The Passive House and its Significance for the Future of the Canadian Construction Industry

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Abstract

This report will discuss the significance of the Passive House in Canada. The objective is to show that the Passive House standard is a viable construction method, which will benefit the Canadian construction industry, as well as the consumer - the home owner - and the environment by reducing the environmental footprint and running costs while providing a comfortable home to the owner.

This report is laid out to discuss the significance of the Passive House not only in Europe, specifically looking at the origins in Germany (where the first Passive House was built), but most importantly, its significance in Canada.

Firstly, the concept of the Passive House will be explained, and guidelines as well as the reasoning behind the creation of the Passive House will be considered. Positive and negative aspects of the Passive House will be analyzed to determine its overall benefits.

Next we will look at the components of a comfortable living space, and determine how the Passive House is able to provide such a space by enumerating some of the technical details regarding the construction. Furthermore, we will compare different techniques used not only in Canada but also in Europe and determine what impact the Passive House would have on the Canadian industry, especially the construction industry.

To conclude, a case study will be performed looking at how a Passive House can be built in Canada. The performance of said house will be analyzed, and the cost will be looked at to determine whether the Passive House technology is viable in Canada in the immediate or distant future.

Key Words: Timber framing, sustainability, energy efficiency, building technology, insulation, renewable resources.
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1. Introduction

The home is one of the most important places in our daily lives. It offers a place of rest, social gatherings as well as physical well-being, security and safety. The envelope of a home provides both a psychological as well as physical barrier to the environment surrounding it. Looking back in history and all around the world, one can see how many different types of solutions have been used to tackle different types of climates.

Simple tents and huts have been used, mostly in warm climates, to protect from the sun and rain. Larger, solid structures in colder climates also aim to keep the cold out, while keeping heat in. Different climates require different priorities. In warmer climates, a cool house is important to provide a comfortable living environment. In colder climates, a warm home is vital, protecting the inhabitants from the cold weather.

These different situations require different approaches, and centuries of construction experience have yielded a wide array of solutions to the problems presented. Regions with similar climates even use different construction techniques: European construction for example typically uses heavy masonry, while North American housing units are generally built out of wood.

Furthermore, decreasing fossil fuel reserves in recent times have caused large increases in fuel prices. This increase in energy prices has led to a heightened awareness of the need for more efficient use of resources. As a result, the Low Energy Home, Net Zero Energy Home and the Passive House have been developed. This report will focus on the Passive House.

The Passive House has been promoted as an energy efficient solution to high heating and electricity bills. It comes at a time where the global population is slowly realizing that the depletion of certain resources could be reached within our lifetime. As some of these resources or newer alternatives are needed for normal life to continue, solutions have to be created to either preserve said resource or find a replacement for them. It has become increasingly clear that sustainable practices are eminent to not end up in a situation of dire need where the needed resource has been depleted without an alternative solution.

This report will focus on examining the origin and significance of the Passive House, exploring the different aspects required for construction, looking at how it is implemented
in Europe and comparing this with how it could be implemented in Canada, as well as looking at a case study to determine if the Passive House and the Canadian construction industry are compatible.
2. History of the Energy Efficient Building

Despite the development of energy efficient houses being a more modern notion sparked by higher energy prices, energy efficient buildings have not only been built in recent years. Some construction types in particular have shown very unique and creative methods to improve the interior climate of buildings. Traditional turf houses for example were built in Iceland over 1,000 years ago (Figure 1). Built on stone footings, a wooden structure forms the main envelope of the house. Driftwood was most commonly used for these structures, since Iceland was never a highly forested area. This envelope is surrounded by a thick layer of turf which is a very efficient insulator. Generally, an air space is left between the turf and the walls, which allows for air circulation. The circulating air prevents rot on the structural elements of the wall. Smaller branches are used to form the roof in between the rafters. A layer of birch bark is often used to waterproof the roof, which goes in between the two layers of turf that are used to cover the roof. The open construction of the rafters and the branches allows for air circulation, making it difficult to rot. This type of construction has been used for centuries, but interestingly, with wood being of shorter supply in the 19th century, the older buildings were roomier and more comfortable. The “newer”, 19th century versions of these houses seem to have a damp and cold interior in the summer taking away from the comfort (Hurstwic, 2013) (National Museum of Iceland, 2011).

In warmer regions, thicker stone and brick walls have been used effectively to keep the interior of the building at reasonable temperatures. These good performances are not reached because of good insulating values of the material. In fact, stone, brick and concrete are poor insulators for temperature. To obtain the same insulating values as 2 cm of insulation
material with a thermal conductivity ($\lambda$) of 0.04, one needs a whole metre of reinforced concrete (Königstein, 2008). What makes these materials so effective in hot climates is their ability to store large amounts of energy (heat). Basically, during the heat of day, these walls absorb the heat from the sun while still allowing the inside of the building to remain comfortable. At night, with cooler air temperatures, the absorbed heat is released again into the air, basically freeing the walls to accept more heat the next day. These thick walls are fairly effective heat sinks given their high density.

Very effective insulation is not only important in houses, as was shown by the research ship *Fram*. The *Fram* was built specifically to spend extended periods of time in the Arctic and Antarctic regions. This meant that it had to be built in a way to provide comfortable living quarters to the crew while being able to transport large amounts of provisions and fuel. Generally speaking, a layer of cork was used as primary insulator followed by wooden panels with tarred felt, covered by another layer of panels. The skylight was built using three glass panes, similar to modern Passive House standard windows, to prevent excessive heat loss. While trapped in the Arctic ice caps, Captain Fridtjof Nansen wrote about a comfortable interior where the stove could even be removed, as it was barely needed.

After several years it was found that large parts of the insulation inside the ship’s walls had begun to decay and allowed fungus to grow. This is a problem which might also cause issues in Passive Houses (as we will address a little later) given the air-tightness of the envelope (Ward, 2001) (Passipedia.org, The Passive House - Historical Review).

During the 1970s more direct studies began to emerge around the idea of low energy houses. Various research institutes built test homes to experiment with different technologies aimed at improving energy efficiency. The Technical University of Denmark built the “DTH zero-energy house” in 1973, which performed a lot of research on solar technology. The *Philips Experimental House* was built in Germany in 1975, integrating ground heat exchangers, active ventilation and solar technology. Constant monitoring of the sensors built into the *Philips House* allowed the researchers to understand the potential of the technologies in this house, proving that the methods used could be applied in similar climates around the world. The research was not only conducted in Europe. A series of “super insulated houses” were built in North America starting in the ’70s, obtaining very encouraging results. The *Rocky*
Mountain Institute (RMI), built at an altitude of 2164 metres in Old Snowmass, Colorado, is another well insulated home using solar power for most of the heating needs. Built by Amory Lovins, the RMI showed the effectiveness of good insulation in this home that rarely uses its stove. Lovins would later become one of the strongest proponents of the Passive House standard (Passipedia.org, The Passive House - Historical Review).

This desire for experimentation did not just stop south of the Canadian border, as the Saskatchewan Conservation House was built in 1977. The almost airtight envelope featured walls with R-value of 40, and a roof with an R-value of 60 (the R-value will be explained in the next section). No furnace was built in. Only a small hot water system was required to heat the house throughout the year. The building was designed in a cubic shape, minimizing the exterior surface, with windows placed on the southern façade to allow sunshine to warm the inside. Deciduous trees in front of these windows provided shade in the summer, while allowing the sun to penetrate in the winter (Paulsen, 2011).

All of these projects were a first step in the right direction, but some of the unproven technology brought about a few problems. These projects had not yet focused as much on airtightness. Gaps in the airtight envelope would allow the creations of heat bridges, which ultimately counteract the otherwise good performance of the insulation.

Window technology was also not as advanced as it is today. Given their lower performance compared to modern, high efficiency windows, they were kept smaller and often had to be manually covered and manipulated to insure proper insulation.

A lot of the technologies implemented were rather complicated, which often led to improper functioning. Often these mechanisms were just given up upon as they were just too complicated and had a tendency to fail, without delivering the desired performance (Passipedia.org, The Passive House - Historical Review).

Based on the already existing knowledge and research, and with demands for more energy efficient buildings, Wolfgang Feist together with Bo Adamson launched the “Passive House” in May of 1988. Supported by the Hessian Ministry for economics and technology, several research projects were laid out to specifically measure the performance of the construction of the first Passive House finished in October of 1991 in Darmstadt-Kranichstein (Passipedia.org, passipedia.org).
2.1 What is a Passive House

The term *Passive House* refers to a modern energy efficiency standard in the construction industry. Realistically one should also take into account buildings that actually are able to passively maintain a comfortable and livable climate inside. Taking this into account, one can argue that many houses built in the past were Passive Houses, since they were a comfortable envelope in which more or less comfortable daily life took place, without the need for *active* heating or cooling.

Before we define the Passive House, it is important to understand what is meant by R-value and U-factor. The U-factor measures the thermal transmittance of an object, used to describe a material’s insulation properties. It is the inverse of the R-value. The U-factor SI units are W/(m²K), and US units are BTU/(h°F ft²), but they are commonly omitted when written out. For the remainder of this report, R-values will be given in US units if not otherwise noted, since that is the customary unit as used by builders in North America (University of Alaska, 2005).

The construction industry uses the R-value and U-factor to measure thermal resistance. It depends on the material, its thickness, and density. If several layers add up to a larger insulating unit, their respective R-values are added. Some questions have been raised regarding these measurements, as R-values of elements in service are affected by conditions that were not in place when the rating of the given element was determined in the lab. These conditions, including wind, temperature and moisture, can seriously reduce the actual R-value of an insulating component (Department of Energy, 2008).

The founders of the Passivhaus Institute, Wolfgang Feist and Bo Adamson, define a Passive House as a building that does not require active heating and cooling systems to keep the interior climate at comfortable levels (Passivhaus Institut, 2012). The passive heating (or cooling) is what lends the Passive House its name. The strict definition used by the Passivhaus Institute requires a Passive House to have a heating load inferior to 15 kWh/(m²a), or 4755 Btu/ft²/yr (Figure 3).

Further guidelines stipulate low-emissivity triple glazing and well insulated window frames, with U-factors of $\leq 0.75$ W/(m²K) and $\leq 0.8$ W/(m²K) respectively (which translates to US R-values of approximately 7). South facing windows are installed to let in solar heat, which is
to provide a large amount of the passive heat generated (Figure 2). Technical specifications throughout this report are specific for northern, colder climate Passive Houses as would be required by the Canadian climate (CEPHEUS, 2001).

The envelope has to be as airtight as to only allow 0.6 air changes per hour at n50. The airtightness is measured with the blower door test, which creates a 50 Pascal pressure difference (hence the term n50) and measures the amount of air sent into the building. Being nearly airtight means that less warm air leaks out of the building, allowing cold air to enter which has to be heated, thereby increasing the heating load of the house.

It is important to distinguish between airtight and watertight at this point, as the walls in a Passive House should still allow for moisture to diffuse through. This moisture can come from several sources: moisture can be trapped inside the walls during construction, and it can also be increased by normal daily activities (showers, cooking, laundry, etc.) and by changing weather conditions.

Materials are to be chosen wisely to allow this diffusion to happen, as moisture might get trapped inside the walls. This trapped moisture can then reduce the actual insulation properties of the wall, and will over time encourage the decay of the wall components as well as growing mould. Together with a building envelope combined R-value of over
50 as well as the minimization of thermal bridges, all these criteria help reach the proposed energy efficiency (Sommer, 2011).

A ventilation system has to be installed, able to provide more than enough fresh air in all parts of the house, and a heat recovery ventilator (HRV) with heat transfer efficiency of $\eta \geq 80\%$ is required. This means that over 80% of the heat produced remains in the house. The HRV is also very important to reduce the amount of moisture in the house, increasing comfort and reducing the possibility of moisture build-up which can lead to mould growth and other issues.

Besides reducing heating costs, the Passive House standard also aims to reduce the combined yearly electricity and hot water use to less than 120 kWh/(m$^2$a) (38,039 Btu/ft$^2$/yr).

Solar energy as well as geothermal heating is recommended to cover additional energy needs to further offset the energy efficiency in houses built to this standard (Passivhaus Institut, 2012).

To reach such high performance, four key elements are the main focus when building a Passive House: proper insulation, airtight envelope, high efficiency glazing that allows for passive heating and a heat recovery ventilation system.

### 2.2 Measuring the Performance of the Passive House

To confirm their expected performance, Passive Houses have been fitted with probes to measure and monitor their performance throughout the years. Results obtained from this testing have shown that the building methods are actually effective.

The CEPHEUS project (Cost Efficient Passive Houses as European Standards) is one of the main projects still measuring different Passive Houses.

For this project, 250 residential units were built in five European countries. The purpose is to test out different aspects of Passive House construction: construction cost efficiency has to be attained; actual energy usage is measured, to confirm extra construction costs are offset by lower energy costs. The measurements showed an average yearly heating load of 16.6 kWh/(m$^2$a), coming very close to the calculated values and confirming the calculation model
to be correct.
Temperature and comfort levels inside the buildings are measured to test performance in different weather conditions; those living in the test units found that the temperatures were kept at a very consistent level, and were happy with the overall comfort. New materials and innovative construction techniques are also tested to understand their effectiveness; and overall, this project serves to showcase the technology to builders as well as to the regular population (CEPHEUS, 2001) (Königstein, 2008).

The organization PASS-NET has also built up a large database, estimating there will be about 70,000 Passive Houses in the 10 PASS-NET countries in 2013 (Figure 4). It encompasses statistics on Passive Houses in Austria, Belgium, Croatia, Czech Republic, Germany, Romania, Slovakia, Slovenia, Sweden and the United Kingdom. Almost 60,000 of these units are in Germany and Austria alone (Lang, 2009).

The growth of the Passive House standard in Europe is a good indication that the benefits are seen as clearly outweighing the drawbacks. To better understand this standard, the next two sections will explore the positive and negative aspects of the Passive House.

2.3 Why a Passive House

This section will look at the positive aspects of a Passive House, looking first at the environmental impact and sustainability.

*Environmental Consciousness and Sustainability:* besides considerably reducing the use of energy, most Passive Houses are also built within a philosophy of environmentally friendly
construction. With time the general public has become more aware of the need to use resources sustainably, to conserve them for current and for future generations.

With the evolution of construction techniques, a large amount of different construction materials have been used, including non-renewables like clay, rocks, iron and sand, as well as renewable materials like wood, straw and leather. The source for these materials is our environment. Consequently, resources are removed from the environment. With repeated use, this leads to the material’s depletion – unless the material grows back and is managed properly and sustainably.

This depletion of resources has not been an issue in the past, with smaller populations and materials readily available. Today, however, a rapidly growing population depletes these resources at much faster rates. Because of this, awareness has risen regarding the need for a more sustainable use of natural resources, especially considering having to conserve some of these resources for future generations. This has led to more responsible uses of the available resources. These shifting ideals have affected common habits of the construction industry; an increased use of sustainable materials and striving to make more energy efficient buildings are the logical result, and the Passive House not only seeks to be energy efficient, but also built of sustainable materials.

But these shifting ideals are usually only achieved because of cost considerations or government requirements. Only when it becomes too expensive to continue in old habits does the general population start using new ones, as can be seen in the fuel consumption of cars for example: low gas prices allow the population to drive far without giving much thought as to how much is spent on gas. High prices on the other hand get the consumer to pay more attention to distances driven (to minimize fuel costs), and in the long run, to purchase more fuel efficient vehicles.

Similarly, in the construction industry, building costs and energy prices are compelling arguments for smarter building decisions. An interesting contrast in approach can be seen between Northern European countries and North America. In Europe, high heating and electricity prices have led to more energy efficient buildings, a trend that only slowly begins to emerge in North America. Higher initial construction costs are paid back quicker if they
allow a more efficient use of resources, as is the case in Europe (and specifically, the Passive House).

Furthermore, regulations in Europe already require the construction of more energy efficient buildings. Some countries, like Austria, require all of their buildings to be certified as to their energy usage. The construction of low energy homes and Passive Houses is subsidized to allow new buildings to still be affordable, even with these stringent requirements, and existing, low efficiency buildings are encouraged to be renovated to meet higher standards (Jilek, 2010). Low energy prices for the Canadian consumer have not yet forced a similar development in Canada, which we will elaborate on more in Cost Considerations.

Furthermore, another physical benefit of the Passive House is its orientation, which allows the south face the most efficient solar exposure for passive heat gain through the windows. This means that these houses are ideal for solar photovoltaic panels. While not necessary, photovoltaic cells can further reduce the carbon footprint of a Passive House by producing its own electricity, reducing the dependence on the power provided by the grid. These photovoltaic cells are used most efficiently if they are installed facing the south, to maximize solar exposure. They also decrease the need for electricity potentially generated by non-renewable resources, as we will see next.

Energy Efficiency: as already discussed, a Passive House uses energy much more efficiently than a regular house. This means that living costs are lower, and non-renewable energy resources are depleted at a much smaller rate. Using electric heat sources can even enable a Passive House to run without using any fossil (or other non-renewable) fuels at all, provided the electricity used comes from renewable energy sources. Most of the power generated in Canada already comes from renewable resources (see Figure 5) (Canadian Nuclear Association, 2010). Running without the use of fossil fuels would be a big step towards better sustainability.

Comfort and Health: both offering a comfortable living space as well as lower energy usage, the Passive House claims to be the “house of the future.” Older designs for environmentally
friendly homes focused mainly on saving energy and not on living comfort. They were often small, had small windows, and were hot in the summer, amongst other issues which were just considered a side effect of saving energy.

One of the main claims of the Passive House is its comfortable interior. This new approach is a result of the technological advances that allow a more efficient use of the available energy without having to sacrifice comfort. The temperatures as well as the moisture levels are kept at comfortable levels that do not change too drastically. A constant air exchange facilitated by the HRV allows a constant provision of fresh air, while filtering out potentially harmful particles, without having to regularly manually ventilate the house by opening the windows.

Not only is the ideal temperature and moisture level considered, but also the presence in the air of potentially health hazardous particles. Besides filtering the air with the HRV, special consideration is given to formaldehyde, a chemical found in many engineered wood products commonly used in construction. Formaldehyde has been classified as “carcinogenic to humans” by the International Agency for Research on Cancer (IARC), and studies throughout the years have shown higher than normal levels in homes, resulting from the use of materials containing formaldehyde. Studies performed recently have shown indoor levels of formaldehyde in homes to have decreased over the years, in large part due to stricter regulations in the use of formaldehyde – especially urea-formaldehyde – containing products such as engineered wood products, wood finishes and insulating materials. (CDC, 2008).

While it is not clear how much exposure to formaldehyde is required to cause cancer, and everyone is exposed to it, it is recommended to reduce the exposure to minimize risks. It was also found that good ventilation dramatically decreases the formaldehyde buildup, thereby reducing exposure (CPSC, 2013). Given these considerations, the constant ventilation in a Passive House, coupled with a use of materials which emit less formaldehyde (a decision made by health conscious home builders) can make the indoors of a Passive House healthier than a regular home.

*Smart long term economic choice:* while carrying an initial extra cost, reduced running costs throughout the lifetime mean a lower cost in the long term. As we will see later on, incentives like eco-mortgages even make the benefit a lot more immediate.
Encouraging new construction technologies: the need for new types of more efficient construction elements, especially the windows, and possibly the insulation materials, should encourage the appearance of new products on the market. This can give the construction supply industry a boost where some of the older products have become harder to sell.

Aside from the building materials, new employees need to be trained to properly construct a Passive House. As demonstrated in Austria, the high level of attention to detail requires proper training of the involved employees (Jilek, 2010). This would encourage the formation and education of more trades people, hopefully redefining and strengthening the Canadian labour industry.

Next we will explore the drawbacks of the Passive House.

2.4 Drawbacks of the Passive House

High initial cost: a decision that every builder faces before starting construction is how much to spend on the new building. A Passive House does cost a good amount of money more than a regular home. In the case of the home built by the Nauglers, which will be looked at in more detail in section 3, the additional costs amounted to around $40,000 (roughly 15%). If there are no incentives by the government or banks, this can be a costly initial investment that most home owners cannot afford or just do not deem it to be worth it.

More difficult to build: a Passive House needs to be built right. The envelope needs to be fairly airtight to maximize insulating properties; the air circulation system needs to be properly installed to maintain comfortable and consistent conditions inside, distributing fresh air evenly throughout. Heat bridges need to be reduced to a minimum to reduce heat loss.

An improperly installed ventilation system could not just be less comfortable: improper ventilation can lead to moisture build up, which, coupled with heat bridges, can encourage the growth of mould. Overall, the construction of the Passive House requires immense attention to detail in order to perform properly. If details are missed, the savings will not be as large as initially intended.

Lack of trained workers: with the strict requirements expected from a Passive House, well trained employees are required for proper construction. Besides proper materials, very
detailed workmanship is required to insure all construction elements are installed correctly to reach their highest potential.

As an example, if a window is installed and the installer is not able to perfectly seal the gap between the window and the wooden frame of the house, a heat bridge is formed. This spot will allow heat to escape at a higher rate, which requires the heating system to generate more heat and potentially costing thousands of dollars in the long run.

*Unknown variables:* the performance of the Passive House depends on the proper working of all of the installed elements. Since some of the components used may be new types of materials, there may not be sufficient information to determine if they will still perform as well in the distant future. The question arises, if for example the tape used to seal gaps in the wall might lose air stopping properties over time, or if the air tight envelope might encourage the growth of mould and rot on the inside of the wall, shortening the durability of the home.

Unexpected things could happen, such as animals burrowing into the walls – if they find access to it, which they often do even with pre-emptive measures taken. By making room for themselves in the insulation, for example, the effective insulation of the house is reduced. While this particular issue is not just an issue for Passive Houses, it could be an important one since the proper insulation of the house as a whole plays a large role in its effectiveness.

*Small windows (except for the south face):* since the windows are far less effective at insulating the house, the most effective wall for insulation will have no window surface. This means that the walls not facing south on a Passive House generally have few and comparatively small windows, decreasing natural light in these rooms and thereby also affecting the comfort level.

It is clear that there are benefits and drawbacks in a Passive House. The research around the Passive House is ongoing, and positive results suggest that the Passive House’s positives outweigh its negatives.

The next item needed to be discussed is the energy used in Canada. As the limitations of available energy have forced more awareness in Europe, we will compare energy pricing in
Germany and Canada, which will show us one big reason why standards like the Passive House standard have not yet become as popular in Canada.

2.5 Energy Use in Canada

When looking purely at the amounts of energy used, comparing Canada and Germany – the place where the Passivhaus standard originates from – a large difference can be noticed. While this does not necessarily indicate more energy saving habits in housing in Germany, it does seem to show how there is a more widespread concern to reduce the use of energy. In Figure 6 we can see that Canadians use about twice the amount of energy as Germans (all energy measured in kilograms of oil equivalent) use (World Bank, 2012). These figures are used here, because it was hard to find data that specifically separates the amounts of fossil fuels used for heating in Germany.

As discussed later though, in Cost Considerations, we do see that electricity and natural gas prices are both about three times as high in Germany as they are in Canada. This makes it clear that any activity that uses any type of energy – be it electricity or fossil fuels – will be considerably more expensive in Germany.

At the same time, Canadian electricity consumption per person is about 2.5 times as high as it is in Germany (World Bank, 2012). Further looking at the graph we can see a significant
drop in energy use in Canada. This can possibly be explained by governmental policy measures encouraging Canadians to reduce excessive energy use.

The Passive House standard development makes a lot of sense if we compare costs in Germany with the same costs in Canada: at such high energy prices, Germans have to build more efficient buildings to reduce the use of energy, and thus, reduce costs.

The high prices in Germany can be understood a little better when considering that over 80 million people inhabit an area as big as about one third of the area of British Columbia. They all need to be provided with energy (for heating and electricity), water and other resources. British Columbia, contrastingly, with a population of only 4.5 million has large natural resource reserves that will be long lasting (CIA, 2013) (BC Stats, 2011).

When calculating the total annual energy used in Canadian households, we obtain an average of 220 kWh/m². Of this amount, 140 kWh/m² is used for space heating (see Appendix 3 for more details) (Natural Resources Canada, 2013). These numbers are actually lower than the average amount used for heating per m² in Europe (shown in Figure 8), but assuming that housing units in Canada are larger than in Europe (given the lower density), the overall energy consumption will be similar or higher than in Europe. With lower energy prices in Canada, the average heating bill might still be cheaper than in Europe.

![Figure 8: European home energy ratings](image)

The average amount of energy needed for heating in an average Canadian home is still higher than the total maximum energy allowance of a Passive House of 120 kWh/m². With low gas and electricity prices, the population in Canada does not need to worry too much about saving energy, yet. But with growing population and demand, these prices are bound to grow.
3. Important Technical Considerations

Looking more closely at the important technical aspects of a Passive House, we will now look at what makes a comfortable home, the effects which affect the home owners as well as some more specific and technical construction aspects.

3.1 Aspects of a Comfortable Living Space

One of the most important intentions of the Passive House standard is not only to reduce energy consumption drastically, but to do so in a manner that renders the home comfortable. While attempts to reduce energy consumption in the past have often led to uncomfortable conditions – too cold or too hot interior, small windows, small/tight rooms, too much moisture, which can lead to moulding and other problems – adapting the learned lessons can lead to creating a comfortable, energy conscious living space.

Personal perception of physical comfort varies, but generally speaking there are ranges of environmental conditions that will be comfortable to most if not all people. A person’s comfort depends mostly on the surroundings, the temperature, the moisture and quality of the air, as well as reduced air movement and reduced temperature fluctuations. These are all aspects that the Passive House seeks to provide.

As seen in Figure 9, a range of comfortable conditions is found roughly between 20 and 22 °C, with a relative humidity of 35% to 70%. Taking this into account, the interior of a Passive House should be able to be kept within these parameters (Educate Sustainability) (Sommer, 2011).

The constantly running HRV is used to keep the moisture levels within these limits, as well as the temperatures.
As already established, an air tight envelope as well as highly effective insulation keeps the temperature transfer to a minimum. By design, the south-facing windows in a Passive House designed for cooler climates located in the northern hemisphere allow rays from the sun to heat the inside on sunny winter days. This is one of the most important passive sources of heat, complemented by the heat gain of the people inside the house as well as from appliances and electronic devices. Heat from the latter is kept low by the implementation of energy saving electronics required to meet the energy efficient demand expected from a Passive House.

While positive in the winter, the heat entering through the windows turns into a negative side effect in the summer: the windows will still allow heat from the sun to enter the house. An example is given in *Comparing Timber Framing with Masonry* below, which illustrates the effects of solar heating on a Passive House. The example presented will also determine the difference between lighter and heavier building materials as well as how opening windows might be necessary to help alleviate the heat.

A higher solar angle in the summer time helps reducing the amount of solar radiation that enters the house directly. To further protect the inside from the sun, exterior shading is highly recommended on south facing windows. Opening windows may also be required to allow the interior temperature to cool down. To explore some further considerations that help create an ideal climate inside a Passive House, the next section will look at different construction techniques and approaches that could be used in Canada and elsewhere.

### 3.2 Building Techniques in Canada and Elsewhere

As mentioned before, Canadian housing construction is mostly timber framed, contrasting with European construction which is generally heavier, masonry and concrete based. This next section will compare these two types of construction and analyze the advantages of timber as a sustainable material, explaining why timber is a good material for the Passive House.

First, here is a brief look at the approach towards sustainable construction taken in Canada.
3.2.1 Sustainable Construction in Canada

The Passive House standard is not the only standard created to encourage sustainable and energy efficient construction. Looking specifically at Canada, the Province of BC made an important step towards making the local construction industry more sustainable when passing the “Wood First Act” in 2009. This act requires any new provincially funded building to use timber as its main structural material, if physically possible (Bell, 2009).

Two notable examples are the CIRS (Centre for Interactive Research on Sustainability) and the new Earth and Ocean Sciences Centre on the UBC campus. Both buildings are built mainly out of wood. On top of that, the CIRS claims to be the greenest building in North America, harvesting its own energy and recycling its own waste water. It is expected to receive a LEED Platinum certification (Drexhage, 2010).

The LEED certification encourages provincially funded as well as other corporate buildings to be more sustainable and energy efficient (LEED, 2012). However, as with so many other environmental certifications, one can wonder if it is more of an environmental prestige oriented business or if it really serves the purpose of creating a more sustainable construction industry, but that is a subject for a separate report.

The Passive House technology uses a different approach than the LEED certification, which awards points towards the integration of different elements into a building. The Passive House standard seeks to be a holistic approach that sets certain goals to be reached, allowing the builders to reach these goals through different methods. Encouraging different solutions to similar problems, a wide variety of solutions used by different entities can be compared and studied.

The Passive House is slowly making its way into the Canadian market, where trial homes have been built in Whistler and in Quebec, all with satisfactory results. It now is probably just a question of time before rising energy prices will offset higher housing costs, encouraging more sustainable construction. But many years may pass until that day comes (Noguchi, Athienitis, Delisle, Ayoub, & Berneche, 2008).

Next we will look at a comparison between British Columbia’s sustainable material of choice, timber, and masonry in a Passive House application.
3.2.2 Comparing Timber Framing with Masonry

Traditionally, construction techniques have been very different across the world. North American housing construction typically employs a lightweight wood framing technique, whereas European construction typically employs a heavier technique, using masonry and concrete.

Strictly speaking, timber framing is a very environmentally friendly construction method. Wood is a renewable resource that easily grows back, if managed appropriately. It also acts as a carbon sink while used as a building element. The lightweight structure makes it easy to use, allowing for a quick assembly of buildings and helps reduce transportation costs.

The lesser weight also makes wood an ideal building material for areas endangered by potential earthquakes, as is the case on the entire Canadian and American West coast; lighter weight means the building will resist the motion of the earthquake less, thereby decreasing the forces acting upon the building in such an event.

While allowing very well insulated structures, the light weight of timber framing also has a downside: being light means that the building envelope itself is not able to absorb as much heat as a denser building material, like concrete, is able to. The light weight is beneficial when having to heat the entire building, as there is less mass that needs to acquire the applied...
heat, allowing the room to heat up more quickly. On the other hand, with less heat storage
capacity, the wood is also not able to absorb as much heat on a hot summer day, meaning that
the room will heat up faster. As a direct consequence, more measures have to be taken to
keep a timber framed Passive House cool during a hot summer day.

The two graphs in *Figures 10 & 11* show the inside temperatures of two Passive Houses
identical to each other, except for their main structure, throughout a specific year
built with masonry, shows a much smoother line, as the temperature in it does not change as
drastically as in the light timber framed house. Its heavier masonry walls allow it to absorb
more heat before the air surrounding the walls also heat up. As can be seen in *figure 10*,
without opening the windows the unit was able to keep the temperatures below 30 °C. At the
same time, the temperature inside the timber framed unit reached 30 °C on several occasions,
getting to a high of 33 °C.

This means that a timber framed Passive House will require the ventilation system to have an
increased workload to expel the hot air inside, as well as potentially requiring the opening of
windows and other measures on a more regular basis in the summer. Further actions, such as
increasing the shading of windows will also improve the indoor temperature in any Passive
House, or any building for that matter.

**Figure 12:** Masonry Passivhaus temperatures without window ventilation.

**Figure 13:** Masonry Passivhaus temperatures with window ventilation.
Similar to the previous test, when comparing two identical units (both timber framed) with one having no open windows, and one with open windows we can see the effect opening the windows has in the summer. On the hottest day two days (5\textsuperscript{th} and 6\textsuperscript{th} of September) the highest temperature in the unit with closed windows is almost 5 °C hotter than in the unit with open windows (Figures 12 & 13).

Looking beyond the thermal properties of the different construction techniques (heavy masonry vs. light timber framing), it is important to look at the overall environmental impact of each product. The carbon footprint of a material is determined by the carbon emitted during the production of the material, the transport to the final destination, the construction and installation of the material, as well as the carbon stored inside the component.

In Figure 14 we see that wood products in general have net negative CO\textsubscript{2} emissions because they sequester carbon while in service, i.e. as structural components of a building (BCclimatechange.ca, 2012).

In summary, wood is not an ideal material as a heat sink, because it allows larger temperature changes. On the other hand, wood allows the easy installation of very effective insulation material as well as being a good insulator. From an environmental point of view, wood is definitely a positive choice: being renewable, as well as having a carbon footprint much lower than concrete, masonry and other heavier construction materials, wood has to be considered as an option wherever possible. With the availability of wood in BC, the “Wood First Act” should come as no surprise; wood is an inherently environmentally friendly building material for Canada, and one could argue, for the rest of the world too.
3.2.3 Insulation

This next section will briefly touch on a few different types of insulation and describe their suitability and application in a Passive House. Many different materials are available, with different insulation values. Some materials are also more sustainable, as they are made out of renewable materials.

The thermal conductivity (\(\lambda\), measured in W/mK) of these materials is used to calculate the R-Value (m²K/W) and U-Factor (W/m²K) obtained. In other words, the smaller \(\lambda\) is, the thermal conductivity is worse, which means better thermal insulation values.

As an example, a material with \(\lambda\) of 0.03 W/mK at a thickness of 1 cm will have SI values of \(R = 0.34\) m²K/W (1.93 h·ft²·°F/Btu in imperial measurements) and \(U = 3\) W/m²K. This would mean that to reach R 60 (imperial) with this material, a thickness of almost 32 cm is required. At \(\lambda\) of 0.04 W/mK, more than 42 cm would be required. Following is a look at some materials typically used as insulation material (Sommer, 2011) (Department of Energy, 2008) (Königstein, 2008).

### 3.2.3.1 Fiberglass Batts

Available in shapes which typically fit well into standard stud walls and easy to install, fibreglass is probably the most common type of insulation used in North America. It provides very good sound and temperature insulating qualities. This material is somewhat difficult to deal with, as the small fibres could be a cancer causing material. Fiberglass insulation does require a large amount of energy in production, making it a less sustainable choice even though the raw materials are abundant. It has a \(\lambda\) of approximately 0.03 – 0.05.

### 3.2.3.2 Cellulose Blown-in Loose-fill

Providing good thermal and sound proofing properties, cellulose fibres are usually blown into place. Commonly made out of old paper, this material is ideal to fill in small cavities and spaces that are hard to reach and fill with conventional fibreglass. As a recycled material it is also highly sustainable. It has a \(\lambda\) of approximately 0.04 – 0.045 and also provides decent
sound insulation. While not an ideal insulator, its reduced price and good sustainability make
it a great candidate as insulating material in new, environmentally friendly buildings, as long as a thicker wall can be built to offset the lower insulation values.

3.2.3.3 Polyurethane Foam

Sprayed in place, polyurethane is also suitable for hard to reach places. Exceptional insulation values make it an effective insulator at reduced thicknesses. Polyurethane is also highly resistant against decay. It requires a large amount of energy in production and is not easily recyclable, making polyurethane a less eco-friendly material. It is recommended not to inhale the dust formed by polyurethane while cutting, and toxic gases formed when burning Polyurethane also limit its application if health and fire safety is taken into account. Depending on the crystalline structure used, the $\lambda$ ranges from 0.02 – 0.035, making it one of the best insulating materials available.

3.2.3.4 Expanded Polystyrene

Expanded polystyrene is a typical component of rigid insulation. It provides good to average insulating properties in places with limited space. Commonly used for insulating basement walls, it can even be obtained in load-bearing strengths. The production process produces considerable CO$_2$ emissions, which slightly increases its environmental footprint. The $\lambda$ values range from 0.03 – 0.04.

3.2.3.5 Cotton

Albeit renewable, cotton is often grown in monocultures which use pesticides. Most production also happens at a relatively large distance from Canada, increasing the transportation footprint. Mould growth is an issue to consider with cotton. It is renewable however and easily manufactured into batts or mats, has decent insulation values ($\lambda$ of 0.04), and is not too expensive.
3.2.3.6 Hemp

Hemp is usually used with addition of polyester (as support fibre) and often borax (to prevent insect attacks). Even though the polyester makes it more difficult to recycle, and the production is labour intensive, the availability and renewability make hemp overall fairly sustainable. Decent insulation values ($\lambda$ from 0.04 – 0.08) and a fairly low price also make it a good, natural insulation alternative.

In this list of materials it can be seen that the best insulators are often the less sustainable ones. Their production methods often carry a greater environmental footprint, but as they have been proven on the market, and with less durability issues, they continue to be trusted by the overall market.

Some of the more sustainable options are often not as popular due to higher production difficulty, as well as a usual lesser resistance to decay and since they are not too common in the application of home insulation, at least in North America, the normal user is hesitant to experiment with a new material over a material that has been proven effective over the years. This lack of experience, one could argue then, seems the biggest stumbling block for these alternative materials as insulation materials, since methods to prevent rot and decay are available.

3.2.4 Windows and Doors

Doors and especially windows are the weakest point of the insulation in a house. Strict insulation requirements can only be fulfilled by properly built windows and doors. To allow a nearly airtight envelope, windows and doors along the outside wall need to be well sealed. The window-frame is filled with insulating material or air gaps that minimize heat loss through it (see Figures 15 & 16). Special care is necessary to insure proper installation, to prevent heat bridges to be formed between the window frame and the
window opening in the wall.

Triple glazing is necessary for windows to provide better thermal and sound insulation. The void between the glasses is often filled with either of the noble gases argon, xenon or krypton, which reduces the amount of heat transferred. A thin metal oxide (usually silver) layer is often applied to the inside of the glass to help trap inside the house most of the heat waves emitted by the sun (Sommer, 2011).

Most Canadian window manufacturers have not embraced this technology yet as regular building requirements in Canada are not nearly as strict as to require similar insulation values. Producing this new type of triple glazed window would mean they have to invest in new infrastructure, which will only be profitable once a large enough market is available, as has been the case for German manufacturers.

### 3.3.1 Impact on the Canadian Industry

Construction is often seen as an indicator for economic growth, as new construction requires the use of construction materials as well as employment of labour forces. The Passive House will not only contribute in this manner, but also through using a variety of new building materials and techniques.

Together with more advanced windows and doors, other alternative construction techniques would mean an opening to new alternative construction materials. Innovative approaches to better solve old problems (like how to insulate a home efficiently) could mean the development and use of newer, more efficient, or at least more sustainable materials. A standard which aims at as high a performance as the Passive House standard often requires the use of better solutions than currently available. In the case of the Passive House, this is especially noticeable with the insulation, windows and doors used.

Further benefits are reaped by companies that focus on more energy efficient electric equipment, which includes the HRV manufacturers, as well as all other appliances – which
seek to be more energy efficient in the overall scheme of eco-friendliness. Some products, like the lumber used for the building envelope, will reap benefits even though they do not have to be redesigned, but rather because more lumber needs to be used.

On a larger scale, the reduced energy demand from a Passive House would mean a reduction of the energy needed to be produced. This enables the energy industry to potentially reduce the amount of non-renewable energy sources (such as fossil fuels and nuclear energy), making the entire energy consumption across Canada more sustainable in the long run. While there are still enough fossil fuels available in Canada for the next few decades, it would be wise to start reducing the dependence of the housing industry on natural gas. By building highly efficient homes, the existent reserves are preserved for much longer, and fewer greenhouse gases are emitted.

The construction of more renewable energy sources requires large investments. One of the reasons for the high electricity prices in Europe is the ongoing investment into producing more power from renewable, and less from non-renewable resources. With the use of less energy, a rise in electricity prices can be absorbed by the user, while a more sustainable power generating industry can be created.

### 3.3.2 Impact on the Canadian Industry of Insulation and Other Building Elements

To reach the insulation values necessary to meet the Passive House standard, a large amount of proper insulating material is required. This will lead to insulation manufacturers increasing their sales, as well as possibly developing more efficient insulation materials.

While potentially boosting sales, the demand for new products should encourage the development and improvement of alternative insulation materials. This could encourage the upstart of newer and more environmentally conscious technologies to compete, for example, with the dominant fibreglass insulation in the Canadian (and North American) market.

Two of the most important components of the Passive House are the windows and doors. As they need to be airtight as well as having very high insulation values, a superior quality product is required. With the early development of stricter standards, German window manufacturers have proven themselves to be frontrunners in this technology.
Current Canadian manufacturers for the most part have not been able to reach the same efficiency, and while this sector of the market is catching up to the technological advances, high efficiency windows need to be brought in from other countries. As mentioned before, the lack of demand on a larger scale does not warrant the production of triple paned windows in Canada just yet. In Germany on the other hand, a high level of competitiveness and a large market has led window manufacturers to produce these windows at fairly affordable prices. Besides the influence passive housing could have on the manufacturing industry, it is important to also consider the effects on the labour market.

3.4 Construction in Canada: need for new specialized training

New construction projects in Canada need to conform to the Canadian Building code. At this point in time, the code has not been adapted to the requirements of the Passive House, and current Passive Houses built in Canada generally obtain special exemptions from having to be built within the code. Passive House builders however make sure that their homes are built as closely as possible to the Canadian code, and ongoing research and trials are aiming to incorporate effective building techniques into the code. Most importantly, new buildings need to be built to withstand climatic conditions while remaining structurally stable.

As demonstrated by the Saskatchewan House, it is possible to apply current construction technology into energy efficient buildings. The typical construction method of stick framing lends itself to build well insulated envelopes. On top of being a fast and cost effective method, its lightweight properties allow for beefier structures without really compromising the structural integrity. In fact, one could argue, the added wall components could help to stiffen the overall structure.

Being simple and fast, framing is a forgiving manufacturing style. Precision is important, but not as important as for example for a watch maker. Herein lays a great challenge in the implementation of the Passive House standard. While traditional Canadian construction workmanship has been able to perform as well as the constructor and the eventual client desired and allowed, the biggest drawback would be a lower finishing quality.
With a Passive House however, extreme attention to detail is required to build a proper envelope that leaves no room for error. This means that any construction contractor who wants to build a Passive House needs to be properly trained in the proper techniques to insure proper attention to detail. To insure that builders are doing a good job, a builder that wants to build a Passive House needs to finish the specialized Passive House training.

The need for trained personnel is highlighted by the fact that many houses built to Passive House standards have not performed as well as desired due to lack of good workmanship. This is the case in Austria, where the Passive House promoting IG Passivhaus has found underperforming Passive Houses and encourages a greater interest in proper construction technique training (Putschöggl, 2012).

When not built properly, all of the extra money spent could be wasted since the performance of the final product is not as good as planned, because of improper workmanship. This does not mean that the whole building will be useless, but just that the extra money spent could have well been used otherwise if this high of a standard was not really desired.

### 3.5 Cost Considerations

For any technology to be implemented widely, it is important that it is economically feasible. As we will see in more detail later on in the case study of the Naugler House, a Passive House can be built at a cost of approximately 15% more than a similar, much less energy efficient house built to code with similar features. However, different features added to the building can make this difference vary even more.

In the long term it is also important to consider running costs. The aim of the Passive House is to reduce the cost of
energy used to a fraction of what is used by a regular house. Benefits are higher if energy costs are higher. This makes the concept of Passive Housing especially useful in areas of high energy demand for heating, as well as areas with high energy costs.

Currently, Canadian energy costs are relatively low. The average kWh in Canada costs about 9 cents, but costs over 29 cents in Germany. As can be seen in Appendix 7, the Canadian price for electricity is even very low compared to most other places (CME, 2012).

Natural gas used for heating is one of the main running costs in any household. In Germany, the average paid for a kWh of natural gas is just over 6.5 cent Euro (Figure 17). This translates to around $24.25 per gigajoule, which is roughly three times as high as one gigajoule in Canada. The price differences can be attributed in large part to the abundant availability of natural gas in Canada, whereas Germany and most other western European countries have to import natural gas from eastern countries. However, prices have varied in Canada over the last few months, suggesting that higher heating prices are not as stable as in the past (Verivox, 2013) (Energyshop, 2013) (CBC, 2013).

With these high differences in prices it is understandable that the benefits of the Passive House standard are much more immediate in countries like Germany compared to Canada. But with energy prices rising at some point in the future, which they are likely to, the Passive House will be beneficial to the Canadian consumer in the not too distant future. Some have already embraced the Passive House technology, such as the Naugler family in New Brunswick. Their home will be the subject of the case study, coming up next.

For the purposes of this case study, I would like to give a big thank you to Win Naugler, who willingly and enthusiastically shared the details about everything important that there is to know about the Naugler’s home built to Passive House standards in Fredericton, New Brunswick.

The house is in the process of receiving the Passive House certification, but Win is positive that it will pass all tests. The contractors in charge of the construction of this house – Southern Exposure, run by his son Tim Naugler – have been generous to post many pictures and details of the construction process of the Naugler House. Southern Exposure had previously built two houses that aim for better performance than normal buildings built to code, which served as good “practice” before building their first actual Passive House. These houses already have walls with an R-value of 40.

All of the information about the Naugler House comes from Win Naugler and from their website, Nauglerhouse.com unless otherwise indicated. To begin with, this study will look at some of the technical details of the Naugler House.

4.1 How the House was Built – Technical Details

To insulate a well-insulated envelope, the foundation has to be built in a way to provide insulation from the ground up. To ensure proper insulation, the ground was leveled and a polyethylene vapour barrier laid on top. Expanded polystyrene was placed on top as an insulating layer between the ground and the concrete slab. Type 3 loadbearing polystyrene had to be used at the base of the outside walls, while type 2
polystyrene was sufficient for the non-load-bearing parts of the basement (*Figure 18*). The installed vapour barrier also serves as a barrier against radon leakage into the house.

The polystyrene used under the slab provides an R-value of 36 to the floor. Two layers combining to 9 inches were used to reach these values. Before the concrete floor was poured, sand was filled into the middle part of the basement floor (on top of the insulation) to save costs. On the sides, a 12 inch wide layer provides an R-value of 48. It also served as form for the concrete poured as floor slab.

Once the concrete walls in the basement level had been built, they were covered by 12 inch 2foam® expanded polystyrene insulation (*Figure 19*). To insure proper insulation and connection, foam adhesive is used to hold the foam in place. Keyways between the pieces further insure a tight fit. This foam cures quickly, so leaving it to cure overnight was enough to reach desired properties. Blueskin is used on the outside of this layer to insure the wall is also waterproof. A further, flexible, layer of black insulation material is used between the Blueskin and the polystyrene for better adhesion and waterproofing. To prevent these layers from separating over time, they are tacked onto the top of the solid material.

A jig was used to glue and screw the wall components together. Basically, two walls were built which are held together with sheets of OSB (Oriented Strand Board) at the ends (*Figure 20*). These thin boards connect the two walls without forming a large thermal bridge. The outside walls are built of a 2x6 wall, which is loadbearing, and a 2x4 wall that basically serves as a shell for the insulation.
To reduce thermal bridging to a minimum, the floors sit on the inside wall. The outer shell of the house is comparable to a balloon framed house, since it envelopes the entire house from the first floor to the second without a break in between for the floor (Wikipedia.org, 2013). The minimal contact prevents any thermal bridging from forming.

A primer was placed on the concrete and OSB facing the exterior. *Siga Rissan ®* tape then was placed on the primer. This very stretchy tape designed for this purpose (used on Passive Houses in Europe, *Figure 21*) provides a very good air seal. It is also used by a loghouse company in Quebec to seal possible air voids in between logs. The inside walls were insured to be air tight by taping every gap between the sheets on the shearwalls. Special care was taken to cover every single penetration and joint. The few penetrations that connect to the outside – necessary to connect water and electricity – were covered with special care by specially made rubber gaskets to prevent the formation of thermal bridges.

To further reduce the formation of thermal bridging, the trusses were hung from laminated veneer lumber (LVL) beams placed on top of the load bearing wall components of the exterior wall (*Figure 22*). The shingles used, made to look like slate shingles, are actually made from recycled plastic and rubber. The material was chosen to further reduce the environmental impact of the house. Being guaranteed for fifty years, these shingles are also of superior quality. To further reduce the environmental footprint of their
house, the Nauglers sourced most of their building materials from nearby places.

The windows were installed in the middle of the window opening. This is done to protect the window from the wind, thereby increasing their insulating value. Wind moving by the window would draw heat from its surface and thereby speed up the heat transfer from the inside. By connecting the window to the OSB sheet, which connects the two outside wall components (the 2x4 and the 2x6 walls), further thermal bridging is reduced. If the window was connected to the stud, this stud would represent a thermal bridge right around the window frame.

These triple-paned windows are rated at an R-value of almost 8, which is significantly higher than regular, double-paned windows which reach R-values of up to 4.5. The design of the frames increases the insulation values.

The gap between the window frame and the window rough opening is filled with foam for insulation covered by tape, for air tightness (Figure 23).

To easily accommodate the plumbing and electrical installation in the house, an extra 2x4 layer was added to the outside wall. This allowed installing cables and pipes easily without having to drill through the insulation, where further attention has to be also paid to insure the airtight seal is kept airtight. This extra wall means that the plumbing and electrical installations are all within the airtight envelope of the house.

To insulate the house, it was decided to use dense pack cellulose. A fabric mesh was used to keep the insulation in place (Figure 24). The cellulose has a density of 4 lbs/ft³ with an R-value of 3.5 per inch. This means that a
16 inch thick wall has an R-value of 56. The service layer of the wall also got insulated with fiberglass, which increases the R-value by 15. When taking into account the studs as well as the insulation and other wall components, the estimated insulation of the wall reaches approximately R - 65 (schematic in Figure 25).

The insulation in the Naugler House was built in a way to contain about one third of the insulation inside the airtight layer, with the rest outside.

The insulation of the attic is much higher, as heat generally dissipates much more vertically (through the attic) than horizontally (through the walls). An R-value of over 100 insures that the attic of the Naugler House is properly insulated.

With the air-tight envelope, ventilating the building is essential to keep a healthy mass of air inside. An HRV (heat recovery ventilator) system is the typical solution in a Passive House. The Passive House standard requires HRVs to be at least 75% effective. The HRV built into this house is rated to recover 92%, but testing shows it actually running at 86%. The HRV is the only active system used to heat the entire house. In the picture above (Figure 26), the little metal box is the 2 kW heater.

A homemade preheater is also attached to the HRV (Figure 27). It is composed out of a radiator which constantly receives glycol pumped into it from about 5 feet below ground. This ground heat used is able to increase the outside air temperature considerably. By going through the radiator, if the outside air is at -20 °C, the ground heat will elevate its
temperature to about 2°C. By increasing the fresh air temperature this way, the heater is required to spend less energy. The pre-heater is also effective to help cool the house in the summer, as the ground temperature sent through the radiator, now cooler than the air temperature, cools down the fresh air taken in. To further enhance the versatility of the HRV, a humidity collector is installed to keep the inside air dryer in the summer.

As required by code, a rain screen is built onto the outside of the outside wall (Figure 28). Required by code is a thickness of ¾ inches, but 2x4s were used instead to increase the thickness to 1-1/2 inches. The thicker wood used only cost an estimated $75 extra, and should allow for a better air circulation, which will reduce moisture buildup. The rain screen used in the Naugler House incorporates a layer of Tyvec® plastic, to prevent moisture to enter the wall. The larger gap between the siding and the wall also allows moisture to get away much faster. Altogether, the entire outside wall is around 24 inches thick.

To further reduce the amount of energy needed from the grid, a solar domestic hot water (DHW, Figure 29) system was also installed. Two collector panels are installed on the roof of a solar shed. A small photovoltaic panel produces enough electricity to power the entire system. The panels have pipes filled with glycol, which captures the heat of the sun and is pumped to the solar boiler in the shed. The solar
system is able to produce about 70% of the hot water used. An in-line hot water heater provides whatever excess hot water is required when the water in the storage tank is not hot enough for use.

### 4.2 Performance

Win Naugler keeps track of the house’s performance and posts regular updates on their website. So far this year, the heating costs have gone up to $14.56 in January, $20.84 in February and $7.67 in March. Up to the 18th of April, the heating costs for the month have only been $0.92. If one considers that January and February are two of the coldest months of the year, the estimate to use $120 for a year’s worth of heating is doable. Assuming the four coldest months of the year require about $20, the next four about $10 with four months of no heating needs, we can obtain a total of $120. To see an excerpt of the table please refer to Appendix 8.

The HRV, running *continuously* to provide fresh air, is a high efficiency HRV that only costs about $35 per year in operating costs. Considering that most new houses either have an HRV installed or a forced-air furnace, it can be assumed that they will have similar or higher costs for their air-moving equipment. Because of this, the HRV running cost is left out of our cost calculations, and even if it was included in the heating costs, these heating costs would still be well below those of a typical house.

The question was raised regarding the airtight envelope and the arising risks inherent with moisture potentially being locked into this envelope. This is a very important issue to consider, as excessive moisture on the walls could encourage the growth of mould which is both not healthy for the inhabitants as well as pernicious to the building.

To prevent this from happening, Mr. Naugler mentioned that the proper functioning of the HRV is the key in the prevention of moisture build ups. The constant air exchange insures that the moisture levels remain at comfortable levels while also preventing moisture build-ups inside the envelope which could lead to mould growth. Furthermore, thermal bridging has to be minimized, as cold spots on the walls – caused by thermal bridges – encourage
moisture contained in the warmer inside air to condensate here. These moist spots on the wall are ideal growing places for mould.

Further talking about the HRV, Win Naugler mentioned that a modulating heater of only 2000 W of capacity is required to keep this house warm. As a comparison, a regular toaster uses about 1500 W of energy. Being a modulating heater means it can adjust the amount of heat expended depending on how much heat is actually required. Given the effectiveness of the insulation and the passive heat gains (through the sun, people in the house, etc.) the heater rarely runs, and when it does it seldom uses its whole heating capacity.

While not yet certified, Win Naugler is confident that the Naugler House will be able to meet and exceed the stringent Passive House standards. The air tightness rating – which has to be below 0.6 air changes for Passive House standards – was measured at 0.19, making it the most airtight house in Canada. The heating load of 7.5 kWh/m² is also well below the required permissible maximum heating load set at 15 kWh/m².

Overall, the Nauglers are very satisfied with the performance of their house, as it keeps a comfortable interior temperature and the energy use is at expected levels. This brings us to the cost considerations of their Passive House.

4.3 Costs

The Naugler House has several custom features, which by itself makes the house a little bit more expensive than a similar sized house built to code. To compare apples to apples, Win Naugler compared the costs of a code built house with the same features as their house (except for the energy efficiency) with the costs of their own house. The code built home would cost roughly $130 per square foot, while the Passive House ended up costing about $150. At 1940 square feet, this translates to about $291,000 for the Passive House, and $252,000 for the regular house.

Upon consultation with a local builder in Vancouver, Ed Goertzen, it was established that a typical house ranges between $120 and $160 per square foot. While it is difficult to determine an average construction cost across the country, these numbers are not too far off from the costs estimated for the Naugler House. It is also important to note that these figures
do not include the price of the real estate, which varies largely from location to location all across Canada. Given that the real estate price does not change for a regular house or a Passive House, its cost is not significant to these calculations.

While a 15% difference is not necessarily always the case, the extra material requirements on a Passive House will always be more expensive than an equivalent, “regular” house. For the purpose of this study we will also calculate the costs in a case where the Naugler House costs 30% more than the compared regular house cost (i.e. $115 per square foot for the “regular” house). With more knowledge gathered over the years, and new possible solutions, some of the extra costs could potentially be reduced to make the Passive House more economically feasible.

To establish a comparison, we will assume that the Passive House in question needs about $120 per year in heating, while the regular home requires about $2,400. Taking these numbers as such, we can calculate the breakeven point, i.e. when both houses have paid the same amount (adding their respective construction and heating costs). In the case of the Naugler House the breakeven point lies at just over 17 years, but if the same code built home was built for $115 per square foot, the breakeven point would only be reached after 29 years. These numbers are also bound to change if heating costs increase over time.

However, as money does not always behave in such linear way, we can make this situation a little bit more realistic by looking at mortgages and their effect on monthly costs.

Win Naugler inquired about different types of mortgage rates at BMO (Bank of Montreal) in February, finding that Eco Mortgages have a rate 1.95% lower than conventional mortgage rates. These Eco Mortgages are given to customers that fulfill certain requirements making their homes more energy efficient.

At an eco-Mortgage interest rate of 3.29%, a $292,000 mortgage on a Passive House would require a monthly payment of around $1,420. On a regular house without the eco interest rate and with a $252,000 mortgage rate, given the current base mortgage rate (at the time of writing this) of 5.24%, monthly payments would ascend to around $1,500, just over $80

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1 current rates can be found at http://www.bmo.com/home/personal/banking/rates/mortgages
more per month. Considering $190 in heating savings, the monthly costs for our Passive House are actually over $250 less than for the equivalent regular home in this scenario (please refer to Appendix 9 for more details). As mentioned before, the HRV operating costs would amount to only about $3 monthly, which would barely put a dent into the calculated values.

If we look at the larger price difference scenario, at $115 per square foot and assuming a mortgage of around $224,000 to cover the costs of this cheaper new house, a monthly payment of around $1,340 is required. After adding the $190 extra paid in monthly heating, the Passive House’s mortgage payment of $1,420 is still over $100 cheaper per month, still allowing some extra money to pay for heating (see Appendix 10 for more information).

The Eco-mortgage is generally cheaper for a Passive House which costs up to about 20% more than an equivalent home (see Appendix 9 to 11). In other words, if a regular home costs $80,000 and a Passive House $100,000, the monthly payments are almost the same; the savings in heating and electricity costs however makes the Passive House’s monthly costs cheaper.

Of course these figures are based on assumptions and are specific to a house similar to the Naugler House. Cost differences could vary in other cases, but these particular calculations are here to serve as a comparison between an actual Passive House built in Canada, to show that this concept is actually a viable concept to consider as an energy efficient alternative to a regular, typical house.

4.4 Case Study Conclusion

The Naugler House is a great example of creative solutions to build a Passive House in Canada. Mostly local materials were used, further reducing the environmental footprint and showing that most of the necessary building materials are already available. Only the windows, brought in from Europe because there is no local manufacturer of high efficiency windows, raise the environmental footprint. This higher footprint is offset after a short time by the reduction of heating needs. High attention to detail was required as wrongly installed
parts of the house could allow the envelope to not be airtight, severely reducing the insulation’s effectiveness.

Having lived in the house for over a year, the house has proven to be as efficient and comfortable as expected by the Nauglers. Heating and electricity costs are kept at a minimum while the interior temperature remains at a comfortable temperature – even when the outside measures less than -20 °C.

Looking at the cost, the calculations show that building a Passive House today does not cost more than an equivalent regular house if considering the better interest rates given by some banks for eco-friendly houses. Even without a mortgage, the extra cost of the Naugler House would be paid back in about 17 years in energy cost savings – assuming energy costs remain the same.

As a whole, the Passive House works as expected and is economically viable. Further observation in time will show if this holds true in the long run.
5. Conclusion

With global resources slowly being depleted, a change in mentality in the use of these resources is needed. Electricity and heating, resources that specifically affect housing, are limited by their sources which are often non-renewable. As awareness of their depletion is rising, more energy friendly housing solutions have come up in different markets. Generally those are markets where energy supplies become too expensive, forcing them to be the first to try out and adapt new technologies.

In recent decades there has been a lot of experimentation with energy efficient housing, ultimately leading to the Passive House standard. This standard has established itself quite strongly in western European countries, where high energy prices can be dealt with by building energy conserving buildings. The initial extra cost is paid back after a few years in the form of cost savings.

Because energy costs are still very affordable in Canada, the general population is still content with their homes, as investing in energy saving measures does not seem profitable. The general mentality is still more wasteful compared to their European counterparts, largely because of the extensive availability of resources like natural gas in Canada.

However, a slow movement has begun to reduce the wasteful use of natural resources. This has led to some people adapting energy efficient standards such as the Passive House in Canada as well.

Looking at collected data from the European Passivhaus Institut as well as data gathered by Win Naugler and others, the Passive House seems to be a success. Comfortable living conditions are kept without an excessive use of energy.

Questions are still remaining though, as it is all but impossible to find data on wear and tear in Passive Houses. With the oldest Passive House being barely over 20 years old, it is not yet clear how some of the newer materials used, such as tapes and membranes to create airtight envelopes, will last. If these materials deteriorate at rates worse than expected, insulation values will plummet resulting in rising heating costs.

But the experience and data collected seem to indicate that the Passive House is indeed an energy friendly and sustainable construction method that will ultimately be for the benefit of
the Canadian economy too: Canada’s natural resources have a large potential to supply materials for the construction of environmentally friendly buildings around the world, especially the vast softwood forests. New building technologies have the potential to further develop the Canadian construction material industry, and new, specialized jobs created can diversify and strengthen the Canadian labour market.

But while heating and other energy prices are still not too high as to put Canadians in need to build more efficient homes, the government needs to start encouraging the population to change their mentality before it comes to a time of resource shortage. Without government regulations and incentives, the Passive House standard will take a long time before it really takes off in Canada.
6. References


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7. Appendices

Appendix 1: Large view of Figure 4. Numbers in kilogram of oil equivalent
Appendix 2: Large view of figure 5. Numbers in kilowatt-hours per capita

Appendix 3: Calculations of Canadian Energy consumption (page 17, data from 2009):

Canadian heating energy use: 

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Average Total energy use: 0.795025154 GJ/m²

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Canadian Energy Data from: http://oee.nrcan.gc.ca/corporate/statistics/neud/dpa/tablesanalysis2/res_00_1_e_1_4.cfm?attr=0

Appendix 4: Analysis of the specific additional costs of three building types (in Europe).

Note the heating costs in standard house are just over 1/10 of the extra costs incurred in a Passive House.
Appendix 5: Breakeven points of different building types in Europe (taking into account forecast of increasing energy costs). This graph looks at the heating costs for each building type plus additional costs incurred to reach higher efficiency standard compared to a standard house. After about 18 years, the Passive House has paid itself off, and after 50 years it is expected that heating a standard house has cost over 250,000 € more than the additional building and heating costs of the Passive House combined.

Appendix 6: Development of Energy-costs in the Average German Household
Figure Comparison of electricity costs in different parts of the world

Appendix 7: Chart showing the differences between energy prices in different parts of the world, given in Aus$ (table found on a Australian website). 9 cents in Canada, 29 cents in
Germany. Rate is at approximately 1 Aus$ = 1.03 Cad$ (CME, 2012).
## Appendix 8: Excerpt of the Daily Data Table (Naugler, 2013)

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<td>0.4</td>
<td>4.4</td>
<td>19.8</td>
<td>22.9</td>
<td>5,440.00</td>
<td>9.5</td>
<td>0.94</td>
</tr>
<tr>
<td>2</td>
<td>-0.2</td>
<td>4</td>
<td>19.3</td>
<td>22</td>
<td>5,430.50</td>
<td>12.3</td>
<td>1.21</td>
</tr>
<tr>
<td>1</td>
<td>-2.2</td>
<td>0.6</td>
<td>19.4</td>
<td>21</td>
<td>5,418.20</td>
<td>12.5</td>
<td>1.23</td>
</tr>
</tbody>
</table>

http://www.nauglerhouse.com/daily-data.html

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### Appendix 9: Different Mortgage Scenario Calculations

<table>
<thead>
<tr>
<th></th>
<th>Passive House</th>
<th>Regular House</th>
<th>(all calculations assuming monthly payments)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Full Construction Price</strong></td>
<td>291000</td>
<td>252200</td>
<td></td>
</tr>
<tr>
<td><strong>Mortgage Rate</strong></td>
<td>3.29%</td>
<td>5.24%</td>
<td></td>
</tr>
<tr>
<td><strong>Amortization Period</strong></td>
<td>25 years</td>
<td>25 years</td>
<td></td>
</tr>
<tr>
<td><strong>Interest Term</strong></td>
<td>25 years</td>
<td>25 years</td>
<td></td>
</tr>
<tr>
<td><strong>Monthly Payment</strong></td>
<td>1420.81</td>
<td>1501.46</td>
<td><strong>80.65</strong> savings in passive house monthly</td>
</tr>
</tbody>
</table>

**Assuming only 200,000 is mortgaged:**

<table>
<thead>
<tr>
<th></th>
<th>Passive House</th>
<th>Regular House</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mortgage Amount</strong></td>
<td>200000</td>
<td>200000</td>
<td></td>
</tr>
<tr>
<td><strong>Mortgage Rate</strong></td>
<td>3.29%</td>
<td>5.24%</td>
<td></td>
</tr>
<tr>
<td><strong>Amortization Period</strong></td>
<td>25 years</td>
<td>25 years</td>
<td></td>
</tr>
<tr>
<td><strong>Interest Term</strong></td>
<td>25 years</td>
<td>25 years</td>
<td></td>
</tr>
<tr>
<td><strong>Monthly Payment</strong></td>
<td>976.51</td>
<td>1190.69</td>
<td><strong>214.18</strong> savings in passive house monthly</td>
</tr>
</tbody>
</table>

**Assuming 250,000 is mortgaged:**

<table>
<thead>
<tr>
<th></th>
<th>Passive House</th>
<th>Regular House</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mortgage Amount</strong></td>
<td>250000</td>
<td>250000</td>
<td></td>
</tr>
<tr>
<td><strong>Mortgage Rate</strong></td>
<td>3.29%</td>
<td>5.24%</td>
<td></td>
</tr>
<tr>
<td><strong>Amortization Period</strong></td>
<td>25 years</td>
<td>25 years</td>
<td></td>
</tr>
<tr>
<td><strong>Interest Term</strong></td>
<td>25 years</td>
<td>25 years</td>
<td></td>
</tr>
<tr>
<td><strong>Monthly Payment</strong></td>
<td>1220.63</td>
<td>1488.36</td>
<td><strong>267.73</strong> savings in passive house monthly</td>
</tr>
</tbody>
</table>

**Assuming 40,000 is paid up front:**

<table>
<thead>
<tr>
<th></th>
<th>Passive House</th>
<th>Regular House</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Mortgage Amount</strong></td>
<td>251000</td>
<td>212200</td>
<td></td>
</tr>
<tr>
<td><strong>Mortgage Rate</strong></td>
<td>3.29%</td>
<td>5.24%</td>
<td></td>
</tr>
<tr>
<td><strong>Amortization Period</strong></td>
<td>25 years</td>
<td>25 years</td>
<td></td>
</tr>
<tr>
<td><strong>Interest Term</strong></td>
<td>25 years</td>
<td>25 years</td>
<td></td>
</tr>
<tr>
<td><strong>Monthly Payment</strong></td>
<td>1225.51</td>
<td>1263.32</td>
<td><strong>37.81</strong> savings in passive house monthly</td>
</tr>
</tbody>
</table>
## Appendix 10: Comparison of houses at $150/ft^2 and $115/ft^2, and others

<table>
<thead>
<tr>
<th></th>
<th>Passive House</th>
<th>Regular House</th>
<th>(all calculations assuming monthly payments)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Construction Price</td>
<td>291000</td>
<td>252200</td>
<td></td>
</tr>
<tr>
<td>Mortgage Rate</td>
<td>3.29%</td>
<td>5.24%</td>
<td></td>
</tr>
<tr>
<td>Amortization Period</td>
<td>25 years</td>
<td>25 years</td>
<td></td>
</tr>
<tr>
<td>Interest Term</td>
<td>25 years</td>
<td>25 years</td>
<td></td>
</tr>
<tr>
<td>Monthly Payment</td>
<td>($1,420.35)</td>
<td>($1,503.25)</td>
<td><strong>$82.90</strong>. savings in passive house monthly</td>
</tr>
</tbody>
</table>

### Assuming regular house at $115/ sq.ft

<table>
<thead>
<tr>
<th></th>
<th>Passive House</th>
<th>Regular House</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortgage Amount</td>
<td>291000</td>
<td>223846.15</td>
<td></td>
</tr>
<tr>
<td>Mortgage Rate</td>
<td>3.29%</td>
<td>5.24%</td>
<td></td>
</tr>
<tr>
<td>Amortization Period</td>
<td>25 years</td>
<td>25 years</td>
<td></td>
</tr>
<tr>
<td>Interest Term</td>
<td>25 years</td>
<td>25 years</td>
<td></td>
</tr>
<tr>
<td>Monthly Payment</td>
<td>($1,420.35)</td>
<td>($1,334.25)</td>
<td><strong>($86.11)</strong>. savings in passive house monthly</td>
</tr>
</tbody>
</table>

### Assuming Passive House cost 20% more:

<table>
<thead>
<tr>
<th></th>
<th>Passive House</th>
<th>Regular House</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortgage Amount</td>
<td>300000</td>
<td>250000</td>
<td></td>
</tr>
<tr>
<td>Mortgage Rate</td>
<td>3.29%</td>
<td>5.24%</td>
<td></td>
</tr>
<tr>
<td>Amortization Period</td>
<td>25 years</td>
<td>25 years</td>
<td></td>
</tr>
<tr>
<td>Interest Term</td>
<td>25 years</td>
<td>25 years</td>
<td></td>
</tr>
<tr>
<td>Monthly Payment</td>
<td>($1,464.28)</td>
<td>($1,490.14)</td>
<td><strong>$25.86</strong>. savings in passive house monthly</td>
</tr>
</tbody>
</table>

### Assuming 40,000 is paid up front:

<table>
<thead>
<tr>
<th></th>
<th>Passive House</th>
<th>Regular House</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Mortgage Amount</td>
<td>251000</td>
<td>183846.15</td>
<td></td>
</tr>
<tr>
<td>Mortgage Rate</td>
<td>3.29%</td>
<td>5.24%</td>
<td></td>
</tr>
<tr>
<td>Amortization Period</td>
<td>25 years</td>
<td>25 years</td>
<td></td>
</tr>
<tr>
<td>Interest Term</td>
<td>25 years</td>
<td>25 years</td>
<td></td>
</tr>
<tr>
<td>Monthly Payment</td>
<td>($1,225.12)</td>
<td>($1,095.82)</td>
<td><strong>($129.29)</strong>. savings in passive house monthly</td>
</tr>
</tbody>
</table>
Appendix 10: Comparison of houses at different price difference steps. Price of *Regular House* is the percentage (given on the right) of Passive House price.

<table>
<thead>
<tr>
<th></th>
<th>Passive House</th>
<th>Regular House</th>
<th>(all calculations assuming monthly payments)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Full Construction Price</strong></td>
<td>300000</td>
<td>255000</td>
<td>Regular House: 85% of Passive House</td>
</tr>
<tr>
<td><strong>Mortgage Rate</strong></td>
<td>3.29%</td>
<td>5.24%</td>
<td></td>
</tr>
<tr>
<td><strong>Amortization Period</strong></td>
<td>25 years</td>
<td>25 years</td>
<td></td>
</tr>
<tr>
<td><strong>Interest Term</strong></td>
<td>25 years</td>
<td>25 years</td>
<td>Monthly Payment ($1,464.28) ($1,519.94) $55.66 savings in passive house monthly</td>
</tr>
<tr>
<td><strong>Assuming regular house at $115 / sq.ft</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mortgage Amount</strong></td>
<td>300000</td>
<td>240000</td>
<td>Regular House: 80% of Passive House</td>
</tr>
<tr>
<td><strong>Mortgage Rate</strong></td>
<td>3.29%</td>
<td>5.24%</td>
<td></td>
</tr>
<tr>
<td><strong>Amortization Period</strong></td>
<td>25 years</td>
<td>25 years</td>
<td>Monthly Payment ($1,464.28) ($1,430.53) $33.75 savings in passive house monthly</td>
</tr>
<tr>
<td><strong>Assuming 15 % less for regular house</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mortgage Amount</strong></td>
<td>300000</td>
<td>225000</td>
<td>Regular House: 75% of Passive House</td>
</tr>
<tr>
<td><strong>Mortgage Rate</strong></td>
<td>3.29%</td>
<td>5.24%</td>
<td></td>
</tr>
<tr>
<td><strong>Amortization Period</strong></td>
<td>25 years</td>
<td>25 years</td>
<td>Monthly Payment ($1,464.28) ($1,341.12) $123.16 savings in passive house monthly</td>
</tr>
<tr>
<td><strong>Assuming 40,000 is paid up front</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Mortgage Amount</strong></td>
<td>300000</td>
<td>210000</td>
<td>Regular House: 70% of Passive House</td>
</tr>
<tr>
<td><strong>Mortgage Rate</strong></td>
<td>3.29%</td>
<td>5.24%</td>
<td></td>
</tr>
<tr>
<td><strong>Amortization Period</strong></td>
<td>25 years</td>
<td>25 years</td>
<td>Monthly Payment ($1,464.28) ($1,251.72) $212.57 savings in passive house monthly</td>
</tr>
</tbody>
</table>