Building Energy Simulation vs Actual Energy Consumption and Impacts of Climate Change

by

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Bachelor of Science in Mechanical Engineering,

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Abstract:

Energy modeling is necessary to determine the energy consumption of buildings and identify ways to reduce it. HOT2000 is an energy simulation modeling software developed and maintained by Natural Resources Canada that plays a pivotal role in Canada's home energy rating, labeling, and code compliance systems. This research examines the energy performance gap between modeling and actual energy consumption in two detached houses, located in Vancouver, BC were modeled with HOT2000 software. The architectural drawings were obtained from a design farm. It was observed that the actual energy consumption of the homes exceeded the predicted values by 40 to 45%. The discrepancies were attributed to the limitations of the energy modeling program, inconsistencies between the energy model and the actual buildings, and additional energy loads in the homes. Additionally, the study considers building performance under future climate scenarios, predicting an increase in energy consumption. Furthermore, this study conducted a parametric analysis of wall construction and energy sources to enhance energy efficiency. With just the change of energy source for space heating from Gas Boiler to Air Source Heat Pump (ASHP) the energy consumption dropped and saved 15 to 35% and CO2 decreased from 45 to 75% per year. Improving the wall R-value from R-14 to R-28 the space heating energy saved around 12 to 15%. Based on the energy modeling results, the South-facing house in Vancouver, BC, is more energy-efficient (~5%) than the North-facing house. Climate change is expected to intensify temperature extremes and fluctuations, which will likely increase the need for combined cooling and heating energy.

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Acronyms

ACH	Air Change Rate per Hour
ASHP	Air Source Heat Pump
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BC	British Columbia
BEPG	Building Energy Performance Gap
BPE	Building Performance Evaluation
CGBS	Canada Green Buildings Strategy
CO2	Carbon Dioxide
CDD	Cooling Degree Days
DHW	Domestic Hot Water
NRCan	Natural Resources Canada
EUIs	Energy Use Intensities
GHG	Greenhouse Gas
GCMs	General Circulation Models
HDD	Heating Degree Days
HRV	Heat Recovery Ventilator
HVAC	Heating, ventilation, and air conditioning
IPCC	Intergovernmental Panel on Climate Change
LEED	Leadership in Energy and Environmental Design
NBC	National Building Code of Canada
PCIC	Pacific Climate Impacts Consortium
RH	Relative Humidity
UNEP	United Nations Environment Programme

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Dedication

Dedicated to my beloved parents, family members, teachers, and loved ones, who loved me, protected me, and cared for me.

Author’s Note

This report is based on observations from an academic pilot study and is not intended for direct implementation in practical applications. The author acknowledges and appreciates the significant contributions of the design teams responsible for these homes. While every effort has been made to ensure the content's accuracy and reliability, some errors may persist.

Building Energy Simulation vs Actual Energy Consumption and Impacts of Climate Change

1. Introduction

1.1 Background and Importance of Building Energy Performance

Over the years, the number and size of residential and commercial buildings have increased significantly, inevitably leading to a corresponding rise in energy consumption. In 2021, the buildings and construction sector were responsible for approximately 37% of the global energy- and process-related CO2 emissions, while also accounting for over 34% of the global energy demand (Figure 1) [1].

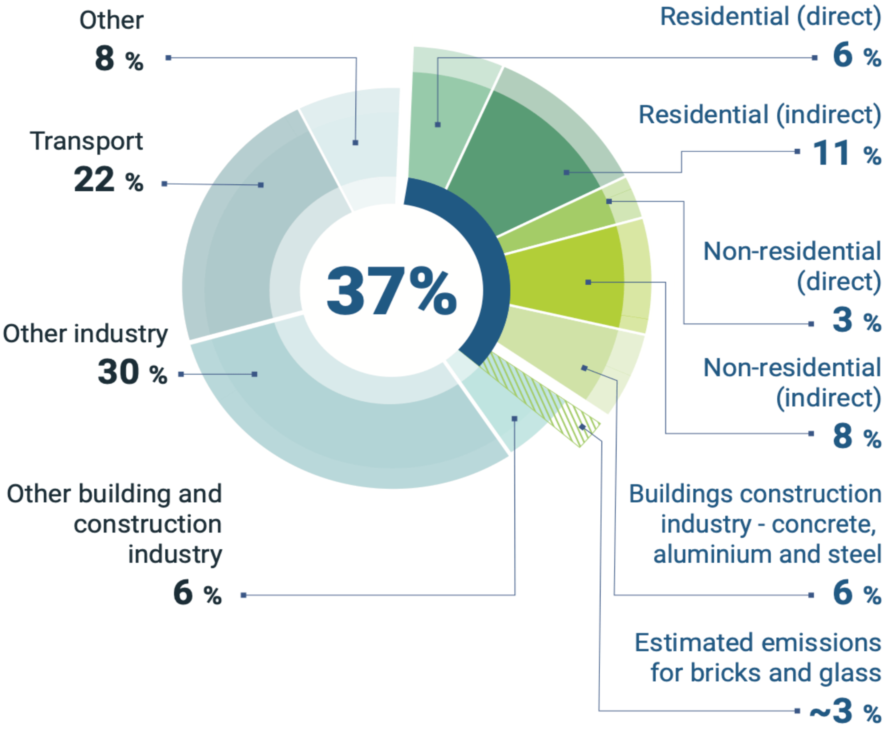


Figure 1: Global share of buildings and construction operational and process CO2 emissions [1].

The concern is that the rate of emissions is growing. The Fourth Assessment Report of the IPCC estimates that building-related greenhouse gas emissions were approximately 8.6 million metric tons of CO2e in 2004. Between 1971 and 2004, carbon dioxide emissions, including those generated by the use of electricity in buildings, increased by 2.5% per year for commercial buildings and 1.7% per year for residential buildings [2].

Therefore, in pursuing a sustainable future, energy efficiency has emerged as a fundamental strategy to decarbonize buildings. Consequently, the construction of high-performance buildings has become increasingly crucial. These energy-efficient buildings are designed to consume less energy which, in turn, reduces greenhouse gas emissions. Moreover, they offer significant financial benefits by lowering operating costs for owners. Beyond these tangible advantages, energy-efficient buildings provide occupants with more comfortable and healthier living and working environments. Overall, improving energy efficiency within the building sector presents a unique opportunity to achieve multiple objectives simultaneously: saving energy, reducing greenhouse gas emissions, and lowering operating costs for buildings.

In this context, energy modeling plays a vital role in achieving such levels of efficiency. This sophisticated process is essential for accurately determining the energy consumption of buildings, thereby identifying potential avenues for reducing energy usage. By leveraging energy modeling, stakeholders can make informed decisions that contribute significantly to mitigating the adverse impacts of climate change through the decarbonization of the built environment.

The inclusion of energy efficiency mandates within the National Building Code of Canada (NBC) signifies a substantial advancement in the promotion of sustainable building practices. Looking ahead, the effects of future climate change are expected to have profound implications on building performance, energy consumption, and occupant comfort [3].

In this regard, Canada stands out as one of the world's most energy-intensive economies. This distinction is attributed to several factors, including the country's vast geographical size, cold climate, high standard of living, and expanding energy industry. Over the past 15 years, energy demand in Canada has grown at an average rate of 0.8% per year, a trend that is projected to continue under the current policy scenario [4].

Therefore, the need to implement robust energy efficiency measures in Canada's building sector is not only crucial for meeting national energy and environmental goals but also for contributing to global efforts in combating climate change.

The building sector in Canada, which includes residential construction, accounts for 28% of the country's total energy consumption, with more than half of this energy being used within the residential sector. Over the years, energy use per household and unit of floor space has seen a significant decrease due to improvements in energy efficiency across various residential energy end uses and sources. Despite these advances, the overall energy consumption for space heating saw a slight increase of 0.3% between 1990 and 2013, however space heating energy intensity (GJ/m^2) decreased by 38.5% during the same period [5].

A closer examination reveals that a vast majority, approximately 82%, of the energy consumed in the residential sector is dedicated to space and water heating (Figure 2) [6]. Therefore, targeting reductions in energy consumption in these two areas is not just important, but critical. For instance, Figure 2 illustrates the distribution of residential energy use by end-use in 2018, underscoring the significant portion attributed to space and water heating.

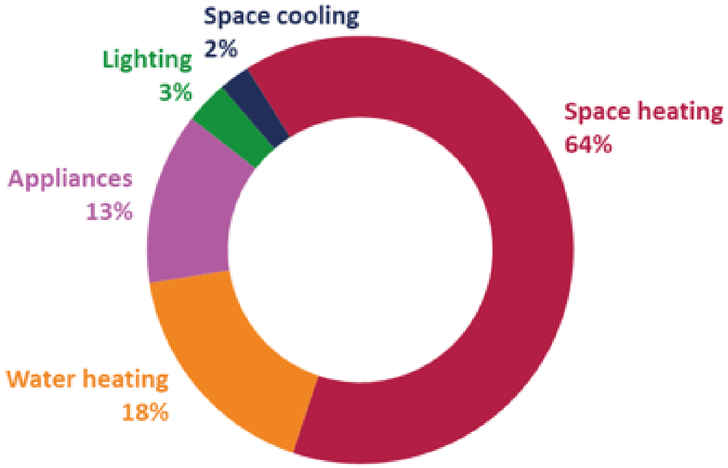


Figure 2: Distribution of residential energy use by end-use [6].

Considering these facts, it becomes evident that there is an urgent need for policies and measures specifically aimed at maximizing energy efficiency within residential and service buildings. Implementing such measures could significantly reduce the energy demand of these buildings, leading to both economic and environmental benefits. The certification process for these buildings, which involves rigorous inspections and precise calculations to estimate energy demand and primary energy consumption based on standard occupancy patterns, plays a crucial role in this effort.

However, it is important to recognize that there often exists a substantial gap between the energy consumption simulated during the design phase and the actual energy consumption observed once the building is in use, as reflected in energy bills [7].

This discrepancy highlights the need for research that analyzes and understands these differences, which is the purpose of this study. By exploring these gaps, the research can contribute to the development of more accurate modeling techniques and better energy efficiency strategies, ultimately bridging the gap between projected and actual energy use. The British Columbia (BC) Energy Step Code is a set of building standards that helps ensure new buildings are energy efficient. BC Energy Step Code says that new buildings are "performing as billed," [8]. It means they are living up to the energy efficiency standards that were promised when they were designed and built.

Most building energy codes and regulations primarily aim to enhance the energy efficiency of newly constructed buildings. However, the energy use of existing buildings also requires greater attention from policymakers, as these buildings often have higher energy use intensities (EUIs) compared to new ones [9].

Therefore, transparency in building energy consumption is a critical component of sustainable design and construction practices. Stakeholders must have the capability to compare the actual energy performance of a completed building with the predicted performance established during the design phase. This research specifically focused on evaluating the alignment between predicted and actual energy performance in two houses certified by Natural Resources Canada (NRCan) in Vancouver, British Columbia. The study was done by the HOT2000 energy modeling program to compare the energy use predicted during the design of the houses with the actual energy use once people are living in them.

1.2 Energy Efficiency in the National Building Code of Canada (NBC)

Energy efficiency is a cornerstone of contemporary building practices, and the National Building Code (NBC) has made substantial progress in embedding these principles within its regulatory framework. The NBC now incorporates specific energy efficiency requirements, reflecting the growing importance of sustainable building practices in Canada's construction industry. A key method for demonstrating compliance with the energy requirements outlined in Part 9 of the NBC is through the performance path, detailed in NBC 9.36.5. This compliance pathway allows the use of energy modeling to demonstrate that a building meets the energy standards outlined in NBC 9.36. The performance path is particularly advantageous as it offers greater flexibility to code users, enabling them to explore more innovative and efficient designs for low-rise residential buildings, compared to the traditional prescriptive energy efficiency provisions outlined in NBC 9.36.2 through 9.36.4. [10].

It's a compliance method that utilizes specific energy metrics, like Energy Use Intensity, to prove adherence to regulations. This performance-based approach gives designers or builders the greatest flexibility in satisfying the building energy code standards [11] .

In furtherance of this initiative, Natural Resources Canada (NRCan) has played a pivotal role by executing the provision of an energy modeling tool that aligns with the NBC 9.36.5 Energy Performance Compliance requirements [12]. Through this energy modeling, builders and designers are allowed to explore a broader range of design options and materials in their efforts to achieve compliance. This flexibility not only fosters innovation but also facilitates the adoption of emerging technologies and building practices, which can result in the construction of more energy-efficient homes.

1.3 Building Energy Modeling

Building energy modeling is a process that uses computer software to simulate and assess its energy performance. It helps analyze and improve energy use in buildings, identifying areas for better energy efficiency [13].

Hot2000, eQUEST, EnergyPlus, IESVE, and RETScreen are the most widely utilized energy modeling software tools. These tools are indispensable for architects, engineers, and energy consultants who are dedicated to designing and retrofitting buildings to achieve exceptional energy performance and sustainability.

Building energy modeling tools have been used to focus on energy efficiency and sustainability in the building industry. Energy modeling becomes more important due to energy security and cutting CO2 emissions. Therefore, accurate energy modeling is important for future climate change impacts on building performance and comfort.

In addition, the inclusion of energy efficiency requirements in the NBC marks a major step forward in promoting sustainable building practices. As energy efficiency becomes increasingly vital in the global effort to combat climate change, these measures will be key in establishing Canada as a leader in building a more sustainable future. [12] .

Within this context, HOT2000 stands out as a widely recognized and essential energy modeling software. It plays a central role in both provincial and federal energy rating, labeling, and incentive programs. It is equipped with the necessary computational capabilities to ensure compliance with building performance codes, and it is extensively utilized by design professionals and builders to enhance the energy efficiency of residential house designs specialty for part-9 buildings.

In this research project, the HOT2000 software is used for the calculation of energy consumption, and the following chapter will provide a detailed discussion of the functionalities and application of the HOT2000 software in this context.

1.4 HOT2000 software

The NBC introduced minimum energy performance requirements in 2012. These requirements could be satisfied either by adhering to specific prescriptive standards or by following a performance pathway. The performance pathway, in particular, requires that builders demonstrate that the energy consumption of their house is lower than that of a reference house constructed according to the prescriptive standards [12]

In this regard, Natural Resources Canada developed and maintained an energy simulation modeling software HOT2000 which supports residential energy efficiency initiatives such as the EnerGuide Rating System, Energy Star for new homes, and R-2000. Through these simulations, designers and builders can ensure that their projects not only meet the stringent energy efficiency standards of the NBC but also optimize both cost and performance.

In addition, HOT2000 plays a crucial role by calculating a building's energy consumption and greenhouse gas (GHG) emissions based on a variety of factors, including material type, construction method, building orientation, and the dimensions of walls, ceilings, foundations, and windows. Moreover, the type of heating and cooling systems employed, the energy sources used, and the thermal characteristics of the house further influence the energy consumption results. The outputs produced by HOT2000 are consistent with those generated by other similar energy modeling software, ensuring its reliability and accuracy in energy performance assessments [14].

For this research project, the HOT2000 (version 11.11) energy modeling tool has been deliberately selected due to its robust capabilities and widespread use in Canada. Needless to say, this software has some shortcomings as well. According to Moreno et all., the key strengths and weaknesses of HOT2000 are as follows [15]:

Strengths of the HOT2000 Software:

- Numerous default options accompanied by illustrations
- Detailed error reports
- Applicability on a global scale
- Estimates for heating and cooling loads in addition to energy demands

Weaknesses of the HOT2000 Software:

- Lack of interactive graphic images to instantly visualize the energy use profile
- Complexity in custom user input.

Figure 3 shows the input parameters required by the HOT2000 model to simulate and evaluate the energy performance of a building. There are several important inputs including details on the mechanical systems, the building envelope, the base loads, and other parameters such as temperature set points, air tightness, and location. The outputs of the model primarily focus on calculating the building's energy consumption and its associated GHG emissions. Moreover, it estimates annual fuel consumption for space heating & cooling, domestic hot water (DHW) heating, baseloads, and ventilation. As well, it calculates heat loss (MJ) and % annual heat loss for the Ceiling, Main Walls, Doors, Exposed floors, and Windows individually. From this data, the Energy Advisor can advise Builders/Homeowners on where they need to improve to minimize energy consumption.

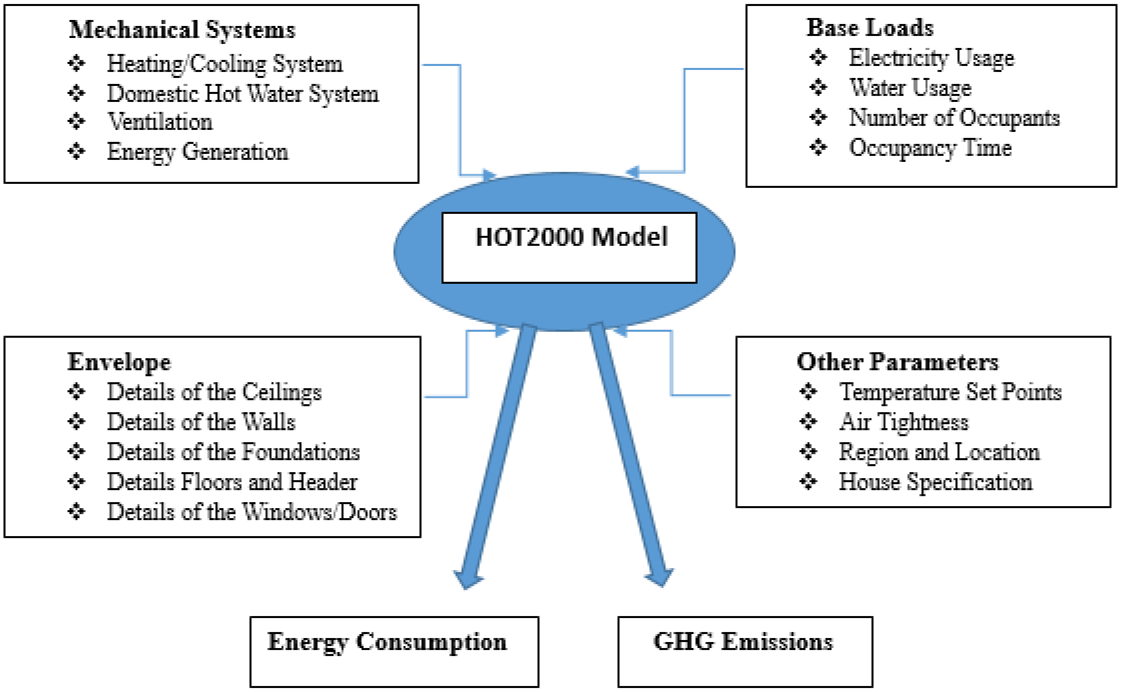


Figure 3: HOT2000 Energy Simulation Details

2. Literature Review

2.1 Variation between modeling result and actual:

According to the International Energy Agency report building operations are responsible for 30% of global final energy consumption and contribute 26% of global energy-related emissions [16].

In Canada, only residential buildings are responsible for 47% of the emissions from the building sector, excluding those from electricity [17].

In response to these significant figures, the Canada Green Buildings Strategy (CGBS) has been developed to create greener, more energy-efficient, and affordable buildings. This strategy emphasizes reducing energy bills, lowering carbon emissions, and safeguarding homes and workplaces from the impacts of climate change, while simultaneously fostering the creation of sustainable jobs. By promoting the transition of buildings to clean energy sources and reducing overall energy consumption, the CGBS supports both environmental sustainability and the financial well-being of Canadians [17].

This is imperative to mention that the way we build and manage our buildings is crucial to the health and vitality of the nation. The United Nations Environment Programme (UNEP) published a report in 2022 that highlights the urgency of this issue. Energy-related carbon dioxide emissions from building operations and construction reached a record high of 10 gigatons, accounting for 37% of global carbon dioxide emissions [18].

In this context, building simulation has become a widely utilized tool for conducting energy and environmental assessments of buildings. This process enables the analysis of building physics, either statically or dynamically, to assess thermal comfort, predict energy performance, and determine system sizing. The importance of building simulation has grown over the years, primarily due to the significant benefits it offers in optimizing building performance [19].

According to ASHRAE Guideline 14, the whole building calibrated simulation approach employs an approved computer program to model the physical characteristics of a building, enabling the determination of energy and demand savings. The ASHRAE Standards Committee endorses this approach as a reliable method for assessing building energy performance [20].

As well, Building Performance Evaluation (BPE) is a systematic process that assesses a building's performance after at least one year of occupancy, comparing the actual performance with the initial expectations. This evaluation process provides valuable insights into building usage by monitoring performance, engaging stakeholders to address issues from design through post-occupancy, and ultimately enhancing occupant productivity and building management. Some case studies within BPE offer both qualitative and quantitative analyses, sharing lessons that drive industry improvements. While many commercial and institutional buildings have been evaluated through BPE, residential buildings—particularly in Canada—have been the subject of fewer studies. The discrepancies between design predictions and actual energy consumption, especially regarding space heating and unregulated loads, raise questions about the accuracy of energy modeling and suggest a need for revisions in rating systems and assumptions, particularly for energy-efficient homes [21].

The difference between the actual or measured energy use and the energy use predicted or simulated is known as the building energy performance gap (BEPG). Many factors contribute to the growing frequency of BEPG cases over the past twenty years, including: (1) restrictive policies and building regulations designed to reduce energy consumption, (2) unrealistic compliance calculations, and (3) operational issues.

Saunders et al. (2012) argue that if building energy consumption cannot be reliably predicted, the effectiveness of energy modeling comes into question, which has broader implications, including concerns about the credibility of LEED certifications [22].

Not enough studies have been conducted on such BEPGs in Canada. Most existing research indicates that actual energy consumption often exceeds the predictions made by energy modeling. Several factors can contribute to increased energy use during building operation, including construction quality issues such as degraded insulation or imperfect air barriers, as well as occupant behavior. Occupant behavior affects energy consumption in two primary ways: through the control of unregulated loads and through intervention in building systems, such as bypassing lighting controls or opening windows, which can alter the indoor climate [23].

A review of the literature reveals that while a few studies have been conducted in Europe and Ontario, Canada, no similar studies have been identified in British Columbia. Examining the energy performance gap between modeling predictions and actual energy consumption in residential homes is particularly timely. Such an analysis can identify the reasons for higher-than-expected energy consumption and uncover their root causes. Understanding these discrepancies is crucial for developing strategies to reduce energy consumption and greenhouse gas emissions in the long term. This process is not only essential for achieving energy efficiency but also for contributing to global efforts to mitigate climate change. Therefore, the comparison between the energy consumption predicted by simulation and the actual energy usage recorded by meter readings will give a valuable perception.

2.2 Energy consumption through parametric analysis:

Addressing energy efficiency and reducing carbon emissions within the industry has become increasingly critical due to the growing volatility in energy markets and the tightening of environmental regulations. Implementing intelligent energy efficiency solutions throughout the entire value chain can significantly lower energy consumption across all operational aspects, thereby reducing costs without compromising productivity [24]. For example, to achieve low-energy usage in buildings, wall assembly designs like split-insulation and thick-wall assemblies are employed [25].

In this regard, the CleanBC initiative represents a comprehensive plan for fostering a cleaner and more sustainable future, rooted in developing a low-carbon economy that offers opportunities for all. British Columbia (B.C.) is committed to achieving ambitious GHG reduction targets, aiming for a 16% reduction below 2007 levels by 2025, 40% by 2030, 60% by 2040, and 80% by 2050. To reach these targets, the B.C. government is actively taking measures to decrease pollution and waste while exploring new technologies and opportunities that will contribute to long-term climate goals [26].

It is important to note that technological solutions alone will not suffice; their effectiveness is contingent on building occupants' commitment to using energy-efficient systems properly [27].

The Kyoto Pyramid offers a strategic, step-by-step approach to achieving energy efficiency, beginning with fundamental actions to reduce energy demand and progressing towards the integration of sustainable energy sources. Each stage in this model builds upon the previous one, creating a holistic method for minimizing total energy use and environmental impact [28].

In the context of rising natural gas prices, it has become increasingly cost-effective for the average household in B.C. to transition from a natural gas furnace to an electric heat pump. According to BC Hydro, heating with an electric heat pump costs about $642 per year, compared to $731 per year for a natural gas furnace. Additionally, by switching to an electric heat pump powered by renewable energy sources, the average household can reduce its greenhouse gas emissions by approximately two tonnes annually, while also achieving cost savings [29].

In light of this, it is crucial to reconsider traditional heating and cooling methods to reduce energy consumption and greenhouse gas emissions. Heat pumps offer a viable solution across various applications, whether in new construction or retrofitting existing systems. Also its a cost-effective option for replacing air conditioning systems, as the additional expense of upgrading to a heat pump is often minimal [30].

Canadian Prime Minister Justin Trudeau's plan to increase the carbon tax to $170 per tonne by 2030, along with the B.C. government's intention to raise its carbon tax, underscores the urgent need to adopt energy-efficient equipment to avoid incurring higher costs soon [31].

2.3 Climate Change Impacts on Building Energy Consumption:

Global warming changes ecosystems and may impact the built environment in various ways—particularly in terms of building energy demands and urban energy systems. It is scientifically well-established that greenhouse gas (GHG) emissions, particularly carbon dioxide (CO2), are the primary drivers of global warming. The Intergovernmental Panel on Climate Change (IPCC) Fifth Assessment Report (2014) unequivocally asserts that the warming of the climate system is undeniable. Over the past century, the global mean surface air temperature, encompassing both land and ocean temperatures, has risen by approximately 0.6°C, with a more pronounced increase of 0.85°C recorded between 1880 and 2012 (IPCC, 2014) [32].

Even though this small temperature change might seem minor, it has led to many extreme weather events around the world. Projections from various general circulation models (GCMs) indicate that the global mean surface air temperature is expected to continue its rapid rise in the future. Researchers have conducted an analysis of seasonal temperature variations at Canadian weather stations with long-term data, as depicted in Figure 4 [33]. These variations were mapped on a 50-kilometer grid and averaged to observe national trends. The differences were then compared to the 1961-1990 averages, where positive values indicate warmer temperatures and negative values indicate cooler temperatures.

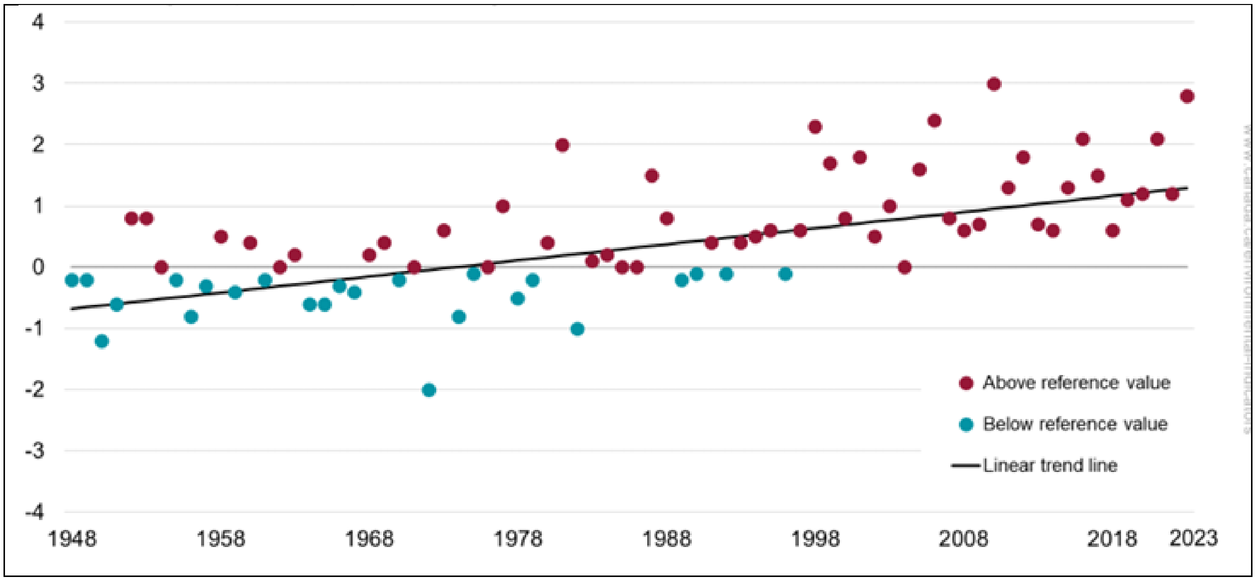


Figure 4: Annual average temperature departures from the 1961 to 1990 reference value, Canada, 1948 to 2023 [33].

The Pacific Climate Impacts Consortium (PCIC) at the University of Victoria (UVic) also provides similar data and future predictions on its website. Figure 5 shows that average temperatures during both winter and summer have shown an upward trend. Some research shows that the Moisture Index is increasing due to changes in climate behavior (Defo, Maurice). Therefore, some changes in the Building Code are needed in line with the prediction of climate change.

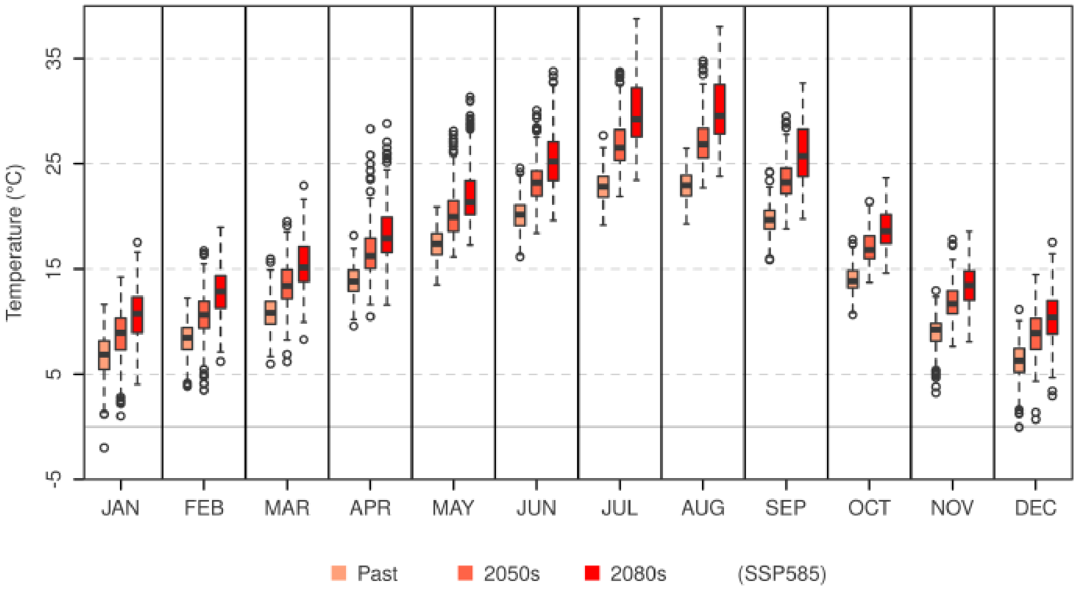


Figure 5: Annual monthly mean daytime high-temperature cycle in the Past, 2050s and 2080s periods [34].

Therefore, builders must reflect the impact of extreme weather and increased temperature on their construction. In addition to these climatic challenges, new constructions must also align with the global transition towards low or zero-carbon emissions. Buildings—whether they are residences, workplaces, or educational facilities—will need to optimize passive design strategies, such as enhanced insulation, improved airtightness, and increased thermal mass. Leveraging solar energy and other renewable sources more effectively is also crucial. Furthermore, integrating innovative technologies will be essential in reducing not only operational energy consumption but also the embodied energy of the materials used in construction [27].

Viseh et al. (2023) revealed the potential effects of climate change on cities across Canada and the associated risks to the performance of the built environment. This study suggested improving awareness of climate change risks and understanding the potential requirements for climate adaptation at the municipal level across Canadian cities [35].

The anticipated impacts of climate change present significant challenges for the built environment, including damage from winter storms, heightened flood risks, increased demand for cooling during summer months, and greater thermal discomfort within buildings. Addressing these challenges requires an evaluation of building design modifications with a strong focus on mitigation—achieving low carbon emissions while maintaining occupant comfort. Key design principles include super insulation, high-performance windows, ventilation heat recovery systems, and the utilization of building mass for thermal storage [27].

The annual energy required to heat or cool a building in a specific location is, therefore, approximately proportional to the total number of heating and cooling degree days recorded for that location over a year. Different countries utilize varying base temperatures for these calculations; for instance, the base temperature is set at 18.3°C in the United States, 15.0°C in Germany, and 18°C in Canada [36].

In the Canadian climate, this implies a potential decrease in energy requirements for heating, while the demand for air conditioning may rise. As a result, research aimed at determining whether overall energy consumption will increase, or decrease is crucial for future building construction planning. Addressing these challenges necessitates solutions that focus on reducing CO2 emissions from buildings. This involves constructing new buildings with net-zero emissions, capable of withstanding the impacts of a changing climate and upgrading existing buildings to meet these rigorous standards. This study also analyzes energy consumption based on HDD and standard deviation of Temperature.

2.4 Research Objectives

Based on this context, the study has three primary objectives:

1. To compare the energy simulation results of the two buildings with their actual energy consumption data.

2. To investigate the effect of various building parameters on energy consumption through parametric analysis, aiming to develop a modeling approach that assesses the retrofit potential of residential buildings under future, stricter building codes.

3. To determine the impact of a changing climate on the performance of residential buildings in the Vancouver, BC region, specifically assessing the potential changes in heating and cooling energy requirements under future weather conditions.

Research Questions:

1. How much variation between the modeling result and the actual result is based on the energy consumption of the residential house and why?

2. To what extent can energy consumption be reduced through retrofitting based on parametric analysis?

3. How do climate change influence heating and cooling energy requirements and the associated GHG emissions?

3.0 Research Methodology

The research methodology for this academic project is structured around three primary objectives: comparing energy simulation results with actual energy consumption data, conducting a parametric analysis to assess the impact of various building parameters on energy consumption, and evaluating the effects of a changing climate on residential building performance. The methodology involves the following systematic steps:

3.1 Comparison of Energy Simulation Results with Actual Energy Consumption Data:

Energy consumption data will be gathered from the two selected residential buildings for two years. To ensure accuracy and comprehensiveness, this data will be sourced from utility bills, energy meters, and building management systems. The data will then be aggregated to determine each building's annual energy consumption, which will subsequently be compared to the output modeled by HOT2000.

The schematic diagram (Figure 6) illustrating the research methodology for comparing energy simulation results with actual energy consumption is presented in this section. This diagram visually outlines the process, highlighting the steps in achieving a rigorous and accurate comparison between the simulated and actual energy consumption data.

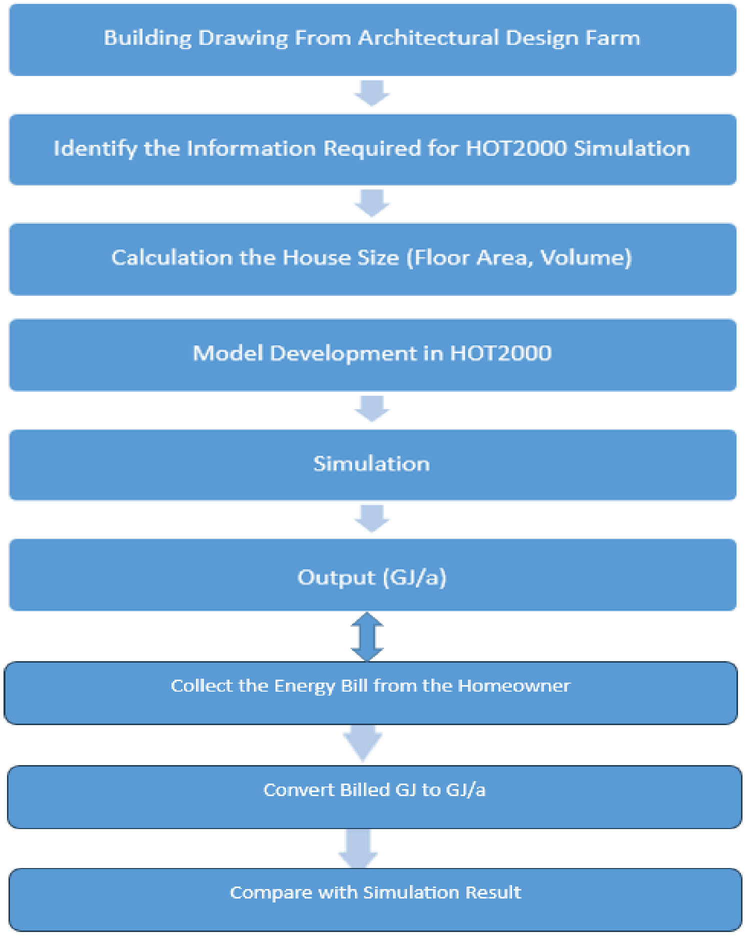


Figure 6: Methodology for comparison of energy simulation results with actual energy consumption results.

3.2 Parametric Analysis of Building Parameters

A parametric analysis is conducted on an energy model considering with energy source, wall resistance, and orientation. The study explores the potential benefits of replacing gas boilers with heat pumps, aiming to assess the resulting energy savings, cost reductions, and decreases in CO2 emissions. This analysis offers valuable insights into the advantages of transitioning to more sustainable heating solutions.

Parameter Selection: The first step involves identifying the key building parameters that have a significant influence on energy consumption. These parameters include insulation layer (R-value), energy source, building orientation, HVAC system efficiency, and occupancy schedules. By selecting these critical factors, the analysis can focus on the elements most likely to impact energy performance.

In this specific analysis, the parametric study will focus on wall thickness with corresponding R-values, the energy source of space heating/cooling systems, and the orientation of the building. House-2, energy consumption will be calculated using different wall constructions with original 2x4 @ 16 O.C, and modeled on 2x6 @ 16 O.C, and 2x8 @ 24 O.C walls. Furthermore, the actual Gas boilers in both houses will be compared with an Air Source Heat Pump (ASHP) to evaluate the impact of this change on energy consumption. And GHG. House-1 front door facing North, will change the orientation and find out new directions that show optimum energy consumption The resulting energy consumption for each scenario will be analyzed to understand the effects of these variations.

The objective of this analysis is to develop a modeling approach that can assess the retrofit potential of residential buildings by evaluating the energy savings achievable through various retrofitting measures, particularly in the context of future, stricter building codes. The results of the building orientation analysis will provide valuable insights for policymakers, offering a clearer picture of the potential impacts on future building developments.

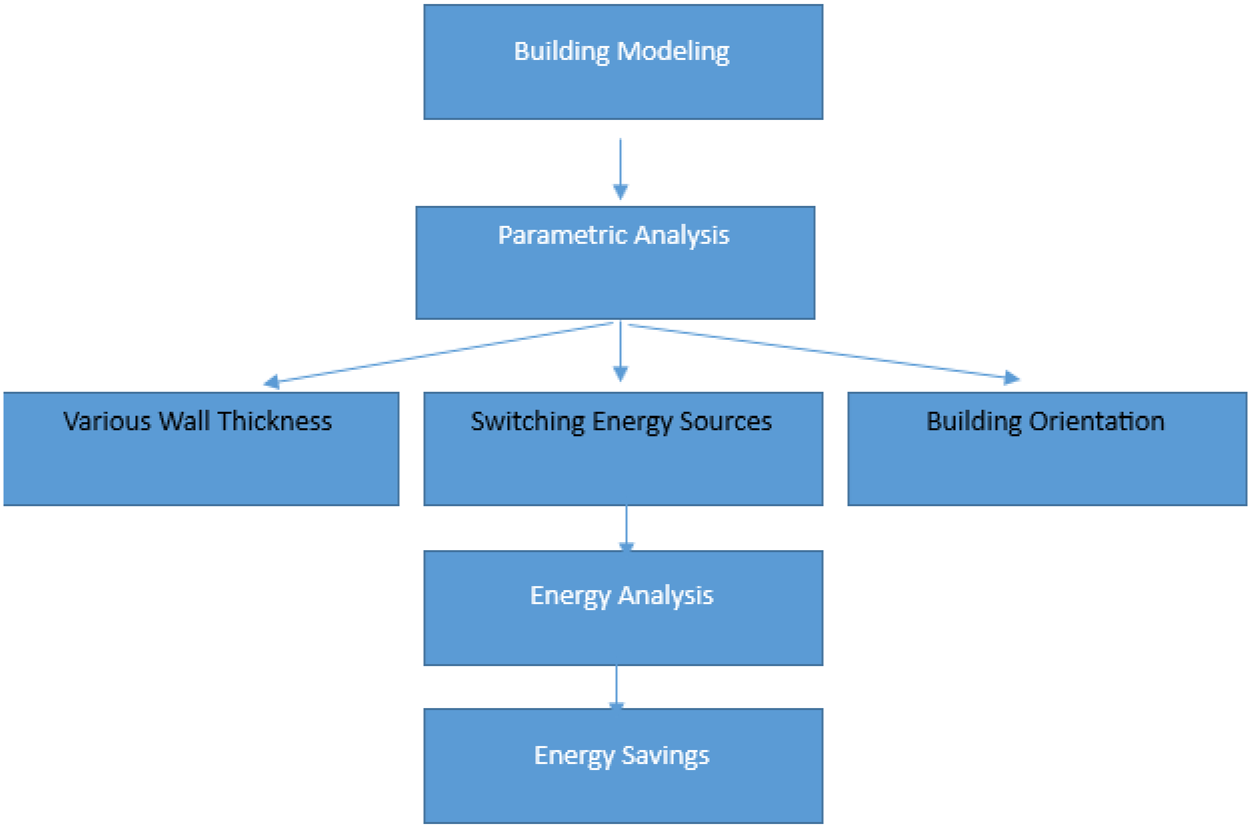


Figure 7: Methodology for Parametric Analysis.

3.3 Impact of Changing Climate on Building Performance

To assess the impact of a changing climate on building performance, energy simulations are conducted on selected residential buildings under various climate scenarios. These simulations will focus on the resultant heating and cooling energy requirements of the buildings, facilitating an assessment of how these energy demands may vary under projected climate conditions. This research aims to offer helpful ideas for future building practices and policies.

In this analysis, twelve locations across British Columbia, Canada, were examined, each with slightly varying but generally comparable HDD values. These locations include Abbotsford, Agassiz Howe, Esquimalt, Estevan, Pitt Meadow, Vancouver, Victoria International Airport, Victoria Gonzales, Victoria University, White Rock, and West Vancouver.

4.0 Development of the HOT2000 Model

As previously discussed, HOT2000 is a sophisticated energy simulation software developed and maintained by Natural Resources Canada. This tool plays a pivotal role in supporting major residential energy efficiency programs such as the EnerGuide Rating System, ENERGY STAR for New Homes, and the R-2000 initiative. HOT2000 is recognized for its robustness and versatility, making it indispensable for accurately modeling residential energy consumption and optimizing energy efficiency in homes.

In this section, the various input parameters required by the HOT2000 model are systematically presented in tabular format to provide a clear understanding of the data utilized in the simulation process. Before going there, a short description of modeling houses is below:

House Description:

House-1: House-1 is a two-story residential building constructed in 2020, located in Vancouver, BC. It consists of two dwelling units, with the front orientation facing north. The exterior walls are built using 2x6 framing at 16 inches on center (O.C) and have an effective insulation rating of R-22. The roof is designed with a hip configuration and includes R-49 blown insulation. The above-grade area of the house is 1,449 square feet, while the below-grade area comprises 564 square feet. The highest ceiling height within the house reaches 27.46 feet. The space heating system is powered by a gas boiler, and the hot water system also relies on gas. Additionally, the house features a Heat Recovery Ventilator (HRV) system integrated into its mechanical infrastructure to enhance energy efficiency.

House-2: House-2 is a two-story residential building that was built in 2008 and located in Vancouver, BC. Like House-1, it contains two dwelling units unlike a front orientation facing south. The exterior walls are constructed by 2x4 wood studs at 16 inches O.C., providing an effective insulation rating of R-14 batt insulation. The type of roof is hip similar to House-1 and filled with R-49 blown insulation. The above-grade floor area of the house is 2428 square feet, with a below-grade area of 1212.51 square feet. The highest ceiling height in House-2 reaches 34.39 feet. Both space heating and hot water systems are powered by a gas boiler, and the mechanical system includes an HRV system, contributing to improved indoor air quality and energy efficiency as well.

Table 1: Information Required for HOT2000 Simulation

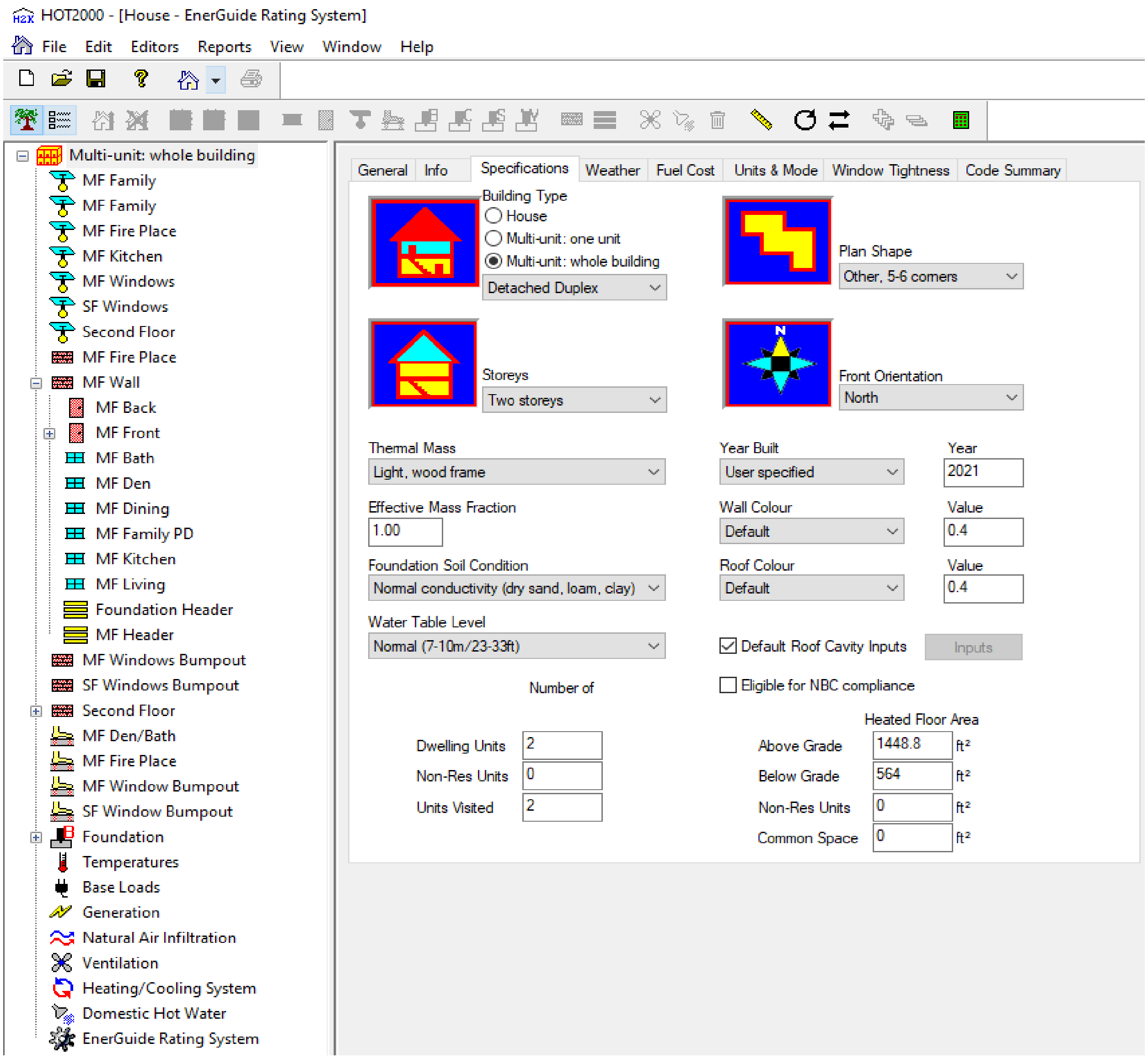
Required Data	User-Input Data	Specifications	Calculated Value
Building Type			
Location	Province		
	City		
Layout	Number of Stories		Shape
Size			Floor Area
	Above Grade		
	Below Grade		
	Total		
	House Volume		
Building Envelope			
Roof, Wall, Floor		R-Values	Layer Specification
		Roof Safe	
		Adjacent to enclosed unconditioned space	
Windows	Length-Width	R Values	Layer Specification
Foundation	Configuration		Layer Specification
Operations			
Air Changes per Hour			Blower Door Test
HVAC-DHW Equipment			
Heating/Cooling Equipment	Type	Efficiency	Capacity
	Fuel		
DHW Equipment	Size		
	Fuel Type		
	Location		

Table 1, a comprehensive synopsis of HOT2000 is provided to summarize the software's capabilities and applications. For a more detailed exploration of the model's features, functionality, and input requirements, additional information is provided in the appendices attached to this document. This structured approach ensures both an overview and an in-depth understanding of HOT2000's development and its critical role in advancing residential energy efficiency.

One limitation of this research is the air change per hour (ACH) rate, which is a critical factor in assessing a building's energy performance. Porttris Kear demonstrated a correlation between ACH and the construction year of homes in his MASc. thesis at UVic (2020). While factors such as build quality, home maintenance, and building envelope integrity can vary significantly between individual homes, the data clearly shows a decreasing trend in ACH50 with newer construction years [37].

Kear compared the overall ACH_{50} values (Air Changes per Hour at 50 Pascals) between Aboriginal-owned and non-Aboriginal buildings. He found that the ACH_{50} range for Aboriginal-owned houses (1920–2018) is 1.26 to 36.18, with an average of 5.47. In contrast, the ACH_{50} range for non-Aboriginal buildings (1780–2018) is 0.43 to 55.91, with an average of 7.99 [37].

In this study, the ACH rate is considered according to the standards set by the British Columbia Building Code. However, the HOT2000 model was subsequently calibrated using a more accurate ACH value that was directly obtained from a Blower Door Test. This difference in ACH values underscores the importance of using building-specific data for energy modeling to achieve more accurate predictions of energy consumption and building performance.



Building Type
○ House
○ Multi-unit: one unit
● Multi-unit: whole building
Detached Duplex

Plan Shape: Other, 5-6 corners

Storeys: Two storeys

Front Orientation: North

Thermal Mass: Light, wood frame

Year Built: User specified
Year: 2021

Effective Mass Fraction: 1.00

Wall Colour: Default
Value: 0.4

Foundation Soil Condition: Normal conductivity (dry sand, loam, clay)

Roof Colour: Default
Value: 0.4

Water Table Level: Normal (7-10m/23-33ft)

☑ Default Roof Cavity Inputs

☐ Eligible for NBC compliance

Number of
Dwelling Units: 2
Non-Res Units: 0
Units Visited: 2

Heated Floor Area
Above Grade: 1448.8 ft²
Below Grade: 564 ft²
Non-Res Units: 0 ft²
Common Space: 0 ft²

Figure 8: Input items for HOT2000 Energy Model

5.0 Results and Discussion

5.1 Part 1 – Energy Consumption: Model vs Actual:

5.1.1 Energy Consumption Summary Report (House-1)

Estimated Annual Space Heating Energy Consumption = 30075.22 MJ = 8354.23 KWh

Ventilator Electrical Consumption: Heating Hours = 749.00 MJ = 208.06 KWh

Estimated Annual DHW Heating Energy Consumption = 13809.84 MJ = 3836.07 KWh

Estimated Annual Space + DHW Energy Consumption = 44634.07 MJ = 12398.35 KWh

Table 2: Estimated Annual Fuel Consumption Summary (House-1)

ESTIMATED ANNUAL FUEL CONSUMPTION SUMMARY						
Fuel	Space Heating	Space Cooling	DHW Heating	Baseloads	Ventilation	Total
Natural Gas (m3)	780.9	0.0	370.6	0.0	0.0	1151.5
Electricity (KWh)	272.3	588.8	0.0	305.6	305.6	9692.9

Table 2 provides a detailed summary of the estimated annual fuel consumption for House-1, broken down by fuel type and specific end-use categories. The table delineates the energy consumed by different systems within the house, including space heating, space cooling, domestic hot water (DHW) heating, baseloads (such as lighting, appliances, and other electrical devices), and ventilation. The consumption is measured in cubic meters (m^3) for natural gas and kilowatt-hours (kWh) for electricity.

Natural Gas (m^3): The table shows that natural gas is primarily used for space heating and domestic hot water (DHW) heating in House-1. Specifically, the space heating system consumes 780.9 m^3 of natural gas annually, while the DHW heating system uses 370.6 m^3. The total natural gas consumption for the house amounts to 1151.4 m^3 per year, indicating that these two functions (space heating and DHW heating) are the sole contributors to the natural gas usage in this household.

Electricity (kWh): Electricity usage is segmented into various categories, with the most significant consumption attributed to baseloads, which include essential household operations such as lighting, appliances, and electronic devices. The baseloads account for 9692.9 KWh of electricity annually, representing the majority of the electrical consumption in the house. The space cooling system also utilizes 588.8 kWh, and the ventilation system consumes 305.6 kWh annually. The total electricity consumption for the house is calculated to be 9693 KWh per year.

The combined data from this table highlights the energy consumption patterns of House-1, with natural gas being the primary energy source for heating needs, while electricity supports cooling, ventilation, and other base household functions. This breakdown allows for a clear understanding of how energy is distributed across different functions within the home, providing a basis for evaluating energy efficiency and identifying potential areas for improvement in energy management.

Table 3: Monthly Estimated Energy Consumption by Devices (MJ) (House-1)

	Space Heating		**DHW Heating**		**Lights & Appliances**	**HRV & Fans**	**Air Conditioner**
Month	Primary	Secondary	Primary	Secondary			
Jan	6076.5	0.0	1279.4	0.0	2606.9	298.2	0.0
Feb	4715.4	0.0	1170.4	0.0	2354.6	243.3	0.0
Mar	3932.2	0.0	1279.4	0.0	2606.9	226.0	0.0
Apr	1960.3	0.0	1194.9	0.0	2522.8	156.5	0.0
May	323.3	0.0	1173.6	0.0	2606.9	114.9	190.0
Jun	34.0	0.0	1076.6	0.0	2522.8	129.8	294.5
Jul	1.0	0.0	1067.8	0.0	2606.9	179.1	521.3
Aug	0.0	0.0	1051.4	0.0	2606.9	171.6	484.3
Sep	19.5	0.0	1033.3	0.0	2522.8	113.8	232.7
Oct	1451.1	0.0	1112.5	0.0	2606.9	142.8	161.1
Nov	4300.7	0.0	1135.7	0.0	2522.8	235.3	0.0
Dec	6280.9	0.0	1234.7	0.0	2606.9	305.0	0.0
Ann	29094.9	0.0	13809.8	0.0	30694.3	2316.2	1884.0

Table 3 provides estimates of household energy consumption in MJ for Space Heating, DHW Heating, Lights & Appliances, HRV & Fans, and Air Conditioners. In January and December, when Space Heating consumption peaks at 6076.5 MJ and 6280.9 MJ, respectively, the data illustrates the seasonality of energy consumption. Conversely, the energy usage for Space Heating drops to negligible levels during the warmer months.

DHW Heating remains relatively consistent throughout the year, with a slight increase during the spring and summer, leading to an annual total of 13809.8 MJ. Lights & Appliances exhibit steady consumption across all months, with a total yearly consumption of 30,694 MJ. HRV & Fans and the Air Conditioner show more varied usage, with the Air Conditioner being used predominantly during the summer months, peaking at 636 MJ in July. Moreover, the table showed a seasonal distribution of energy consumption in these categories, emphasizing the need for enhanced energy efficiency in residential settings.

Figure 9 provides a comparative analysis between the predicted energy consumption from the Hot2000 energy model, and the actual energy consumption recorded on energy bills for House-1. The data is categorized as Electricity, Natural Gas, and Total Energy. The energy model predicts electricity consumption at 34.89 GJ, while the actual is marginally lower at 29.02 GJ. For natural gas, there is a more significant discrepancy, where the energy model predicts 43.88 GJ and the actual consumption reaches 113.8 GJ. Accordingly, the total energy consumption, as predicted by the model, is 78.78 GJ, whereas the actual energy usage recorded is substantially higher at 142.82 GJ. Energy modeling requires significant improvements as a result of discrepancies between estimated and measured quantities of energy use. Reducing these inconsistencies is crucial to improving prediction models.

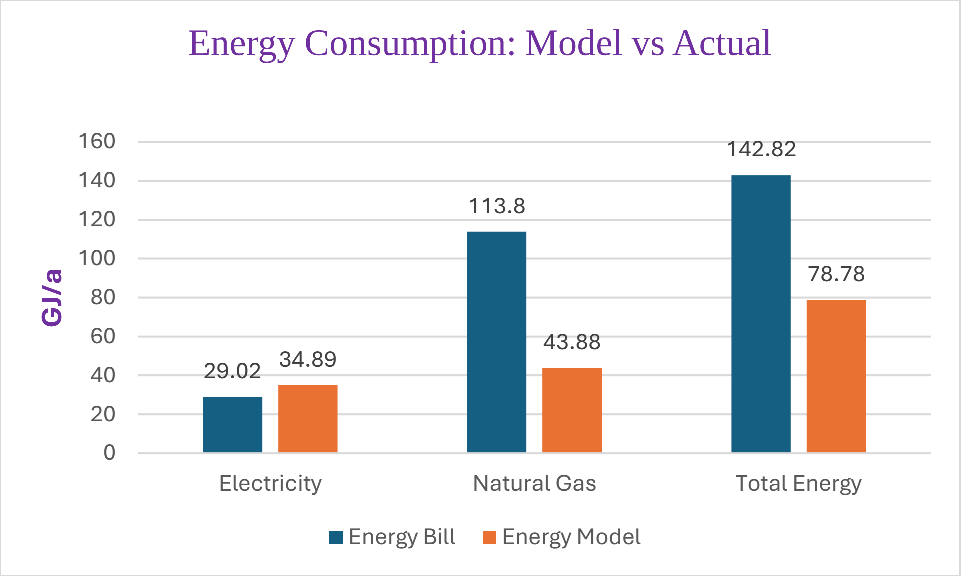


Figure 9: Energy Consumption: Model vs Actual (House 1)

5.1.2 Energy Consumption Summary Report (House-2)

Estimated Annual Space Heating Energy Consumption = 96530.80 MJMJ = = 26814.11KWh

Ventilator Electrical Consumption: Heating Hours = 781.98 MJ = 217.22 KWh

Estimated Annual DHW Heating Energy Consumption = 13988.05 MJ = 3885.57KWh

Estimated Annual Space + DHW Energy Consumption = 111300.84 MJ = 30916.90 KWh

Table 4: Estimated Annual Fuel Consumption Summary

ESTIMATED ANNUAL FUEL CONSUMPTION SUMMARY						
Fuel	Space Heating	Space Cooling	DHW Heating	Baseloads	Ventilation	Total
Natural Gas (m3)	2533.2	0.0	375.4	0.0	0.0	2908.6
Electricity (KWh)	595.8	574.7	0.0	7117.4	321.0	8608.9

Table 4 provides a concise overview of the estimated annual fuel consumption, broken down by energy source and specific end-use categories, including Space Heating, Space Cooling, Domestic Hot Water (DHW) Heating, Baseloads, and Ventilation. The data reveals that natural gas is predominantly used for Space Heating and DHW Heating, with a total annual consumption of 2908.6 m³. On the other hand, Electricity is primarily utilized for baseloads, contributing 8608.9 KWh to the overall annual consumption. Notably, there is no recorded usage of natural gas for Space Cooling or baseloads, and no electricity is allocated to DHW Heating, indicating a clear division of energy use between these two fuel types.

Table 5: Monthly Estimated Energy Consumption by Devices (MJ) (House-2)

	Space Heating		DHW Heating		Lights & Appliances	HRV & Fans	Air Conditioner
Month	Primary	Secondary	Primary	Secondary			
Jan	16944.4	0.0	1295.9	0.0	2176.2	483.2	0.0
Feb	13884.8	0.0	1185.5	0.0	1965.6	404.2	0.0
Mar	12759.3	0.0	1295.9	0.0	2176.2	388.1	0.0
Apr	8257.1	0.0	1210.3	0.0	2106.0	282.7	0.0
May	3605.7	0.0	1188.7	0.0	2176.2	185.2	182.9
Jun	337.5	0.0	1090.5	0.0	2106.0	128.1	278.6
Jul	0.0	0.0	1081.6	0.0	2176.2	174.2	558.1
Aug	0.0	0.0	1065.0	0.0	2176.2	163.2	497.6
Sep	1088.3	0.0	1046.7	0.0	2106.0	131.0	207.8
Oct	7047.6	0.0	1126.9	0.0	2176.2	258.4	160.9
Nov	13048.1	0.0	1150.4	0.0	2106.0	391.5	0.0
Dec	17413.3	0.0	1250.6	0.0	2176.2	493.8	0.0
Ann	94386.1	0.0	13988.0	0.0	25622.6	3483.5	1885.8

The above table 5 presents a detailed breakdown of monthly energy consumption across various end-uses, including Space Heating, DHW Heating, Lights & Appliances, HRV & Fans, and Air Conditioning. The data is segmented into primary and secondary sources where applicable. Space Heating shows the highest consumption during the winter months, peaking in January at 16944.4 MJ and totaling 94386.1 MJ annually. DHW heating remains relatively stable throughout the year, with a slight increase during the summer months, leading to an annual total of 13988.0 MJ. The Lights & Appliances category shows consistent usage across all months, accumulating a significant annual total of 25,622.6 MJ. The HRV & Fans category exhibits lower consumption, with the highest usage recorded in December at 384.3 units, amounting to 3483.5 MJ annually. Air Conditioning, as expected, is only active during the warmer months, particularly in July and August, contributing an annual total of 1885.8 MJ. This comprehensive data highlights the seasonal variability and distribution of energy use within the building, emphasizing the importance of targeted energy efficiency measures, which will be a central focus in the forthcoming thesis analysis.

The following section provides a detailed energy-based comparison between the modeled and actual energy consumption data. This analysis aims to highlight any discrepancies between the two datasets and discuss the underlying factors contributing to these differences. By examining the variations between the modeled predictions and the actual consumption patterns, valuable insights can be gained into the limitations of the simulation model, the building's energy performance, and potential areas for improvement. This comparison is critical for refining the accuracy of energy models and enhancing their ability to predict real-world energy usage, ultimately informing better design and operational strategies for energy-efficient buildings.

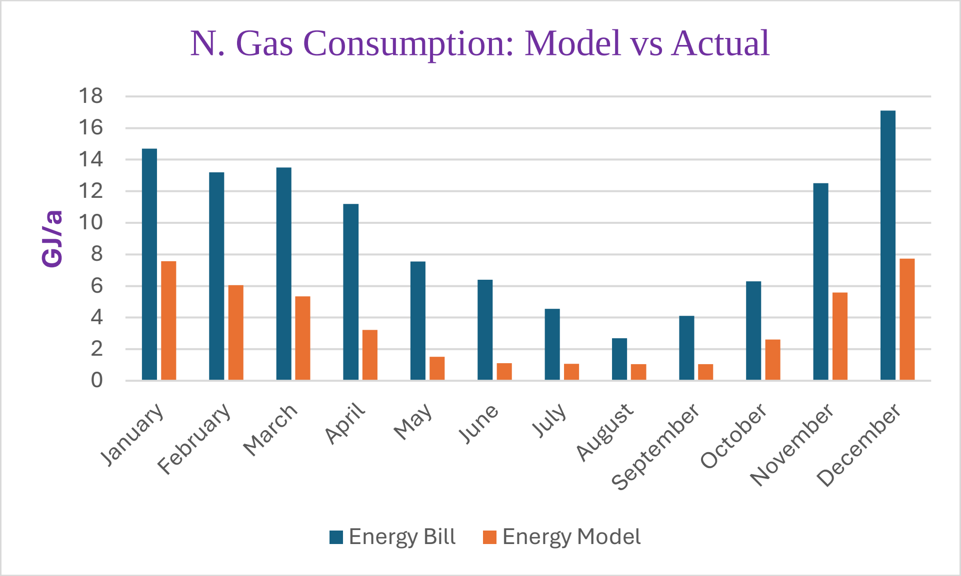


Figure 10: N. Gas Consumption: Model vs Actual (House-1)

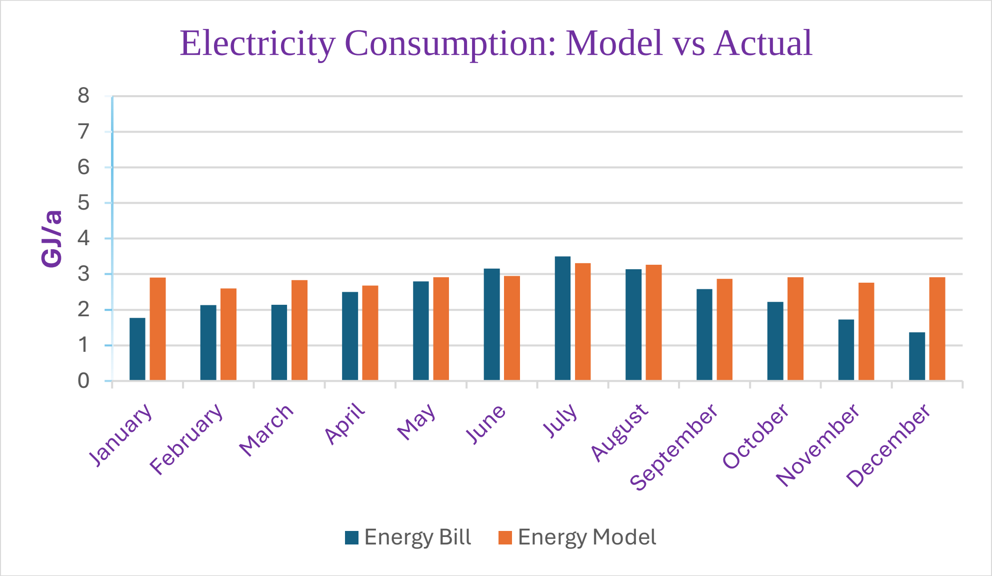


Figure 11: Electricity Consumption: Model vs Actual (House-1)

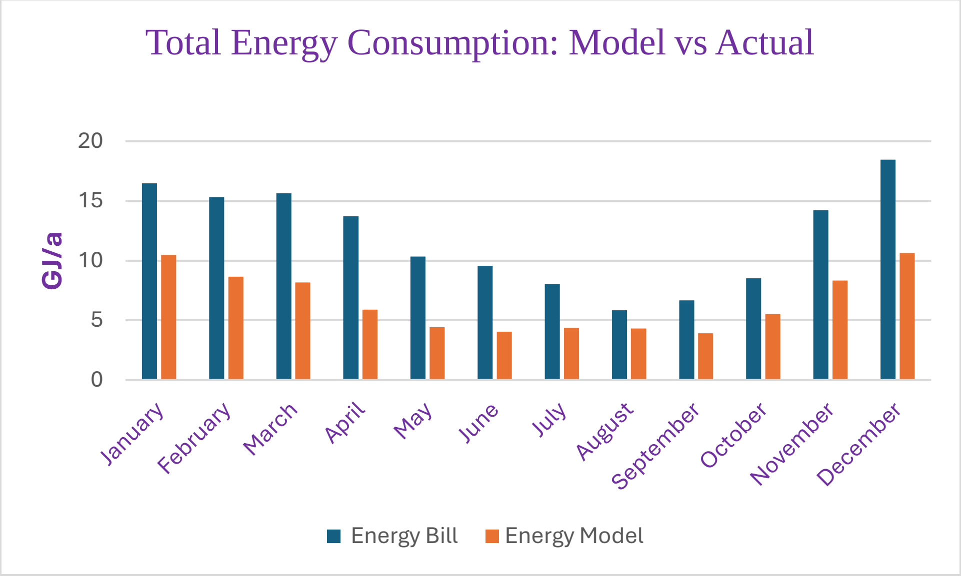


Figure 12: Total Energy (Gas+Electricity) Consumption: Model vs Actual (House-1)

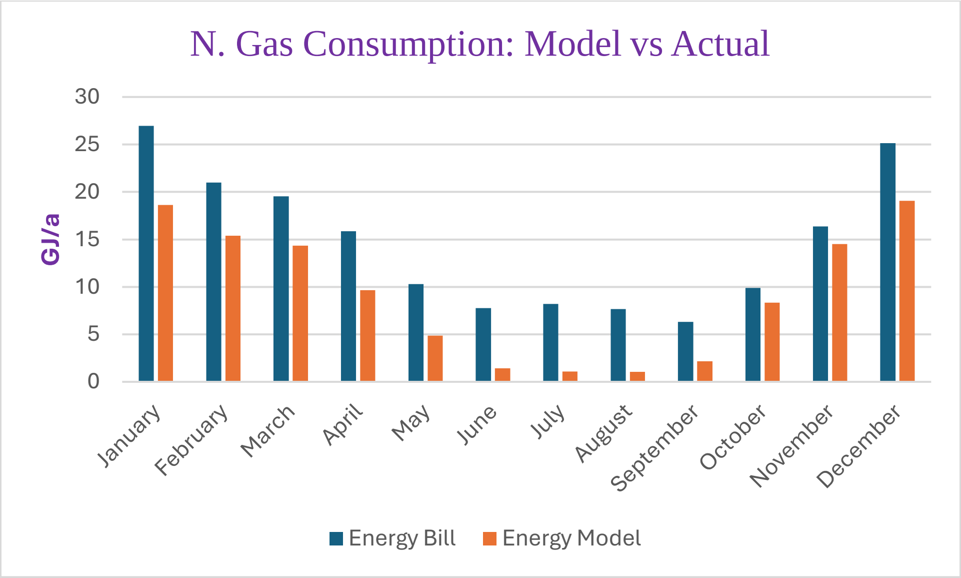


Figure 13: N. Gas Consumption: Model vs Actual (House-2)

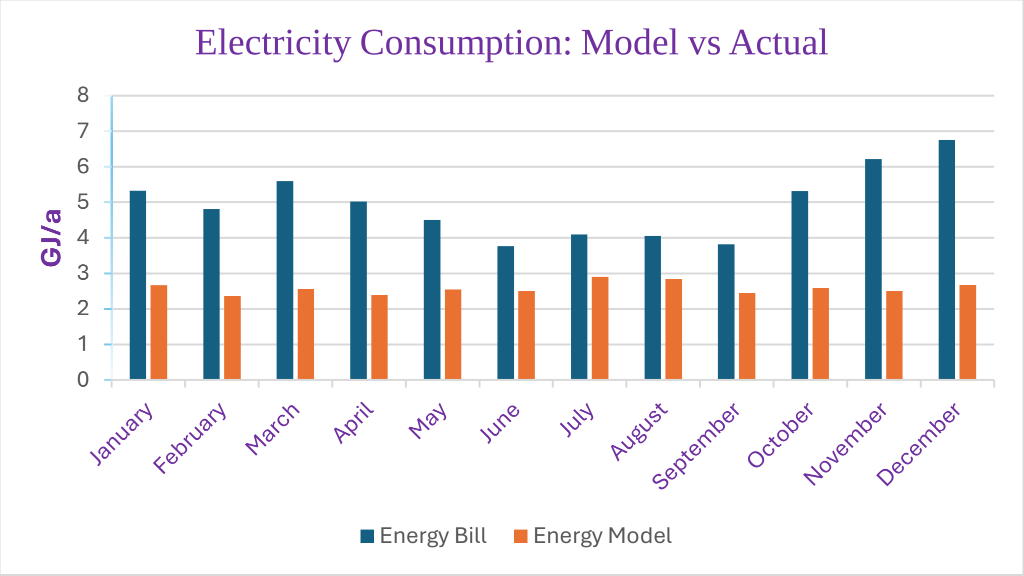


Figure 14: Electricity Consumption: Model vs Actual (House-2)

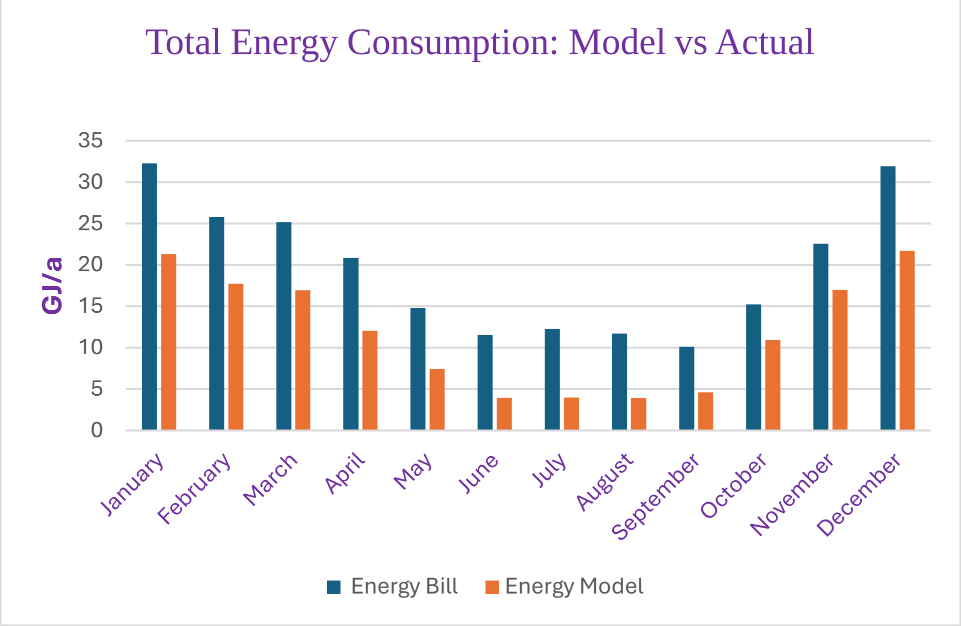


Figure 15: Total Energy (Gas+Electricity) Consumption: Model vs Actual (House-2)

The above graphs "Energy Consumption: Model vs Actual" for both two houses (1 & 2) presents a comparative analysis of the energy consumption data, expressed in gigajoules (GJ), for each month throughout the year. The blue bars represent the actual energy consumption based on utility bills, while the orange bars indicate the modeled energy consumption derived from the simulation. It is evident that the modeled values consistently underestimate the actual energy usage, particularly during the colder months of January, February, and December, where the disparity is most pronounced.

Conversely, during the summer months, from May to August, the differences between the modeled and actual values are smaller, though the actual consumption remains higher in most cases. This suggests that the model may not fully account for the building's operational dynamics, particularly during periods of high heating demand.

Figure 16 illustrates a detailed comparison between projected energy consumption based on an energy model and the corresponding actual consumption data derived from energy bills. The chart segregates the data into three main categories: Electricity, Natural Gas, and Total Energy. The energy model forecasts electricity usage at 30.99 GJ, which contrasts with the actual usage recorded at 59.30 GJ, indicating a significant underestimation. Similarly, for natural gas, the energy model estimates consumption at 110.52 GJ, while the actual consumption is markedly higher at 174.95 GJ. Consequently, the total energy consumption is projected at 141.51 GJ by the model, whereas the actual consumption stands at 234.25 GJ, revealing a substantial discrepancy. These variances between the modeled and actual energy consumption values underscore critical challenges in energy modeling accuracy. Addressing these disparities is essential for refining predictive models.

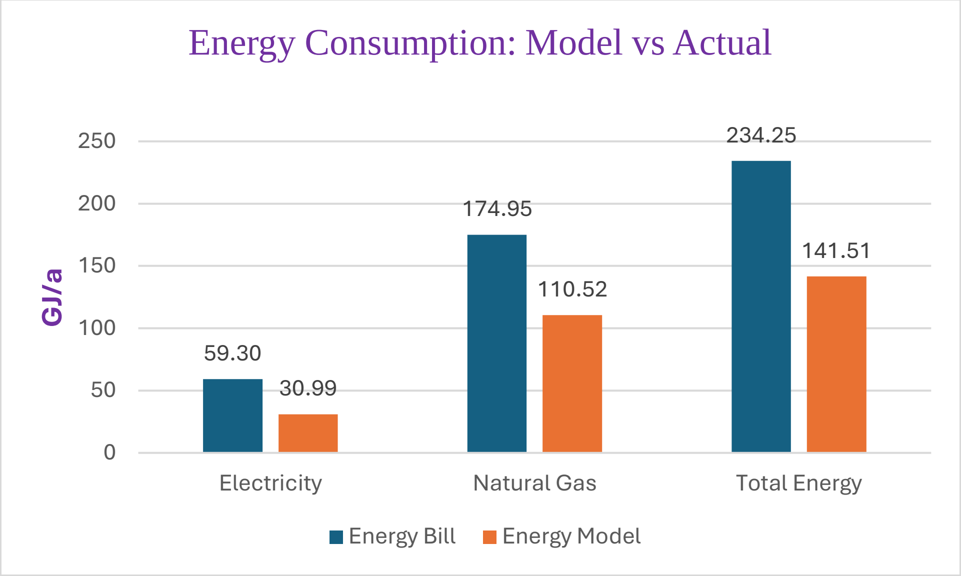


Figure 16: Energy Consumption: Model vs Actual (House 2)

These variances between the modeled and actual data from two houses in Vancouver, BC underscores the potential challenges in accurately forecasting energy usage and highlights the importance of refining energy models to better align with real-world data. The analysis of such discrepancies is crucial for the validation and improvement of energy modeling techniques, which is a focal point of my thesis submission.

Approximately 58% of households in British Columbia (BC) rely on natural gas as their main heating system and if considered only detached homes in BC then about 66% primarily use natural gas for heating. Additionally, 40% of BC Hydro customers depend on natural gas as their main fuel source for water heating [38].

As mentioned earlier, both House-1 and House-2 use natural gas for space heating and water heating. The table below illustrates the actual energy consumption for both gas and electricity. This indicates that 77% of the energy consumption in detached homes still relies on natural gas, and only 23% depends on electricity.

Energy Consumption (GJ/a)	Actual Gas Consumption	Actual Electricity Consumption
House-1	113.80 GJ (79.68 % of Total)	29.02 GJ (20.32% of Total)
House-2	174.95 GJ (74.69 % of Total)	59.3 GJ (25.31 % of Total)

Table 6: Energy consumption based on energy sources for House-1 & House-2

Therefore, replacing gas appliances with electrical equipment is a better idea to achieve environmental targets, reduce greenhouse gas emissions, and align with policies such as BC's CleanBC and Net-Zero objectives.

Figure 17: Door and Window (House-2)-No visible deficiencies

Based on the above calculations, house-1 has increased by around 44.84 % energy compared to its energy modeling result. House-2 also showed that energy consumption is more than 39.59 %. Moe Otsubo investigated the discrepancy in energy performance between the energy consumption of three buildings certified by LEED during his doctoral studies. According to his study, these homes' actual energy consumption exceeded the estimations of energy consumption established during the design phase by 23% to 77% [21].

I also conducted a comparison of modeled versus actual energy consumption during the winter season (October to March) for both houses. The results indicate that the discrepancies are smaller during the heating season compared to the entire year. For House-1, the annual energy performance gap was 44.84%, which decreased to 41.5% during the heating season. Similarly, for House-2, the gap was 39.59%, however, during the heating season it is 30.95%.

These findings suggest that the HOT2000 software does not accurately account for cooling energy consumption. To reduce the energy performance gap and improve the accuracy of the modeling, it is recommended to incorporate CDD into HOT2000, similar to how HDD are utilized. This enhancement would strengthen the software's ability to model energy performance accurately.

The EnerGuide Rating System Program is selected, and parameters such as the number of occupants and daily average interior loads are automatically set to default values in HOT2000. These defaults are based on the typical household usage of lighting and appliances. The assumed number of occupants includes two adults and one child, with the child present 50% of the time. But, in the real picture, most of the house has more occupants than that.

Here are some possible reasons for discrepancies between actual and modeled energy consumption:

1. Insulation Degradation: Over time, insulation materials may settle, compress, or deteriorate, reducing their effectiveness.
2. Air Leakage: Seals around windows, doors, and other penetrations can degrade, leading to increased air leakage and higher energy use.
3. HVAC System Efficiency: The heating, ventilation, and air conditioning (HVAC) system may not be operating at peak efficiency due to age, lack of maintenance, or incorrect settings.
4. Occupant Behavior: Energy consumption can be significantly influenced by how occupants use the space. Factors like thermostat settings, appliance usage, and the number of occupants can greatly impact energy use.
5. Climate Variability: Changes in weather patterns over time can affect energy consumption. If recent years have been unusually cold or hot, this could lead to higher energy usage than originally anticipated.
6. Improper Installation: There could be more thermal bridging than assumed during modeling, or structural shifts that create gaps, leading to inefficiencies.
7. Thermal bridging: The vulnerable spots in the building envelope where heat transfer occurs more readily than anticipated by the model.
8. Occupancy Variations: While the model assumes a standard occupancy of four people, in reality, more people live there (as in House-2), resulting in higher energy consumption.
9. Unrealistic compliance calculations, and operational issues.

Further investigation into these factors could help pinpoint the specific causes of the higher-than-expected energy consumption. Additionally, the researcher conducted a hygrothermal analysis for House-2, which was constructed with 2x4 studs @16 inches on center. The WUFI modeling indicated a potential for water formation inside the wall, which could contribute to increased energy consumption.

A 2 x 4 stud stucco wall is used for this project. The stud cavity is filled with insulations and other layers incorporating a sheathing board with a membrane, a vapor barrier, and drywall (Figure 18).

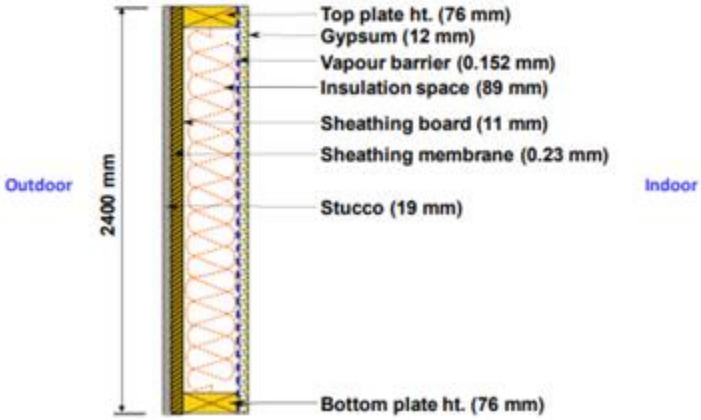
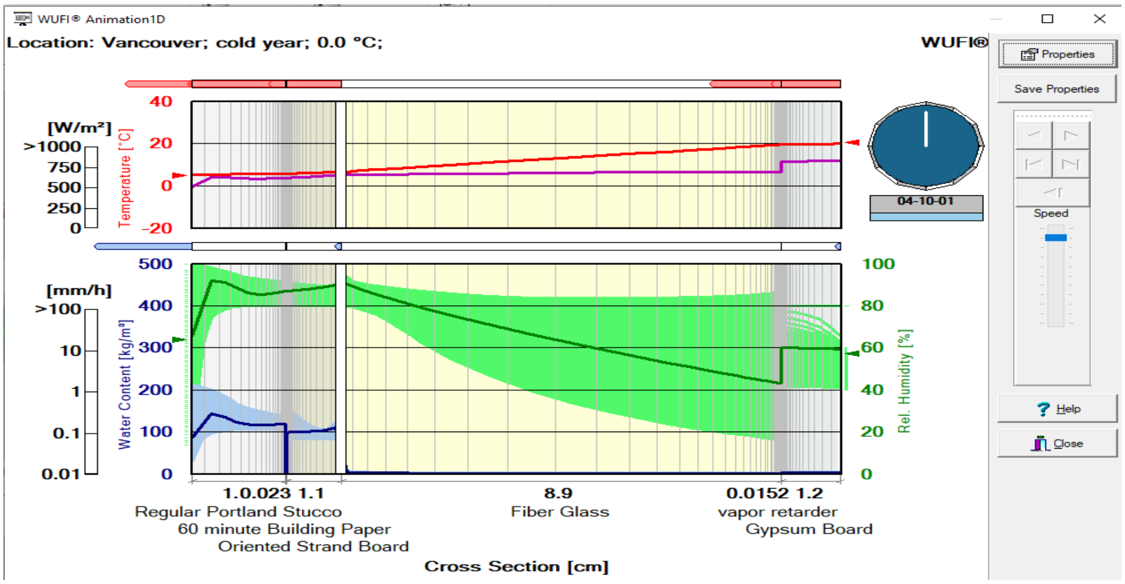


Figure 18: Wall construction of House 2 details


WUFI® Animation1D

Location: Vancouver; cold year; 0.0 °C;

Figure 19: WUFI output (Water contents, Temperature, RH) for Vancouver

The study showed that the substantial moisture content within the wall assembly can be attributed to the considerable temperature difference between the indoor and outdoor environments, leading to condensation and moisture accumulation. As Vancouver in winter is monsoon weather, therefore have chance to be moisture failure.

5.2 Part 2 – Parametric Analysis:

The Ministry of Natural Resources is leading Deep Retrofits to lower greenhouse gas emissions. Reducing emissions from existing buildings is essential to achieve British Columbia’s climate action targets. In this regard, the BC Government launched the Deep Energy Retrofit Pilot Program, which aims to enhance the building envelopes and mechanical systems of multi-unit residential buildings throughout the province. The objective of this pilot is to cut their energy consumption and related greenhouse gas emissions by at least 50 percent [38].

This study analysis for renovating building enclosures and enhancing mechanical systems to improve energy performance. First, provides an overview of the current thermal performance of the building enclosure elements, followed by recommendations for upgraded thermal performance by replacing the natural gas boiler/furnace with a heat pump. The upgrades are designed to enhance comfort, reduce energy costs, and qualify for Canada’s Greener Homes Grant. Based on Natural Resources Canada (HOT2000) guidelines, the areas for improvement through renovation have been identified including Air Seal, Main Walls, Ceilings, Exposed Floors, Foundation, Windows, Doors, HVAC systems etc.

House-1 is 4 years old, while House-2 is 15 years old. The researcher conducted several parametric analyses for House-2, exploring the impact of upgrading the wall structure from 2x4 to 2x6 and 2x8 and replacing the gas boiler with a heat pump. In contrast, House-1 focused solely on replacing the gas boiler with a heat pump. Finally, the energy savings from these changes were compared.

Table 7: Percentage Annual Heat Loss by Components (House -1):

Building-1 Parameters Summary:	
Component	% Annual Heat Loss
ZONE 1: Above Grade	
Ceiling	5.03
Main Walls	22.15
Windows	20.47
Doors	6.42
Exposed floors	1.89
Total Above Grade	**56.05**
ZONE 2: Basement	
Walls above grade	9.83
Windows	5.36
Doors	2.03
Below grade foundation	6.39
Total Basement	**24.40**
Air Leakage and Mechanical Ventilation	**19.55**
	100%

Table 8: Percentage Annual Heat Loss by Components (House -2):

Building-2 Parameters Summary:	
Component	% Annual Heat Loss
ZONE 1: Above Grade	
Ceiling	2.91
Main Walls	30.07
Windows	12.46
Doors	2.77
Exposed floors	0.44
Total Above Grade	**48.66**
ZONE 2: Basement	
Walls above grade	1.96
Windows	1.91
Doors	0.44
Below grade foundation	5.44
Pony Wall	3.18
Basement Floor Header	0.14
Total Basement	**12.93**
ZONE 3: Crawl Space Foundation	
Crawl space wall area	4.08
Air	0.39
Foundation	0.84
Total Crawl Space	**5.32**
Air Leakage and Mechanical Ventilation	**33.09**
	100%

Based on the summary tables 7 and 8, the greatest heat loss occurs through the walls, windows, air leakage, and mechanical ventilation.

Since House-1 is only 4 years old and was constructed according to the current building code, a parametric analysis has been conducted focusing on two aspects: 1) switching from a natural gas boiler to a heat pump, and 2) considering the building's orientation.

For House-2, the analysis also covers two aspects: 1) switching from a natural gas boiler to a heat pump, and 2) upgrading the wall structure from 2x4 to 2x6 to 2x8.

Below is the analysis for replacing the gas boiler with a heat pump for both houses:

5.2.1 Natural gas boiler to heat pump:

The following two Tables are based on the average price of a Gas bill and Electricity bill:

Table 9: Natural Gas Bill (Fortis BC)

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
Month, 2023	Billed GJ	Basic charge	Delivery charges	Storage and transport	Commodity charges	GST	Clean energy levy	Carbon tax	Total $	$/GJ
	9.33	12.81	56.37	8.85	35.95	7.10	0.46	28.02 (3.01$/GJ)	149	15.97
April, 2024								37.19 (3.99$/GJ)	158	16.95

Source: Fortis BC Gas Bill ((Homeowner)

Table 10: Electricity Bill (BC Hydro)

1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Month, 2023	KWh Usage	Basic Charge	Usage Charge	Levies	GST	Total $	$/KWh
	776	12.77	74.59	3.79	4.5	95.08	0.1225

Source: BC Hydro Electric Bill (Homeowner)

Table 11: Energy Rating & CO2 production: Gas Boiler (House-1)

House-1 Heating by Gas Boiler	**Energy Consumption GJ/a**	**Cost, $**	**Emissions Factor**	**Kg CO2e**
Electricity	34.89	1187.23	3.0	104.67
Natural Gas	43.88	743.77	51.0	2237.88
Total	78.77	1931		2342.55

Source (Emission Factor): [38]

Table 12: Energy Rating & CO2 production: Air Source Heat Pump (House-1)

House-1 Heating by Heat Pump	Energy Consumption GJ/a	Cost, $	Emissions Factor	Kg CO2e
Electricity	43.6	1483.61	3.0	130.8
Natural Gas	24.5	415.28	51.0	1249.5
Total	68.1	1898.89		1380.3

Source (Emission Factor): [38]

Table 13: Annual Savings in Energy, CO2 Emissions, and Cost from Switching Gas Boiler to Heat Pump (House-1)

House-1	Rating, GJ/a	Energy Save	CO2 Save	CAD Save/a
Gas Boiler	78.77	10.67 GJ (13.55%)	44.1% (1488 Kg CO2e)	$32
Heat Pump	68.1			

According to Table 13, replacing the natural gas boiler with a heat pump in House-1 could result in annual savings of $32 and a reduction of 962.25 kg of CO2e (41%). This change could significantly contribute to greenhouse gas reduction. It is important to note that both the Canadian Government and the BC Government offer heat pump rebate programs, providing financial support to homeowners. Additionally, the CO2 tax is expected to increase soon, further incentivizing the transition to more energy-efficient heating solutions.

Table 14: Energy Rating & CO2 production: Gas Boiler (House-2)

House-2 Heating by Gas Boiler	Energy Consumption, GJ/a	Cost, $	Emissions Factor	Kg CO2e
Electricity	31	1054.86	3.0	93
Natural Gas	108.4	1837.38	51.0	5528.4
Total	139.4	2892.24		5621.4

Source (Emission Factor): [39]

Table 15: Energy Rating & CO2 Production: Air Source Heat Pump (House-2)

House-2 Heating by Heat Pump	Energy Consumption GJ/a	Cost, $	Emissions Factor	Kg CO2e
Electricity	69.4	2361.53	3.0	208.2
Natural Gas	22.9	388.16	51.0	1167.9
Total	92.3	2749.69		1376.1

Source (Emission Factor): [39]

Table 16: Annual Savings in Energy, CO2 Emissions, and Cost from Switching Gas Boiler to Heat Pump (House-2)

House-2	Rating, GJ/a	Energy Save	CO2 Save	CAD Save/a
Gas Boiler	139.4	47.1 GJ (33.79 %)	75.52 % (4245.3 Kg CO2e)	$ 272.51
Heat Pump	92.3			

Analysis of two Vancouver homes revealed that switching from a furnace or boiler to an Air Source Heat Pump (ASHP) is the most effective way to reduce energy consumption and greenhouse gas emissions. This option is favored because of the energy savings and the rebates offered by the BC government for heat pumps. The ASHP system is also more sustainable and efficient compared to traditional heating methods and proves to be more cost-effective over time.

5.2.2 Stud Wall 2x4 @16 O.C to 2x8 @24 O.C

Table 17: Energy savings due to changing 2x4 stud wall to 2x8 wall

Wall Stud Size	R-Value	Energy Rating	Energy Save from 2x4 to 2x8
2x4	14	139	
2x6	22	130	17 GJ/a (12.23 %)
2x8	28	122	

The table-17 shows the energy savings associated with changing wall stud sizes from 2x4 to 2x8, along with their respective R-Values and Energy Ratings. The Parametric analysis shows that increasing the stud size from 2x4 to 2x8 results in improved insulation (higher R-value), better energy efficiency (lower Energy Rating), and significant energy savings (17 GJ or 12.23% reduction).

5.2.3 Relationship between energy consumption and airtightness (ACH$_{50}$)

Air changes per hour at a pressure of 50 pascals (ACH$_{50}$) serve as a critical metric for assessing home quality. It is the only consistently and objectively measured parameter included in all home energy assessments.

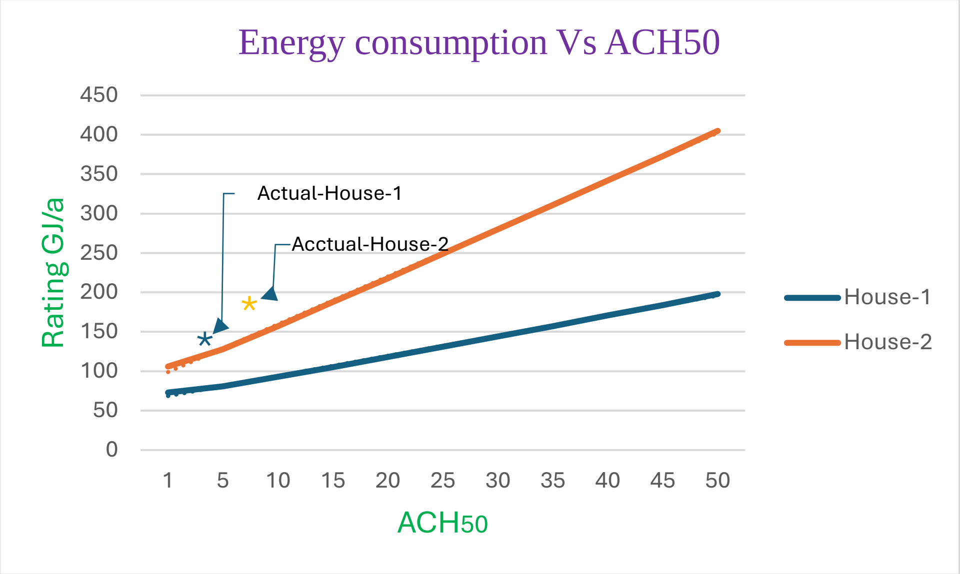


Figure 20: Relationship between energy consumption and airtightness (ACH$_{50}$)

Figure 20 illustrates the relationship between simulated energy consumption (GJ/a) and ACH$_{50}$ for two homes, House-1 and House-2. House-2 exhibits a steeper increase in energy consumption with rising ACH$_{50}$ compared to House-1, likely due to greater natural air infiltration. House-2 has a larger volume, and its above-grade highest ceiling height is higher than House-1, which explains this difference.

5.2.4 Change front direction from north to south

Table 18: Energy savings due to change in orientation (North to South)

House-1	**Direction-North (Original)**	**Direction-South**
Energy Rating (GJ)	78	74
Energy Saving	4 GJ/a (5.13%)	

Vancouver's climate is relatively mild, but it has wet winters. Table 18 shows that the south-facing front is more energy-efficient. This orientation allows for better solar heat gain in the winter, which can help reduce heating costs. Conversely, appropriate shading and ventilation are important to mitigate warmness during the summer months.

5.3 Impact of Climate Change on Building Performance

The weather data from the PCIC indicates an apparent trend where HDD is decreasing, while CDD is on the rise, as illustrated in Table 19. Given that HDD is diminishing in a country predominantly characterized by winter conditions, there arises a potential for a corresponding reduction in energy consumption during the colder months. This observation raises an important question: Is the decrease in HDD truly indicative of a potential reduction in overall energy consumption? This thesis examines this hypothesis to determine whether the observed changes in HDD and CDD indeed translate into measurable energy savings, considering various factors that may influence the overall energy demand.

Table 19: Heating Degree Days (HDD) / Cooling Degree Days (CDD) of Vancouver, BC

Vancouver	**2020**	**2050**	**2080**
	Average	Average	Average
HDD	2542	2170	1686
CDD	86	233	472

Source: Pacific Climate Impacts Consortium (PCIC), UVic, 2024 [40]

Researchers utilize a blend of climate models (simulations) alongside observations from land, air, sea, and space to study the changing patterns of extreme weather events over time. NASA reports that as Earth's climate continues to change, these extreme weather events are becoming increasingly frequent and severe on a global scale [41].

Variations in weather patterns over time can have a profound impact on energy consumption. When temperatures in recent years have deviated from the historical averages, either becoming significantly colder or hotter, this often leads to increased energy usage beyond what was initially predicted in energy models. This observation is consistent with existing research. For example, in my analysis of multiple cities in British Columbia, I utilized HDD data, as well as minimum and maximum temperatures (refer to Table 20), and employed the HOT2000 software to simulate and calculate energy ratings.

Typically, an increase in HDD correlates with higher energy consumption. However, a more nuanced analysis, which considers both the minimum temperature in January and the maximum temperature in July, reveals that energy consumption escalates when there are greater fluctuations between these temperature extremes. The results showed that, although HDD increased across the board, the three highest energy consumption figures were associated with the greatest temperature differences. Conversely, lower energy consumption was observed in scenarios with smaller temperature fluctuations. This pattern is attributable to the combined effect of increased heating and cooling demands. Consequently, it can be inferred that if no proactive measures are implemented, energy consumption is likely to rise because of climate change. To address this challenge, it is imperative to construct more climate-resilient homes that can better withstand these changing conditions.

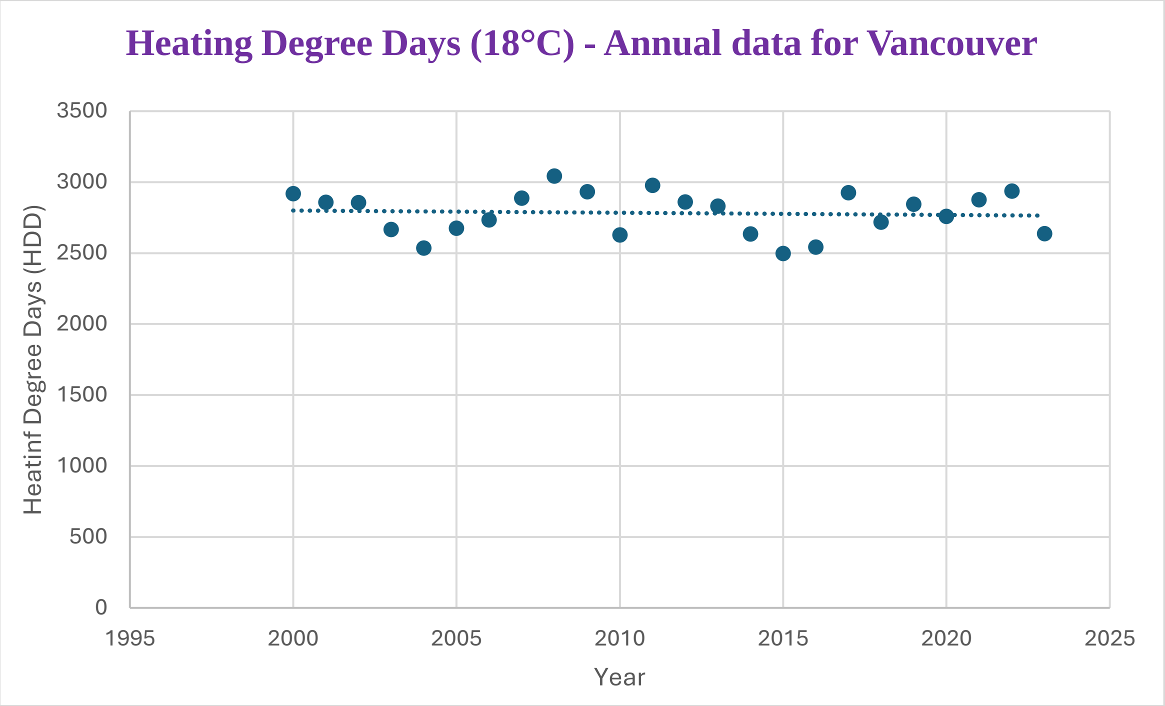


Figure 21: Heating degree days for Vancouver, BC [42].

Table 20: Energy Consumption vs HDD and Standard Deviation of Temperature

City	HDD	Min Temp 2.5%	Max Temp 2.5%	Energy Rating	STDV Temp
Howe	2627	-2	24.1	58.8	13.05
White Rock	2644	-4	24.5	58.2	14.25
Victoria Univ	2674	-1.1	26.6	57.7	13.85
Abbotsford	2760	-5.9	29	60.5	**17.45**
Vic Gonzel	2763	-1.3	22.8	57.3	**12.05**
Aggassiz	2764	-7.6	29.7	60.9	**18.65**
Vancouver	2768	-4.4	24.9	59.2	14.65
W. Vancouver	2823	-4.2	27.1	60.2	15.65
Pitt Meadow	2851	-6.3	29.5	61.2	**17.90**
Victoria Int	2858	-2.9	26.2	59.2	14.55
Esquimalt	2900	-1.2	21.5	57.5	**11.35**
Estevan	3054	-1.3	18.5	57.5	**9.90**

Data source: HOT2000 Energy Model Software, NRCan [43].

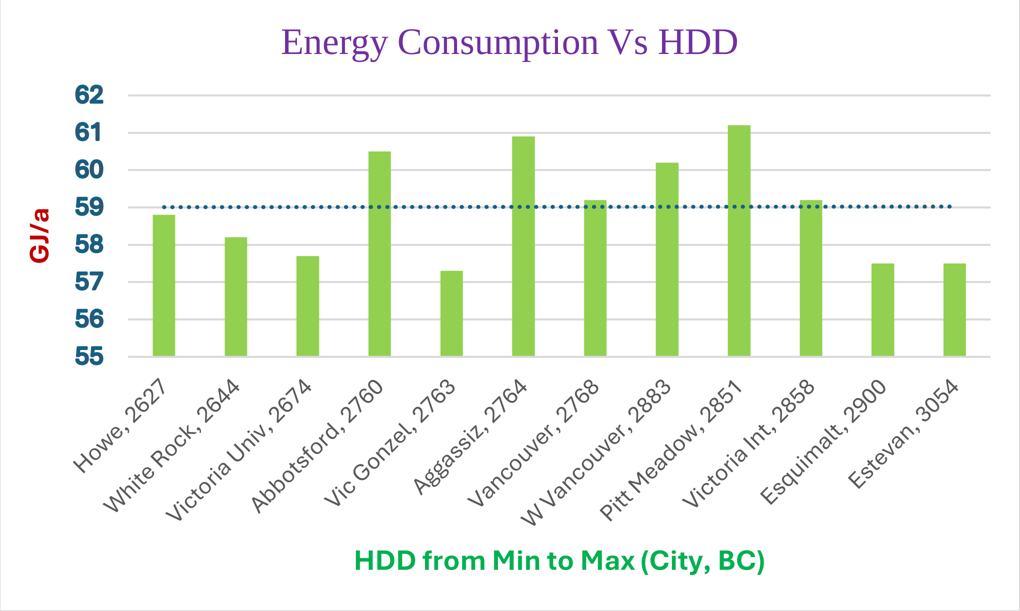


Figure 22: Energy consumption vs HDD

Table 20 and Graph 22 collectively illustrate that energy consumption is influenced not only by HDD but also by temperature fluctuations, as evidenced by the data across various cities in British Columbia. The table highlights the relationship between HDD, temperature extremes, and energy consumption for space heating and cooling. Cities with greater temperature fluctuations tend to exhibit higher energy consumption, even when HDD levels are similar. For example, Abbotsford and Pitt Meadows, with significant temperature differences, also show elevated energy consumption for both heating and cooling. HDD along with other factors, such as temperature fluctuation, play a crucial role in determining overall energy use. This finding is particularly relevant when considering future climate change phenomena, as it suggests that merely analyzing HDD may not be sufficient to predict energy consumption patterns accurately in North America, it also depends on temperature fluctuation. For doing this analysis and calculating the energy rating, House-1 is selected. A heat pump is used for heating, and electricity is used for domestic hot water (DHW).

As climate change is expected to intensify temperature extremes and fluctuations, energy demand for combined heating and cooling will likely increase. Therefore, future studies and energy models must consider the impact of temperature variability alongside HDD to more accurately forecast energy consumption in a changing climate. This thesis explores these dynamics further, aiming to provide insights that can guide the development of more resilient and energy-efficient building designs capable of withstanding the challenges posed by future climate conditions.

6. Conclusion and Recommendation

6.1 Conclusion

Energy efficiency is vital in the pursuit of building decarbonization, and the construction of high-performance buildings and efficient energy sources is crucial to this endeavor. This research, which rigorously investigates the energy performance gap between modeled and actual energy consumption, underscores the critical importance of accurate energy modeling. By conducting a detailed examination of two detached houses in Vancouver, BC, using HOT2000 software, the study uncovered that actual energy consumption exceeded predicted values by a significant margin of 40 to 45%. These discrepancies are attributed to inherent limitations in the energy modeling software, inconsistencies between the modeled parameters and the actual building conditions, as well as the presence of unaccounted-for additional energy loads. Furthermore, the research projects an increase in energy consumption under future climate scenarios.

A comprehensive parametric analysis was conducted to advance energy efficiency, focusing on optimizing wall construction and evaluating different energy sources. The analysis revealed that transitioning from a Gas Boiler/Furnace to an ASHP can reduce energy consumption by 15 to 35%, while simultaneously cutting CO2 emissions by 44 to 76 %. Moreover, enhancing the wall resistance from R-14 to R-28 led to a reduction in space heating energy by 12 to 15%. The energy modeling further demonstrated that houses with a South-facing orientation are more energy-efficient than those with a North-facing orientation in Vancouver.

These findings underscore the significant potential for both design improvements and changes in energy sources to substantially lower energy consumption and emissions in residential buildings. Climate change is expected to intensify extreme temperatures and fluctuations, which will likely lead to an increase in the demand for combined heating and cooling.

The research suggests that future efforts should focus on refining energy modeling tools to better reflect real-world conditions, as well as prioritizing the adoption of energy-efficient technologies and materials in building design. Such strategies are essential to achieving meaningful reductions in energy use and carbon emissions, particularly considering the challenges posed by climate change.

6.2 Recommendations

Based on the insights gained from the literature review and the results of this thesis, it is evident that there exists a significant gap between energy simulation results and actual energy consumption data in residential buildings. To address this, it is recommended that the first three years of actual energy consumption data be systematically collected and compared with the design-estimated data. If a substantial discrepancy is observed—specifically, if the difference exceeds 100 %—a thorough investigation should be conducted to identify the underlying causes. Understanding these discrepancies is crucial for refining energy modeling techniques and improving their accuracy. To improve modeling accuracy and reduce the energy performance gap, it is recommended that CDD be incorporated into HOT2000, similar to HDD.

Furthermore, considering the findings, it is imperative to advocate for the replacement of all gas boilers and furnaces with heat pumps, supported by government rebate programs. This transition is needed to align with broader environmental goals by significantly reducing energy consumption and carbon emissions.

Finally, considering the ongoing challenges posed by climate change, new construction needs to prioritize the use of green materials and a higher-resistance building envelope that can contribute to lower energy use and reduced embodied carbon/ greenhouse gas emissions. These strategies will ensure that residential buildings are better equipped to meet future energy efficiency standards while minimizing their environmental impact.

7. Limitation of the Project

One of the key limitations of this project lies in the reliance on the HOT2000 software, which requires specific input data of Blower Door Test results to accurately simulate a building's energy performance. In this study, the Blower Door Test results were not available; therefore, the air change rate (ACR) at 50 Pa values are based on standard practices outlined in the Vancouver Building By-Law (VBBL).

Additionally, the power and efficiency of some equipment were set to the standard values as stipulated by the same by-law. While these assumptions align with local regulations, they may not perfectly reflect the actual conditions of the buildings under study. HOT2000's energy performance results may be inaccuracy due to these approximations, which illustrates the need for precise input data to improve the accuracy of energy modeling and its alignment with real-world outcomes in the future.

In this study, energy consumption was also compared between the model and actual data every month. The model output is based on calendar months, but the energy bills vary, covering periods from 28 to 31 days. To account for this, the consumption was adjusted according to the number of days in each month.

8. Future Work

Based on the findings of this thesis, future research should focus on more precise input data, such as actual Blower Door Test results, and develop more sophisticated algorithms that account for occupant behavior and unanticipated energy loads. Additionally, future studies should expand the scope of analysis to include a broader range of building types and geographic locations, particularly those with diverse climate conditions. This would allow for a more comprehensive understanding of how climate variability influences energy consumption and the performance of different energy efficiency measures.

Moreover, considering the projected impacts of climate change, it will be essential to explore adaptive building designs that can respond effectively to extreme weather conditions. This includes investigating the potential of emerging technologies and materials that could further reduce energy consumption and greenhouse gas emissions in residential buildings.

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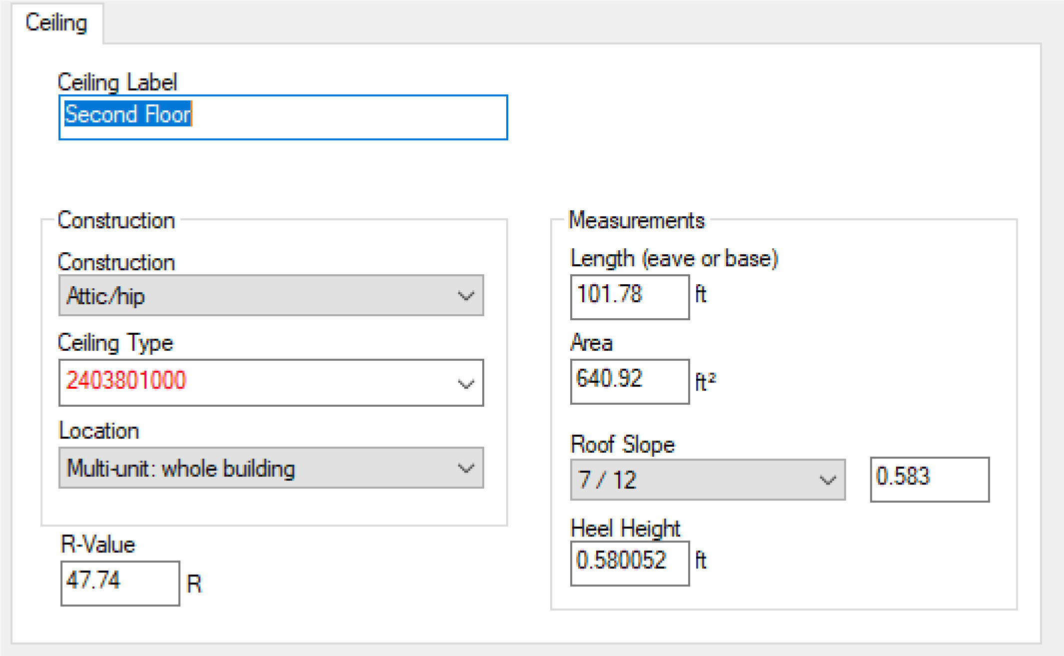
Appendix 1.

HOT2000 Model:



Ceiling Label: Second Floor

Construction

Construction: Attic/hip

Ceiling Type: 2403801000

Location: Multi-unit: whole building

R-Value: 47.74 R

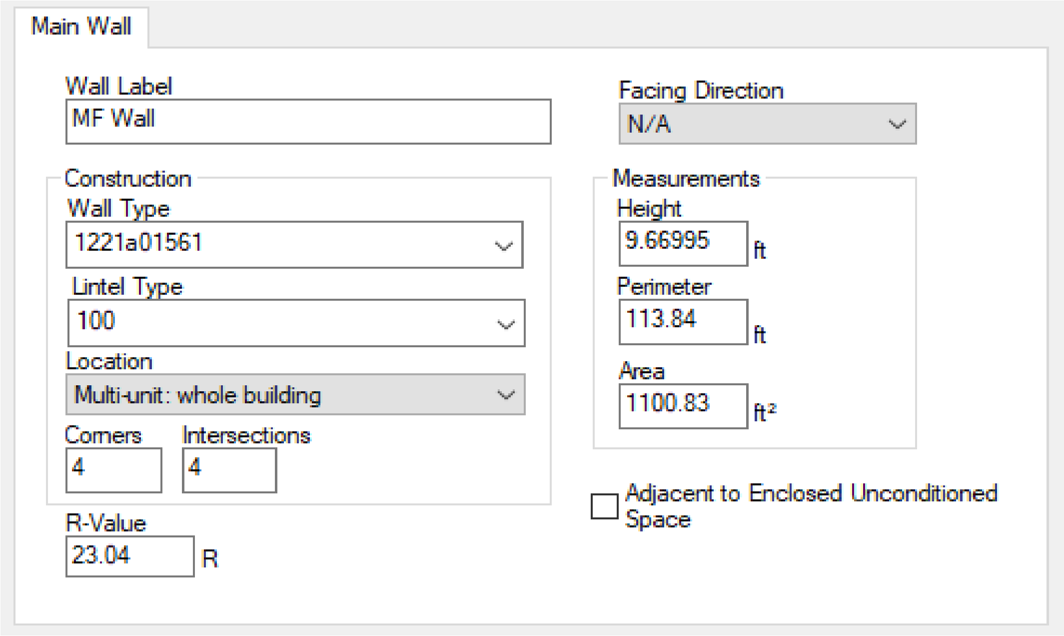
Measurements

Length (eave or base): 101.78 ft

Area: 640.92 ft²

Roof Slope: 7 / 12 0.583

Heel Height: 0.580052 ft



Wall Label: MF Wall

Facing Direction: N/A

Construction

Wall Type: 1221a01561

Lintel Type: 100

Location: Multi-unit: whole building

Corners: 4

Intersections: 4

R-Value: 23.04 R

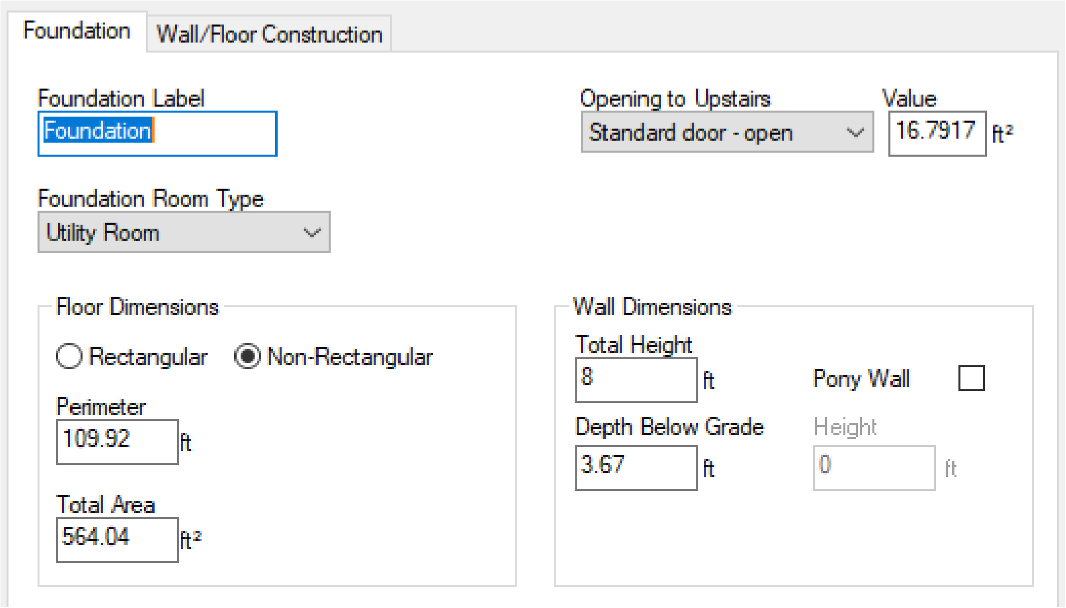
Measurements

Height: 9.66995 ft

Perimeter: 113.84 ft

Area: 1100.83 ft²

☐ Adjacent to Enclosed Unconditioned Space



Foundation Label: Foundation

Opening to Upstairs: Standard door - open

Value: 16.7917 ft²

Foundation Room Type: Utility Room

Floor Dimensions

○ Rectangular ● Non-Rectangular

Perimeter: 109.92 ft

Total Area: 564.04 ft²

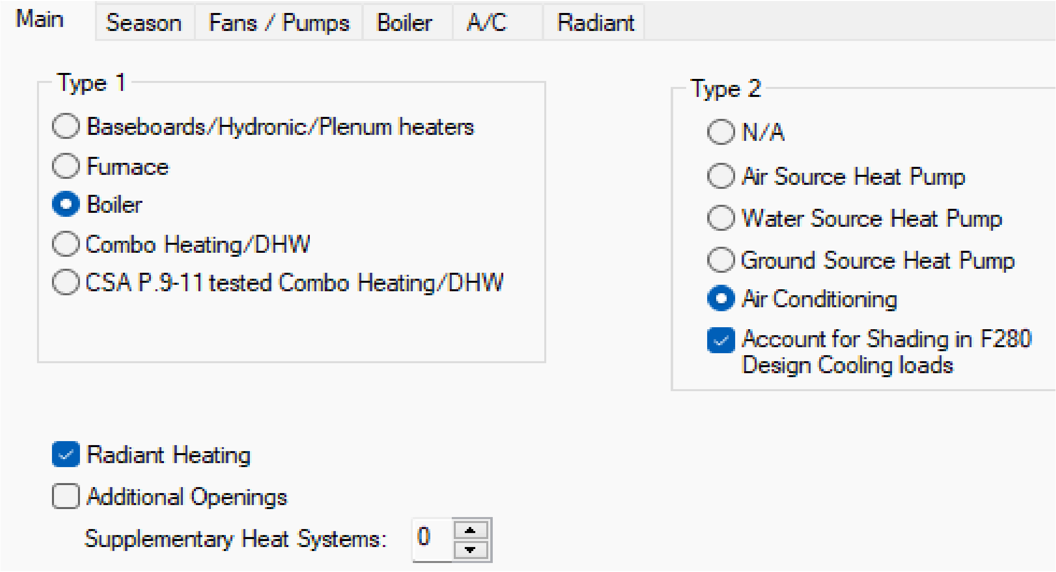
Wall Dimensions

Total Height: 8 ft

Pony Wall ☐

Depth Below Grade: 3.67 ft

Height: 0 ft



Type 1

○ Baseboards/Hydronic/Plenum heaters
○ Furnace
● Boiler
○ Combo Heating/DHW
○ CSA P.9-11 tested Combo Heating/DHW

Type 2

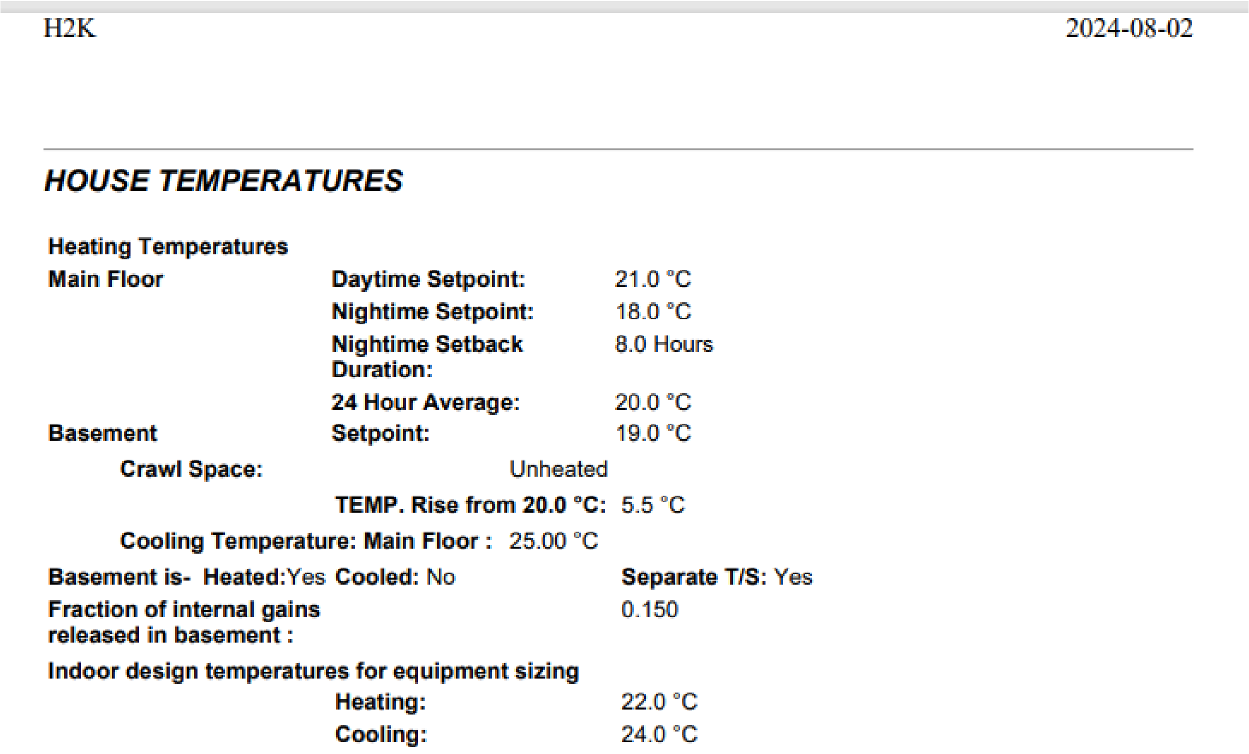
○ N/A
○ Air Source Heat Pump
○ Water Source Heat Pump
○ Ground Source Heat Pump
● Air Conditioning
☑ Account for Shading in F280 Design Cooling loads

☑ Radiant Heating
☐ Additional Openings

Supplementary Heat Systems: 0

Appendix 2.

Design Temperature



H2K 2024-08-02

HOUSE TEMPERATURES

Heating Temperatures

Main Floor	**Daytime Setpoint:**	21.0 °C
	Nightime Setpoint:	18.0 °C
	Nightime Setback Duration:	8.0 Hours
	24 Hour Average:	20.0 °C
Basement	**Setpoint:**	19.0 °C

Crawl Space: Unheated

TEMP. Rise from 20.0 °C: 5.5 °C

Cooling Temperature: Main Floor : 25.00 °C

Basement is- Heated: Yes **Cooled:** No **Separate T/S:** Yes

Fraction of internal gains released in basement : 0.150

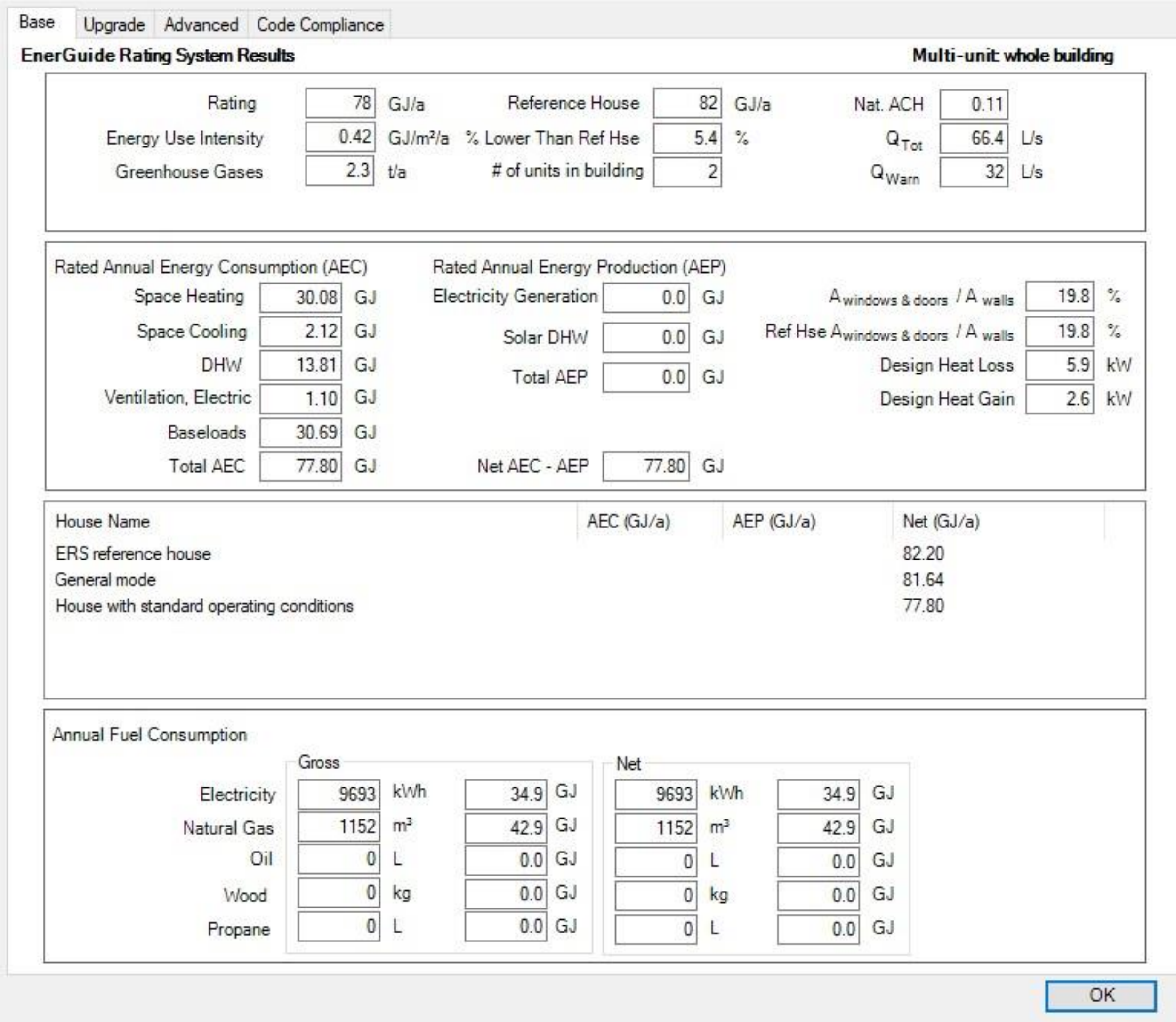
Indoor design temperatures for equipment sizing

Heating: 22.0 °C

Cooling: 24.0 °C

Appendix 3.

Energuide Rating System (House-1)



EnerGuide Rating System Results **Multi-unit: whole building**

Rating	78	GJ/a	Reference House	82	GJ/a	Nat. ACH	0.11	
Energy Use Intensity	0.42	GJ/m^2/a	% Lower Than Ref Hse	5.4	%	Q_{Tot}	66.4	L/s
Greenhouse Gases	2.3	t/a	# of units in building	2		Q_{Warn}	32	L/s

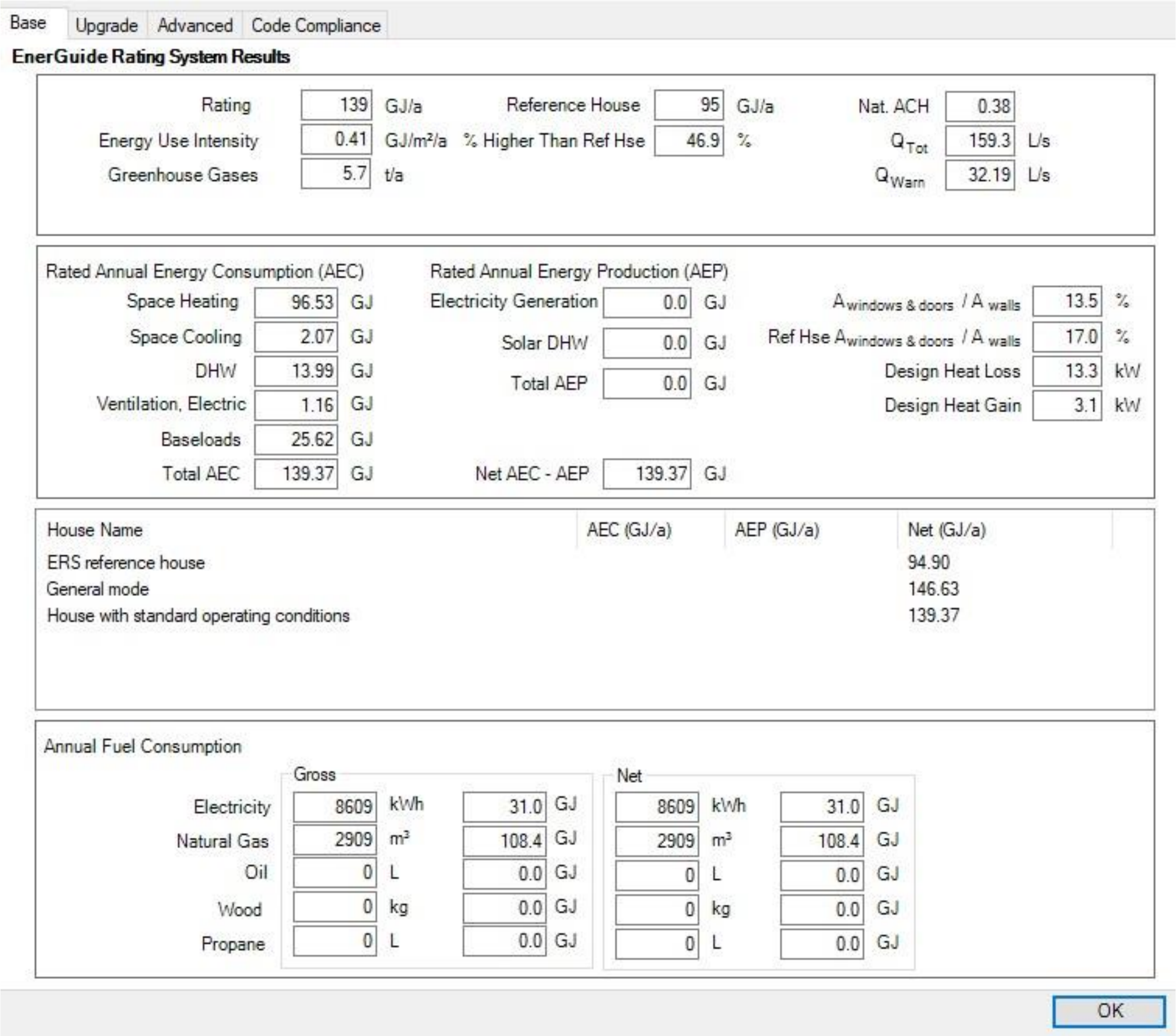
Rated Annual Energy Consumption (AEC)			Rated Annual Energy Production (AEP)					
Space Heating	30.08	GJ	Electricity Generation	0.0	GJ	$A_{windows \& doors} / A_{walls}$	19.8	%
Space Cooling	2.12	GJ	Solar DHW	0.0	GJ	Ref Hse $A_{windows \& doors} / A_{walls}$	19.8	%
DHW	13.81	GJ	Total AEP	0.0	GJ	Design Heat Loss	5.9	kW
Ventilation, Electric	1.10	GJ				Design Heat Gain	2.6	kW
Baseloads	30.69	GJ						
Total AEC	77.80	GJ	Net AEC - AEP	77.80	GJ			

House Name	AEC (GJ/a)	AEP (GJ/a)	Net (GJ/a)
ERS reference house			82.20
General mode			81.64
House with standard operating conditions			77.80

Annual Fuel Consumption

	Gross				Net			
Electricity	9693	kWh	34.9	GJ	9693	kWh	34.9	GJ
Natural Gas	1152	m^3	42.9	GJ	1152	m^3	42.9	GJ
Oil	0	L	0.0	GJ	0	L	0.0	GJ
Wood	0	kg	0.0	GJ	0	kg	0.0	GJ
Propane	0	L	0.0	GJ	0	L	0.0	GJ

Energuide Rating System (House-2)



EnerGuide Rating System Results

Rating	139	GJ/a	Reference House	95	GJ/a	Nat. ACH	0.38	
Energy Use Intensity	0.41	GJ/m²/a	% Higher Than Ref Hse	46.9	%	Q_{Tot}	159.3	L/s
Greenhouse Gases	5.7	t/a				Q_{Warn}	32.19	L/s

Rated Annual Energy Consumption (AEC)			Rated Annual Energy Production (AEP)					
Space Heating	96.53	GJ	Electricity Generation	0.0	GJ	$A_{windows \& doors} / A_{walls}$	13.5	%
Space Cooling	2.07	GJ	Solar DHW	0.0	GJ	Ref Hse $A_{windows \& doors} / A_{walls}$	17.0	%
DHW	13.99	GJ	Total AEP	0.0	GJ	Design Heat Loss	13.3	kW
Ventilation, Electric	1.16	GJ				Design Heat Gain	3.1	kW
Baseloads	25.62	GJ						
Total AEC	139.37	GJ	Net AEC - AEP	139.37	GJ			

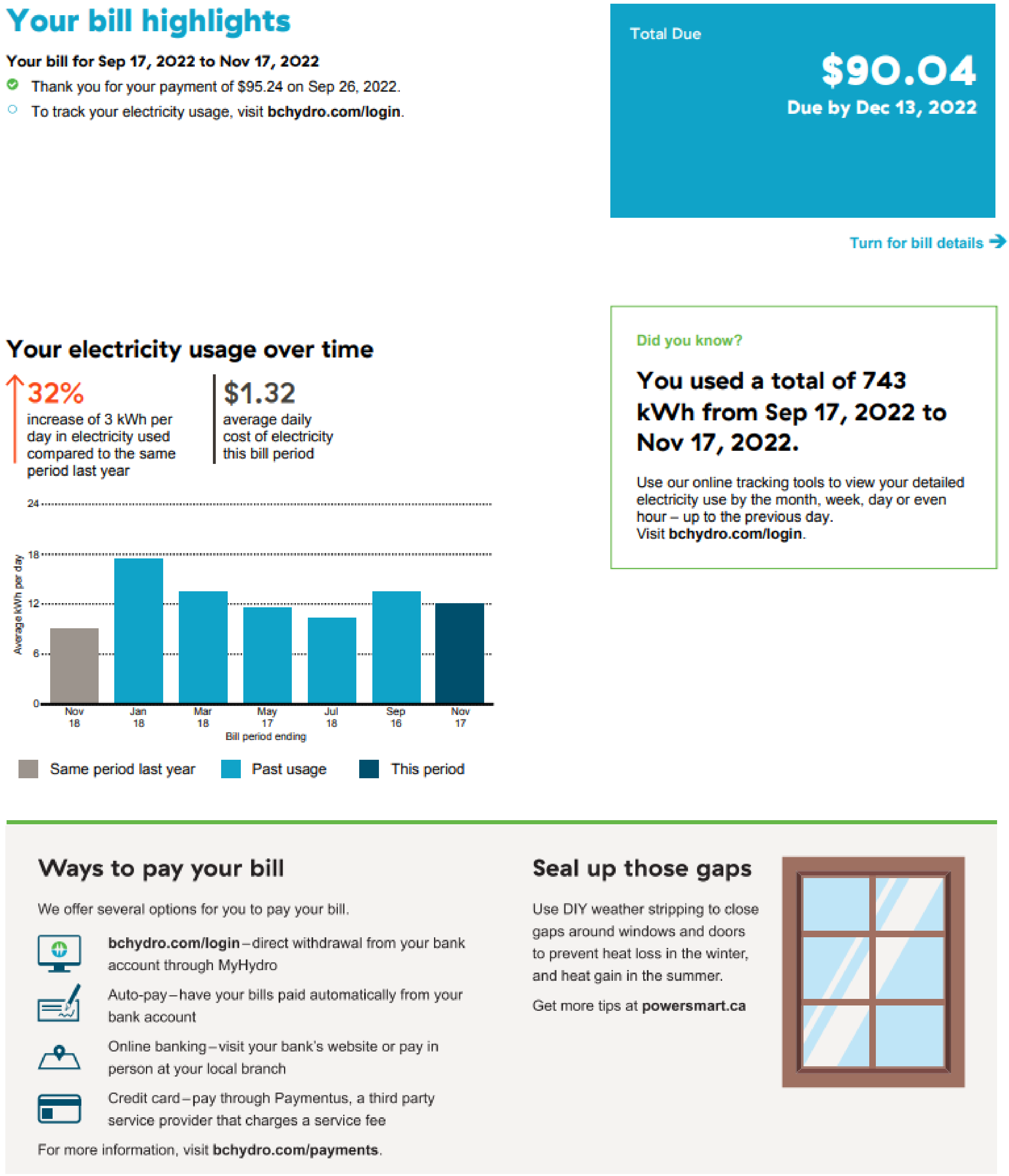
House Name	AEC (GJ/a)	AEP (GJ/a)	Net (GJ/a)
ERS reference house			94.90
General mode			146.63
House with standard operating conditions			139.37

Annual Fuel Consumption

	Gross				Net			
Electricity	8609	kWh	31.0	GJ	8609	kWh	31.0	GJ
Natural Gas	2909	m³	108.4	GJ	2909	m³	108.4	GJ
Oil	0	L	0.0	GJ	0	L	0.0	GJ
Wood	0	kg	0.0	GJ	0	kg	0.0	GJ
Propane	0	L	0.0	GJ	0	L	0.0	GJ

Appendix 4.

Sample: Hydro Bill



Your bill highlights

Your bill for Sep 17, 2022 to Nov 17, 2022

- ✓ Thank you for your payment of $95.24 on Sep 26, 2022.
- ○ To track your electricity usage, visit **bchydro.com/login**.

Total Due

$90.04

Due by Dec 13, 2022

Turn for bill details →

Your electricity usage over time

↑ **32%** increase of 3 kWh per day in electricity used compared to the same period last year

$1.32 average daily cost of electricity this bill period

▨ Same period last year ■ Past usage ■ This period

Did you know?

You used a total of 743 kWh from Sep 17, 2022 to Nov 17, 2022.

Use our online tracking tools to view your detailed electricity use by the month, week, day or even hour – up to the previous day. Visit **bchydro.com/login**.

Ways to pay your bill

We offer several options for you to pay your bill.

- **bchydro.com/login** – direct withdrawal from your bank account through MyHydro
- Auto-pay – have your bills paid automatically from your bank account
- Online banking – visit your bank's website or pay in person at your local branch
- Credit card – pay through Paymentus, a third party service provider that charges a service fee

For more information, visit **bchydro.com/payments**.

Seal up those gaps

Use DIY weather stripping to close gaps around windows and doors to prevent heat loss in the winter, and heat gain in the summer.

Get more tips at **powersmart.ca**

Appendix 5.

Bill: Fortis BC

No. of days	Billed GJ	Basic charge	Delivery charges	Storage & transport	Commodity charges	GST	Clean energy levy	Carbon tax	Amount
31	8.9	13.07	59.7	2.13	19.85	6.51	0.38	35.47	137.11
29	10	12.23	67.08	2.39	22.3	7.12	0.42	38.37	149.91
31	13.8	13.07	92.57	3.3	30.77	9.22	0.56	44.69	194.18
29	12.5	12.23	83.85	2.99	27.88	8.37	0.51	40.48	176.31
30	16.3	12.65	108.1	5.32	36.35	10.76	0.65	52.79	226.62
33	15.9	13.91	94.33	18.03	35.46	10.66	0.65	51.49	224.53
28	11.2	11.8	66.45	12.7	24.98	7.61	0.46	36.27	160.27
30	7.4	12.65	43.9	8.39	17.34	5.31	0.33	23.96	111.88
32	3	13.49	17.8	3.4	9.48	2.69	0.18	9.72	56.76
31	3.3	13.07	19.58	3.74	10.42	2.88	0.19	10.69	60.57
32	4.5	13.49	26.7	5.1	14.82	3.73	0.24	14.57	78.65
29	5	12.23	29.67	5.67	20.8	4.23	0.27	16.19	89.06
31	6.2	13.07	36.78	7.03	25.79	5.14	0.33	20.08	108.22
31	12.3	13.07	72.98	13.95	54.05	9.6	0.62	37.86	202.13
29	13.1	12.23	77.72	14.86	67.58	10.3	0.69	33.52	216.9
29	13.8	12.23	81.88	15.65	71.19	10.81	0.72	35.31	227.79
29	13.1	12.23	77.03	15.23	68.85	10.34	0.69	33.52	217.89
32	18.2	13.49	100.57	24.59	107.51	14.64	0.98	46.57	308.35
30	13.7	12.65	75.71	18.51	80.93	11.14	0.75	35.06	234.75
30	5.2	12.65	28.74	7.03	30.72	4.62	0.32	13.31	97.39
32	2.1	13.49	11.6	2.84	12.4	2.29	0.16	5.37	48.15
30	2.1	12.65	11.6	2.84	12.4	2.24	0.16	5.37	47.26
32	4.6	13.49	25.42	6.21	25.77	4.13	0.28	11.77	87.07
29	7.8	12.23	43.1	10.54	35.12	6.05	0.4	19.96	127.4