actions that help further develop the business case around building to the Passivhaus standard at BCIT.

1. BCIT could consider replacing NE1 with a LEED GOLD certified building while meeting the Passivhaus standard. Next steps could include:

   a) Perform a detailed costs and benefits analysis, or Lifecycle cost (LCC) study of building to the Passivhaus standard.

   b) Perform cost and compatibility comparison in the context of Canadian Regulation and prospective market incentives between a Passivhaus building and conventional building.

c) Conduct an in-depth analysis on the challenges/barriers faced by developers building to LEED certification while meeting the Passivhaus standard.

d) Initiate conversation with BC Hydro regarding the New Construction incentive program to adopt PHPP as a recognized tool for energy modelling.

2. BCIT could further explore what it would mean to position BCIT as an educational leader in Passivhaus design and construction:

   a) BCIT could create a PassivHaus implementation guide.

   b) BCIT could engage in study tours to interact with experts and visits to relevant sites.

   c) BCIT could educate in the form of curriculum development through the SEMAC program or architecture or construction programs.

   d) BCIT could develop/offer a formal program on Passivhaus Design and Construction for those who aim to become a Certified Passivhaus Designer/Consultant.

   e) BCIT could develop/offer a formal program on Passivhaus Trades Person training.

   f) BCIT could consider becoming a Passivhaus accredited building certifier and/or resource hub in North America.

Being in its infancy for large scale commercial buildings in BC, and representing the last piece of the SoCE Factor Four puzzle (i.e. the missing piece that would allow SoCE to deliver its program on 25% of its historical energy consumption), both re-building NE1 to the Passivhaus Standard and becoming a Passivhaus educational hub could serve BCIT's reputation well and fulfill its vision of being integral to the economic, social and environmental prosperity of British Columbia.

References

ASHRAE (2010). *ASHRAE Standard 55-2010: Thermal Environmental Conditions for Human Occupancy*. Retrieved from https://www.ashrae.org/resources--publications/bookstore/standard-55

Building Evolution (2015). Retrieved from http://www.buildingevolution.ca/passive_house.html

BRE (2014). *Passivhaus Primer: Introduction*. Retrieved from http://www.passivhaus.org.uk/filelibrary/Primers/KN4430_Passivhaus_Primer_WEB.pdf

Canadian Construction Association. (2015)
Retrieved from http://www.cca-acc.com/en/about-cca

Canadian Passivhaus Institute West (2015). *What is the extra cost to building to the Passivhaus Standard?* Retrieved from http://canphi.ca/our-resources/faq/

Green Building Rating Systems (2014). In D2L (Comp.), *CESA-5500-NET: Codes and Standards*. Burnaby, BC: BCIT

Holloday, M. (2009, May 27). *Passivhaus for Beginners* [Web article]. Retrieved from http://www.greenbuildingadvisor.com/blogs/dept/musings/passivhaus-beginners

International Passivhaus Association (2015), Retrieved from http://www.passivehouse-international.org/index.php?page_id=65

Passive House Institute (2012), Retrieved from http://www.passiv.de/en/index.php

Passivhaus Institute US (2015). Retrieved from http://www.phius.org/passive/faq

Paulsen, M. (2013, Sep 23), *Ten Misconceptions about the Passive House Standard [Blog post]*. Retrieved from http://www.greenbuildingadvisor.com/blogs/dept/guest-blogs/ten-misconceptions-about-passive-house-standard

Rosenbaum, M. (2014). [Web article]. Retrieved from http://www.rightenvironments.com/index.php?/writing/text-1/

Scofield, J. (2009), *Do LEED-certified buildings save energy? Not really...*
Energy and Buildings, Volume 41, Issue 12, December 2009, Pages 1386–1390,
doi:10.1016/j.enbuild.2009.08.006

Pacific Institute for Climate Solutions. (2008). *Building and Climate Solutions*. Retrieved from http://pics.uvic.ca/sites/default/files/uploads/publications/WP_Sustainable_Buildings_November2008.pdf

Synergy Enterprises (2014), Retrieved from: Passive House Survey Results.doc

UK Passivhaus Trust (2011), *Passivhaus and Zero Carbon*. Retrieved from http://www.passivhaustrust.org.uk/UserFiles/File/Technical%20Papers/110705%20Final%20PH%20ZC%20Brief.pdf

Appendix A: List of Passivhaus windows

Currently, there are four companies in North America that produce passivhaus suitable windows

1. Euroline (Canada)
2. Casagranda Woodworks (US)
3. Alpen Windows (US)
4. Marvin Windows (US)