Comparing Apples & Oranges

- A Life Cycle Perspective on Energy Requirements in Swedish & British Columbian Building Codes

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Abstract

"Comparing Apples & Oranges – A Life Cycle Perspective on the Energy Requirements in Swedish and British Columbian Building Codes"

The requirements to decrease the energy use in a building vary in the building codes. "British Columbia Building Code" (BCBC) prescribes a nominal thermal resistance of insulation, while "Boverket's Building Regulations" (BBR) requires an annual specific energy use for the whole building. A type-house of wood-frame construction complying with BCBC proved to have greater momentary heat losses and a greater average heat transfer coefficient than a type-house of wood frame construction complying with BBR. Further, energy simulations showed that the type-house complying with BCBC did not comply with specific energy use requirement in BBR.

The life cycle primary energy use takes into account all stages and all upstream losses during a building's life cycle. The life cycle perspective takes into account site conditions such as climate and infrastructure. The type-house complying with BCBC proved to use 31-38% more primary energy. The occupancy state proved to use 79-91% of the buildings' total primary energy.

The life cycle perspective can also take into account the greenhouse gas (GHG) emission caused by a building throughout its life cycle. The GHG emissions proved to be strongly dependent on primary energy use. The type-house complying with BCBC emitted 18-42% more GHG than the type-house complying with BBR. GHG emissions occurred predominantly during the occupancy state.

BBR takes into account the functionality of the whole building, while BCBC is prescriptive regarding each building assembly. The comprehensive approach towards the building as a system in BBR is according to us a more effective way to decrease the energy use in a single family house.

Keywords: energy requirement, primary energy use, greenhouse gases, BBR, BCBC

Sammanfattning

“Comparing Apples & Oranges – A Life Cycle Perspective on the Energy Requirements in Swedish and British Columbian Building Codes”

Energikraven för en byggnad varierar med byggnormen i respektive land. “British Columbia Building Code” (BCBC) föreskriver en nominell värmeisolerförmåga för isolering i varje byggdel, medan ”Boverket Byggregler” (BBR) föreskriver ett krav på årlig specifik energianvändning. Ett typhus med träregelstomme som följer BCBC visade sig ha större effektförluster och en högre genomsnittlig värmekoefficient, än ett typhus med träregelstomme som följer BBR. Vidare visade energisimulationer att typhuset som följer BCBC inte klarade BBR:s krav på årlig specifik energianvändning.

Primärenergianvändningen under en byggnads livscykel, tar hänsyn till alla stadier och alla förluster ”uppströms” byggnaden genom dess livscykel. Livscykelperspektivet tar hänsyn till platsspecifika förhållanden som klimat och infrastruktur. Typhuset som följer BCBC visade sig använda 31-38% mer primärenergi än det typhus som följer BBR. Under brukarstadiet förbrukades 79-91% av den totala primärenergianvändningen.

Livscykelperspektivet tar också hänsyn till växthusgasutsläpp under byggnadens hela livscykel. Växthusgasutsläppen visade sig vara starkt beroende av primärenergianvändningen. Typhuset som följer BCBC orsakade 18-42 % mer växthusgasutsläpp mer än det typhus som följde BBR. Brukarstadiet orsakade lejonparten av växthusgasutsläppen.

BBR tar hänsyn till byggnadssystemets funktionalitet, medan BCBC föreskriver tekniska specifikationer för varje byggnadsdel. Helhetssynen i BBR är enligt oss ett mer effektivt sätt att minska energianvändningen i ett enbostadshus.

Nyckelord: energikrav, primärenergianvändning, växthusgaser, BBR, BCBC

Foreword

We would like to thank Mats and Stephen for letting us skiing while writing this thesis. Word to Nelson’s fantastic people, dust-on-crust and the incredible hitchhiking community giving us rides to & from the ski hill everyday.

We wish we were as brave as Joe.

List of contents

Introduction

The authors' visits to North America have included varied places such as Arizona, New York City, Washington State and interior British Columbia, Canada. The trips have led to the notion that not only the amount one is supposed to tip at the bar is different from back home, but also the construction of buildings. The trips have not only included backcountry touring in Roger's Pass, but also leaky windows when minus 25°C outside. Not only the Gilbert & George-exhibition at the Brooklyn Museum of Arts, but also the plenty air-conditioners disfiguring sky-scrapers' façades.

The sheer largeness and height of the sky-scrapers was needless to say overwhelming. The tickle of excitement when entering the vast Husky Stadium and the feeling of well-being entering the comfy Safeco Field was inspiring. But also, it was in North America the thoughts of a building's functionality first struck, freezing though sleeping with more clothes on than when skiing. Or functionality to what cost, always having the right temperature indoors even though the outdoors temperature rose above 40°C.

However, those were observations prior to entering university studies as construction engineers, haphazardly noticed, far from scientific methodology. When opportunity rose to challenge our conception that North American houses are poorly built, we were elated to combine this with going to supposedly powder country of British Columbia.

Hence, the purpose of this bachelor's thesis is to investigate the different energy use and the greenhouse gas emissions for a wood framed single family house from a life cycle perspective, when built according to the British Columbia Building Code and Boverket's Building Regulations respectively.

1 Background

The environmental impact from the building sector is vast. Along with contributing to a toxic environment and excessive water use, the building sector is one of the largest contributors to greenhouse gas emissions and a main energy consumer. Globally the building sector emits annually 8.6 Giga ton carbon dioxide ($GtCO_2$) and 2.0 Giga ton of carbon dioxide equivalent ($GtCO_2eq$) from non carbon dioxide greenhouse gases. This adds up to 25 % of the world's total emissions of greenhouse gases (IPCC, 2007). The building sector uses 40 % of the total energy demand in Sweden, and is the biggest consumer of energy in Canada.

However, the Intergovernmental Panel on Climate Change (IPCC) states that the building sector is the one sector where the largest mitigation of greenhouse gases (GHG) is cost-effectively possible. Further it states that a substantial part of this reduction can be achieved by well-known techniques that have not yet been adapted practically to a necessary extent. Examples of such techniques are thermal insulation and efficient cooling and heating system.

Essentially there are two ways for a jurisdiction to promote the use of such techniques, legislating and incentives. In Sweden a building code has been used since the 1960's to decrease the energy use in buildings (DS2005:55), while the British Columbia Government has relied more on incentives (Government of British Columbia Home page). One example of incentive programmes is the Retrofit programme, where house-owners can deduct cost for retro-fitting their houses and replacing old furnaces (Willems, 2009). Along with the incentive programmes a National Building Code has been in effect since 1949 (Barret, 1998)

This thesis focuses on the legislation which offers enough set rules to make a comparison possible. Another reason is that even though the standards given in the British Columbian building codes are minimum requirements, John Southam building inspector said "minimum for us [building inspectors] is maximum for them [builders]", i.e. houses will to a large extent be built according to the minimum requirements in the building codes (2009). Don Willems (2009) estimated that 75-90% of the houses in the Nelson area just complied with the minimum requirement in BCBC.

1.1 The Problem

This thesis will compare the life cycle primary energy use and GHG emissions during the life span of a building complying with the "British Colombia Building Code" and "Boverket's Building Regulations" respectively.

The thesis has a life cycle perspective on the primary energy use and GHG emissions. The necessity of such perspective is shown by Catharina Thormark. As buildings become more and more energy efficient, more energy is embodied within the construction. During 50 years life-span, 45 % of total energy need was embodied (Thormark, 2007). Ignoring the embodied energy while making energy use simulations might result in a substantial underestimation of the total energy use.

While Canada's vastness as the world's second largest country and its to some extent autonomic provinces and territories makes a comparison to homogenous Sweden impossible, the province of British Columbia offers enough consistency and similarities to make a comparison feasible. However, the building codes are written in different ways. Boverket's Building Regulations (BBR) is focusing on the buildings' functionality, while the British Columbia Building Code (BCBC) states what technicalities being required in a building. From an energy use perspective this leads to a nominal thermal resistance requirement of the insulation in each building assembly in BCBC. In BBR on the other hand an energy use requirement for the whole building is specified. Hence, designing one "British Columbian" house and one "Swedish" house and carrying out energy simulations are necessary for comparing the annual energy use.

A vast majority of the 2 million new homes built in Canada and the U.S. are of wood-frame construction (Burrows, 2008), thus the two type-houses are of this construction. As climate and other site-conditions are of great importance when determining the total primary energy use, both houses will be simulated at two locations, Helsingborg in southern Sweden, and Nelson in interior British Columbia.

As descriptive and regulating a building code ever can be, it cannot be fully comprehensive regarding the energy use, and certainly not from a life cycle perspective. Amongst a varieties of factors, type of fuel, customer choice and building practices are major determents of energy use and GHG emissions (IPCC 2007) and not steered by a mere building code. Moreover, a building code seldom prescribes only one acceptable system or one choice of material; therefore assumptions have to be made, that will affect the energy use and thus comparison between the two building codes might be difficult to perform.

1.2 Nelson, British Columbia

Nelson is a small city in the Southern interior of British Columbia, Canada. Surrounded by the Selkirk Mountains and the great Kootenay Lake, Nelson with close to 10, 000 inhabitants remains the largest city in the region.

Elevated 603 meters above sea level the climate is comparable to that of Stockholm, Sweden. The average temperatures are -2.7 °C in January and 19.9 °C in July, with a median relative humidity of 84.3%. (National Climate Data and Information Archive)

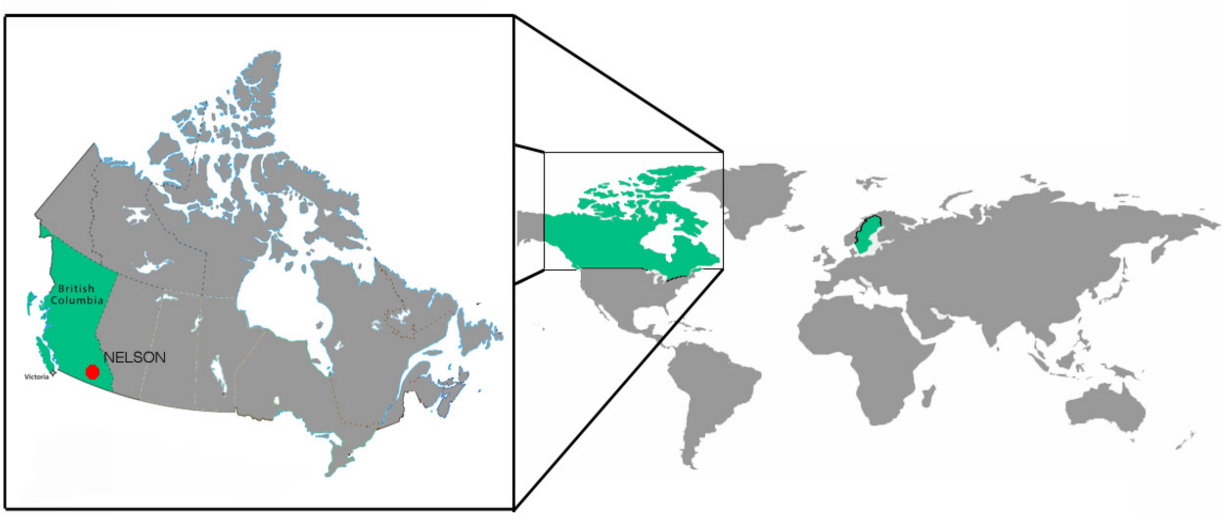


Figure 1. *Map showing the location of Nelson, Canada*

As many other cities of British Columbia Nelson is an old mining town. Gold and silver findings at Forty-nine Creek, west of Nelson, in 1867 started a minor rush of miners and prospectors to the area (Discovernelson.com, 2009). Though miners moved to the area in 1867 it was not until the first lumber mill was opened in 1889 that wood frame buildings replaced tents and log shacks and a town began to take shape. Starting off to supply the mining industry with timber, lumbering soon took over as the main industry of the area and remains important to this day. (City of Nelson, 2005)

Incorporated in 1897 Nelson had 3, 000 inhabitants and was a booming town. The city’s first High School, Hotel, courthouse, and many commercial buildings where built around the turn of the century. After the early booming years the population of Nelson stabilized and little was done to preserve or rebuild the city center. Discovering that old facades still existed underneath metal sheeting and stucco on Baker Street in late 1970s, Nelson was chosen as a pilot project for heritage revitalization in early 1980s. Together merchants and civic leaders developed a revitalization plan spending $3 million restoring the city center to its early glory days, and at the same time help Nelson out of the worst economic recession the city has seen (De Grace & Thornton, 2001).

Figure 2. *Baker Street, Nelson 1915 and today*

Due to its geographic position Nelsons economy has historically been resource based. The sector still plays an important part of the areas employment, though it has been exceeded as main industry in the Kootaneys. Being the Kootanys' administrative center, district and regional offices have traditionally been placed here. Along with the increasing tourism, the economy is balanced in a way promising way for the future.

Nelson as a municipality owns a hydro power plant. When demand is peaking, electricity is bought from the BC Hydro grid. In town there is a well-developed natural gas piping system. The gas is pumped from Alberta. Solid waste, including building materials, is transported by ship to a landfill 50 km from the city (Vaughn).

1.3 Helsingborg, Sweden

As the nickname "Pearl of the Sound" hints, Helsingborg is beautifully situated right by Öresund on the southern west coast of Sweden. As the Öresund region has been booming during the last decade Helsingborg today has population of 95,000 people making it the 8th largest city in Sweden (Helsingborg .se, 2007). The climate is as in better parts of Sweden, consisting of cool temperatures with an average mean temperature of -0.1°C during January and 16.8°C in July (sverige.de, 2004). Though its not very cold, located on the coast it can be windy, helping the cooling effect make temperatures feel more severe.

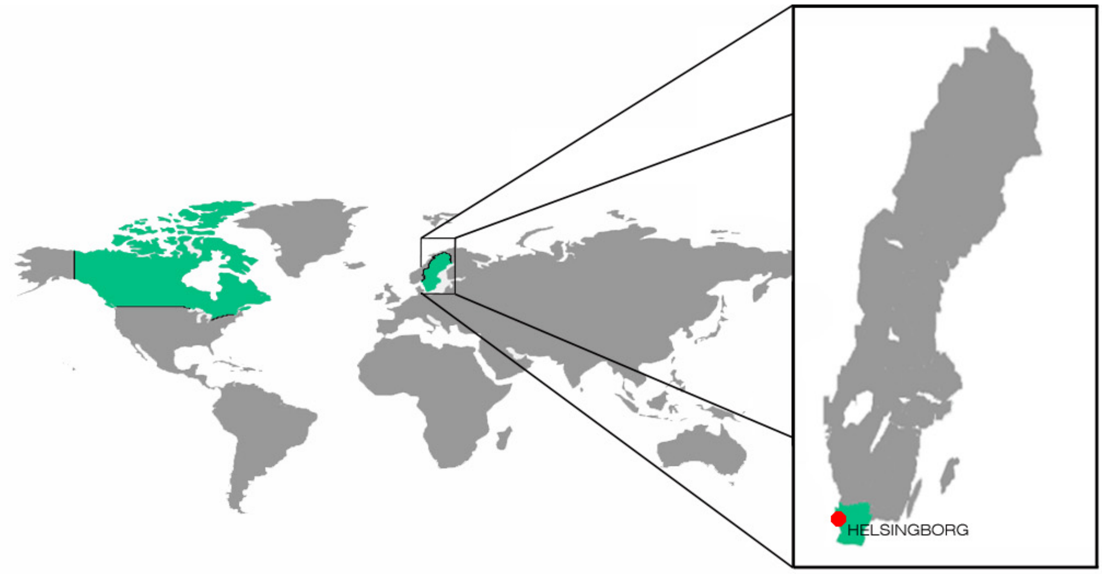


Figure 3. *Map showing the location of Helsingborg,, Sweden*

Founded in 1058 Helsingborg is one of the oldest cities in Scandinavia, serving as a Danish military stronghold and administrative center in its early years. Situated in what has historically been a conflict zone between Denmark and Sweden, the town was captured and lost six times by the Swedes during the 17th century alone. It was not until the year of 1710, in the battle of Helsingborg that Danes where finally defeated and Helsingborg became a part of Sweden. During this century of wars the town and its people suffered. Most of the old Helsingborg was ruined, leaving only a few buildings intact with St. Mary's church still standing today being one of them and leaving only around 700 inhabitants Helsingborg struggled in the aftermath of the war (Helsingborg.se, 2007).

It was not until the industrial revolution during the 19th century that Helsingborg came back on its feet. With a new built harbor and a large number of industries founded the population quickly increased and when the ferries between Helsingborg and the Danish town of Helsingör opened the city was established as one of Sweden's most important ports and has won the "European Port of the Year" award at two occasions (Helsingborg.se, 2007).

Figure 4. *Panorama picture of Helsingborg*

During the 20th century Helsingborg expanded from a population of just below 25,000 people, this mainly because of a vast expansion of factories and industry after World War II. Since 1955 commerce and intercommunication has taken over as the main industries in Helsingborg with IKEA as the largest private employer (Helsingborg.se, 2007).

Helsingborg has the highest share of district heating connected small residential buildings in Sweden. Totally, the district heating system serves 40 000 families and 6 500 small residential houses. The length of the district heating system ads up to 450 km.

2 Methodology

The methodology of this thesis can be divided into three major parts, a literature review, a field-trip to Nelson and energy simulations combined with the construction of a life cycle inventory.

2.1 Literature Review

The literature review has been to our standards extensive, as much data has been collected. The literature has covered everything from energy systems over degradation of organic material in a landfill to building legislation. Reports, literatures, statistics and online resources have all been used in the literature review.

2.2 Field-trip to Nelson

To gather site-specific data and knowledge regarding British Columbian building practises, a field-trip to Nelson took place during the winter of 2009. John Southam, local building inspector, Don Willems, local construction engineer and Dave Vaughn, local city planner were interviewed. Dr. Miljana Horvat at Ryerson College has taken part in a mail interview.

2.3 Energy Simulations & Life Cycle Inventory

To perform the energy simulations two type-houses are designed. The type-houses are assumed to be typically Swedish and British Columbian. The space heat load and the average heat transfer coefficient are calculated with Isover Energi 2. The climate data for Nelson is gathered using Meteonorm. As Isover Energi do not include climate data for Helsingborg, data for Lund, a city 60 km towards the south, is used instead.

The life cycle inventory takes into account production, transportation, occupancy state and “waste”. Data on energy use and CO_2 emission during production of the building materials is gathered from the database “Inventory of Carbon & Energy” by Professor Geoff Hammond and Craig Jones (2008). Exerts from the database is presented in Appendix 1. The life cycle inventory is calculated in an Excel spreadsheet, documented in Appendix 2.

3 Results & Discussions

The results of the literature review and the field-trip is presented and discussed in chapter 3.1-3.5. The results of the life cycle calculations and energy simulations are presented and discussed in chapter 3.6. A detailed spreadsheet of the life cycle inventory is presented in Appendix 2.

3.1 Wood Framed Residential Houses

The construction of wood framed houses in Sweden is very much inspired by the North American way with wood studs. In the 1950's, Swedish houses were built with vertical boarding, requiring four times the amount of lumber as a North American house (Miller & Stone, 1994). However there are nowadays differences in both legislation and the design of the building assemblies. Though this thesis focuses on the legislative part, non-regulated building and housing practises will affect assumptions being made about the representative houses.

3.1.1 Building Legislation in British Columbia

The Institute for Research in Construction (IRC) is a part of National Research Council (NRC), a governmental organization for research and development (OEE, 3, 2009). IRC develops the National Building Code (NBC), on which the provincial constructional regulations are based. The latest edition was released in 2005.

British Columbia's legislation regarding the construction of buildings is "British Columbia Building Code" (BCBC). It is an alteration of NBC to meet the wet and mild climate of British Columbia. Even within British Columbia climate differences can be of such importance that the building code is altered for different municipalities. For example the use of rain screen in exterior walls is mandatory in the moist coastal region of Vancouver and Victoria, but not in the dryer interior BC. Nelson as a municipality has not altered the building code (Southam, 2009).

BCBC lists technical requirements mandatory to a building (Southam, 2009). The Barrett Commission Report investigated a mould scandal in Vancouver in the 1990's. Amongst its conclusions, it stresses that meeting these requirements not is "a criterion for quality or workmanship" but "minimum standards regarding life safety, health, and structural sufficiency of buildings." The part of BCBC concerning "Housing and Small Buildings" part is more detailed and prescriptive than other parts of the code, due to the notion that less sophisticated builders would be involved in such projects (Barrett, 1998). This part is applicable to houses of less than 5 storeys in height (BCBC), thus being the focus of the thesis due to its purpose to investigate a wood-framed single family house.

In 2006 the latest version of BCBC was issued, though additional changes came in effect September 5th 2008. Changes included a new part “Energy and Water Efficiency”. This new part prescribed new requirements regarding the thermal resistance in different building assemblies, along with presenting an alternative way of complying with BCBC, using computerized modelling (Changes to the BC Buildng Code, 2008).

To be granted a building permit, drawings must pass a building inspector’s scrutinizing (Southam, 2009). This inspection makes sure the building comply with the intent of BCBC (Barrett, 1998). The governmental control does not end here, site visits are mandatory. Site visits are conducted by the building inspector usually at time of staking-out, plumbing, gas-fitting, stature of the load-bearing walls and roofing (Southam, 2009).

A municipality regulates the land use with by-laws. As long as a building meets the requirements in this zoning, a building permit will be granted. Requirements are of such sort as use of the building, building height and width (Southam, 2009).

3.1.2 Building Legislation in Sweden

Boverket – The National Board of Housing, Building and Planning – is the central governmental authority for building and housing in Sweden. The authority is not legislative, but based mainly on the laws “Planning and Building Act”, “The Environmental Act” and “Law on Technical Requirements for Construction Works”. It issues mandatory provisions and general recommendations such as “Building Regulation” (BBR) and “Design Regulations” (BKR). The mandatory provisions are in form functional requirements (Boverket, 2008). The provisions regarding the energy use of a building are located in BBR.

To lawfully construct a building in Sweden, a building permit needs to be granted by the concerned municipality’s building committee and a notice of building start sent to the same authority. A building permit is granted based on whether a building complies with “Plan- och Bygglagen” and local requirements concerning the exterior design of the house, not the technical functionality. The responsible of the building’s technical functionality is solely the builder’s. Nonetheless the building committee can inform of certain works that should not be started due to not meeting requirements when scrutinizing the notice of building start (Boken om lov, tillsyn och kontroll, 1995).

Conversely to Canadian legislation there are no requirements of governmental site visits in Swedish legislation, except for the staking out of the building. To nonetheless make sure that the society's requirements are met, a "quality appraiser" is appointed. The title is somewhat confusing; the quality appraiser is not responsible for the quality in the building process, but for the quality of the builder's system controlling the quality in the building process (Boken om lov, tillsyn och kontroll, 1995). However, in the newly added Chapter 9 on energy efficiency in BBR, it is stated that the annual energy use should be measured to ensure it does not exceed the allowed value.

Sweden is homogenous enough to have one national building code; nevertheless the requirements are based on the varied climate throughout the country e.g. buildings in the northern part of Sweden are allowed a greater energy use than buildings in the southern part. Totally there are three different climate zones, all prescribing different energy requirements.

As Boverket states, BBR is functionality based. That is to say that BBR defines what function or quality a building or building component is supposed to have e.g. "Buildings shall be designed so that a satisfactory thermal climate can be achieved". Strongly recommended advices are usually added such as "the operational temperature in the occupied zone is estimated at 18°C in habitable rooms", thus defining a requirement but not defining how this is achieved. The difference in the wording of shall and should secerns a requirement and an advice.

The latest edition of BBR was issued June 1st 2008; however changes in the section concerning energy efficiency came in effect as late February 2009.

3.1.3 Energy Use Requirements in the Building Codes

Though the building codes addresses all the factors for creating an acceptable house, such as accessibility, load-bearing capacity and fire-safety, only the regulations concerning the energy use of a single family wood-frame house is presented below.

3.1.3.1 Energy Requirement in BCBC

BCBC's objective concerning the energy use of a building is "to limit the probability that, as a result of design, construction or renovation of a building the use of energy will be unacceptably inefficient or the production of greenhouse gas will be unacceptably excessive" (Changes to the BC Building Code, 2008 page 2).

This objective is complied with, either constructing a thermal envelope with the given thermal resistance or scoring acceptable rating using the EnerGuide rating system (Southam, 2009). While the first option is strictly regarding the nominal thermal resistance of the insulation in different building assemblies, the latter option is considering other options for mitigation of energy use and

GHG emissions (Changes to the BC Building Code, 2008). Examples of such are heat recovery ventilation systems and fenestration. As a building complying with BCBC's thermal resistance requirement would score lower than the acceptable score with the EnerGuide rating (Southam, 2009), complying with the EnerGuide system can not be seen as minimum requirements and hence it will be disregarded in this thesis.

The thermal resistance is in BCBC given as Resistance of Insulation (RSI). The unit is (m^2°C/W). The values given in BCBC is the nominal resistance of insulation (Southam, 2009), which does not take into account thermal bridges, interior and exterior cladding, and the thermal resistance of the air film closest to the building assembly (Burrows, 2008). The method to calculate the effective thermal resistance of the building assembly is described in chapter 3.3.1.3.

Minimum Thermal Resistance of Insulation RSI, m^2°C/W	
Building Assembly	Value Required
Attic Space	7,7
Frame Wall	3,5
Foundation Wall (insulation to 600 mm below grade)	2,1
Windows	Double Glazed
Doors	7

Figure 5. *Minimum Thermal Resistance of Insulation in Canadian small houses.*

The quantity of the thermal resistance is derived from the standard thickness of Canadian building timber (Southam, 2009), since insulation is expected to fit in the cavities between the studs (Burrows, 2008). Notable is that the concrete slab used as basement floor does not need to be insulated. When complying with the set standards of insulation thickness, lengthwise thermal bridges, such as connection between framing walls and floor, can be ignored (Southam, 2009).

3.1.3.2 Energy Requirements in BBR

The objective with BBR's part concerning energy efficiency is: "Buildings shall be designed in such ways that energy consumption is limited by low heat losses, low cooling demands, efficient use of heat and cooling and efficient use of electricity" (Boverket, 2008, BBR page 17) An important reservation is that the energy efficiency will not affect the indoor environment negatively.

BBR states that this objective is complied with a set specific energy use and least acceptable thermal insulation, efficient use of electricity and appliances to measure the annual energy use. The specific energy use of the building is defined as “the energy which, in normal use, need to be supplied to a building (often referred to as ‘purchased energy’) for a period of one year for heating, cooling, hot tap water and operating building installations (pumps, fans, etc), as well as other electricity for the property.” (Boverket, 2008, BBR page 18). However the consumption of electricity for cooking, refrigerating and other household purposes, lightning and domestic appliances is not included in the specific energy consumption. The unit is [kWh/(m^{2}yr)], where m^2 is the liveable area. For the Southern climate zone, and a house not using electricity as energy source for heating, the set specific energy use is given as 110 [kWh/(m^{2}yr)]. When calculating the specific energy use, the intent is to show the actual energy use during the occupancy state. As the energy use shall be verified by measuring, a safety margin is advised. Calculations should also take in account occupant behaviour such as indoor temperature and airing.

When calculating the average heat transfer coefficient, the measurement for acceptable low transmission losses, thermal bridges has to be taken in account. The average heat transfer coefficient is given by: $U_m = \frac{\left(\sum_{i=1}^{n} U_i A_i + \sum_{k=1}^{m} l_k \psi_k + \sum_{j=1}^{p} \chi_j\right)}{A_{om}}$ [W/(m^2°C)]. This is the formula for the transmission losses divided by the area of the exterior surfaces. The average heat transfer coefficient must not exceed 0.5 [W/(m^2°C)]. The average thermal resistance of the thermal envelope will then be 2 [(m^2°C)/W]. The method of calculating the average heat transfer coefficient is described in chapter 3.3.1.3.

BBR limits its requirements of efficient electricity use to that of the air handling system, lightning fixtures, fans, electrical heaters, circulation pumps and motors. The specific fan power (SFP), the energy needed to operate the ventilation system, is the only of the above requirements that is quantified, while the other processes should be providing “sufficient efficiency”.

Ventilation System	**SFP [kW/(m^{3}s)]**
Supply & Exhaust w/ heat recovery	2.0
Supply & Exhaust	1.5
Exhaust w/ heat recovery	1.0
Exhaust	0.6

Figure 6*.Specific Fan Efficiency Requirements in BBR*

3.1.4 Building & Housing Practices

In this chapter accepted practises in both Sweden and British Columbia for constructing building assemblies are presented. Where there are several accepted methods, the most widespread, most time-saving and cheapest method will be presented. The presentation will not only discuss the methods from a mere energy use standpoint, but also take into account other important aspects such as load-bearing capacity and moisture control. These somewhat elaborate presentations, is due to the notion that a building must be looked upon as one system, and that the amount of building material evidently will affect the life cycle performance. Extra emphasis will be put on basements as the designing of that building assembly varies more than for the other building assemblies.

Due to that BBR is written with a specific energy use requirement and an average heat transfer coefficient for thermal envelopes, all building parts as well as all thermal bridges has to be well insulated and thought of when constructing a house. These requirements make it somewhat difficult to know how well the separate building parts have to be insulated. To assist in the matter the Swedish Energy Agency stated guideline heat transfer coefficients for each building assembly.

3.1.4.1 Basements

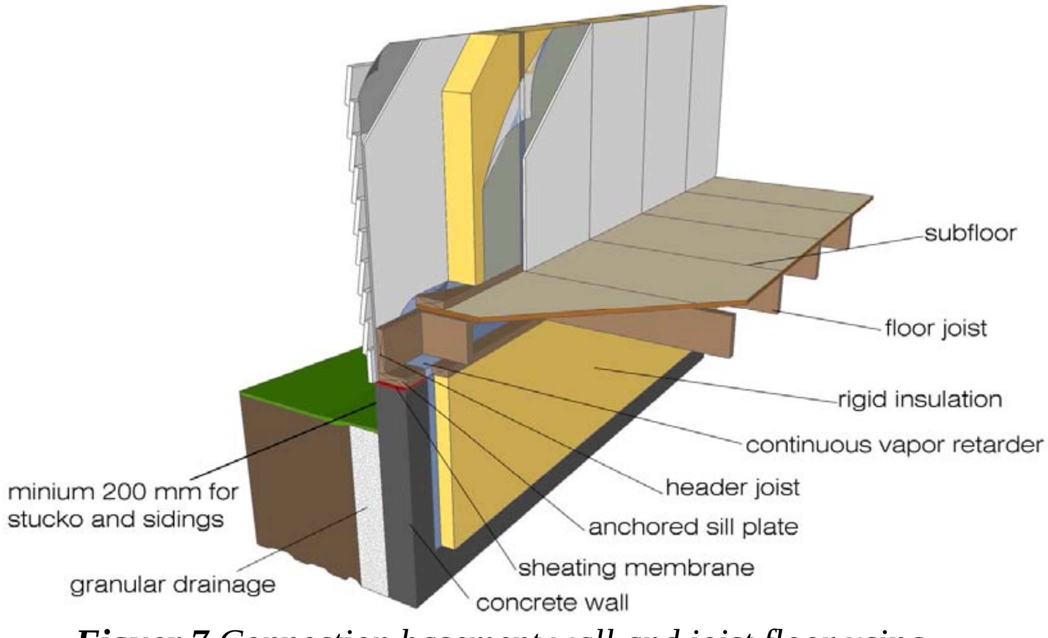
Canadians commonly considers a basement as a liveable space, which should provide the same quality environment as the rest of the building (Kesik & Swinton, 2005) and building permits for houses designed with a liveable basement are usually granted (Southam, 2009). Being considered as a liveable space, the basement will be inside the thermal envelope, sharing the above ground spaces humidity, temperature and contaminants. NBC recognizes this and provides - as always - minimum requirements for acceptable performance (Kesik & Swinton, 2005).

Looking at the existing small house stock, basements is found to have been a frequently used foundation method in Sweden, especially in houses built in between 1940-80 (viivilla.se, 2009). Due to often occurring moist and mould problems in basements, new built small houses, such as the one in this thesis, do customary not have a basement (Nevander, 2006).

The foundation walls in British Columbian basements are most commonly made of continuous cast-in-place concrete foundation walls. Wall thickness varies from 150 to 300 mm. To avoid or control cracks susceptible to appear in the concrete wall, either steel reinforcing rods or control joints should be used. Control joints are thin strips of wood nailed to the exterior and interior wall forms, creating slits in the concrete wall where cracks will appear (Burrows, 2008). Concrete slabs are used for basement floors. Steel reinforcing rods or control joints are used for slabs as well (Burrows, 2008).

If providing sufficient foundation for the house is pretty straight forward, the providing of liveable space has proven more troublesome. Mould, moisture seepage through basements walls and flooding are reported problems in both new and older homes. Swinton (2005) et al recognize in “Performance Guidelines for Basement Envelopes System and Materials” that the minimum requirements regarding basement spaces in NBC does not always provide acceptable performance in less than favourable site conditions. Nonetheless minimum requirements are self-evident accepted and hence the house in this thesis will be designed according to these.

The control of heat losses is essential to create a liveable space in the basement. Though the surrounding soil and snow provide thermal insulation, Swinton (2005) et al argues that insulation is both justifiable and desirable. CMHC recommends in “Canadian Wood-Frame House Construction” that foundation walls are insulated to their fully height and states that un-insulated foundations walls are a major factor to heat losses. BCBC requires however that foundation walls are insulated on the interior of the cast-in-place concrete to 600 mm under grade.



Figuer 7.*Connection basement wall and joist floor using sill-plate method,*

To drain the surrounding soil and to thwart capillary action, the slab and the footing should rest on granular material. Since there are no insulation underneath the slab, the concrete will be cold and of high relative humidity (Kesik & Swinton, 2005). To damp-proof the floor, a polyester sheet is applied under the slab. The concrete foundation wall is damp-proofed by cladding bituminous materials on the exterior before backfilling (Burrows, 2008).

3.1.4.2 Slabs-on-Ground

Since the technique of concrete slab foundation was introduced in Sweden in the 1950s it has after a few decades of moist related problems, such as mold and rot, become the method of choice for most Swedish contractors (Nevander, 2006). As a part of a buildings thermal envelope all slab-foundations are today well insulated to meet the BBR's requirements and government guideline U-value of 0, 19 [W/ (m²K)] (Persson, 2008).

There are two separate methods of constructing a slab-on-ground foundation, either with insulation on top off or below a concrete slab. The two methods differs a great deal in regards to moisture control, in the method with superjacent insulation the concrete slab stays cold which affects the moisture level in the concrete and is generally not regarded as safe as the method with underlying insulation which keeps the concrete drier (Nevander, 2006).

The most conventional method today is thus to cast-in-place a 100 mm thick concrete slab resting on top of at least 100 mm thermal insulation. The most widely used insulation material is cellular plastic due to its low thermal conductivity combined with high compression strength, which is important since it is the soil underneath the slab that supports the foundation. To prohibit cracks in the concrete it is for the most part steel reinforced and often provided with footings underneath load taking walls to give the foundation an adequate load capacity (Sandin, 2004).

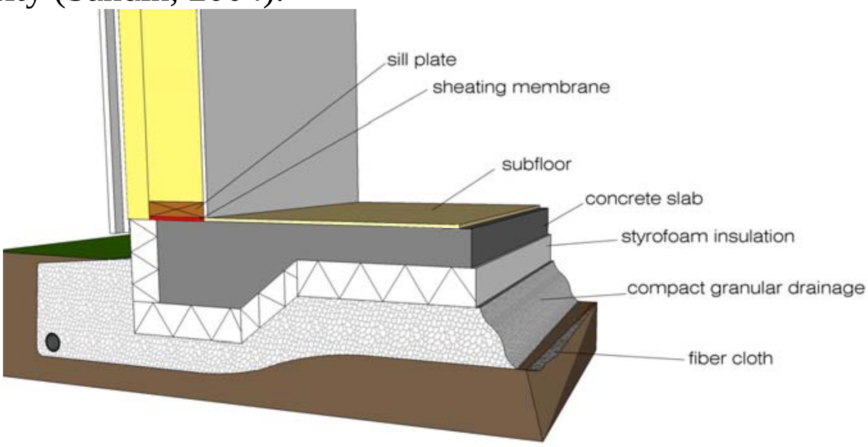


Figure 8. *Concrete slab foundation with underlying insulation*

To prevent moisture from reaching the concrete through capillary action and to secure a sufficient drainage the topsoil is removed and replaced with a 150 mm capillarity-breaking layer of macadam, which in most cases is separated from the soil with a fiber cloth (Nevander, 2006).

3.1.4.3 Wood Floor Framing

At the connection between the floor joist and the foundation wall in the Canadian type-house or the slab on the ground in the Swedish type-house, moist problem and thermal bridges can occur.

In the Canadian type-house, the connection between floor joists and foundation walls is a wooden sill-plate, anchored atop the foundation wall to fasten floor joist and headers. The junction can either be caulked or the sill plate should be placed on an air-impermeable material (Burrows, 2008). It is notable that BCBC do not require that the cavity in the connection to be insulating and thus creating a thermal bridge. This goes for the connection between storeys as well. However, Canadian Wood House Construction, show as an example of a floor framing method where insulation limits the thermal bridge.

In the Swedish type-house, it is equally important to not let the header get in contact with the wet concrete. Although not specifically required in BBR, the thermal bridge is decreased.

Both in Sweden and British Columbia, floor joist dimension are required based on the ability to support anticipated loads. Dimensions should also meet requirements to ensure that deformation under heavy load does not lead to defects and that the floor is adequately firm.

The spacing is in British Columbian houses general 400 mm on centre width dimensions varying from 38x140 up to 38x286 mm (Burrows, 2008). The typical dimensions for the Swedish house ranges from 45x145 to 45x220.

3.1.4.4 Wood Framed Walls

Historically and still the most common outer wall structures in both Swedish and British Columbian small houses are load-bearing wood framed walls. Though the designs has changed from massive timber walls in early 20th century to modern walls consisting of up to nine layers of different materials (Sandin, 2004).

The modern Swedish wood framed wall consists of load-bearing studs spaced 450 or 600 mm on centre. The stud dimension varies from 38 x 95 mm up to 45 x 145 mm depending on insulation thickness. Due to BBR’s increased requirement on thermal envelopes, 145 mm depth is seldom enough to obtain the recommended heat transfer coefficient of 0, 16 [W/ (m²°C)] for a wall in the thermal envelope. It has therefore become a common practice to put crossbars outside or inside the load-bearing studs instead of thoroughgoing to secure enough thermal insulation, as illustrated in figure 20 (Sandin, 2004).

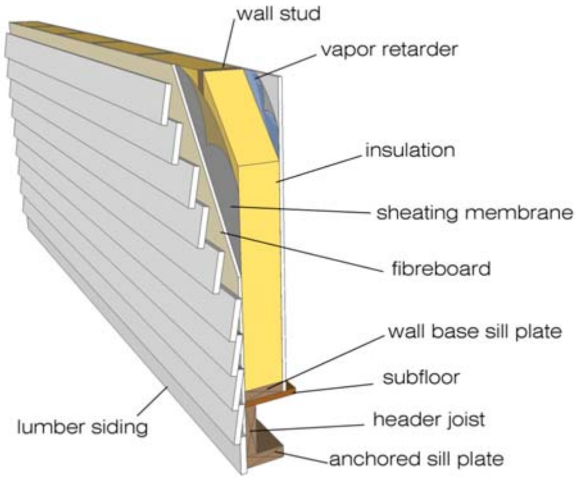


Figure 9. *Canadian type wall*

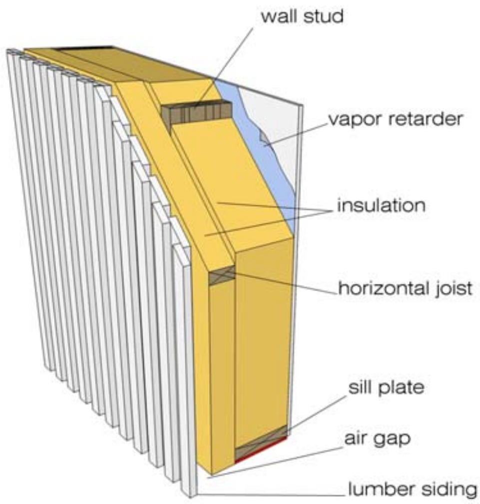


Figure 10. *Swedish type wall*

From a load-bearing perspective, the studs in a British Columbian house are required by the NBC to have minimum size 38 x 89 mm and be spaced 400 mm on centre, or 38 x 140 mm and be spaced 600 mm on centre (Burrows, 2008). Due to BCBC requirements regarding thermal resistance, only the latter option is an acceptable solution. In the past it has not been usual to insulate the cavities of wood framed (Willems, 2009). Although not required, Canadian Wood House Construction argues that thicker insulation might be needed to decrease the heat losses. Also Miljana Horvat strongly argues for more insulated walls (2009).

Air-leakage is a problem both for the heat losses it causes and for being one of two mechanism forcing water vapour through the building envelope. To obtain desired air tightness and hinder moist from traveling through the wall it is provided with different layers of water-, moist- and air-barriers. On the warm side of the wall an air-barrier/vapor retarder made of plastic or foil sheets prevent both diffusion and convection. This air barrier/vapor retarder is at times indented into the wall to minimize piercings made for power outlets and cables, though the barrier should not be indented longer than ¼ of the walls thickness (Nevander, 2006 & Burrows, 2008).

On the cold side of the wall a wind-tight board is mounted to prevent air-movement and penetrating rainwater from reaching into the insulation. Outermost is the exterior cladding, which can be done in many ways. Traditionally and still the most used methods and material in small Swedish houses are either brick or wood cladding. In British Columbia the cladding is most commonly of wood, stucco, or masonry (Burrows, 2008). In Sweden the wood framed walls are constructed with an underlying air-cavity of 15-30 mm (Nevander, 2006). In the interior British Columbia a solution without rain-screen is accepted (Southam, 2009).

Innermost of the wall construction is customary a plasterboard fastened as it is cheap and gives a good fire-resistance. This is common for both Sweden and British Columbia.

3.1.4.5 Roofs & Ceilings

Load-bearing structure of the roof can provide a liveable space in the attic. This practice is however not common in Canada (Southam, 2009). More frequent is the use of truss attic spaces, being created by pre-assembled roof trusses spanning from exterior wall to exterior wall (Burrows, 2008).

Since the attic space will not provide a habitable space, this space should be outside the building envelope. Therefore adequate ventilation should be provided not to create a good indoor environment, but to remove moisture. Air should pass through screened gable openings or ridge vents (Burrows, 2008). In the representative house, a prefabricated W-shaped roof truss is assumed.

Thermal insulation of truss roof-ceilings is not only an excellent way to enhance the building's heat transfer coefficient, it also important to avoid ice-dam creation, when heat transfer through the ceiling and sunlight melts snow during the wintertime (Burrows, 2008).

To provide nailing base for the roof covering and laterally brace the roof framing, sheathing is nailed over roof trusses. Atop of the lower part of the sheathing, a water-proof sheet is applied. Roof coverings should be water-proof, and as for exterior finishes of the exterior wall, there is a large variety of materials. Among them are asphalt shingles the far most widespread (Burrows, 2008).

The air-tightness and the control of diffusing water vapour are secured by a polyethylene sheet on the warm side of the thermal envelope (Burrows, 2008).

In a 1 ½ story house, as the Swedish type house in this thesis, the roof is a part of the thermal envelope. As a part of the thermal envelope, the roof has to be well insulated to be able to attain the government recommended U-value of 0, 1 [W/ (m^{2}K)].

A common construction for a roof on a 1 ½ story house is a combination of two separate roof types, partly a cold outside ventilated roof and partly a parallel roof. This roof construction nowadays normally consists of a pre-assembled load-bearing roof truss, which often acts as joist floor for the upper level. Standard dimensions for the timber in a roof truss are 45 x 170 mm spaced 1200 mm on center (Nevander, 2006).

Though the roof is a hybrid construction it has a joint exterior, protecting insulation and roof truss from rain water. The exterior generally consists of roofing-tiles attached to roof battens creating an air gap between the roof-tiles and underlying wooden boards which traditionally is covered with any type of tar paper, e. g. roofing felt (Sandin, 2004).

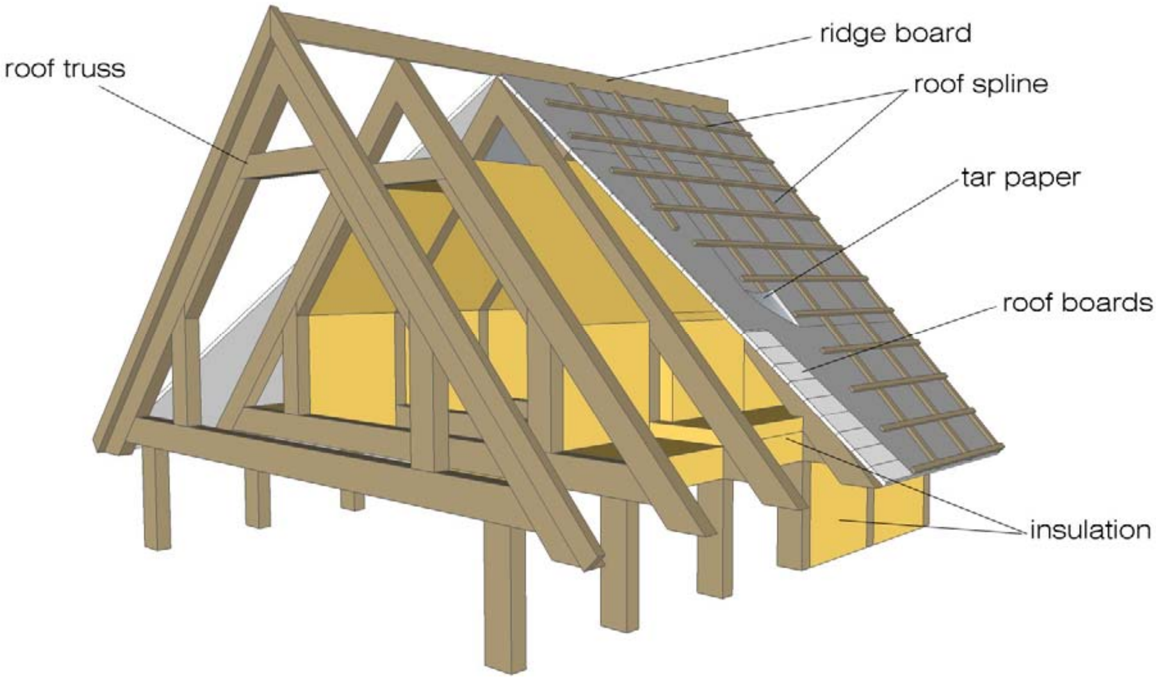


Figure 11. *Traditional roof construction for a 1 ½ storey house*

The roof is normally ventilated through openings at the base and ridge of the roof. As shown in figure 22 there is a section of the roof where insulation and interior walls have the same angle as the exterior. This sloping part of the construction is in fact working as parallel-roof, and it is of the essence to make sure the ventilation air-gap is adequate in this part of the roof so that it does not hinder the air-flow (Nevander, 2006).

In addition to fill all cavities in the roof truss with mineral wool insulation an extra layer of insulation is often fasten on the inside, this extra layer helps reducing thermal bridges as well as lowering the roof's heat transfer coefficient. In-between the layers of insulation a vapor retarder are pinned and on the inside are customary an interior gypsum board attached.

3.1.4.6 Heating & Ventilation System

In Canada, the most common heating system is the forced air heating system (FAH) (Southam, 2009). Such heating system is a combined heating and ventilation system. The supply air is heated and via ducts distributed into the liveable space. To cover the heat load at normal air exchange rate, the supply air had to be so hot it would not mix with the air in the room. Thus, supply air flow is mixed with circulation air as shown in figure 9 (Warfvinge, 2007).

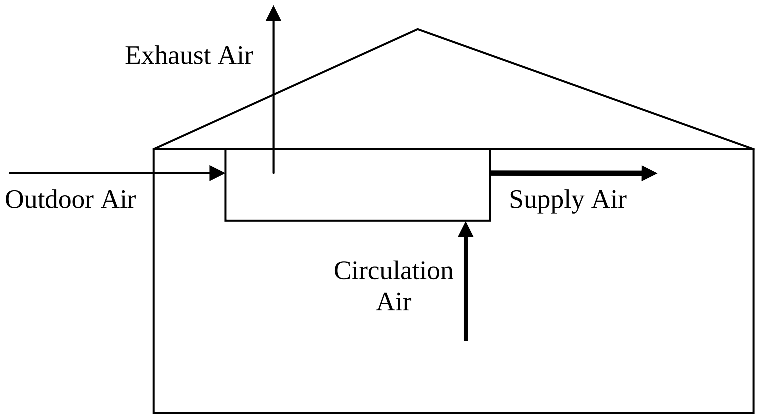


Figure 12. *Principal sketch of a forced air heating (FAH) system.*

The furnace heating the air can be both of gas combustion type and electrical. In this thesis a gas furnace is assumed to heat the air in the FAH system. The exhaust gas needs to be removed from the furnace and building via a chimney (Willems, 2009). This energy loss and the input electricity (part of operational electricity) to operate the FAH system, makes the FAH system less effective than the hot water heating system (Rivard, 2008). The embodied energy and embodied carbon, and weight of a forced air system for are given by Rivard, Yang and Zmeureanua in their report, "*Comparison of environmental impacts of two residential heating systems*" (2008). Although this value is specific for another residential small house, the difference from the FAH system in the type-houses is neglected.

In Sweden the most common heating system is the hot water heating system (HWH), where hot water is circulated to radiators (Warfvinge, 2007). There are two types of HWH systems. In the one pipe system the radiators are connected in series, whereas the radiators in the two pipe system are shunted. In this thesis the two pipe system is assumed. The temperature difference over the each radiator is equal in the two pipe system. The temperature in the water going to the radiator is in newer systems 55°C and going back to the heat exchanger 45°C (Warfvinge, 2007). The energy source can be both electrical or fuel boilers or district heating. The last alternative is assumed in this thesis.

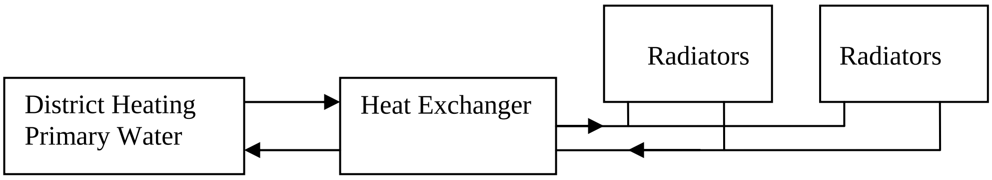


Figure 13. *Principal sketch of a HWH system*

The HWH system demands a separate ventilation system. Although there are several types of systems, the exhaust air system is the most common. In this system, the driving force for the exhaust air is an electrical fan. In an air-tight building, all the supply air is distributed via air inlets, which can cause draught (Warfvinge, 2007). Figure 14 shows the schematic sketch of an exhaust air ventilation system.

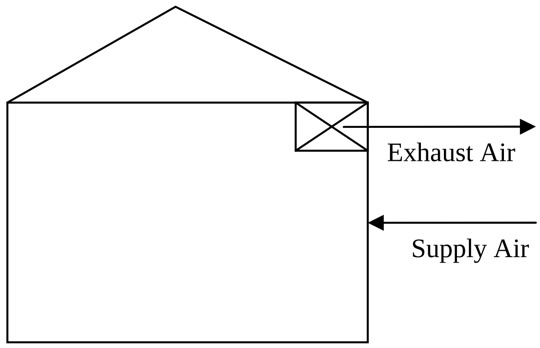


Figure 14. *Principal sketch over an exhaust air ventilation system.*

An electrical boiler, commonly used to heat domestic water in Canada has 100% utilization rate. This due to that no incomplete combustion occurs and no fumes need to be removed (Willems, 2009). However, as the hot water is stored and warmer than the surrounding air heat transfer will occur. Gas boilers are also an option, although they are substantially less effective (OEE, 2, 2009).

District heating is mainly used for heating of buildings and heating of tap water. The principle is that one large heat production facility replaces small private furnaces. Water is heated at the heat production facility. The hot water is distributed to a user, where an heat exchanger converse the heat energy from the distribution system's water to the tap water used in the building (Warfvinge, 2007). The environmental gain from the district heating is partly more efficient use of the heat content in the energy source, and partly the use of energy sources with less environmental impact e.g. wood pellets replacing oil as fuel (Warfvinge, 2007). Depending on which system boundaries being used, district heating will have different utilization rate. This is further discussed in chapter 3.2.1.1.

3.1.5 Building Codes & Practices Compared

The discrepancy between the two building codes' objective concerning the energy efficiency is evident. While BCBC mentions "the use of energy [should not] be unacceptably inefficient", BBR states that the "energy consumption [shall be] limited" (Boverket, 2008, BBR page 17).

Except from a higher ambition, BBR's strength compared to BCBC is the fact that it treats the building as a whole system. This enables e.g. avoidance of thermal bridges without prescribing every type of thermal bridge. BCBC must be seen from the perspective that is written for uneducated builders (Barrett, 1998). The type of functionality-based building code that treats the building as a system, demands a more educated workforce (Burke, 2009). Miljana Horvat, building scientist at Ryerson College, states that there are builders in Canada who do not understand the complexity of a building system. The necessity to treat the building as one system is exemplified with the R-2000 houses, a voluntary programme for certified builders, addressing energy efficiency. A R-2000 used 50% less energy than a conventionally wood frame houses at time. However, uncertified builders started building “copies” of the R-2000 houses without fully implementing all required features. These houses might be energy efficient, but high humidity, bad air-quality, and mould and moisture problems occurred due to an air-tight house without proper ventilation (Horvat, 2009).

Miljana Horvat also points out that there is a resistance in the Canadian building industry towards the new techniques that better thermal envelopes would demand. The adaption of new techniques is hindered by a shortage of qualified construction labourers (Horvat, 2009).

Don Willems, Nelson-based construction engineer, argues that new techniques will increase the cost of building and mentions great improvements in energy requirements over the last decades. Coming from un-insulated cavities between the wooden studs, the percentagewise energy improvement of further insulation will be substantially lower for further improvements. Willems (2009) argues that new improvements with lesser effect to a higher price might be hard to argue for. However, such argument assumes constant energy prices.

3.1.6 The Type-Houses

As a result of the literature review and the interviews, the type-houses have been designed what can be assumed in typical Swedish and British Columbian way.

The type-houses are assumed to be spec-houses. A spec-house is a house built on speculative basis, without an order on the books. Hence, such houses tend to use low costing and time saving construction systems. The two type houses are designed in compliance with the latest building code in affect. When the houses are placed in Helsingborg, Sweden both type-house will have a hot water heating system with district heating as energy source. When placed in Nelson, both type-houses will have a forced-air heating system with natural gas as energy source. Otherwise throughout the thesis, the most common method or design is assumed for the two houses.

The British Columbian type-house is a two storey house, with a liveable basement. This design is common in British Columbia (Southam, 2009). The liveable space is 235 m^2.
The pictures below present some of the blueprints used as base of calculation for the two type-houses.

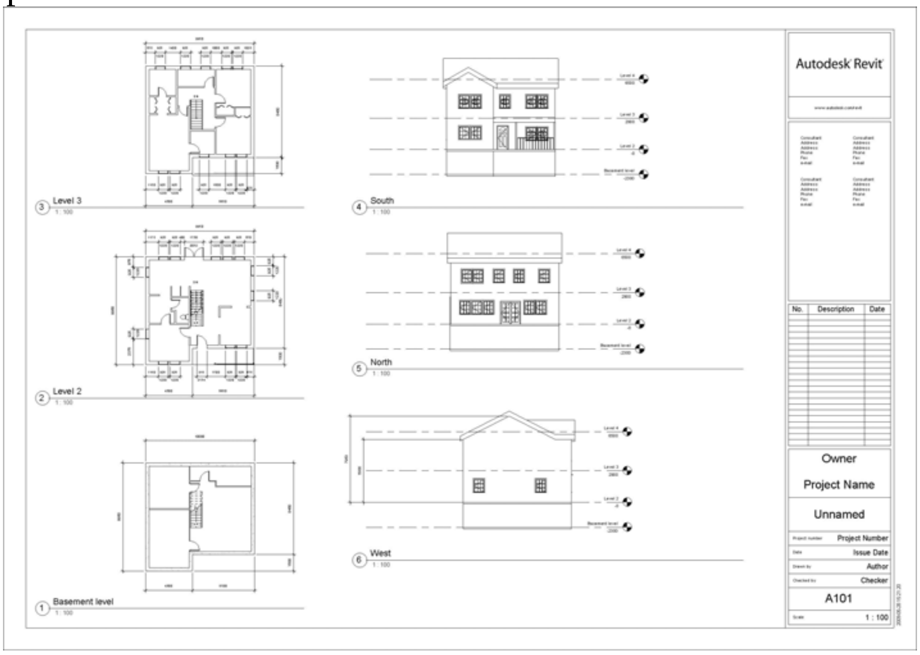


Figure 15. *Blueprint of the British Columbian Type-house, see Appendix 3*

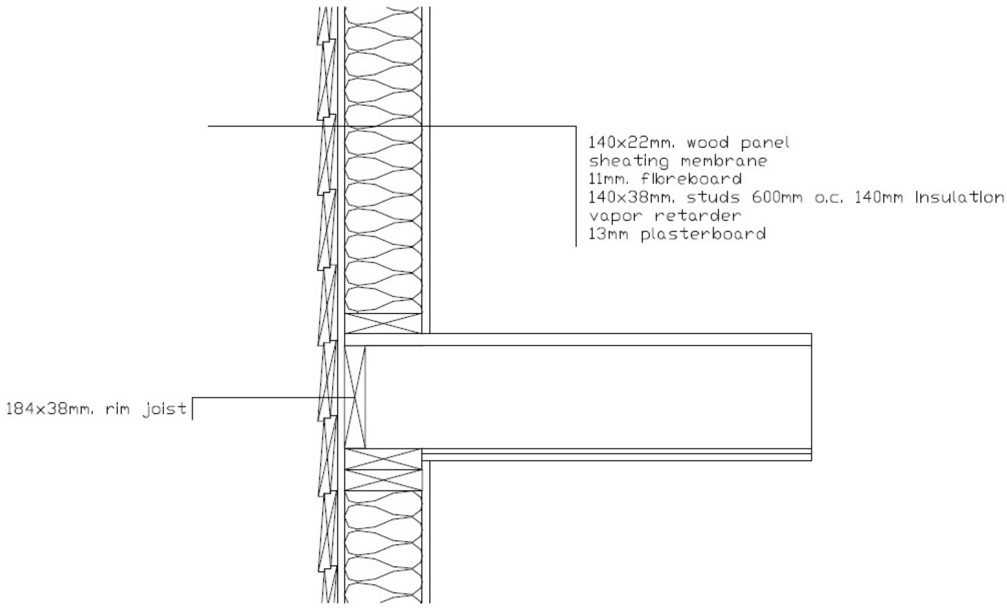


Figure 16. *British Columbian Type-house and joist floor construction.*

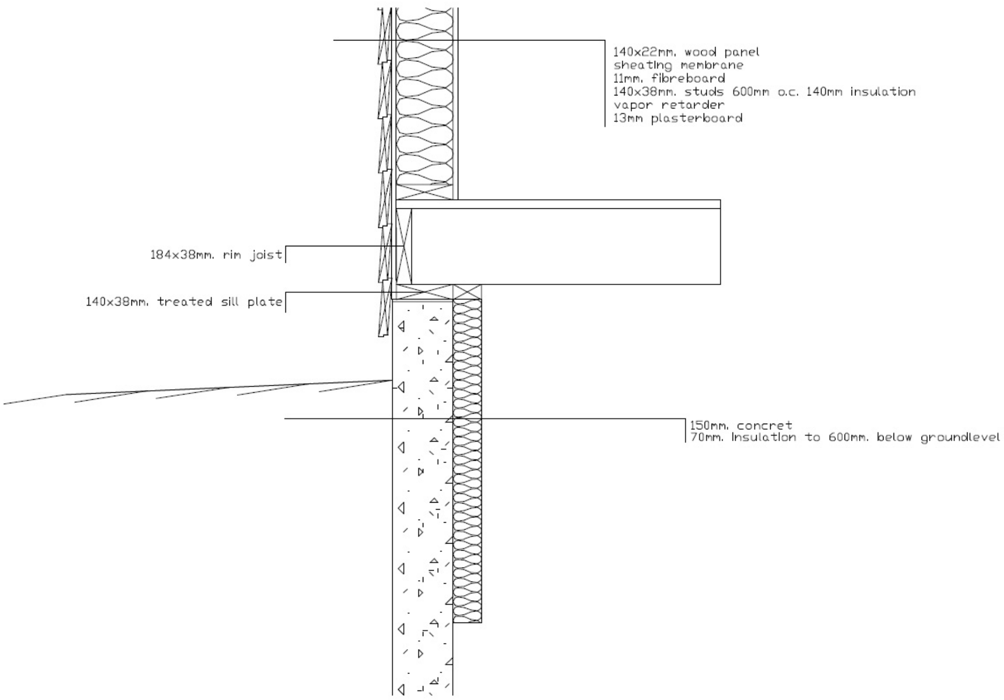


Figure 17. *British Columbian Type-house basement wall and stud wall constructions*

The "Swedish" house is assumed to be a 1.5 storey house with a concrete slab-on-ground, with a liveable area of 185m^2. The design is similar to the "Villan Villan", assumed to be typical Swedish houses used for educational purposes at Campus Helsingborg.

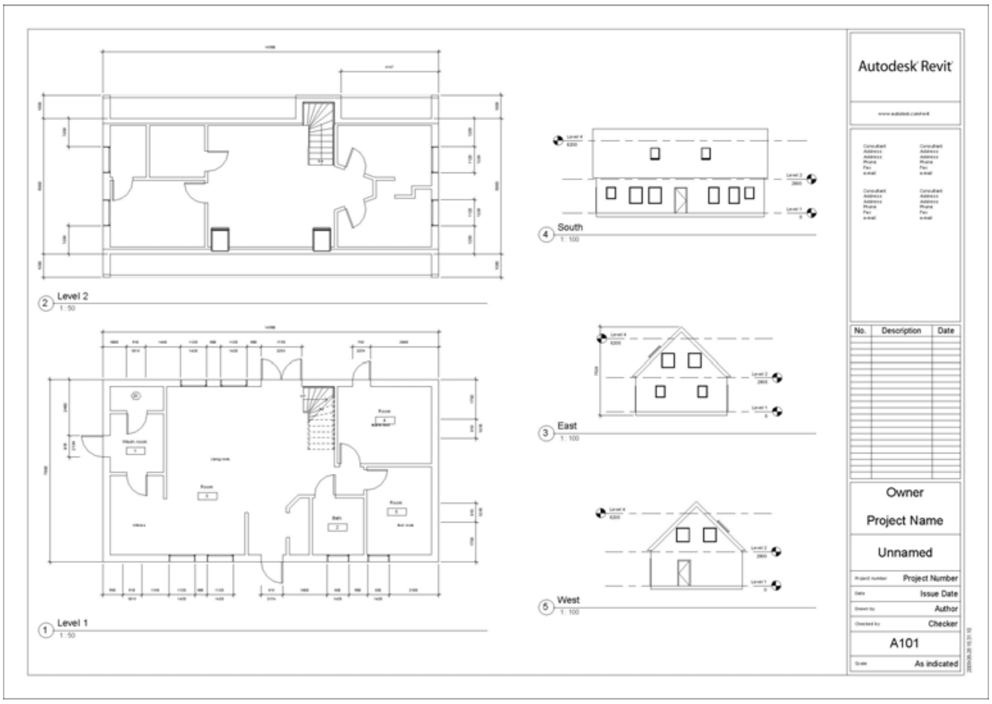


Figure 18. *Blueprint of the Swedish Type-house, see Appendix 4*

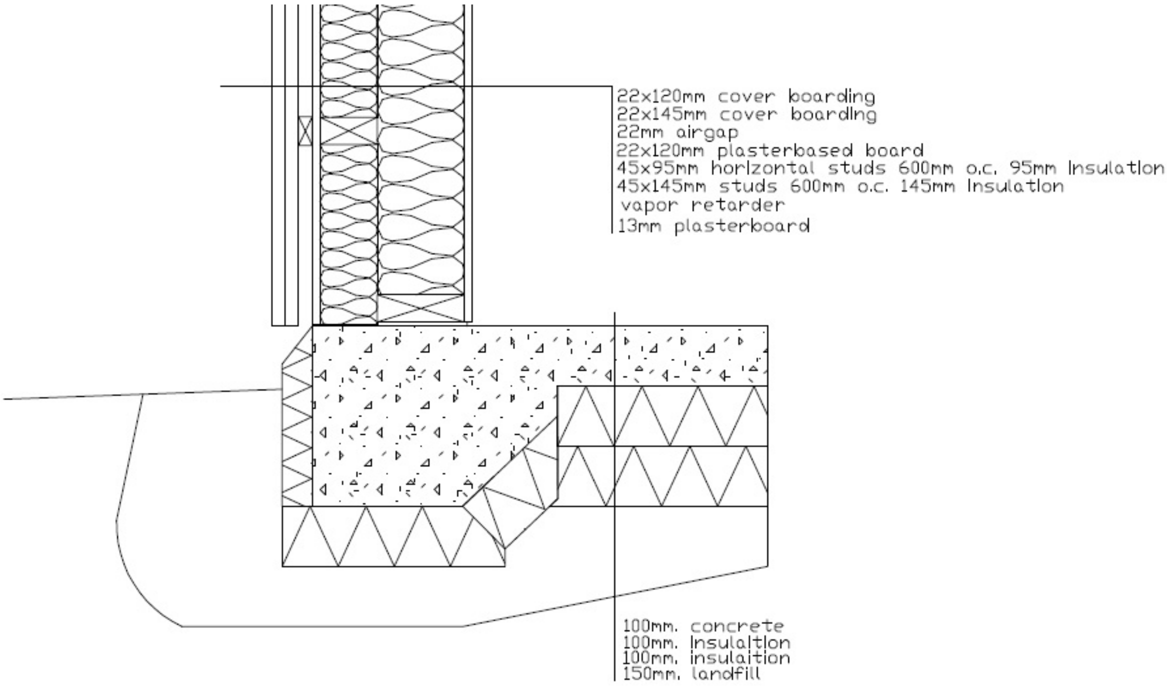


Figure 19. *Swedish Type-house stud wall- and concrete slab constructions.*

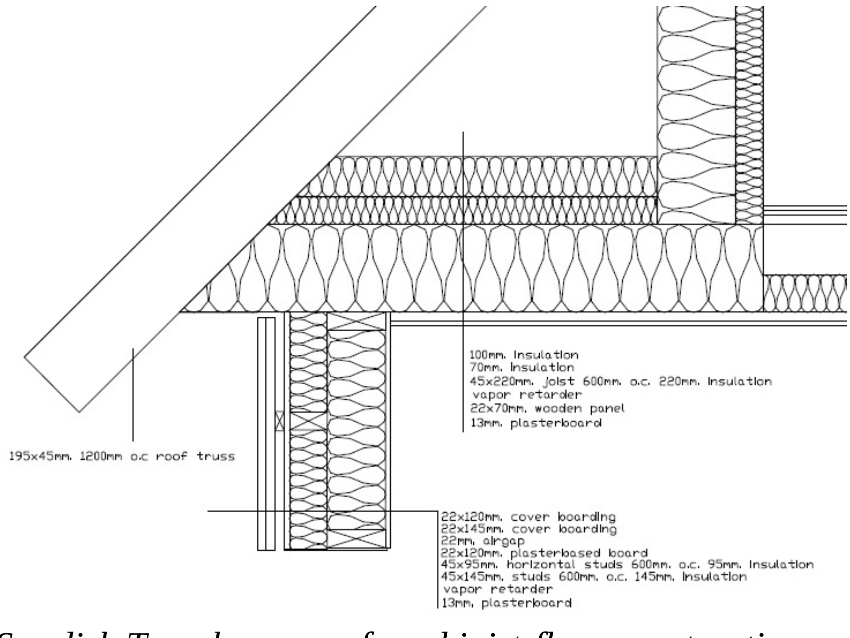


Figure 20. *Swedish Type-house roof- and joist-floor constructions.*

3.2 Energy Use from a System Perspective

Henrikke Bauman and Anne-Marie Tillman (2007) argues that energy use as such causes no environmental impact, and hence it could be argued that a life cycle inventory of a building's energy use is unnecessary, if the life cycle show mass flows of emissions and withdrawal of natural resources (Bauman & Tillman, 2007). However, energy use is a parameter considered to be easily communicated; the electric hydro power consumed in Sweden expressed in TWh, says more than the use of land for the dams being expressed as m^2 and year. Further, energy tends to become less and less effective to produce when the demand is high.

3.2.1 Net Energy Need, End Energy Use & Primary Energy

The SOU 2008:110 “Vägen till ett Energieffektivare Sverige” concludes that the energy use must been seen from a system perspective. Introducing the system perspective on a residential building’s energy use during its occupancy state, three system boundaries are introduced as shown in figure 1.

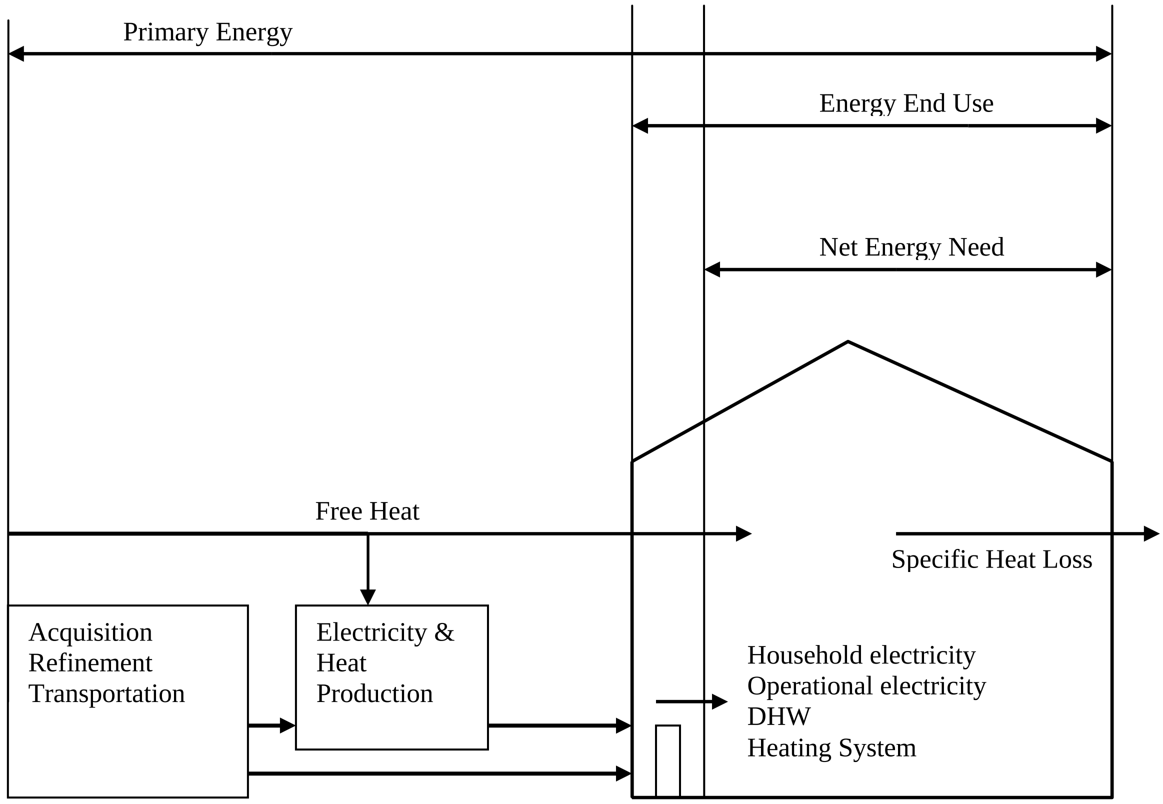


Figure 21. *System boundaries for the energy used in a residential building.*

The net energy need is the amount of utilized energy needed to provide the service regulated by the building code in effect e.g. a good indoor climate and a certain air-quality. The net energy need for a building is dependent on the heat load, the domestic hot water load, the operational electricity, and the household electricity use (SOU2008:25). SOU 2008:25 argues that the system boundaries for net energy need not should include free heat, but that free heat rather should be included in the energy end use system boundaries. However, free heat and sunlight will not increase the utilization rate of the installations, but actually decrease the need to use the heating system e.g. windows towards the south will decrease the need for heating a sunny winter’s day (windows will increase the energy need during nights and cloudy days). Hence, the system boundaries for net energy need include free heat and sunlight.

The end energy use is the total amount of energy delivered to the building i.e. in addition to the net energy need; it also includes energy losses when utilizing delivered energy to useful energy. SOU 2008:25 argues that for a comparison of for a residential building's energy need, the net energy need must be used. This is due to the fact that the energy losses of a district heating system are outside the system boundaries, while a gas furnace's energy losses are within.

Primary energy is the total amount of energy being consumed to cover the net energy need of the building i.e. primary energy takes in account all of the energy losses in conversion and distribution and the input energy for acquisition and transportation of fuels. The losses are referred to as being located "upstream" the end use. SOU 2008:110 states that the primary energy use is what determines the actual environmental load of an energy consuming service provided to the building.

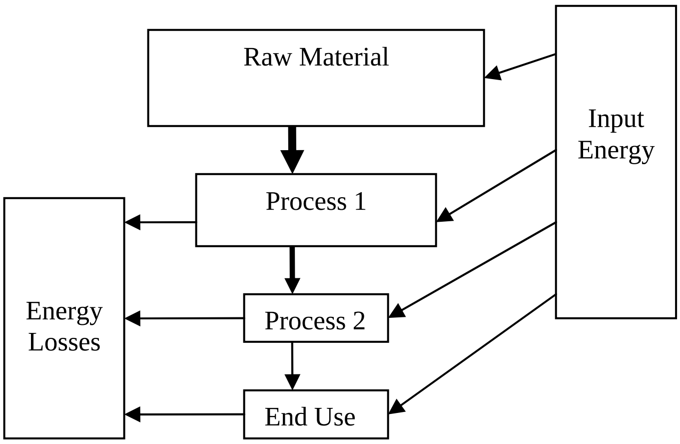


Figure 22*. The schematic energy losses and input energy from raw material to end use.*

For electricity produced by nuclear power the upstream losses can be described as follows: Input energy is first needed to extravagate and refine the uranium to nuclear fuel, after which it is transported to the nuclear power plant. In the power plant two thirds of the energy content in the nuclear fuel is lost when converting to electricity. When distributing, another approximately 8 % is lost to diffuse heat in the grid. Hence, 3 kWh primary energy is needed to provide 1 kWh of end use electricity, giving nuclear power a primary energy factor of 3. (SOU 2008:25).

3.2.1.1 Energy Carriers & Primary Energy Factors

Examples of different energy carriers are electricity and natural gas. All different energy carriers have different upstream losses. These upstream losses can be calculated using two different methods. One is using primary energy factors, and the other method is by knowing the utilization rate, the input energy and the energy losses for each process in the supply chain. When using primary energy factors, the end use of each energy carrier is multiplied with its corresponding factor (SOU 2008:110).

The primary energy factors for different energy carriers are not static and not globally adaptable, but dependent on the energy system. If the energy system changes, so will the primary energy equivalent factors. For example, if wind-power would replace nuclear power as electricity source, the primary energy equivalent factor for electricity would change, as wind-power has different upstream losses. The regional aspect is exemplified by the district heating systems, which can not allocate heat from one system to another. A district heating system using fossil fuel as energy source will have a higher primary energy equivalent factor, than a district heating system using waste heat as energy source (SOU 2008:25).

All in all, three different energy carriers provide the building with energy. Electricity to all appliances, district heating to the HWH and DHW systems for the houses are placed in Helsingborg, and natural gas for the FAH system, when the type-houses in are placed in Nelson. As described in 3.3.1.1, no energy losses are thought to occur within the system boundaries of the building.

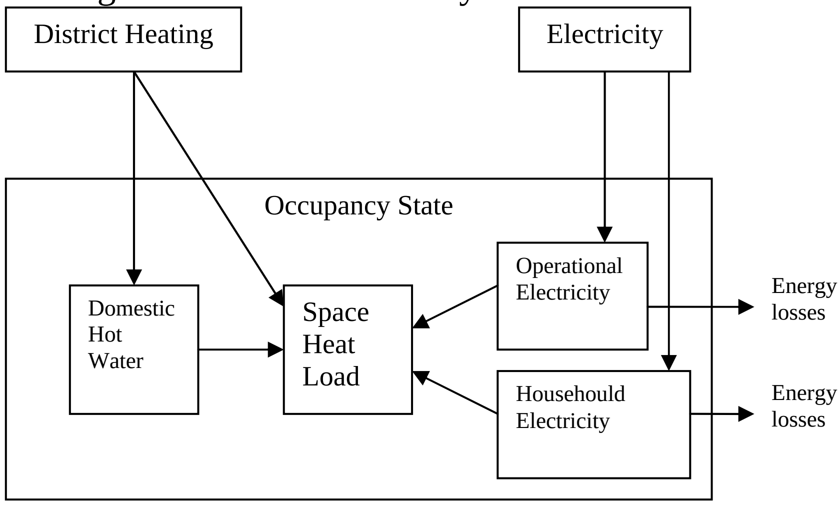


Figure 23. *Different energy carriers for the different energy needs for a house placed in Helsingborg, Sweden.*

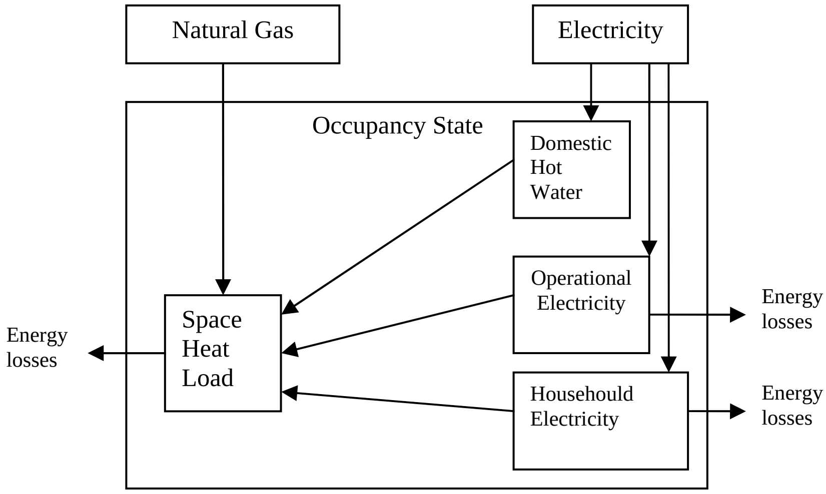


Figure 24. *The different energy carriers for the different energy needs for a building placed in Nelson B.C.*

The primary energy factors are introduced to simplify the system perspective. Erlandsson (2009) argues in "*Bedömning av resurseffektiva byggnader: Faktorer för olika energiformer och energislag*" that the primary energy factors tend to lean more on subjective assumptions than on scientific calculations. Also, the primary energy factors do not differ on the energy carrier's ability to be renewed. For example, bio-fuel (e.g. wood pellets) has the same primary energy factor as fossil fuel. Reasoning regarding the primary energy factors will be presented below.

<u>Nordic Electricity Mix</u>
The Nordic electricity grid is well integrated. This means that in the Swedish grid, electricity from Danish coal steam power, will be running along with Norwegian hydro and Finnish nuclear power. As the energy from one electrical source can not be allocated to one specific activity, the Nordic electricity mix is assumed for all the electrical use in accordance with. 1.5 is the primary energy factor for the Nordic electricity mix (SOU2008:25).

<u>District Heating</u>
As mentioned above, the primary energy use will vary from district system to district system. While the electricity grid is international, the district heating systems are local i.e. one district heating facility provides heat for the costumers in its distribution system and no heat can be allocated to costumers in other district heating systems. SOU 2008:25 divides district heating systems into three categories by heat distributed: small, medium and large. Larger district heating system tends to use more waste heat and have lesser distribution losses than

smaller district heating systems, and hence a lower primary energy factor. A district heating system allow the primary energy factor to be lesser than 1, suggesting that the end use is greater than the primary energy use. This is feasible due to the use of hot waste water and incineration of combustible waste. Waste heat is considered to have no alternative use and the only energy input is electricity for pumping of the slop water. This gives hot waste water a primary energy equivalent factor close to 0. Incineration of waste, including transport, is assumed to have a primary energy equivalent factor of 0.66.

For a large district heating system, the SOU 2008:25 suggests a primary energy equivalent factor of 0.78. A large district heating system provides more than 500 GWh annually, and the district heating system in Helsingborg is in this category with 1100 GWh distributed annually. However, the distribution losses in a district heating system are greater when supplying small buildings than when supplying multifamily dwelling (Persson, 2008). Thus, the primary energy equivalent factor assumed in this thesis is 0.9, the average national value given by SOU 2008:25.

3.2.1.2 Calculating the Primary Energy

As a primary energy factor is not global, the factor for the Nordic electricity mix can not be applied to the British Columbian electricity mix. Neither can the primary energy factor for fossil fuels be adapted to the British Columbian natural gas use. Hence, the primary energy had to be calculated using the equation $Q_{primary} = \frac{Q_{need}}{\eta}$, where η is the utilization rate of each sub-system.

As stated above, the municipality of Nelson owns it own hydro power plant. In accordance with the reasoning of the Nordic electricity mix, the British Columbian electricity mix will be assumed in this thesis, as allocation of electricity source in the grid is impossible. Overall in B.C., hydro power is the most predominant energy source. 89% of the electricity produced comes from hydro power, which primary energy factor is 1. The remaining electricity production comes from steam power using natural gas, wood and diesel as energy sources. The utilization rate in the steam power plants is around 40% (Statistics Canada, 2009). BC Hydro, the governmentally owned power company estimates their energy losses when distributing and transmitting electricity to 12.1%. Hence the primary energy factor for the British Columbian electricity mix will be 1.36.

Compression stations increase the energy head in the gas to transport the natural gas in the pipelines. Energy used to do so come from the natural gas itself (Näslund, 2003). Further, an example is given by Näslund saying that 10% of the energy of the natural gas is lost to distribution in Russian pipelines. If 5% is lost during acquisition and refinement, the primary energy factor will be around

1.17. This is still lesser than the primary energy factor for fossil fuels in Swedish conditions given by SOU2008:25.

3.2.2 Marginal Energy

The term “marginal electricity” is widely spread, but the terms “district heating on the marginal” and “oil fuels on the marginal” are also referred to. Energy “on the marginal” is the energy produced to make up for peaks in the energy need. Energy peaks occurs e.g. during cold winter days when the heat load of buildings is the greatest. Energy produced on the marginal is often produced with less effective and more expensive methods. For the example of electricity, demand peaks is often covered with fossil fuel produced electricity (SOU2008:110).

It is the momentary production cost that decides which type of electricity is being produced. As fossil fuels have high floating costs compared to hydro and nuclear power, it will be the first fuel to stop producing electricity as the demand is decreased. For fossil fuels, the marginal production is refinement of oil-sand and the manufacturing of synthetic oil, two products that is both more expensive and emits more CO_2. Even for district heating, a marginal perspective can be taken. During heat demand peaks, bio fuel and fossil fuel will to a larger extent be used in the production of heat (SOU2008:25).

The marginal energy perspective shall be used when improvements are being investigated (SOU2008:25). Whereas the actual use is compared in this thesis, the average energy better describes the actual emissions and primary energy use. However, the marginal energy perspective is important as it shows that decreased energy need benefits the primary energy use and GHG emission as it allows the energy production to be more efficient.

3.3 Net Energy Need & End Use during the Occupancy State

The net energy need is given by the energy needed for space heat load, domestic hot water load, operational electricity, and household electricity use. The net energy need is strongly dependent on occupant behaviour. When occupants were told their energy use was documented, they decreased their energy consumption with 40% compared to occupants not being told their energy consumption was documented (IPCC, 2007). However, variables dependent on occupant behaviour are either stated in the building codes (indoor temperature and ventilation rates), or given by statistics or template values (domestic hot water outtake and household electricity use). The occupant behaviour will be the same regardless location.

When the net energy need for a building is known, the end use and what energy carrier is used must be known to estimate the primary energy. The end energy use takes into account the utilization rates of the sub-systems e.g. the heating system.

3.3.1 Space Heat Load

A building's space heat load during the occupancy state is given by climate, the air-tightness and insulation of the building, and internal heat transfer (Warfvinge, 2007). The heat balance for a building is shown in figure 5.

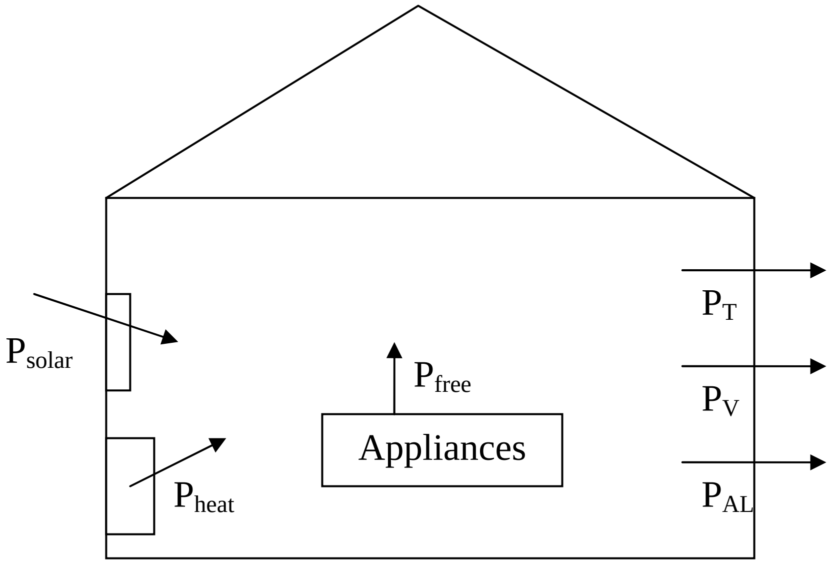


Figure 25. *The heat balance for a residential building.*

As seen in the figure, the heat losses should be covered by a heating system, solar insolation and free heat (Warfvinge, 2007).

3.3.1.1 Heating System

According to Warfvinge the heat load of a building is given by $E = \int P \cdot dt$ (kWh). This describes the amount of the time the heating system is operating at different capacities, as heat losses are proportional to the temperature differential between outdoor and indoor temperature. The indoor temperature during a year is constant, while the varying outdoor temperature will affect a building's heat load (Warfvinge, 2007).

The constant indoor temperature is given in the building codes. BCBC states that the indoor temperature shall be 22°C, and evidently this temperature is assumed in this thesis. BBR states that the indoor temperature shall be 18-22°C. In this thesis 22°C is assumed for the Swedish type-house as well. It is not only the least favorable temperature; it also makes the comparison between the building codes easier. Further, 21°C is the temperature which least inhabitants think is too cold, and 23°C is the temperature which least inhabitants think is too warm (Warfvinge, 2007). It can then be assumed that 22°C is a quite comfortable temperature. It is important to show that the assumed indoor temperature can be corroborated in the building codes as the required indoor temperature will affect the energy use of the building. That is to say, if the building code required the indoor temperature, not to be greater than 15°C less energy would be required and this could be one method to decrease the energy use.

Regardless which heating system assumed in the two type houses, it is assumed that no heat losses occur in the distribution system, as ducts and pipes are located inside the thermal envelope. However the gas furnace heating the air in a FAH system cannot fully utilize the heat content in the natural gas. A gas furnace loses energy due to incomplete combustion and that heat is carried away through the chimney with the exhaust gases (OEE, 1, 2009). The least acceptable utilization rate of a gas furnace is 78% according to OEE. In a HWH system, the heat exchanger transferring heat from the district heating system’s primary water to the secondary water in the building has a 100 % utilization rate. Heat that is not transferred into the secondary water is still remaining in the district heating system. Heat losses in distributing the hot water are taken into account in district heating’s primary energy factor.

As BCBC suggest that the heating system is should operate when it is below 18°C outside, the non-heating season is estimated to 50 days in Nelson, and 40 days in Helsingborg.

3.3.1.2 Solar Insolation & Free Heat

Although heat losses occur constantly, the heating system is not always in use. Summertime no heating is needed, although the mean outdoor temperature is substantially lower than the indoor temperature. Together with “free heat” (heat transfer from appliances and inhabitants), solar insolation make it possible to turn off the heating system before outdoor and indoor temperature is equal. While Warfvinge states that this “border-temperature” traditionally is around 11°C for Swedish houses, BCBC suggests that the heating system shall operate when it is below 18°C outside.

The solar insolation is thought of only to provide heat to the building through windows. When visible light is transmitted through the window, some of the shortwave light will be transferred to long wave heat (Nevander, 2006). The amount of solar insolation is dependent on geographic position and is measured as [W/m^2]. However, this measurement is the amount of solar insolation “hitting” a horizontal space on a blueberry day. The amount of heat transferred through a window is by far lesser than amount of solar insolation of the geographic position. Amongst the number of factors decreasing the heat transfer is numbers of glass in the windows and the degree of cloudiness.

Free heat is heat from household and operational electricity, occupants (Warfvinge, 2007) and domestic hot water. (Willems, 2009). It is referred to as free heat due to the notion that this energy (heat) was not intended for heat, but for other purposes. Although this heat evidently decreases the heat load of the building, electricity's great primary energy factor must be remembered, or a greater primary energy use is possible (SOU2008:110). Occupants emit 80 W (Isover.se). However, all the occupants are not thought of as staying home all day. In a four person household, the average number of occupants at home can be assumed as 3.

3.3.1.3 Specific Heat Loss

A building's specific heat loss is the momentary heat losses trough transmission, ventilation and air-leakage. It is given by $Q_{tot}=Q_{trans}+Q_{vent}+Q_{al}$ [W/°C]. It can be understood as the heat flow through the thermal envelope per every degree Celsius temperature difference between the outdoors and the indoors (Warfvinge, 2007).

Transmission Losses, Q_{trans}

The heat conductivity, λ, is a material's ability to transmit heat through one meter of the material lengthwise the heat flow. It is expressed as [W/m°C]. The heat transfer through a homogenous material is dependent on the heat conductivity, λ, and the temperature gradient differential over the material, $\frac{dT}{dx}$.

It is given by $q = \lambda \cdot \frac{dT}{dx}$ [W/m²].

In practical calculations the term heat transfer coefficient, U, is commonly used. This is defined as "the amount of heat per time unit passes through one area unit when the temperature differential is one degree Celsius" (Sandin, 1996). It is expressed [W/m²°C]. The invert value is a homogenous material's thermal resistance, R. It is expressed as [m²°C/W]. This is the nominal thermal resistance of the insulation required in BCBC. The thermal resistance of a building assembly consisting of several material layers is given by the sum of the included building materials' thermal resistance $R_{ass} = \sum R_{layer}$ [m²°C/W]. Using the heat transfer coefficient U_{ass}, or the thermal resistance, R_{ass}, the actual heat flow through a building assembly is given by $q = \frac{\Delta T}{R_{ass}} = U_{ass} \cdot \Delta T$ [W/m²], where ΔT is the temperature differential over the building assembly (Sandin, 1996). The heat transfer between the building assembly and the air occurs due to radiation and convection (Nevander, 2006). The air film closet to the wall will create a thermal resistance due to less air movement causing convection. This resistance varies widely due to foremost speed of wind. As the outdoors is more exposed to wind, this thermal resistance will be lesser outdoors (Sandin, 1996). Warmer air's lesser density makes the thermal resistance lesser when the cold outside is located above the thermal envelope (Isover.se, 2009). Further, an air-cavity will add to the thermal resistance of the building assembly. However, the building assembly can not benefit from the thermal resistance of the building materials outside the air-cavity. This thermal resistance is due to lesser air-flow occurring inside an air-cavity.

The heat flow through a homogenous layer is at a certain temperature differential of equal quantity. However, there are a several aspects either increasing or increasing this heat conductivity. If a certain part of the layer is of lower thermal resistance, a greater heat flow will occur there (Nevander, 2006). The increased heat flow will self-evidently affect the heat load of the building.

Moreover, some building assemblies will be affected by small defects such as cracks and leakiness, while this on some building assemblies will be of lesser impact (Isover.se, 2009). For example a wood framed wall with only one layer of insulation and thoroughgoing wooden studs, a small crack between two insulation batts will have greater impact on the heat flow than when the wood framed wall have two insulation layers crossed studs.

The momentary transmission losses for a whole building are given by $Q_{trans} = \frac{\sum_{i=1}^{n} U_i A_i + \sum_{k=1}^{m} l_k \psi_k + \sum_{j=1}^{p} \chi_j}{A_{liveable}}$ [W/(m^2°C)]. The first term, $\sum_{i=1}^{n} U_i A_i$, refers to the sum of the total heat transfer through each building assembly, e.g. wall, roof, windows. The second term, $\sum_{k=1}^{m} l_k \psi_k$, is total heat transfer through the lengthwise thermal bridge. Lengthwise thermal bridges are the connection between joists and wood frame wall. The third term, $\sum_{j=1}^{p} \chi$, is the total heat transfer through the punctual thermal bridges.. If the transmissions losses are divided by the exterior area of the building, the average heat transfer coefficient of the building, U_m, is given. This average heat transfer coefficient is required in BBR to be below 0.5 [W/m^2°C].

Ventilation Losses

Ventilation losses are caused by the air exchange of ventilation system. When the building is ventilated the hot indoor air is replaced with cold outdoor air that is needed to be heated. The momentary losses per °C temperature difference between indoors and outdoors, are given by, $Q_{vent} = \frac{q_{vent} \cdot \rho_{air} \cdot c_{air}}{A_{liveable}}$ [W/m^2°C] (Warfvinge, 2007). q_{venr} is the airflow, ρ_{air}, is the density of the air [1,2 kg/dm^3], and c_{air} the heat capacity of the air [1000J/kg].

A forced air heating (FAH) system will have a greater air-flow than what is needed for the ventilation requirements in the building codes during the heating season. However, only the air-flow needed to cover the ventilation is air brought in from outside the building, and in need of being heated to the indoor temperature.

The ventilation rates are given by the two building codes to provide sufficient indoor air-quality. As BBR requires a ventilation rate based on litres per square meter and seconds [l/m^2/s] the total annual air-flow is given by $q_{vent,Swe} = \frac{q_{req} \cdot A \cdot 3600 \cdot 24 \cdot 365}{1000} = 2{,}04 \cdot 10^6$ [m^3], where q_{req} is the ventilation rate [0.35 l/s], and A is the area. This is equal to 0,5 air-exchange per hour.

BCBC on the other hand requires during the non-heating season a certain air-exchange per hour, giving an air-flow during the non-heating season of $q_{vent,BC,non-heat} = q_{reg} \cdot V \cdot 24 \cdot days = 0{,}56 \cdot 10^6$ [m^3], where q_{req} is the ventilation rate (1 air-exchange per hour if the house not is mechanically cooled), V is the volume of the house and $days_{noheat}$ is the length of the non-heating season). During the heating season the requirement is based on litres per second dependent on the amount of bedrooms in the house. The air-flow during the heating season is given as $q_{vent,BC,heat} = \frac{q_{req} \cdot 3600 \cdot 24 \cdot days_{heating}}{1000} = 1{,}22 \cdot 10^6$ [m^3], where q_{req} is the ventilation rate [45 l/s] and $days_{heat}$ is the length of the heating season (315 days). This is equal to approximately 0.35 air-exchange per hour over the whole year.

Air-leakage Losses

Air-leakage gives energy losses as the intruding air needs to be heated. The formula for the momentary losses is the same as for the ventilation losses; however air the flow is substantially lower. The driving force is partly forced convection by wind (Nevander, 2006). The momentary energy losses due to air-leakage are given by $Q_{AL} = q_{AL} \cdot \rho_{air} \cdot c_{air}$ [W/°C]. As earlier shown, both the Swedish type-house and the British Columbian type-house will have a continuous vapor-retarder, creating an air-tight house. Hence, the air infiltration caused by the leakage is assumed to be equal in the two houses. The air-exchanges due to air-leakage are assumed to be 0.1 or approximately 56,000 m^3 for British Columbian type-house and 44,000 m^3 for the Swedish type-house.

3.3.2 Domestic Hot Water Load

The domestic hot water load is strongly dependent on occupant behaviour. The domestic hot water system should provide tap water between 45-60°C to comply with BCBC respectively BBR. The heat of the tap water will pass through the building in the type houses i.e. no heat recovery systems are used.

If the daily outtake of hot water is known, the annual DHW load can be calculated. However, template values of daily hot water outtake vary, and hence the annual domestic hot water load might as well be estimated dependent on the liveable area. The formula is given by Warfvinge. $E_{hw} = (5.0 + 0{,}015 \cdot A) \cdot 365$ [kW]. Hence, the Swedish type-house will have a domestic hot water load of 2800 [kWh/year] and 3100 [kWh/year] for the British Columbian type-house.

Domestic hot water heated by district heating, has no heat losses in accordance with the reasoning above (or rather, energy losses are outside the system boundaries). When the DHW is heated by an electrical boiler, standby losses will be added to the free heat, along with the heat from the distribution losses (Willems, 2009). The standby losses can be in the quantity of 40 [W] (OEE, 2, 2009).

To compensate for heat losses during distribution inside the thermal envelope, two degree Celsius is added to the tap water temperature (a heat loss that will be added to the free energy for the space heating). For the district heating system, this will hold no relevance as the lost tap water heat is gained as heat to the liveable space and the two services is provided by the same energy carrier, the district heating system. In the case of electrically heated water, one energy carrier is to some extent replacing the need of another energy carrier, as electricity is heating the space instead of natural gas.

No energy losses are accounted for the distribution of domestic water i.e. from the municipality water reserve to the outlet point. The least favourable outlet point can still be served by the lowest expected pressure at the connection point. There is evidently energy use in providing domestic water and treating waste water, but due allocation problems and poor data availability results will hold no relevance.

3.3.3 Operational Electricity

Operational electricity is defined by Boverket as the electricity needed to operate the services of the building. Services include foremost operation of the heating and ventilation system. 80% of the operational electricity will be accounted for as free heat.

The calculation of operational electricity is an iterative process, as the heat load to some extent is dependent on the operational electricity, and the operational electricity is dependent on the heat load. In this thesis the heat load is calculated with an estimated operational electricity use, and then the new operational electricity given by the heat load is used in the results.

3.3.3.1 Ventilation & FAH Systems' Operational Energy

It can be difficult to provide the needed air flow only with natural forces as a mean to ventilate the building (Warfvinge, 2007), although none of the building codes prohibits the natural ventilation system as such. Natural ventilation would evidently save the building's operational electricity. An electrical fan forces the air out the building, and hence creating an energy need, in addition to make up for the heat losses. This energy need can be of substantial amount (Warfvinge, 2007). The type of ventilation system assumed in this thesis an exhaust air system, where the supply air is unheated and unfiltered, when a hot water heating system is used. The forced air heating system is a combined heating and ventilation system. This system is a supply and exhaust air system, where the fan also forces the air into the building.

The air-flow will vary with building code requirement and season. The air-flow due to ventilation is discussed in chapter 3.3.1.3. During the non-heating season and when the houses are using a HWH system, the air-flow will be equal with the air-flow of the ventilation rates. For the British Columbian type-house during the heating season, the air-flow to cover the space heat load will with the FAH system surplus the air-flow due to ventilation. Given that when the FAH is in use, it delivers a static air-flow with a static temperature (assumed to be 50°C), the annual amount of air forced by the FAH system to cover for the space heat load is given by $Q = \frac{E_{heat}}{\rho_{air} \cdot c_{air} \cdot (T_{for} - T_{indoor})}$ [m^3]. Hence the total air-flow for the British Columbian type-house when placed in Nelson will be $4.3 \cdot 10^6$ [m^3].

The efficiency of the ventilation system can be described as specific fan power [kW/(m^{3}s)], describing the ventilation system's electric power needed to transport the required air-flow (Warfvinge, 2007). If the specific fan power is stated, the total energy need can be calculated using $E = \frac{SFP \cdot Q_{air}}{3600}$ [kWh]. BBR states that the specific fan efficiency should be below 0.6 [kW/(m^{3}s)] for an exhaust air system. For an exhaust and supply air system, such as a FAH system, the specific fan power should be 1.5 [kW/(m^{3}s)]. BCBC on the other hand states no quantifiable ventilations efficiency requirements. Warfvinge gives 1.0 [kWh/(m^{3}s)] as specific fan power desirable to be below. This will then be assumed for the Canadian type-house when an exhaust air exhaust ventilation system is used.

Type-House	**Operational Energy FAH System (kWh/year)**
Swedish	730
British Columbian	1780

Figure 26. *Operational Energy use for Type-Houses in Nelson*

3.3.3.2 HWH Systems' Operational Energy

In a hot water heating (HWH) system, the moving force is usually created by an electrical pump (Warfvinge, 2007). Neither BCBC nor BBR states any requirements on the efficiency of the pumps. One way to calculate the operational energy for HWH system is looking at the COP-value. COP is the ratio between the heat load of the building and the total on-site energy use. Hence, the operational energy for a HWH-system is given by $E_{op} = \frac{Heat\,Load}{COP} - Heat\,Load$ [kWh]. Rivard, Yang and Zmeureanua showed that the COP for a HWH system is 0.96. In this is however the ventilation system included. The operational energy for a just the HWH system is then given by $E_{op} = \frac{Heat\,Load}{COP} - \left(Heat\,Load + E_{v,op}\right)$ [kWh].

Type-House	**Operational Energy Vent & HWH System (kWh/year)**
Swedish	560
British Columbian	1240

Figure 27. *Operational Energy use for Type-Houses in Helsingborg*

3.3.4 Household Electricity Use

A household's electricity is defined as the electricity used for the household appliances such as computers, stoves and TV's. Though a substantial lowering of the household electricity use has been predicted, in Sweden it has contrary increased. Although the electric appliances are becoming more and more energy efficient, this is increase is explained by greater number of appliances providing a greater number of services (Piska och Morot, 2005). Evidently, household electricity use is strongly dependent on occupant behaviour .The annual household electricity use is for Swedish households given as 41kWh/m^2 (Piska och Morot, 2005). 80% of the household electricity can be accounted for as free heat (Isover.se, 2009).

3.4 The Life Cycle Perspective

Even though a building is an unusual large product to assess, a life cycle assessment (LCA) is according to Leiden University's report on (LCA), an applicable tool to determine a building's total environmental load (Guineé, 2001). International Standardization Organisation (ISO) defines a life cycle assessment (LCA) as the compilation and evaluation of inputs, outputs and the potential environmental impacts of a product system throughout its life cycle. However, explicit choices regarding what environmental load the LCA shall cover (EPA-LCA) can be done. As for this thesis, the life cycle assessment will only investigate the energy use and the GHG emissions. This thesis will not conduct a full LCA, but will present an inventory of the primary energy use and GHG emissions, the first of four steps in a LCA (Guineé, 2001).

The energy use during the occupancy state is widely discussed. The system boundaries of a building's life cycle should also include the production of building materials, the transportation to and from the building site, and what happen to the building materials when the building is demolished.

The holistic approach in a life cycle perspective is a strength, as it enables avoidance of sub-optimizations (Bauman & Tillman, 2007). An example of a sub-optimization is the choice of load-bearing structure. Concrete has less embodied energy during production than steel. However, the decarbonisation of the limestone during cement production emits CO_2 along with the fuel related GHG emissions. Hence, choosing concrete might be a sub-optimization if the non-fuel related GHG emissions off-set the lesser fuel related GHG emissions.

Critique on a LCA includes the linear modelling of its nature (EPA). A LCA can not consider changes in the future. This becomes apparent because of a building's long life span. The problems with the linear modelling for a building's long life span are many. The electricity mix will be the same during the whole life time (although SOU2008:110 states that the energy mix will change as soon as 2016). The designing temperatures for the heating load of the houses are assumed to be the same for the life spans of the houses i.e. the predicted warmer climate will not affect the need for heating. Non-renewal resources will be considered to last throughout the life spans of the buildings, and marginal effects of lesser quantities of the non-renewable resources are disregarded (e.g. natural gas and the uranium used for nuclear power). The utilization rates of each sub-system are assumed to be the same for the life spans of the houses e.g. even though ducts for the ventilation can be assumed to get dirty and thus making the system less efficient, the energy needed to provide sufficient air-flow is assumed to be the same.

Cut off criteria is defined as parts of the life cycle that is negligible or without relevance for the life cycle assessment (Bauman & Tillman, 2007). Capital goods, the assembly of the building materials, and flashing and nailing materials are cut off in this thesis. Capital goods include e.g. the incinerator, district heating and natural gas piping system. One residential building's allocated part of the environmental impact of an extensive piping system is by far negligible to its impact for heating the house. As Thormark (2002) excluded the energy needed to assemble the building, this thesis does as well. Many assumptions about the process of the assembly would have had to be made, and hence the result would have held no relevance. Nailing and flashing materials contribute to a very small portion of the buildings' embodied energy. As well, assumptions of the quantity of these materials would be far from accurate. Leaking natural gas from pipelines (emitting CH_4) will also be excluded, along with distribution of municipality water. The production, transportation and disposal of household appliances are excluded. This will mostly affect the emissions of halocarbons. No further material input is assumed during the type-houses' life span i.e. no renovations are assumed.

3.4.1 Equivalence in System Performance

Both the Dutch System and EPA stress that when a comparative life cycle analysis is conducted, equivalence in the compared systems must be described. Equivalence will in this thesis mean solutions complying with respective building code and applicable with the site-conditions. It is easy to adapt the British Columbian type-house code to the Swedish site; the prescribed dimension in BCBC is used in Sweden as well. The Swedish type-house is somewhat harder to adapt. First it is designed to meet the specific energy use requirement of 110 [kWh/(m^2year)] in Helsingborg. This design (foremost including insulation thickness) was then used when the house is placed in Nelson. The performance of the representative houses will not be the exact same, but what the different building codes states as the minimum requirements regarding a building's function i.e. the requirements regarding a Canadian type-house's performance will still be assumed when it is placed in Helsingborg. Occupant behaviour will be the same at both locations.

As the two type-houses are not of the same area (a two storey house with liveable basement proved hard to be designed with an area less than 235 m^2), the functional unit is [kWh/m^2] and [CO_2eq/m^2]. A functional unit is a unit allowing comparison.

Rivard, Yangand Zmeureanua (2008) showed that there is a significant difference in efficiency for a FAH and a HWH system. A district heating system can not be the energy source for a FAH system (Warfvinge, 2007). To nonetheless choose district heating as heat source is motivated by the location. Helsingborg is the Swedish with the greatest number of small residential houses connected to the district heating network (Oresundskraft, 2009). And according to Sweden Statistics' "Yearbook of Housing & Building Statistics 2009" district heating is the second most common way to heat houses built after 2006, being used by 41% of these houses. Both houses will, when placed in Helsingborg, have a HWH system.

As the type of heating system is not regulated in the building codes, any of the two heating systems could be used when the houses was placed in Nelson (if the heat source for the HWH system was not district heating). It is however more practical if the same heating systems are used for the two type houses. Both house will have a FAH system with natural gas as energy source, as Nelson has a well-developed system for natural gas and it is the most common heating system (Southam, 2009; Willems, 2009), although a “typical” Swedish house not is thought of being heated with such a system.

The life span of the two type houses is assumed to be 50 years. According to Stefan Norrman (2009) at Boverket, this assumption is made in Eurocode. Southam assumes that the life span of Canadian residential building is 30 years; however this assumption is not based on the physical shape of the building, but rather to the real estate market. Willems (2009) on the other hand, states that 50 years is a minimum life span, just looking at the functional aspects of a house.

The two sites will show differences in electricity production, waste management, weather and infrastructure - all determents for a building’s energy use and GHG emissions. These differences will be expressed by the regional average values e.g. different primary energy factors will be used for the Swedish and British Columbian site respectively. Only where average data not can be found (e.g. transportation coefficients for British Columbia) or site-specific data are needed (e.g. climate data), such values will be used.

3.4.2 Energy Flow

Above, the concept of primary energy was elaborated, exemplified with the upstream losses of a residential building’s occupancy state. The upstream losses described will occur for all processes of a building’s life cycle.

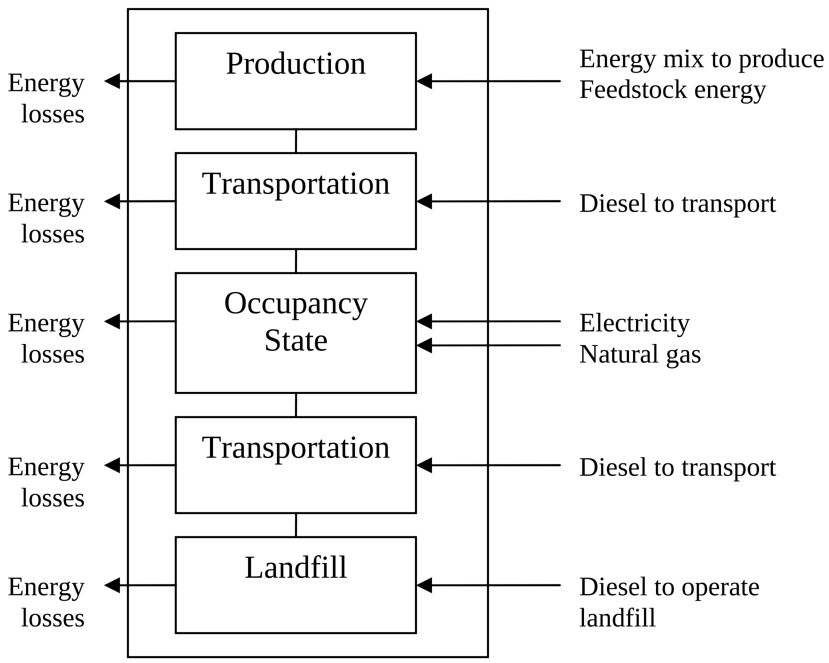


Figure 28. *The energy flow through a building’s life span, when placed in Nelson, B.C.*

Conversely to the occupancy state, the upstream losses for production, transportation and disposal will not be further discussed, but will be included in the data. Inclusion of the upstream losses for these processes makes it possible to consider the presented energy use as primary energy use.

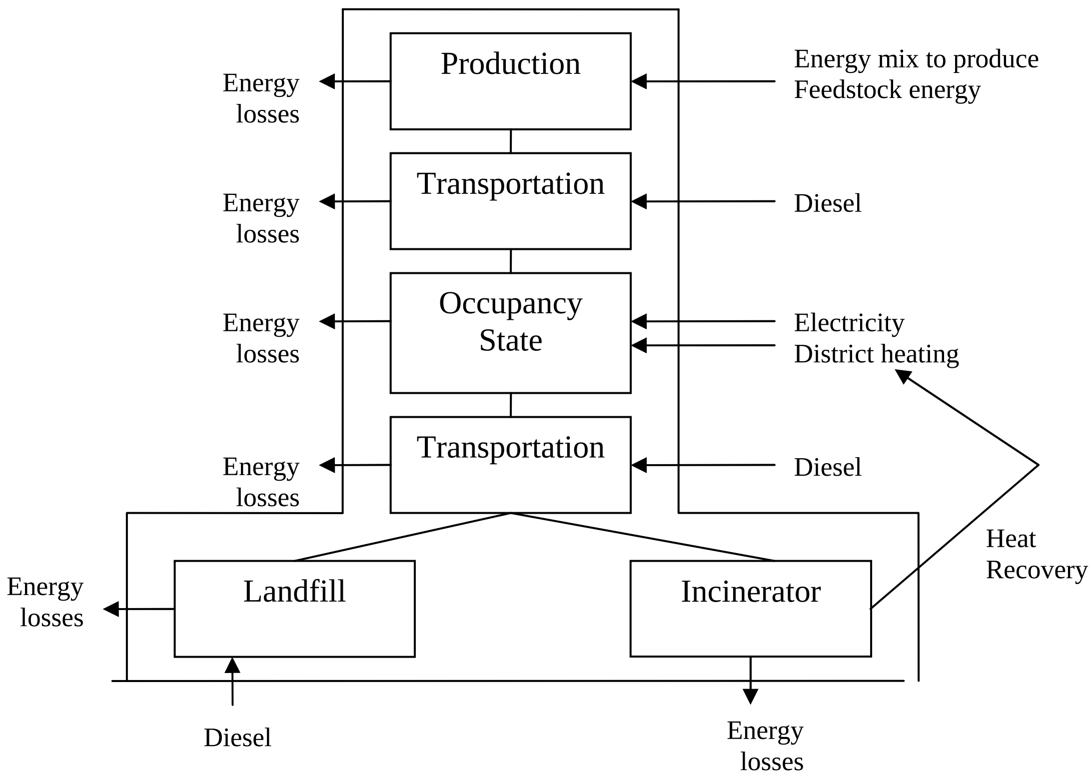


Figure 29. *The energy flow through a building's life span when placed in Helsingborg, Sweden.*

3.4.2.1 Production of Building Materials

As Thormark (2002) showed, the embodied energy for producing the building materials can be significant. Embodied energy is energy consumed while acquiring and refining the raw materials to building materials. Feed-stock energy is defined as "the heat content in raw materials not used as an energy source" (Bauman & Tillman, 2007). This feed-stock energy can later be used as energy e.g. wood and plastics can be incinerated and the heat used in a district heating system and for electricity production. However, diffuse heat is no thought of being recovered energy (Bauman & Tillman, 2007). Building materials with feedstock energy includes asphalt, polyethylene (plastics) and timber. Jones (2008) means that it is optional to account for feed-stock energy separately, although if a waste incinerator recovers the feed stock energy to useful heat (e.g. for a district heating system), it must be accounted for.

3.4.2.2 Transportation to & from the Building Site

Transportations' contribution to the overall environmental impact is usually smaller than expected in many LCA studies, although for building materials due to their large mass, transportation will be significant for many building materials (Bauman & Tillman, 2007). The method of calculating the energy use for each transport of the building materials to and from the building site is given by Tillman et al, 2007. This method uses standard transportation energy coefficients. When knowing what vehicle transporting the material, standard energy coefficient is only dependent weight and distance. In the coefficient are upstream energy input and losses due to the utilization rate in the subsystems included. The coefficient for transportation of goods is based on the assumption of 70% use of the load capacity for long distance and 50% use of the load capacity for short distance distribution (Bauman & Tillman, 2007). Thus, using the standard transportation energy coefficient, no further allocation needs to be carried out, and the energy use for transporting each building material can be calculated separately and only regarding its mass and the travelling distances. Bäcsktröm argues that this method is too simplified. Terminal handling and storing should also be accounted for e.g. the hot and dry storage of framing timber is a process consuming energy. Due too poor data availability, Bäckström's more sophisticated calculation methods will not be used in this thesis.

All building materials are assumed to be transported by long distance trucks from the factory gate to the building site. The transportation coefficients below are given by Tillman and Baumann (2004). Although the coefficients are for European conditions and requirements regarding trucks, these template values will be used for Canadian conditions as well due to no other data was found.

Energy Requirements and CO_2 Emissions (MJ/tkm), (g/tkm)	Light Truck, Short Distance Distribution	Truck with Semi-Trailer, Long Distance Distribution	Small Ship
Energy	2,41	0,72	0,432

Figure 30. *Transportation coefficients*

Catharina Thormark (2002) assumed in “Embodied Energy” that building material to a Swedish building site was on average transported 350 km. This distance is assumed in this thesis as well. The distances the building materials are transported in Canada are 700 km, due to the fact that Canada is a far more spacious country. The transportation of building materials to the building sites are assumed to be carried out by long-distance trucks using diesel as fuel.

The average distance to a Swedish landfill from a household is 15 km. The average distance from a household to an incinerator is 18 km (Bauman & Tillman, 2007). This transportation is assumed to be carried out by trucks in urban areas with diesel as fuel. Only material containing feedstock energy is assumed to be transported to the incinerator, the rest of the building materials is assumed to be transported to a landfill.

As said earlier, in Nelson waste is transported by a small ship to a landfill approximately 50 km away. The transportation by small truck of the disposal from the building site to the dock is assumed to be 5 km. This data is site-specific for Nelson as no data on average distances to landfills was available.

3.4.2.3 Disposal of Building Materials

NSR suggests that building materials are taken care of in the following order (for non dangerous waste); reuse, material recovery, energy recovery, and landfill deposition. However, only the latter two will be recounted in this thesis as they are the two most common methods. The disposal of waste in a landfill is energy consuming due to operational processes at the landfill. The operational process at the landfill is to compress the waste with diesel machines. 40kJ/tonne is consumed (Bauman & Tillman, 2007).

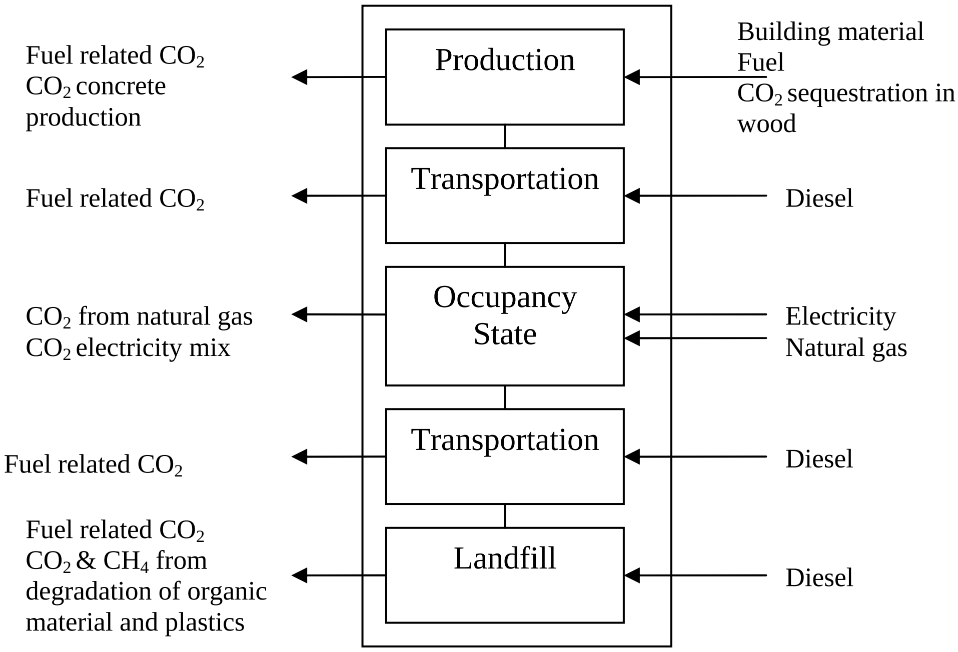
If the feedstock energy in the building materials is recovered in an incinerator, the heat can be used in a district heat system and to produce electricity. The feedstock energy of wood is 14 MJ/kg and 55 MJ/kg for plastics. However, the thermal energy that can be produced from wood and polyethylene is 7.7 MJ/kg for wood and 25.3 MJ/kg for plastics. The electric energy that can be produced at the same time is 3.5 MJ/kg and 11.5 MJ/kg (Sundqvist, 1997).

3.5 Greenhouse Gases from a System Perspectives

Emissions of CO_2 and other greenhouse gases increase the atmosphere's ability to contain heat. IPCC states that non-CO_2 emissions are a non-negligible part of the greenhouse gas emissions. Examples of such greenhouse gases are methane and halocarbons. Different greenhouse gases absorb heat radiation differently effective. Methane (CH_4) is during a 100 years time period 21 times more potent than CO_2, while the halocarbon HCFC-22 is 1700 times as potent as CO_2 (Guineé, 2001). Different GHG emissions also vary in the time they stay in the atmosphere. For CH_4 will during a time period of 20 years be 56 times as potent as CO_2. To more clearly communicate this difference, the greenhouse gas emissions are often expressed in carbon dioxide equivalent, CO_2-eq. The factor to describe how many kg CO_2 one kg of another greenhouse gas is equivalent to is called global warming potential (GWP). GWP_{20} for CH_4 is 56.

Overall in the literature, very little is said on non-CO_2 greenhouse gas emissions. IPCC includes refrigerators and freezers for household use in the building sector. Such appliances use halocarbons for the heat exchange, as shown above a very potent greenhouse gas. However, these appliances have dramatically decreased their halocarbon content over the years and in the western world (IPCC, 2007). In Sweden, the household electricity use from e.g. refrigerators is excluded form the specific energy use of a building. It could be argued that such appliances is included in the manufacturing industry sector, and hold no relevance for the building sector.

The amount of fuel related CO_2 emissions are determined by the primary energy use, although there are processes emitting and sequestrating greenhouse gases irrespective of the fuel being use. Those processes are e.g. decarbonation of limestone (Burström, 2007) and the degradation of organic materials in a landfill (Sundqvist, 1997). Wood on the other hand is thought of sequestrating carbon (Tonne, 2007).



Firgure 31. *The flow of GHG in a building's life cycle when placed in Nelson, B.C.*

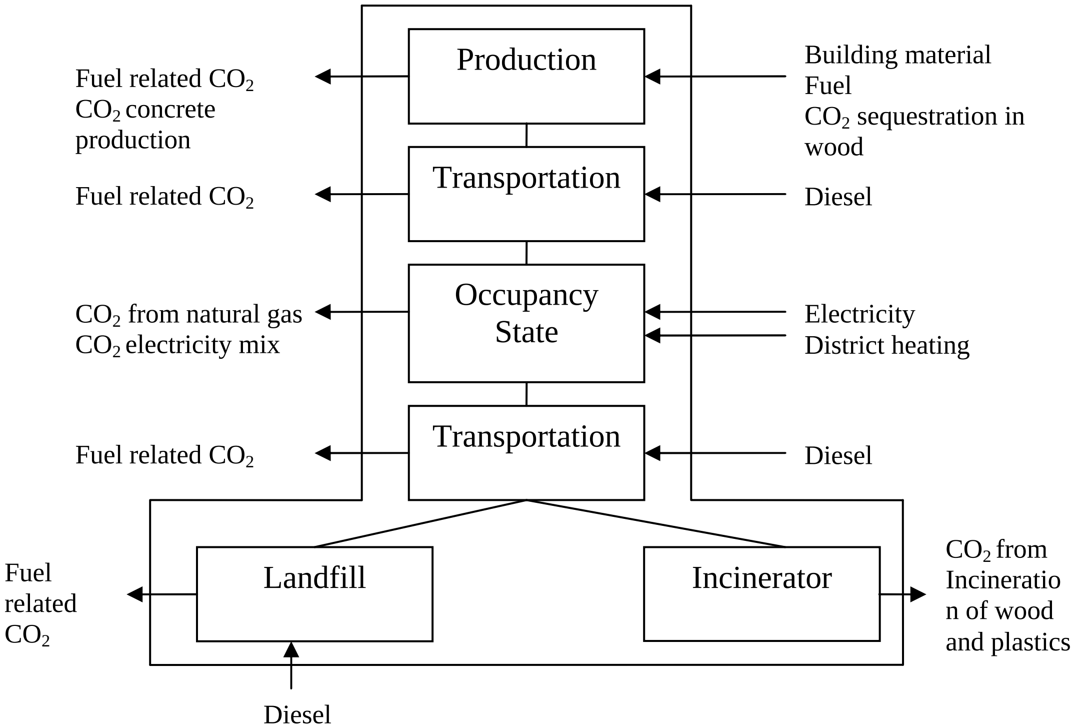


Figure 32. *The flow GHG through a building's life cycle when placed in Helsingborg, Sweden*

3.5.1 Fuel Related CO_2 Emissions from Different Energy Carriers

As emission data for different processes is hard to obtain, it is estimated from the energy use (Bauman & Tillman, 2007). When producing building materials, the energy mix for the manufacturing is used to estimate the CO_2 emissions. During transportation, the emissions are estimated with the same method as when estimating the energy use i.e. the upstream losses are included in the standard transportation coefficient.

Energy Requirements and CO_2 Emissions (MJ/tkm), (g/tkm)	**Light Truck, Short Distance Distribution**	**Truck with Semi-Trailer, Long Distance Distribution**	**Small Ship**
CO_2	176	52	30.8

Figure 33. *CO_2 Emissions from transports.*

The different energy carriers' CO_2 emissions are known and by knowing the primary energy use, the CO_2 emissions can be estimated. As in the case with the primary energy factors, the emissions per unit energy used are not globally adaptable. The CO_2 emissions vary evidently by the means the energy is produced. The Nordic electricity mix emits 75-100 gCO_2/MJ (Persson, 2008). The British Columbian electricity mix emits on average 23.6 g[CO_2/MJ] 1990-2005 (National Inventory Report, 2005). Näslund (2003) states that the CO_2 emissions from natural gas are 57 g[CO_2/MJ]. This value is however based on a supplied and not utilized natural gas. On average, the Swedish district heat emits 25 g[CO_2/MJ] (Svensk Fjärrvärme AB, 2009).

3.5.2 Non-Fuel Related GHG Emissions & Sequestration

The non-fuel related GHG emissions make the mass-flow of a building somewhat more complicated as such emissions occur irrespective of energy use.

3.5.2.1 Concrete

Limestone is the main raw material for concrete production, along with clay. When the limestone is decarbonated, CO_2 emits in the following reaction: $CaCO_3 \rightarrow CaO + CO_2$ (Burström, 2007). Jones (2008) claims these emissions are a large part of the CO_2 emissions for concrete.

3.5.2.2 Timber

Jones (2008) concludes that timber is the building material which's embodied carbon is hardest to define. The issue is the question of carbon sequestration in wood products. Tonn et al, 2007, defines carbon sequestration as "the process of increasing the concentration of carbon content of a carbon reservoir other than the atmosphere". Carbon stored in wood cannot however be stored there permanently, but will be released into the atmosphere either as carbon dioxide or in the case of anaerobic decay in a landfill, as the potent GHG methane (Christensen, Cusso & Stegmann, 1992). It can be argued that unless the storage is permanent, it is not to be considered as sequestration (Tonn & Marland, 2007).

Jones (2008) has not included carbon sequestration in the embodied carbon values. This exclusion is due to the notion that more wood are being used in larger quantities than what is replenished i.e. on a global scale more carbon is released into the atmosphere than what is stored in newly planted trees. In this thesis carbon sequestration will be assumed for the wood actually used in the building. The carbon sequestration is assumed to be 1.11 [kgCO_2/kgwood]. This sequestration is motivated by that the landfill or incineration is included in the technical system, and by not including the sequestration wood would become a net producer of GHG.

3.5.2.3 Plastics & Asphalt

Plastics consist of polymers built up by oil and gas (Burström, 2007). Though this oil and gas is extracted from the natural system, it is not emitting carbon dioxide until the feed stock energy is recovered in an incinerator. Hence, the feedstock carbon in plastics is not included in embodied carbon of plastics, as this refers to upstream CO_2 emissions. Further, the embodied carbon will not sequestrate carbon, as the feedstock carbon has been stored in fossil materials for millions of years.

The asphalt used is the asphalt shingles commonly used as roof sheathing in Canada. The water-proof sheathing underneath the roof-tiles in Swedish construction is also assumed to be of asphalt type. As asphalt consists of fossil fuels, it also includes feedstock energy and stored carbon (Hammond & Jones, 2008). Asphalt will not be incinerated and thus the stored carbon will pass through the technical system back to the natural system.

3.5.2.4 Disposal in Landfill

In a landfill two other non-fuel emissions occur. When disposal ends up on a landfill, their condition and the condition of the landfill is not constant for an infinite time (Christensen, 1992). General organic material degrades under anaerobic condition produce methane [CH_4] and CO_2 (Sundqvist, 1997).

In "Life cycle assessment and solid waste: annual report", a method for calculating the CH_4 and CO_2 emissions from general organic materials in a landfill is presented. In this thesis, it is assumed that the only general organic material in the disposal of the houses is wooden products. Burström (2007) states that pure wood pulp mainly consists of cellulose [$C_6H_{10}O_5$], hemicellulose and ligning. The above mentioned method states lignin will not degrade at all, whereas cellulose and hemicellulose degrade at a 70% rate. 15% of the produced CH_4 will oxidize to CO_2 in the soil cover of the landfill before reaching the atmosphere (Sundqvist, 1997). The formula for the production of CH_4 and CO_2 from a cellulose molecule in an aerobic landfill is $C_6H_{10}O_5+H_2O\text{->}3\ CH_4+3\ CO_2$. Given this, per kg landfilled wooden waste, 158 g CH_4 and 313 g CO_2 is produced (Sundqvist, 1997).

Sundqvist (2007) states further that 1-5% of the polyethylene will degrade to CO_2 and CH_4 during the surveyable time period of the landfill. Per kg polyethylene 26 g CH_4 and 24 g CO_2 are produced (Sundqvist, 1997).

The CH_4 varies over time in a landfill. As the environment becomes more and more anaerobic, more CH_4 is produced. Thus, the shortest time-frame

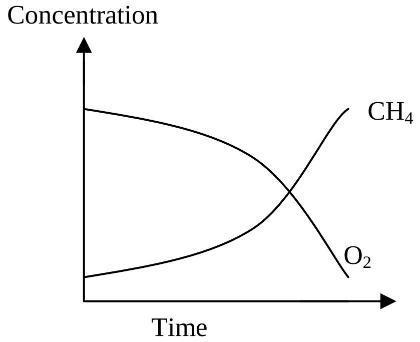


Figure 34.*Methane production in landfill over time (Näslund, 2003)*

Conversely to wood, inert materials do not decay in the landfill. Examples of inert material are insulation and concrete. The state of these materials will to a large extent be the same in hundred years. The main environmental problem with these inert materials is the fact that they are taking up space (Christensen, 1992). GHG emissions from inert materials are the CO_2 emission from diesel engines compressing the waste. Naturvårdsverket (2006) states that the CO_2 emissions from diesel engines are 72g/MJ.

3.5.3 CO_2 Emissions from Incineration

Incineration is the controlled burning of solid, liquid and gaseous waste, to recover the heat content. Wood and plastics materials are suitable for heat recovery. Almost all of the stored carbon in the waste is oxidized to CO_2 when burned in an incinerator (Sundqvist, 1997). As said earlier, the carbon sequestrated in the wood is now emitted into the atmosphere again. The incineration of wood will have no relevance for GHG emissions of a building throughout its life time. It will however allocate CO_2 emissions from the production phase to the disposal/waste phase.

LCA practices states that only CO_2 emissions from products produced with fossil fuels are regarded as an increase of GHG (Sundqvist, 1997). In this thesis, plastics are the only material considered to add to the GHG emissions. Per kg polyethylene incinerated 2.44kg CO_2 is emitted to the atmosphere (Sundqvist, 1997).

3.6 Energy Simulations & Life Cycle Inventory

3.6.1 Average Heat Transfer Coefficient & Specific Heat Loss

A part of the energy simulations is calculating the average heat transfer coefficient of the building. The results showed that the Swedish type-house's average heat transfer coefficient is 0.27 [W/(m^2°C)], and the Canadian house's is 0.46 [W/(m^2°C)]. Both type-houses comply with the average heat transfer coefficient of U_m<0.5 [W/(m^2°C)] in BBR. However, BBR clearly states that complying with the average heat transfer coefficient requirement is not a guarantee for complying with the specific energy use requirement.

The specific heat loss includes not only the transmissions losses but also the heat losses due to ventilation and air-leakage - both regulated in the building codes. A bigger house will have greater specific heat losses, as a greater surface transmits heat to the cold outside, and the ventilation air-flow and air-leakage is dependent of the area and volume. However, if the specific heat losses instead are divided by the liveable space, a three storey house will be benefitted as the exterior area per liveable area is lesser. The results showed the specific heat loss in the British Columbian house is considerable higher than the Swedish type-house's. The British Columbian type-house's specific heat loss is 1.6 [W/(m^2°C)], while the Swedish type house's specific heat loss is 1,0 [W/(m^2°C)].

The results show that a thermal envelope complying with BBR is better than a thermal envelope complying with BCBC. It must be stated that the results is only applicable to the two type-houses. A comparison between BBR and BCBC will never be "fair". For example, a three storey building (still applicable to "Part 9" in BCBC) will include more thermal bridges (e.g. the connection between the storeys) and will favour a building complying with BBR, in which thermal bridges must be accounted for. However, even before the thermal bridges were accounted for in energy simulations, the British Columbian type-house would not comply with specific energy use requirement in BBR.

3.6.2 Specific Energy Use

The results showed that the British Columbian type-house would not comply with BBR's specific energy use requirement of 110kWh/m^2, when placed in Helsingborg using the same heating system and subjected to the same climate as the Swedish type-house. The results also showed that the Swedish type-house would use lesser energy than the British Columbian type-house when placed in Nelson. Another problem when comparing the two building codes, is the advised safety margin regarding the specific energy use in BBR, consequently makes the specific energy use vary in a house complying with BBR. The type-house assumed in this thesis has a set specific energy use 16% below the required 110 [kWh/m^2]. Isover Energi 2, the software used to calculate the energy use, recommends a safety margin of 20% (Isover.se, 2009).

	Swedish House, HBG	**BC House, HBG**	**Swedish House, Nelson**	**BC House, Nelson**
Specific Energy Use [kwh/m^2]	92	145	106	172
% with BBR as reference value	-16	+32	-3	56

Figure 35. *The annual specific Energy Use*

3.6.3 Life Cycle Inventory

The results of the life cycle inventory can not be used as a measurement on the energy requirements in the building codes, as it takes into account conditions not regulated in the building codes. The life cycle perspective shows the primary energy use and GHG emissions with upstream losses included during the type-houses' life span.

3.6.3.1 Life Cycle Energy Inventory

The results showed that the greatest primary energy use occurred during the occupancy state. Notable is the small contribution of transports to the total primary energy use. The services with greatest primary energy use during the occupancy state were the space heat load and household electricity use.

Type-House & Location	**Swedish, Helsingborg**	**Swedish, Nelson**	**British Columbian, Helsingborg**	**British Columbian, Nelson**
Primary Energy Use in Production [GWh/m^2]	1.38	1.31	1.34	1.31
Primary Energy Use in Transportation [GWh/m^2]	0.047	0.088	0.051	0.096
Primary Energy During Occupancy State (50 years) [GWh/m^2]	7.35	8.93	9,91	12.73
Total Energy Recovery [GWh/m^2]	-0.277	-	-0.292	-
Total Energy During Life Span [GWh/m^2] (including energy recovery)	8.26	10.13	10.85	13.96
Ratio Occupancy State/Total	Swedish, Helsingborg	Swedish, Nelson	British Columbian, Helsingborg	Britsh Columbian, Nelson
Energy Use (without energy recovery)	79%	88%	91%	91%

Figure 36. *Results from Life Cycle Energy Inventory.*

The primary energy use can be shown for each service inside the system boundaries of the buildings. The variation in space heat load affected the primary energy use during the 50 years of occupancy the most. The momentary heat losses, the utilization rate in the heating system and the primary energy factor affect the space heat load. Notable is that household electricity primary energy use for the Swedish type-house in Helsingborg, almost adds up to the heat load of the building.

Type House	Swedish, HBG	BC, HBG	Swedish, Nelson	BC, Nelson
Annual Occupancy State Primary Energy Use [kWh/(m^{2}year)]	147	198	179	254

Figure 37. *The annual primary energy use (including household electricit).*

Primary Energy Use during 50 Years Occupancy State [kWh/m2]				
	Swedish, HBG	Swedish, Nelson	BC, HBG	BC, Nelson
Space Heat Load	3 268,65	4 660,58	5 685,28	8 535,35
Domestic Hot water	778,58	1 258,10	595,84	990,42
Operational Electricity	226,99	222,91	556,83	414,96
Household Electricity	3 075,00	2 788,00	3 075,00	2 788,00
Sum	7 349,22	8 929,60	9 912,95	12 728,73

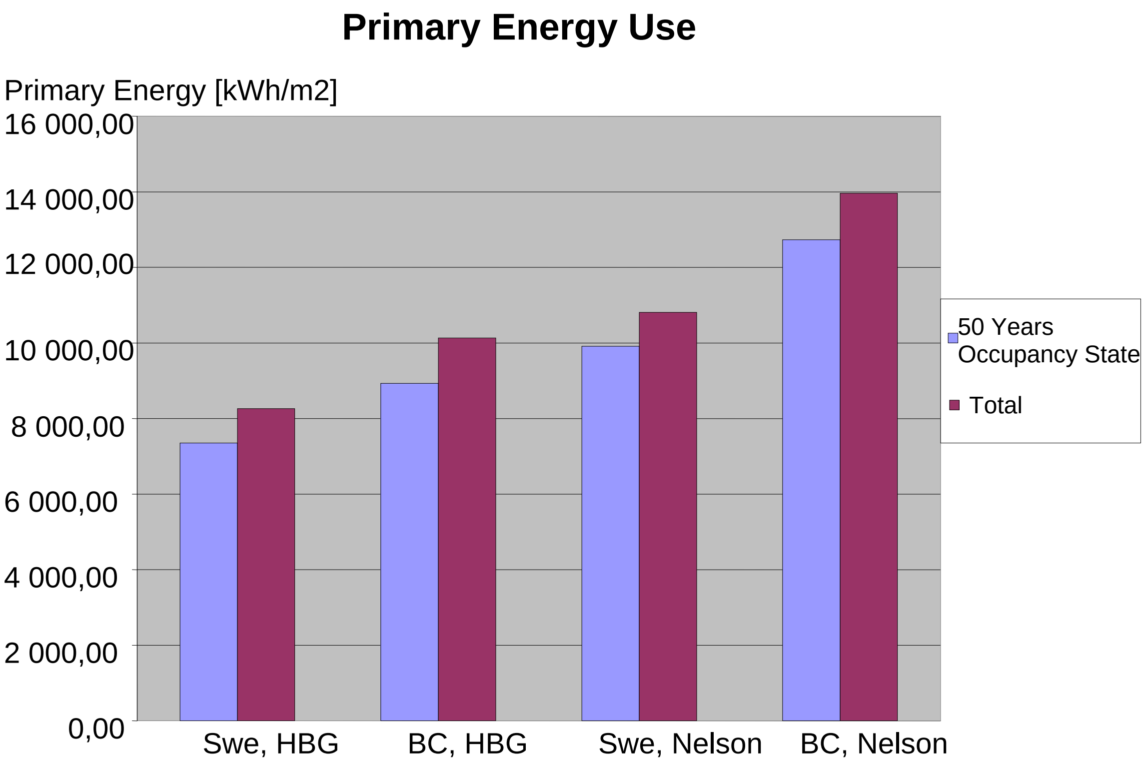
Figure 38. *Primary Energy Use during 50 Years Occupancy State*

The results showed that the Swedish type-house used less primary energy than the British Columbian type house regardless location. The difference was less when the total primary energy use was compared than when the primary energy use during the occupancy state was compared.

- The British Columbian type-house used 38% more total primary energy than the Swedish type-house, when placed in Nelson.
- The British Columbian type-house used 42% more primary energy during the occupancy state than the Swedish type-house when placed in Nelson.
- The British Columbian type-house used 31% more total primary energy than the Swedish type-house, when placed in Helsingborg.
- The British Columbian type-house used 35% more primary energy during the occupancy state than the Swedish type-house when placed in Helsingborg.

  The results show that the location affects the primary energy use and the GHG emissions. The location affects the energy use and GHG emissions by different climates and different infrastructure (e.g. district heating or natural gas system). Nelson proved to have less favourable site-conditions as both type-houses used more primary energy at this location. The results also indicate that when site-conditions are less favourable, the importance of decreasing the space heat load heat increases.

- The total primary energy use for the Swedish type-house was 23% higher when placed in Nelson.
- The primary energy use during the occupancy state was for the Swedish type-house 22% higher when placed in Nelson.
- The total primary energy use for the British Columbian type-house was 22% higher when placed in Nelson.
- The primary energy use during the occupancy state was for the British Columbian type-house 29% higher when placed in Nelson.



3.6.3.2 Life Cycle GHG Inventory

The results showed that the GHG is emitted mostly during the occupancy state. The space heat load was the service predominantly emitting most GHG. Rather is it the energy carrier that determines the GHG emissions. Electricity produced with the Nordic electricity mix and natural gas caused most of the GHG emissions.

Ratio Occupancy State/Total	Swedish, Helsingborg	Swedish, Nelson	British Columbian, Helsingborg	Britsh Columbian, Nelson
GHG Emissions	87%	76%	90%	85%

Figure 39. *Percentage of GHG emissions occurring during occupancy state compared with the total GHG emissions.*

Type-House & Location	Swedish, Helsingborg	Swedish, Nelson	British Columbian, Helsingborg	British Columbian, Nelson
Total CO_2eq Emissions in Production [$kgCO_2eq/m^2$]	117	110	89	81
Total CO_2eq Emissions in Transportation [$kgCO_2eq/m^2$]	12	23	14	25
Total CO_2eq Emissions During Occupancy State [$kgCO_2eq/m^2$]	1,375	1,340	1,68	2,13
Total CO_2eq Emissions in Waste [[$kgCO_2eq/m^2$]	95.3	303.3	101.3	283.3
Total CO_2eq Emissions During Life Span [$kgCO_2eq/m^2$]	1,582	1,758	1,867	2,502

Figure 40. *GHG emissions for the life-cycle's stages.*

CO2 Emission during 50 Years Occupancy State				
	Swedish, HBG	Swedish, Nelson	BC, HBG	BC, Nelson
Space Heat Load	294,18	956,35	511,68	1 751,45
Domestic Hot water	70,07	113,23	53,63	89,14
Operational Electricity	69,46	20,06	170,39	37,35
Household Electricity	940,95	250,92	940,95	250,92
Sum	1 374,66	1 340,56	1 676,64	2 128,86

Figure 41. *CO_2 Emission (kg/m^2) during 50 Years Occupancy State*

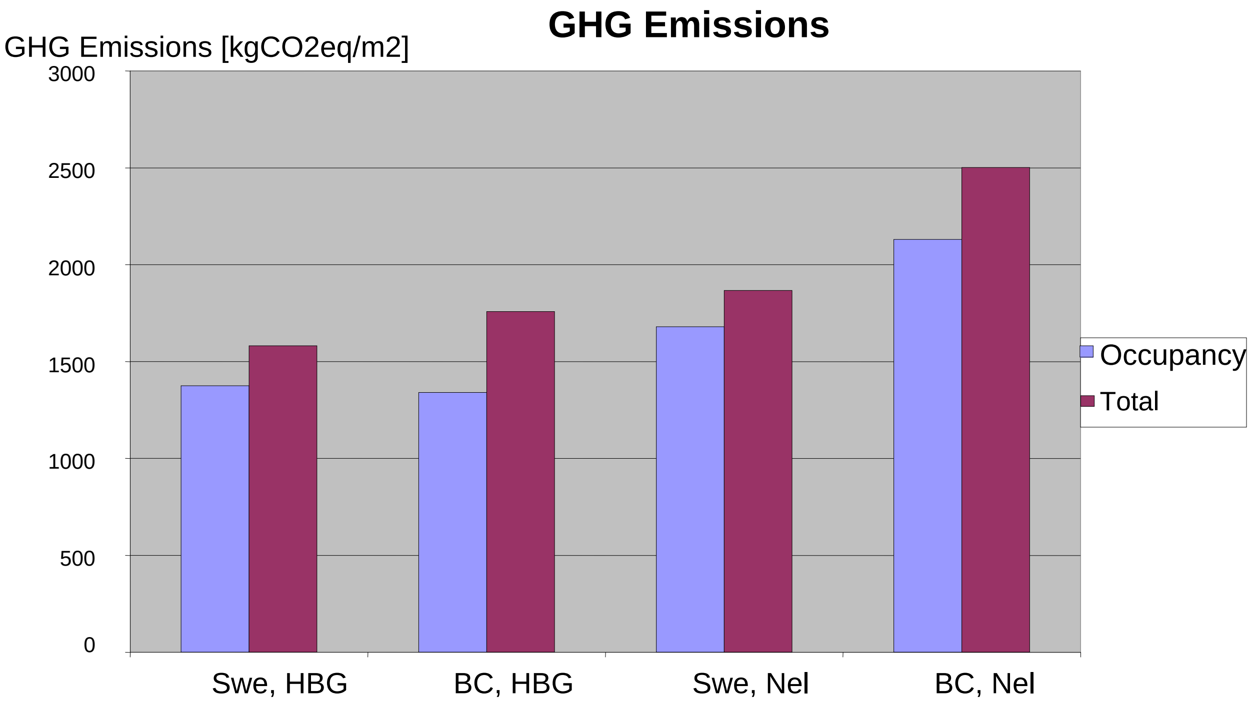
The GHG emissions are strongly dependent on the primary energy use. The non-fuel related GHG emissions proved to be of lesser quantity than expected. The only notable non-fuel related GHG emissions were the disposal of organic material and plastics in an aerobic landfill. This caused 17.3% of the GHG emissions for the Swedish type-house, and 11.3% for the British Columbian type-house. Landfilling instead of incinerating suitable materials, emitted 178-218% more GHG according to the results.

The GHG emissions from household electricity use differ greatly with location. This is due to that it is only dependent on the amount of CO_2 that is emitted during the production of the electricity. Notable is that household electricity use was the major contributor to GHG emissions when the houses were placed in Helsingborg.

As the GHG emissions are dependent on the primary energy use, it is not surprising that the Swedish type-house emits less GHG than the British Columbian type-house at both locations. However, the GHG emissions differed more dependent on the location than the primary energy use does.

- The British Columbian type-house emitted totally 42% more GHG than the Swedish type-house when placed in Nelson.
- The Swedish type-house emitted 58% more GHG during the occupancy state than the Swedish type-house when placed in Nelson.
- The British Columbian type-house emitted totally 18% more GHG than the Swedish type-house when placed in Helsingborg.

- The British Columbian type-house emitted 22% more GHG during the occupancy state than the Swedish type-house when placed in Helsingborg.
- The British Columbian type-house emitted totally 34% more GHG when placed in Nelson.
- The British Columbian type-house emitted 27% more GHG during the occupancy state when placed in Nelson.
- The Swedish type-house emitted totally 11% more GHG when placed in Nelson.
- The Swedish type-house emitted 2.5% less GHG during the occupancy state when placed in Nelson.



4 Conclusion

The single family wood-frame house complying with BBR uses less primary energy and emits less GHG during its life span than the single family wood frame house complying with BCBC. However, as the building codes are written in different ways, an absolute “fair” comparison is not feasible. The predominant primary energy using and GHG emitting phase is the occupancy state.

We believe there is a discrepancy between what is required in BCBC and what is known to be good building practices by the educated builders, and finds this discrepancy somewhat unnecessary. Examples of *recommended* but not *required* solutions in “Canadian Wood-Frame Houses” show far more insulated building assemblies and avoidance of thermal bridges. Miljana Horvat also argues for thicker insulation as highly desirable and practically feasible.

We believe that as long as BCBC is written towards “unsophisticated” builders, the system perspective can not be adapted and this will decrease the possibility to improve the building code from an energy use and GHG emission perspective.

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Appendix

Appendix 1

Building Material	Embodied Energy (MJ/kg)	Embodied Carbon ($kgCO_2/kg$)	Feedstock Energy (MJ/kg)	Comment
Aggregate	0.11	0.005		
Asphalt	2.6	0.045	1.91	As no data were found on either tar paper or asphalt shingles, the data is for general asphalt
Ceramics	9.0	0.59		Ceramics tiles are used in kitchen and bathrooms.
Pottery				
Wool Carpet	106	5.48		
Concrete, non load	0.77	0.096		Two types of concrete is used. One for load-bearing purposes, and one for roof tiles
Concrete, load	0.95	0.125		
Glass	18.5	0.85		The data only refers to the actual glass, not the whole window. The metal fittings are separately documented.
Mineral Wool	16.6	1.2		In addition to insulation batts, the façade sheet is thought of as mineral wool.
Fibreboard	30	0,86	14	Data for hardboard. 1,11kgCO_2/kg hardwood is sequestrated.
Spackling Paste	2.35	0,42		As data was not found for spackling paste, it is assumed to contain 50% cement and 50% sand.
Styrofoam	27	1.86		No data on embodied carbon for Styrofoam insulation was found. The embodied carbon is general data for insulation.
Steel	24.6	1,77		18 kg steel/m^2 is used for reinforcement in the slab.
Stone, general	1	0,056		Fairly uncertain data
Paint	20.4	1.06		

Appendix 1

Gypsum Board	6.45	0.38		Referred to as plasterboard in the spreadsheet
Plastics, LDPE	89.3	1.9	55.2	Two types of plastics are used, low-density polyethylene film used as vapour-retarder, and high-density polyethylene used as pipes.
Plastics, HDLE	84.5	2.0	55.1	
Timber	22.5	14.0	0.46	At the same time 1.11kgCO_2/kg wood is sequestrated in the wood products.
Pottery	29	1,48		Toilets etc

Appendix 2

The life cycle inventory calculations

Swedish House

Outer walls					
Material	Weight [kg]	Embodied Energy [MJ/kg]	Embodied Energy [MJ]	Embodied Carbon [$kgCO_2/kg$]	Embodied Carbon [$kgCO_2$]
paint	50,00	20,40	1 020,00	1,06	53,00
spackeling past	135,00	2,35	317,25	0,42	56,36
plaster board	1 404,00	6,45	9 055,80	0,38	533,52
vapor retarder	24,30	89,30	2 169,99	2,00	48,60
mineral wool	450,23	16,60	7 473,74	1,20	540,27
wood frame 45x145 mm	915,83	22,50	20 606,18	0,46	421,28
mineral wool	294,98	16,60	4 896,59	1,20	353,97
wood frame 45x95 mm	689,85	22,50	15 521,69	0,46	317,33
plasterbased board	1 404,00	6,45	9 055,80	0,38	533,52
facade 22*145 mm	975,16	16,60	16 187,72	1,20	1 170,20
facade 22*120 mm	807,03	16,60	13 396,73	1,20	968,44
paint	100,00	20,40	2 040,00	1,06	106,00
Sum	7 250,38		101 741,48		5 102,49

Interior walls					
Material	Weight [kg]	Embodied Energy [MJ/kg]	Embodied Energy [MJ]	Embodied Carbon [$kgCO_2/kg$]	Embodied Carbon [$kgCO_2$]
paint	50,00	20,40	1 020,00	1,06	53,00
Spackling paste	131,00	2,35	307,85	0,42	54,69
plaster board	1 362,40	6,45	8 787,48	0,38	517,71
wood frame 45x70 mm	387,83	22,50	8 726,07	0,46	178,40
mineral wool	210,91	16,60	3 501,11	1,20	253,09
plaster board	1 362,40	6,45	8 787,48	0,38	517,71
Spackling paste	131,00	2,35	307,85	0,42	54,69
paint	50,00	20,40	1 020,00	1,06	53,00
Sum	3 685,54		32 457,83		1 682,30

Foundation					
Material	Weight [kg]	Embodied Energy [MJ/kg]	Embodied Energy [MJ]	Embodied Carbon [$kgCO_2/kg$]	Embodied Carbon [$kgCO_2$]
concrete	25 645,00	0,95	24 362,75	0,13	3 205,63
concrete edge	3 049,80	0,95	2 897,31	0,13	381,23
steel	2 007,00	24,60	49 372,20	1,77	3 552,39
styrofoam insulation	267,60	27,00	7 225,20	1,86	497,74
styrofoam insulation	267,60	27,00	7 225,20	1,86	497,74
macadam/metal	33 210,00	0,11	3 653,10	0,01	166,05
fiber cloth	18,00	18,60	334,80	0,96	17,28
Sum	64 465,00		95 070,56		8 318,04

Roof					
Material	Weight [kg]	Embodied Energy [MJ/kg]	Embodied Energy [MJ]	Embodied Carbon [$kgCO_2$/kg]	Embodied Carbon [$kgCO_2$]
roofingtiles	7 808,50	0,77	6 012,55	0,10	749,62
battings 23 x 48 mm	164,55	22,50	3 702,34	0,46	75,69
crossbattings 23 x 48 mm	164,55	22,50	3 702,34	0,46	75,69
tar paper	122,50	2,60	318,50	0,05	5,51
wooden boads 23 x 120 mm	2 052,75	22,50	46 186,88	0,46	944,27
mineral wool	547,17	16,60	9 083,02	1,20	656,60
45° roof truss 45 x195 / 45 x 220 mm	929,06	22,50	20 903,89	0,46	427,37
mineral wool	477,02	16,60	7 918,53	1,20	572,42
plaster board	1 268,80	6,45	8 183,76	0,38	482,14
Spackling paste	122,00	2,35	286,70	0,42	50,94
paint	45,00	20,40	918,00	1,06	47,70
Sum	13 701,90		107 216,51		4 087,95

Ceiling/Joist floor					
Material	Weight [kg]	Embodied Energy [MJ/kg]	Embodied Energy [MJ]	Embodied Carbon [$kgCO_2$/kg]	Embodied Carbon [$kgCO_2$]
plaster board 2 layers	1 456,00	6,45	9 391,20	0,38	553,28
fibreboard	785,40	30,00	23 562,00	0,86	675,44
mineral wool	240,35	16,60	8 046,09	1,20	581,64
45° roof truss 45 x195/45 x 220 mm	484,70	22,50	10 905,84	0,46	222,96
extrs joists 45 x 220 mm	444,31	22,50	9 997,02	0,46	204,38
glespanel 22 x 70 mm	1 234,20	22,50	27 769,50	0,46	567,73
plaster board	1 144,00	6,45	7 378,80	0,38	434,72
paint	40,00	20,40	816,00	1,06	42,40
Sum	5 828,97		97 866,45		3 282,57

Fixtures and interiors					
Material	Weight [kg]	Embodied Energy [MJ/kg]	Embodied Energy [MJ]	Embodied Carbon [$kgCO_2$/kg]	Embodied Carbon [$kgCO_2$]
oak parquet	1 955,10	22,50	43 989,75	0,46	899,35
ceramic tiles	1 440,00	9,00	12 960,00	0,59	849,60
ceramic floor tiles	364,65	9,00	3 281,85	0,59	215,14
fixtures plastics	500,00	89,30	44 650,00	1,90	950,00
windows (glass)	875,00	18,50	16 187,50	0,85	743,75
fixtures timber	6 000,00	22,50	135 000,00	0,46	2 760,00
fixtures steel & plate	600,00	24,60	14 760,00	1,77	1 062,00
pottery	30,00	29,00	870,00	0,48	14,40
Sum	11 764,75		271 699,10		7 494,24

Heating System	Weight [kg]	Embodied Energy [MJ]	Embodied Carbon [$kgCO_2$]
HWH	888,00	55 830,00	4 070,00
FAH	698,00	29 870,00	2 072,00

British Columbian Type-House

Outer walls

Material	Weight [kg]	Embodied Energy [MJ/kg]	Embodied Energy [MJ]	Embodied Carbon [$kgCO_2/kg$]	Embodied Carbon [$kgCO_2$]
paint	50,00	20,40	1 020,00	1,06	53,00
Spackeling past	235,00	2,35	552,25	0,42	98,11
plasterboard	2 444,00	6,45	15 763,80	0,38	928,72
vapor retarder	50,00	89,30	4 465,00	2,00	100,00
glass fiber wool	526,40	16,60	8 738,24	1,20	631,68
wood frame 38 x 140 mm	1 124,49	22,50	25 300,93	0,46	517,26
fibreboard	1 163,25	30,00	34 897,50	0,86	1 000,40
Sheating membrane	42,00	89,30	3 750,60	2,00	84,00
facade horizontal 22x140 mm	2 636,70	16,60	43 769,22	1,20	3 164,04
paint	100,00	20,40	2 040,00	1,06	106,00
Sum	8 371,84		140 297,54		6 683,21

Interior walls

Material	Weight [kg]	Embodied Energy [MJ/kg]	Embodied Energy [MJ]	Embodied Carbon [$kgCO_2/kg$]	Embodied Carbon [$kgCO_2$]
paint	70,00	20,40	1 428,00	1,06	74,20
Spackling paste	175,00	2,35	411,25	0,42	73,06
plasterboard	1 820,00	6,45	11 739,00	0,38	691,60
wood frame 38x89 mm	707,02	22,50	15 907,96	0,46	325,23
plaster board	1 820,00	6,45	11 739,00	0,38	691,60
Spackling paste	175,00	2,35	411,25	0,42	73,06
paint	70,00	20,40	1 428,00	1,06	74,20
Sum	4 837,02		43 064,46		2 002,95

Foundation

Material	Weight [kg]	Embodied Energy [MJ/kg]	Embodied Energy [MJ]	Embodied Carbon [$kgCO_2/kg$]	Embodied Carbon [$kgCO_2$]
concrete	18 400,00	0,95	17 480,00	0,13	2 300,00
concrete footing	4 830,00	0,95	4 588,50	0,13	603,75
Basement walls concrete	29 325,00	0,95	27 858,75	0,13	3 665,63
steel	1 530,00	24,60	37 638,00	1,77	2 708,10
Rigid glass fiber insulation	159,60	27,00	4 309,20	1,86	296,86
macadam/metal	51 300,00	0,11	5 643,00	0,01	256,50
polyethylene sheet	17,10	89,30	1 527,03	2,00	34,20
paint	40,00	20,40	816,00	1,06	42,40
Sum	105 601,70		99 860,48		9 907,43

Roof / Ceiling					
Material	Weight [kg]	Embodied Energy [MJ/kg]	Embodied Energy [MJ]	Embodied Carbon [$kgCO_2$/kg]	Embodied Carbon [$kgCO_2$]
asphalt shingles	1 239,60	2,60	3 222,96	0,05	55,78
eave protection	21,60	89,30	1 928,88	2,00	43,20
roof boards 22 x 89	1 346,40	22,50	30 294,00	0,46	619,34
mineral wool Rsi	759,00	16,60	12 599,40	1,20	910,80
27° W roof truss o.c.	1 305,60	22,50	29 376,00	0,46	600,58
plasterboard	832,00	6,45	5 366,40	0,38	316,16
paint	40,00	20,40	816,00	1,06	42,40
Sum	5 544,20		83 603,64		2 588,26

Ceiling / Joist floor					
Material	Weight [kg]	Embodied Energy [MJ/kg]	Embodied Energy [MJ]	Embodied Carbon [$kgCO_2$/kg]	Embodied Carbon [$kgCO_2$]
subfloor fibreboard	1 917,00	30,00	57 510,00	0,86	1 648,62
joists 38 x 184 mm	1 569,00	22,50	35 302,61	0,46	721,74
plywood 10 mm	1 400,00	22,50	31 500,00	0,46	644,00
plasterboard	2 080,00	6,45	13 416,00	0,38	790,40
paint	40,00	20,40	816,00	1,06	42,40
Sum	7 006,00		138 544,61		3 847,16

Fixtures and interiors					
Material	Weight [kg]	Embodied Energy [MJ/kg]	Embodied Energy [MJ]	Embodied Carbon [$kgCO_2$/kg]	Embodied Carbon [$kgCO_2$]
oak parquet	1 715,70	22,50	38 603,25	0,46	789,22
ceramic tiles	1 548,00	9,00	13 932,00	0,59	913,32
ceramic floor tiles	508,30	9,00	4 574,70	0,59	299,90
wool carpet	420,00	106,00	44 520,00	5,48	2 301,60
Glass	575,00	18,50	10 637,50	0,85	488,75
pottery	150,00	29,00	4 350,00	0,48	72,00
fixtures timber	11 000,00	22,50	247 500,00	0,46	5 060,00
fixtured steel + plate	600,00	24,60	14 760,00	1,77	1 062,00
fixtures plastic	500,00	84,50	42 250,00	2,00	1 000,00
Sum	17 017,00		421 127,45		11 986,79

Heating System	Weight [kg]	Embodied Energy [MJ]	Embodied Carbon [$kgCO_2$]
HWH	888,00	55 830,00	4 070,00
FAH	698,00	29 870,00	2 072,00

Total Production

Swedish Type-House, HBG	Weight [kg]	Embodied Energy [MJ]	Embodied Carbon [kgCO_2]	Feedstock Energy [MJ]	Carbon Sequestration [kgCO_2]
Total	107 584,53	761 881,93	34 037,60	127 095,42	15 701,83
Per m^2	581,54	4 118,28	183,99	687,00	84,87
Swedish Type-House, Nelson	Weight [kg]	Embodied Energy [MJ]	Embodied Carbon [kgCO_2]	Feedstock Energy [MJ],[MJ/m^2]	Carbon Sequestration [kgCO_2]
Total	107 394,53	745 209,93	32 039,60	195 895,77	15 130,07
Per m^2	580,51	4 028,16	173,19	1 058,90	81,78
BC Type-House, HBG	Weight [kg]	Embodied Energy [MJ]	Embodied Carbon [kgCO_2]	Feedstock Energy [MJ]	Carbon Sequestration [kgCO_2]
Total	149 265,76	982 328,18	41 213,87	333 405,10	23 677,92
Per m^2	635,17	4 180,12	175,38	1 418,75	100,76
BC Type-House, Nelson	Weight [kg]	Embodied Energy [MJ]	Embodied Carbon [kgCO_2]	Feedstock Energy [MJ]	Carbon Sequestration [kgCO_2]
Total	149 075,76	956 368,18	39 087,81	333 405,10	23 677,92
Per m^2	634,36	4 069,65	166,33	1 418,75	100,76

Total Transporatation

Swedish Type-House, HBG	Weight [tonne]	Distance [km]	Energy requirements [MJ/tonkm]	Energy requirements [MJ]	CO_2 Emissions [$kgCO_2$/tonkm]	CO_2 Emissions [$kgCO_2$]
Total	107,58	350,00	0,72	27 111,30	0,05	1 958,04
Per m^2	0,58	350,00	0,72	146,55	0,05	10,58
Swedish Type-House, Nelson	Weight [tonne]	Distance [km]	Energy requirements [MJ/tonkm]	Energy requirements [MJ]	CO_2 Emissions [$kgCO_2$/tonkm]	CO_2 Emissions [$kgCO_2$]
Total	107,39	700,00	0,72	54 126,84	0,05	3 909,16
Per m^2	0,58	700,00	0,72	292,58	0,05	21,13
BC Type-House, HBG	Weight [tonne]	Distance [km]	Energy requirements [MJ/tonkm]	Energy requirements [MJ]	CO_2 Emissions [$kgCO_2$/tonkm]	CO_2 Emissions [$kgCO_2$]
Total	149,27	350,00	0,72	37 614,97	0,05	2 716,64
Per m^2	0,64	350,00	0,72	160,06	0,05	11,56
BC Type-House, Nelson	Weight [tonne]	Distance [km]	Energy requirements [MJ/tonkm]	Energy requirements [MJ]	CO_2 Emissions [$kgCO_2$/tonkm]	CO_2 Emissions [$kgCO_2$]
Total	149,08	700,00	0,72	75 134,18	0,05	5 426,36
Per m^2	0,63	700,00	0,72	319,72	0,05	23,09

Occupancy State

Swedish Type-House, HBG

Energy	Net Energy Need [kWh/m^2]	Utilization Rate	Energy End Use [kWh/m^2]	Energy Carrier & PEF	Primary Energy [kWh/m^2]	50 years [kWh/m^2]
Space Heat Load	72,64	100,00	72,64	District Heating, PEF=0,9	65,37	3 268,65
Domestic Hot water	15,82	2 degrees	17,30	District Heating, PEF=0,9	15,57	778,58
Operational Electricity	-	-	3,03	Electricity, PEF=1,5	4,54	226,99
Household Electricity	-	-	41,00	Electricity, PEF=1,5	61,50	3 075,00
Sum	**88,46**		**133,97**		**146,98**	**7 349,22**

	Energy Carrier	[$kgCO_2$/MJ]	[$kgCO_2/m^2$]	50 years [$kgCO_2/m^2$]	50 years [$kgCO_2$]
Space Heat Load	District Heating	0,025	5,88	294,18	54 423,04
Domestic Hot water	District Heating	0,025	1,40	70,07	12 963,39
Operational Electricity	Electricity	0,085	1,39	69,46	12 849,88
Household Electricity	Electricity	0,085	18,82	940,95	174 075,75
Sum			27,49	1 374,66	254 312,07

Swedish Type-House, Nelson

Energy	Net Energy Need [kWh/m^2]	Utilization Rate	Energy End Use [kWh/m^2]	Energy Carrier & PEF	Primary Energy [kWh/m^2]	50 years [kWh/m^2]
Space Heat Load	62,14	0,78	79,67	Natural Gas, PEF=1,17	93,21	4 660,58
Domestic Hot water	15,34	Standby Losses 40W, 2 degrees	18,50	Electricity, PEF=1,36	25,16	1 258,10
Operational Electricity	-	-	3,28	Electricity, PEF=1,36	4,46	222,91
Household Electricity	-	-	41,00	Electricity, PEF=1,36	55,76	2 788,00
Sum			142,45		178,59	8 929,60

	Energy Carrier	[$kgCO_2$/MJ]	[$kgCO_2/m^2$]	50 years [$kgCO_2/m^2$]
Space Heat Load	Natural Gas	0,06	19,13	956,35
Domestic Hot water	Electricity	0,03	2,26	113,23
Operational Electricity	Electricity	0,03	0,40	20,06
Household Electricity	Electricity	0,03	5,02	250,92
Sum			26,81	1 340,56

BC Type-House, HBG

Energy	Net Energy Need [kWh/m^2]	Utilization Rate	Energy End Use [kWh/m^2]	Energy Carrier & PEF	Primary Energy [kWh/m^2]	50 years [kWh/m^2]
Space Heat Load	126,34	100,00	126,34	District Heating, PEF=0,9	113,71	5 685,28
Domestic Hot water	13,24	2 degrees	13,24	District Heating, PEF=0,9	11,92	595,84
Operational Electricity	-	-	7,42	Electricity, PEF=1,5	11,14	556,83
Household Electricity	-	-	41,00	Electricity, PEF=1,5	61,50	3 075,00
Sum	139,58		188,00		198,26	9 912,95

	Energy Carrier	[$kgCO_2$/MJ]	[$kgCO_2/m^2$]	50 years [$kgCO_2/m^2$]	50 years [$kgCO_2$]
Space Heat Load	District Heating	0,03	10,23	511,68	120 243,64
Domestic Hot water	District Heating	0,03	1,07	53,63	12 963,39
Operational Electricity	Electricity	0,09	3,41	170,39	40 041,81
Household Electricity	Electricity	0,09	18,82	940,95	221 123,25
Sum			33,53	1 676,64	394 372,09

BC Type-House, Nelson

Energy	Net Energy Need [kWh/m^2]	Utilization Rate	Energy End Use [kWh/m^2]	Energy Carrier & PEF	Primary Energy [kWh/m^2]	50 years [kWh/m^2]
Space Heat Load	113,80	0,78	145,90	Natural Gas, PEF=1,17	170,71	8 535,35
Domestic Hot water	13,24	40W standby losses, 2 degrees	14,57	Electricity, PEF=1,36	19,81	990,42
Operational Electricity	-		6,10	Electricity, PEF=1,36	8,30	414,96
Household Electricity	-		41,00	Electricity, PEF=1,36	55,76	2 788,00
Sum	127,05		207,57		254,57	12 728,73

	Energy Carrier	[$kgCO_2$/MJ]	[$kgCO_2/m^2$]	50 years [$kgCO_2/m^2$]
Space Heat Load	Natural Gas	0,06	35,03	1 751,45
Domestic Hot water	Electricity	0,03	1,78	89,14
Operational Electricity	Electricity	0,03	0,75	37,35
Household Electricity	Electricity	0,03	5,02	250,92
Sum			42,58	2 128,86

Tranposrtation

Swedish Type-House, HBG Total	Weight [tonne]	Distance [km]	Energy requirements [MJ/tonkm]	Energy requirements [MJ]	CO_2 Emissions [kgCO_2/tonkm]	CO_2 Emissions [kgCO_2]
To landfill	90,75	15,00	2,41	3 280,75	0,18	239,59
To Incinerator	16,83	18,00	2,41	730,11	0,18	53,32
Per m^2						
To landfill	0,49	15,00	2,41	17,73	0,18	1,30
To Incinerator	0,09	18,00	2,41	3,95	0,18	0,29

Swedish Type-House, Nelson Total	Weight [tonne]	Distance [km]	Energy requirements [MJ/tonkm]	Energy requirements [MJ]	CO_2 Emissions [kgCO_2/tonk m]	CO_2 Emissions [kgCO_2]
By truck	107,39	5,00	2,41	1 294,10	0,18	94,51
By Ship	107,39	50,00	0,42	2 255,29	0,03	166,46
Sum		55,00		3 549,39		260,97
Per m^2						
By Truck	0,58	5,00	2,41	7,00	0,18	0,51
By Ship	0,58	50,00	0,42	12,19	0,03	0,90
				19,19		1,41

BC Type-House, HBG Total	Weight [tonne]	Distance [km]	Energy requirements [MJ/tonkm]	Energy requirements [MJ]	CO_2 Emissions [kgCO_2/tonkm]	CO_2 Emissions [kgCO_2]
To landfill	128,53	15,00	2,41	4 646,38	0,18	339,32
To Incinerator	20,74	18,00	2,41	899,50	0,18	65,69
Sum				5 545,87		405,01
Per m2						
To landfill	0,55	15,00	2,41	19,77	0,18	1,44
To Incinerator	0,09	18,00	2,41	3,83	0,18	0,28
Sum				23,60		1,7 2

BC Type-House, Nelson Total	Weight [tonne]	Distance [km]	Energy requirements [MJ/tonkm]	Energy requirements [MJ]	CO_2 Emissions [kgCO_2/tonkm]	CO_2 Emissions [kgCO_2]
By truck	149,08	5,00	2,41	1 796,36	0,18	131,19
By Ship	149,08	50,00	0,42	3 130,59	0,03	231,07
Sum				4 926,95		362,25
Per m2						
By Truck	0,63	5,00	2,41	7,64	0,18	0,56
By Ship	0,63	50,00	0,42	13,32	0,03	0,98
Sum				20,97		1,54

Waste

Swedish Type-House, HBG

	Weight [kg]	Heat Recovery [MJ/kg]	Heat Recovery [MJ]	Electricity recovery [MJ/kg]	Electricity recovery [MJ]	CO_2 Emissions [$kgCO_2$/kg]	CO_2 Emissions [$kgCO_2$]
Incinerator, Total							
Wood	14 732,88	7,70	113 443,18	3,50	51 565,08	1,11	16 353,50
Plastics	524,30	25,10	13 159,93	11,50	6 029,45	2,44	1 279,29
Sum	15 257,18		126 603,11		57 594,53		17 632,79
Incinerator, per m^2							
Wood	79,64	7,70	613,21	3,50	278,73	1,11	88,40
Plastics	2,83	25,10	71,13	11,50	32,59	2,44	6,92

Swedish Type-House, Nelson

Landfill, Operational Energy	Weight [tonne]	Energy Requirement [MJ/tonne]	Energy Use [MJ]	CO_2 Emmisons [$kgCO_2$/MJ]	CO_2 Emmisons [$kgCO_2$]
Total	107,39	0,04	4,30	0,07	0,31
Per m^2	0,58	0,04	0,02	0,07	0,00

Landfill, Non-fuel related	Weight [kg]	CH_4 Emssions [$kgCH_4$/kg]	CH_4 Emssions [$kgCH_4$]	GWP CH_4 [kgeq/kg]	CO_2 Emmisons [$kgCO_2$/kg]	CO_2 Emmisons [$kgCO_2$]	CO_2-eq Emissions [$kgCO_2$eq]	CO_2-eq Emissions/m^2 [$kgCO_2$eq]
Wood	15 422,73	0,16	2 436,79	21,00	0,30	4 626,82	55 799,45	301,62
Plastics	524,30	0,03	13,63	21,00	0,02	12,58	298,85	1,62
Sum			2 450,42			4 639,40	56 098,30	303,23

BC Type-House, HBG

	Weight [kg]	Heat Recovery [MJ/kg]	Heat Recovery [MJ]	Electricity recovery [MJ/kg]	Electricity recovery [MJ]	CO_2 Emissions [$kgCO_2/kg$]	CO_2 Emissions [$kgCO_2$]
Incinerator, Total							
Wood	20 168,21	7,70	155 295,23	3,50	70 588,74	1,11	22 386,71
Plastics	588,70	25,10	14 776,37	11,50	6 770,05	2,44	1 436,43
Sum	20 756,91		170 071,60		77 358,79		23 823,14
Incinerator, per m2							
Wood	85,82	7,70	660,83	3,50	300,38	1,11	95,26
Plastics	2,51	25,10	62,88	11,50	28,81	2,44	6,11
Sum			723,71		329,19		101,38

Landfill, Rest of BM	Weight [tonne]	Energy Requirement [MJ/tonne]	Energy Use [MJ]	CO_2 Emmisons [$kgCO_2/MJ$]	CO_2 Emmisons [$kgCO_2$]
Total	128,53	0,04	5,14	0,07	0,37
Per m2	0,55	0,04	0,02	0,07	0,00

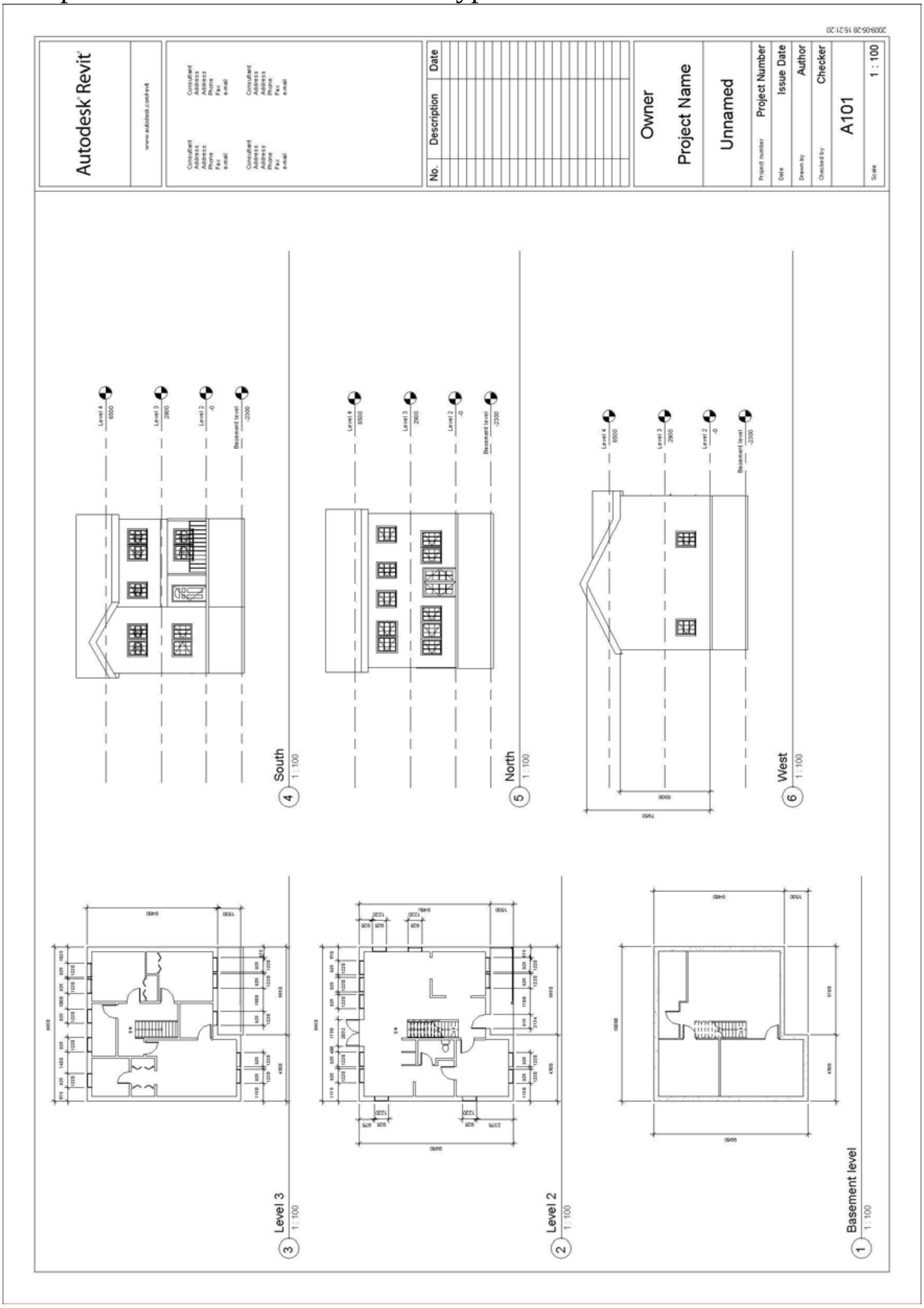
BC Type-House, Nelson

Landfill, Operational Energy	Weight [tonne]	Energy Requirement [MJ/tonne]	Energy Use [MJ]	CO_2 Emmisons [$kgCO_2/MJ$]	CO_2 Emmisons [$kgCO_2$]
Total	149 075,76	0,04	5 963,03	0,072	429,34
Per m2	634,36	0,04	25,37	0,072	1,83

Landfill, Non-fuel related	Weight [kg]	CH_4 Emssions [$kgCH_4/kg$]	CH_4 Emssions [$kgCH_4$]	GWP CH_4 [kgeq/kg]	CO_2 Emmisons [$kgCO_2/kg$]	CO_2 Emmisons [$kgCO_2$]	CO_2-eq Emissions [$kgCO_2eq$]	CO_2-eq Emissions/m^2 [$kgCO_2eq$]
Wood	18 114,79	0,16	2 862,14	21,00	0,34	6 122,80	66 227,67	281,82
Plastics	588,70	0,03	15,31	21,00	0,02	14,13	335,56	1,43
Sum			2 877,44			6 136,93	66 563,23	283,25

Appendix 3

Blueprint of the British Columbian Type-house



Appendix 4

Blueprint of the Swedish Type-house