Design, Simulation and Analysis of a Passive House and its Renewable Energy System for Newfoundland

by

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Abstract

A large amount of energy produced is directly consumed in the form of electricity. This need for energy is continuously growing and leading to new ways to make efficient use of it. When we talk about using energy efficiently, the idea of a passive house system kicks in, which essentially focuses on reducing energy use for space heating or cooling in a house. The main idea is to reduce the energy consumption of the house as well as reducing its impact on the environment when the occupants are using the house. The first phase of the research shows the dynamic modelling of an energy-efficient home that works on the principles and guidelines of a passive house using the EnergyPlus simulation engine. A renewable energy system has been developed for the passive house, which is located at Flat Rock, St John's, NL Canada. The overall design has been simulated using MATLAB/Simulink environment packages. The dynamic simulation indicates that the system gives promising results. In the second phase, a detailed simulation of a renewable energy system using various software and efficient energy management techniques are presented. Finally, for experimental validation, an open-source IoT platform named Ubidots smart home automation is used as Human Machine Interface (HMI) server, an ESP32 Thing microcontroller board as a Master Logic Controller (MLC) where all sensors and output devices such as power meter, relays are connected for data acquisition and control.

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List of Abbreviations and Symbols

ASHRAE	The American Society of Heating, Refrigerating and Air-Conditioning Engineers
SHGC	Solar Heat Gain Coefficient
WUFI	Wärme Und Feuchte Instationär (Software)
HVAC	Heating Ventilation and Air Conditioning
iPHA	International Passive House Association
kWh/ m^2/y	Killwatt Hour / Meter sq / Year
kWh/ m^2	Kilo Watt Hour / Meter sq
MVHR	Mechanical Ventilation with Heat Recovery
NZEM	Net Zero Energy Model
PHI	Passive House Institute
PHIUS	Passive House Institute United States
Wh	Watthour
SCADA	Supervisory Control and Data Acquisition
IoT	Internet of Things
HMI	Human Machine Interface
MTU	Master Terminal Unit
MLC	Master Logic Control
RTU	Remote Terminal Unit
FID	Field Instrumentation Device
PV	Photovoltaic
MQTT	Message Queuing Telemetry Transport
MPPT	Maximum Power Point Tracking
HOMER	Hybrid Optimization of Multiple Energy Resource

Chapter 1

Introduction and Literature Review

1.1 Background

Energy conservation and efficient energy houses have been the topic of discussion for decades. Researchers have made several attempts to build energy-efficient homes. Talking about Canada, one of the first known energy-efficient houses named Saskatchewan Conservation House, built in the early 70s, later became a pioneer of the modern passive house model [1]. All these efforts towards sustainability are being made to mitigate rapidly increasing climate change. Even climate emergencies have already been declared by countries like Canada, Portugal, Ireland, France, and by individual cities such as Paris, New York, Toronto, Vancouver, etc. Now, this has been the first time in history a huge collection of more than 11,000 scientists from 153 countries have declared climate emergency with a primary focus on pollution, greenhouse emission and global warming [2]. This climate change will put billions of people in danger and hundreds of millions at extreme risk from weather-related disasters. Overall, climate change poses a significant threat to individuals and the political stability of countries. The points mentioned above describe the main reason for this study. Furthermore, it is vital to ensure the correct balance between electricity supply and demand as an imbalance will damage the stability and quality (voltage and frequency) of the power supply.

1.1.1 Purpose

Considering the extreme need for a low carbon footprint, a transition to efficient housing that uses renewable energy sources can make a considerable contribution. An energy-efficient and sustainable house design on a wide scale can play an essential role in both developing and developed countries. From a climate change and energy consumption perspective, countries that are using large amounts of fossil-free energy in electricity production and eventually in the housing sector need to rethink policies on housing. Passive house design, coupled with the Net Zero Energy Model (NZEM), can save a tremendous amount of energy and reduce the carbon footprint. So, passive house and smart ways for energy management and conservation are the main focus of this research and will be discussed in detail.

1.1.2 Motivation

During the past couple of years, there has been an increasing trend to promote passive house design and the advantages of renewable energy solutions by Passive House Canada (PHC). Recently, PHC held its second annual conference [3] to spread awareness about sustainable solutions for energy management. Not only in Canada, but there has been an increasing number of passive houses built upon guidelines of passive houses and also certified. In 2018, it was recorded that there have been 171 certified passive houses in France, 24 in Italy, 19 in Spain and 2 in Greece [4]. The most notable number of passive house has been seen in Germany, where certified buildings have reached 441 [4]. Considering the notified trends and growing demands of alternative energy resources, a topic has been selected in which detailed analysis was performed to document the benefits of a passive house design. Most importantly, there has been the first passive house built in Newfoundland at Flat Rock in 2018. This study is dedicated to performing qualitative and quantitative analysis to record results for energy consumption and construction processes and finally proposing a sustainable solution to the current system being used for the house.

1.2 Passive House Overview

1.2.1 What is a Passive House?

The Passive House (Passivhaus) is defined as "a building designed to require minimal energy for comfort by having very good thermal insulation, excellent airtightness, and a ventilation system providing heating or cooling of the incoming air with mechanical ventilation with heat recovery (MVHR) of the warmer air" [5]. The passive house design guideline is an internationally recognized framework with protocols that help achieve a building that consumes nearly zero energy, not compromising high levels of indoor comfort for people living in it. This concept can be applied to any kind of building, construction system, or structure. In the last few decades, thousands of passive houses have been built across the globe. Most of these are present in Germany, the United States of America, the United Kingdom, Austria, and many other developed countries. There are many organizations founded to advance the research on the passive house system, and one of the biggest institutes is called the International Passive House Association (iPHA) [6]. It includes architects, planners, scientists, suppliers, manufacturers, contractors, property developers, and affiliation with other organizations to promote passive house standards and create a greater public understanding of its significance. Guidelines to create understanding in the following chapters are taken from the International Passive House Association[7], Passipedia [8], Passive House Institute PHI [9], Zero Energy and Passivhaus Institute for Research (ZEPHIR) [10] and other literature [11], [12] for sustainable house studies in different climate of around the globe.

1.2.2 Origin of Passive House Standards

These protocols were initially established in 1988 as a result of a research project of Dr. Wolfgang Feist and Prof. Bo Adamson [9]. In the early 1990s, Dr. W. Feist built the first passive house in Darmstadt, Germany, in a district named Kranichstein, which showed that it was possible to construct buildings with near-zero energy consumption [13]. The building has been continually monitored and has an energy consumption demand of $9kWh/m^2$ per year that stayed constant from 1990 until the present. There has been a lot of development in the past, and many developed countries have defined their own passive house building standards. Canadian Passive House Institute was also founded in 2013, which is a non-profit notional institute for passive house standards.

1.2.3 Criteria of Passive House

The main idea of a passive house design is that it requires so little energy than conventional heating and air conditioning systems become obsolete. The Passive House Institute (PHI) standard establishes performance criteria that involve thermophysical and technical characteristics for the building. In order to achieve a passive house design and an overall energy performance that make sure nearly zero consumption of energy while keeping a high level of indoor comfort, the following guidelines are provided by PHI for passive house design [13]:

- The energy required for space heating or cooling less than 15 kWh/ m^2/year";
- Maximizing passive solar gain through low emissive window glazing and very well insulated window frames with efficient design to maximize comfort and desired sunlight exposure;
- Well-insulated or super-insulated components that prevent thermal bridging and air leaks through the building envelope;
- The heat recovery and ventilation system to have controlled humidity, temperature, and quality of air;
- Airtightness of the building should be ≤ 0.6/h at pressure differential 50P;
- Focusing Energy Performance and using energy-efficient appliances that

demand ≤120 kWh/ m^2 per year for domestic heating or cooling, ventilation, auxiliary electric consumption such as lighting and other household appliances;

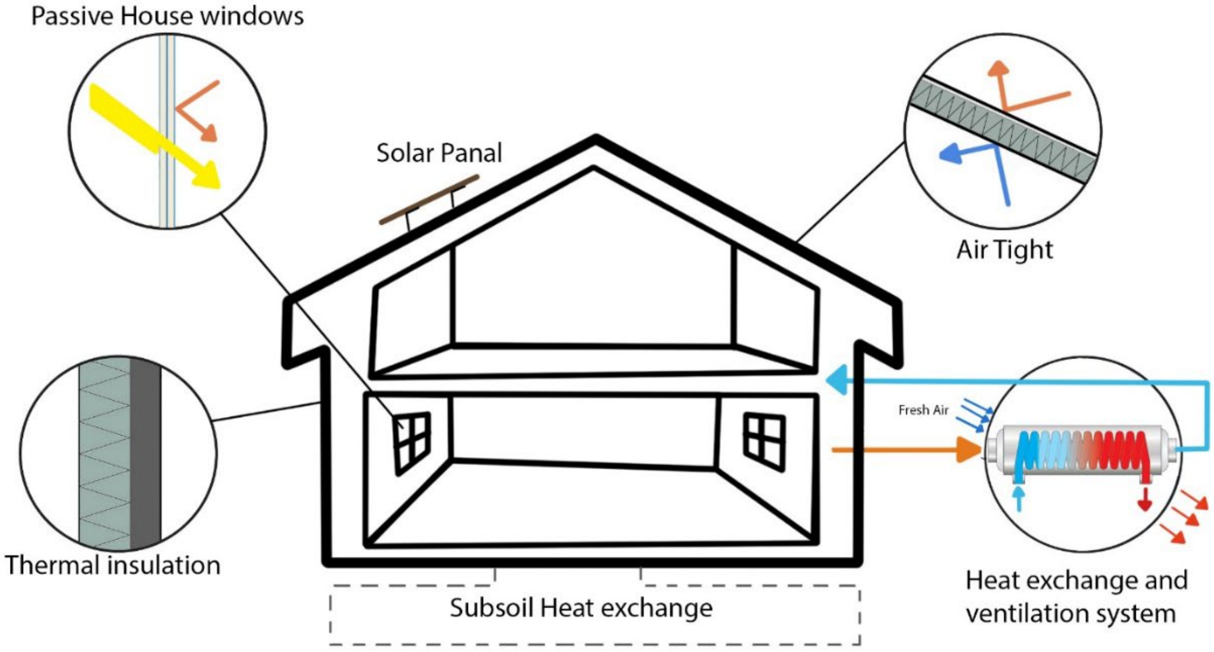

Figure 1-1 Important factors to be considered while designing a passive house [13].

In more simple words, it is a building which is designed considering factors such as efficient energy, comfortable, affordable, and ecological living environment at the same time. Passive house is generally designed in a way that it relies on renewable energy sources and heat storage units to optimize energy management. Figure 1-1 is showing typical factors that play a vital role in the implementation of the self-sustained house, which requires minimal energy to operate, a controlled environment (like humidity, temperature and light) inside the home for comfortable living, and finally, more weather resistance; where inside conditions do not get affected by sudden changes in outside weather. The passive house has five main characteristics, as shown in Figure 1-1, which are; passive house windows, airtightness, thermal insulation, heat exchange and ventilation system.

1.3 Concept of Passive House Planning Package (PHPP)

The Passive House Planning Package (PHPP), WUFI and Energyplus are the most robust design tools available for designing nearly zero energy buildings. Any passive house package is further categorized as Classic, Plus or Premium, introduced during 2015 by PHI. These categories can be achieved in relation to primary renewable energy and the amount of renewable energy produced and utilized [14]. So, a passive house is not just a low energy house, but it is more efficient in regards to saving 75% more energy than an ordinary low energy house, as represented in Figure 1-2.

In order to achieve passive house design and constructive solutions that allow one to achieve the above goals are:

- Envelop structure like walls, ground floor slab and thick layers of insulated walls with the thermal insulating capacity of $U \leq 0.15$ W/ m^2 K [14];
- While keeping the living comfort a priority, the airtightness should also be considered according to the design. Maximum allowable air change cannot exceed 0.6 times a room's volume per hour, and the pressure differential is

limited to 50 Pascals [15];

- Specialized windows with minimum possible U-value of ≤ 0.8 m^2K and designed in a way to utilize sunlight efficiently [13].
- Taking advantage of passive energy resources like subsoil heat exchange and renewable energy production from other sources like sun or even the body heat of inhabitants (100Wh per inhabitant) and other household appliances.

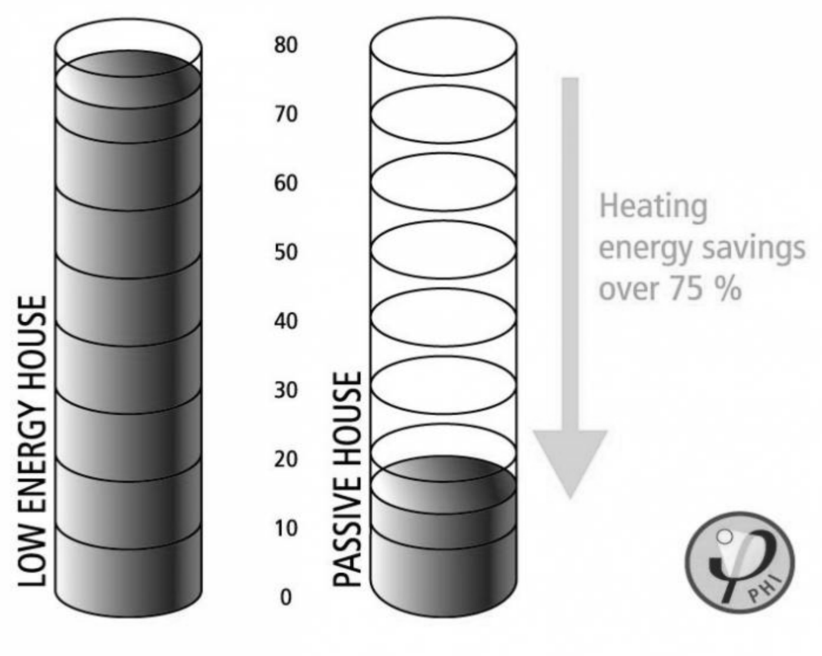

Figure 1-2 Heating energy kWh/m^2year [13].

Design related points, as mentioned earlier, like physical, technical and dimensional estimates are calculated using the final construction design of the building, and then values are inserted in the Passive House Planning Package (PHPP), WUFI or EnergyPlus to estimate energy matrices of the building.

1.4 Literature Review

1.4.1 A Background Discussion of Passive House

A ship named “Farm” was known to be a fully functional sustainable model (passive house) in history, which was a polar ship, not a house. Fridtjof Nansen [16] described that the saloon's total thickness and cabins were just about 15 inches; it had a comfortable environment with a temperature around 22°C, and the fire was not required in the stove.

Figure 1-3 Fridtjof Nansen’s polar ship [16].

The air sail was rigged up; the ventilation was excellent; it was warm and comfortable to sit in. Many kinds of passive house designs were attempted in the past, but some were not adequately insulated or airtight enough. One of the main reasons is that the performance windows were not present. Due to the unavailability of specially designed passive windows, small windows covered with insulating material were kept in a place, which caused less sunlight inside, resulting in electricity consumption for light bulbs.

There have been several attempts in the late 1900s and recent years to work on the idea to build energy-efficient houses. The ideal case would not only be using nearly zero external energy, but the house should be self-sustained and using some sort of renewable energy source to cope up with energy needs. As discussed, the passive house model is specialized house designs using a high level of insulation and specialized windows, which allows less heat transfer and keeps a desirable climate inside. We can also use some traditional ways to overcome the problem of energy/heat loss from the house. If we take a closer look at many conventional ways, which are even currently being used in China[17] and many other countries in Asia [12] and Europe[4]. These houses are specially designed to help fight extreme weather conditions while keeping it low budget, affordable and energy-efficient. Several techniques were implemented to prevent heat loss during winters, like keeping a minimum opening for the doors and windows or envelopes built with a combination of wood and stones with a much stricter structure and green surface on the top. These kinds of traditional techniques are still being used in some parts of Canada called “Sod houses.” Although the material used for these houses may cause increased humidity levels inside the home, a detailed comparison has recently been completed, which shows these traditional houses' has remarkable thermal capabilities [18], [19]. Figure 1-4 and Figure 1-5 shows a general representation of a Sod house even currently being used in frigid weather of Newfoundland and Iceland, which mostly consists of wood and stone as a building material with the combination of earth material. The main idea for these houses is to save energy and create a comfortable living environment. These traditional houses and other standard houses built in Newfoundland can provide substantial protection from the cold climate. Not only that, by following modern techniques of building the homes, it is quite challenging to achieve PHI standards, and that's why it is important to also study PHIUS (Passive House Institute of the United States) standards for passive house building in the climate of Newfoundland [20].

Figure 1-4 Entrance to a Viking sod house in Newfoundland [19].

Figure 1-5 A sod farm structure in Iceland [21].

1.4.2 Modern Examples of Passive House

There has been a lot of attempts to achieve a sustainable greenhouse model with enhanced living comfort and modern design. In the mid-1980s, the low energy building was already a legally required standard for many countries in Europe. Even during that time, the main development features of passive houses, such as airtight envelop, perfect insulation and controlled ventilation, were legally enforced by the government of Sweden and Denmark [21]. So, based on similar consideration, the passive house" was launched in May 1988 by a group of researchers at the University of Lund (Sweden) [21]. Though similar research was going on in other parts of the world, a comprehensive model with a modern, comfortable design was proposed and later completed, as shown in Figure1-6.

Figure 1-6 The world’s first multi-family Passive House, Darmstadt-Kranichstein, Germany 1990 [9].

Figure 1-7 Sol Lux Alpha is an energy-efficient building, the winner of PHIUS 2018 [22].

Nowadays, most of the developed countries have their own passive house certification institutes. These organizations are continually improving resources, guidelines and conduct educational programs to facilitate and promote the adoption of the passive house standards. The most notable passive house Institutes, which are being followed in North America, are PHI and PHIUS [20]. Some of the modern designs can be seen in the recent competition by the PHIUS, as shown in Figure 1-7, the first multi-unit nano grid passive house building that won the best overall performance award [22].

Figure 1-8 The Marienlyst passive house school in Drammen [24].

Passive house design standards do not only focus on low energy houses, but it also creates a path to comfortable living. A study on a passive house school built in Norway shows the high level of comfort of the occupants [23]. Figure 1-8 shows the night view of this school in Norway, which does not only have advanced energy-saving techniques implemented, but it also has ventilation control, CO_2 sensors and temperature sensors installed inside the classrooms to provide a feedback system for enhanced comfort. The whole temperature control system for winter is connected to a local heating system that has energy needs calculated to be 13.4 kWh/ m^2 per year. Though the building is using artificial lights and natural lights, the average lighting consumption is estimated to be 7 W/ m^2 operating time, about 15.5 kWh/ m^2 per year [24].

1.4.3 Passive House in Different Climates

Before delving deep into details of the passive house specification and design model, it is imperative to understand the fundamental differences of each passive house built for a specific environment. Each type of environment affects the overall design, passive heating or cooling techniques and other specifications that might change from one country to another, but the overall concept remains the same. There has been a detailed study [25] that explains different types of climates:

1. Marine
2. Cold and Very Cold
3. Mixed-Dry and Hot-Dry
4. Mixed-Humid and Hot-Humid

Many other pieces of research show similar categorization [26] and discuss the broader classification of the climates. However, each category can further be divided into a subcategory, where site characteristics and requirements being unique to the specific side. For the sake of the research question, Mixed-Humid types of cites have been analyzed in-depth in the following chapters. One thing to keep in mind is that PHI provides general guidelines for all different kinds of climates, which in some cases could become a bit challenging to achieve. On the other hand, PHIUS offers more personalized guidelines for builders depending on the environment and location [20].

There are many factors taken into account while designing an efficient model of a passive house for a cold climate like Newfoundland [27]. Not only efficient modelling of the house but also other factors like energy modelling and sensible energy management system [28] using a renewable energy system. By using alternative energy resources and self-consumption techniques, a passive house can be transformed into a net-zero energy house [29]. Following sustainable living will eventually lead to a smaller carbon footprint, which is the primary goal of the passive house model.

1.4.4 Research Issues

A lot of factors add up to create a sustainable house. To create an in-depth understanding of the working principle of the passive house model and retrofit its design to net-zero energy building, a recently built passive house in Newfoundland has been selected for the case study, which is shown in Figure 1-9. This house is located in a cold and humid environment of Newfoundland and has been built on guidelines of PHIUS standards. This house is divided into two parts, gray colour envelop is the garage consist of a smaller portion of the house, and a red colour envelope is the main living area of the passive house, as shown in Figure 1-10. This building is equipped with passive windows and insulated doors to keep the heating cost low, with most windows facing south to gain as much sunlight possible for heating. A detailed study is required to analyze its energy performance and design considerations. This house is using national grid electricity and wood to meet its energy requirements. Energy performance analysis can be performed by using some of the methodologies mentioned in the recent studies [18], [24], [31]-[33]. After careful examination of energy performance, recommendations could be made on how to reduce the energy expenditure and carbon footprint of the house. One of the main steps is to convert a passive house into a net-zero energy house and integrate renewable energy systems, as shown by some other researchers [25], [29], [33]-[35]. Finally, design and implement an intelligent smart home energy management system [36], [37],

Figure 1-9 First house built in Newfoundland [30].

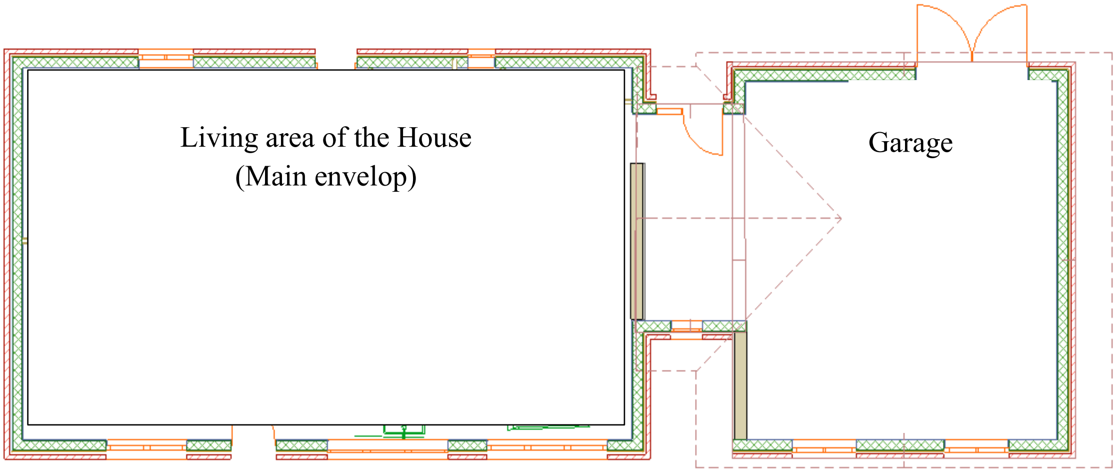

Figure 1-10 Floor plan of the Passive House in Newfoundland, being used for case study.

1.5 Thesis Research Scope:

Considering many benefits of the passive house mentioned on the Passive House Institutes websites (https://passipedia.org) and the results obtained from case studies of several years of experience from around the world [18], [28], [29], [38]-[42], the first passive house in Newfoundland was built by Dr. David Goodyear. This research will not only act to promote sustainable living and spread awareness about the benefits of passive houses in Canada, but it will also provide a complete solution for the smart home system. Passive house design has been analyzed, and lessons learned have also been documented from the collected data. Moreover, the role of passive houses and other important concepts like climate zones, carbon footprint, embodied energy, passive heating and thermal mass, and renewable energy for the passive house is discussed in detail, which is very important for the futuristic house design.

1.5.1 Objectives of the Thesis:

This section gives an overview of the thesis objectives and the present main research questions:

Objective 1:

Analyze and simulate the first passive h in Newfoundland located at Flat Rock using the advanced passive house planning tools. Comparing passive house simulation results from both static and dynamic modelling. Finally, perform critical analysis of simulation results with the actual data of the passive house. Model energy consumption and load profile of the passive house and compare the results from pre-construction planning and post-construction results by data logging.

Objective 2:

Design an optimized renewable energy system to meet the energy requirements and check the solar and wind power generation system's feasibility with the grid-tie system configuration for the first passive house in Newfoundland.

Objective 3:

Analyze the electric devices being used in the house, including the control system for space and water heating. After creating an understanding of the current framework, design an energy management system using the smart home IoT base model and implement a low energy and low-cost monitoring and control (SCADA) system for all the electric devices in the house.

1.6 Thesis Outline

Chapter 1 - Introduction and Literature Review:

Being the introduction and the literature review of the thesis, this chapter explains the main criteria considered while designing a passive house. This chapter also explains some of the examples and the passive house designs already built. An initial roadmap and clear objective have been defined in the chapter as well. Initial criteria for the passive house has been established for the house so that the requirements could be better analyzed and lessons learned could be recorded for study.

Chapter 2 – Building Performance Modelling

It will follow the steps taken to design the passive house from start to finish comparing passive house standards PHI and PHIUS, both applicable in Canada. Moreover, with advanced tools like PHPP, WUFI, DesignBuilder and BEOPT, the house will be analyzed. Finally, with the different comparison guidelines[18], [24], [31]-[33], [43]-[45], the house's performance will be accessed to record the performance and whether the design has met the criteria and expectations. Finally, a renewable energy system has been proposed which can support the electrical needs of the house.

Chapter 3 – Electric Load Analysis and Designing of the Renewable Energy System

Two years of logged data of energy consumption have been used to analyze electricity needs for the house. This consumption includes water and space heating, as well as other day-to-day electricity usage. This chapter focuses on the energy modelling and system designing of the house specific to Newfoundland's climate [46]-[50]. Finally, using advanced computer tools model renewable energy systems with a control system, dynamic modelling and simulation have been performed.

Chapter 4 – Energy Management System using Smart Home Technology

This chapter focuses on the energy management system and optimization of the water heating system, which is using more than 30% of the total electricity consumption. However, the water heater system uses the wood stove and the electric heater with the controller of Steca TR A501 pre-installed with manual control. That sometimes consumes extra energy if the wood is not burning for water heating. According to a similar smart home study [51]-[55], an IoT based intelligent home energy management system for the passive house.

Chapter 5 – Conclusion and Future Work

Finally, record the lesson learned and recommendations for future work in the conclusion chapter. This chapter is also essential because all the future work, limitations and assumptions are discussed in this chapter.

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Co-authorship Statement

I am the primary author of all the research papers used to prepare this thesis, and my thesis supervisor, Dr. M. Tariq Iqbal, is the co-author of the majority of the papers. I carried out most of the theoretical work, conducted the literature reviews, carried out the prototypes, incorporated hardware, experimental setups and analysis of the findings in each of the manuscripts as the principal author. I have prepared the original manuscripts and later revised each of them based on the original manuscripts.

Chapter 2

Building Performance Modelling for a Passive House in Newfoundland and Design of Renewable Energy System

Preface

A version of this manuscript has been published in the ***International Journal of Renewable Energy Research Volume 10, No 3 (2020)*** *, I am the lead author who conducted literature reviews, planned, modelled, and simulated the method, and evaluated the findings. I have written the manuscript's first iteration under the name "Building performance modelling for the First House in Newfoundland built on PHIUS+2015 standards and design of Renewable energy system", and then revised the final manuscript based on the co-author's input and the peer-review process. Dr. M. Tariq Iqbal and David Goodyear, both the co-authors, directed the study, revised and corrected the manuscript, and contributed to the actualization of the manuscript with research ideas.*

Abstract

This chapter presents the building performance of a house in Newfoundland, Canada. This house is built under the guidelines of the Passive House Institute United States (PHIUS+2015) standards. Building this house is an important step took towards sustainable living in Newfoundland and Canada in general. Detailed energy consumption modelling of the house has been performed along with the steps involved in the simulation process of passive house planning and renewable energy system sizing. A significant part of the study presents the majority of the construction details of the house and the components involved. In this study, we present actual energy consumption data acquired from the house and the simulation performed in both pre-construction and post-construction phases. Additionally, steps followed during the planning and construction phase have been discussed in detail, and both static and dynamic energy modelling has been compared. Moreover, a cost comparison has been performed to calculate all the additional costs spent on the resources to build the house according to the Passive House (PHIUS+2015) standards; the analysis indicated a cost of 12% extra when compared with the house built under local regulations. Finally, a renewable energy system is proposed for the house to meet the electricity needs of the house.

2.1 Introduction

In recent years energy consumption has been increasing, and also it is becoming significantly challenging to devise ways to make efficient use of resources that we have. The principles of passive house standards provide options to make efficient use of energy, promoting a more sustainable lifestyle. Residential building construction is expected to increase in future significantly; therefore, building energy conservation has become of utmost importance after the declaration of climate emergency [1]. In a cold climate, a substantial part of electrical energy is spent on heating loads in the residential buildings. Passive house standards have a set of performance metrics that provides planners with goals to meet certain energy requirements for the buildings with considerably low heating and cooling load while maintaining a comfortable living environment. While passive house guidelines are available to help through the construction process [2-5], many things can be done during the planning phase to improve the construction, design and material selection process. These can overall lead to a reduction in the cost and energy expenditures[5] and monthly energy consumption modelling [6]. This study presents a detailed analysis of a recently constructed house built on PHIUS+2015 standards, which is claimed to be the first passive house in Newfoundland. Total energy demand data for two years has been collected, and it was analyzed and compared with both static and dynamic simulation tools. Additionally, a detailed study has been completed for a renewable energy system after a complete load analysis of the house.

The primary purpose of this study is to compare the total energy demand data of the house with the computer-simulated results and propose a renewable energy system to meet the energy demand. The first section presents a detailed site analysis. Afterwards, section two focuses on building envelop descriptions and different considerations of passive house planning and simulation because the simulation is the first step in the construction of a passive house. The simulation approach and validation of the model have been performed with the data logged from the passive house and by sensitivity analysis using the EnergyPlus simulation engine. Results from WUFI simulation software has also been compared with the actual data in section four. Finally, detailed comparison and cost-benefit analysis show there is a payback period of fewer than ten years.

2.1.1 Passive House Site Analysis:

The passive house Standards were developed in 1990 for the first time to achieve a residential model that uses substantially less energy than a typical house [7], [8]. PHIUS+2015 standards have been introduced in 2015, which were actually built on top of German passive house standards [8]. PHIUS+2015 guidelines are said to have more personalized requirements tailored to the climate and geolocation of the house rather than just having one guideline for every house. PHIUS+2015 designs constraints; when converted into system international (S.I.) units include but not limited to [4]:

- Heating demand should be less than 43.155W/m^2.K and 95.39kW/m^2.year
- Cooling demand 7.38-53.94W/m^2.K and 5.67 -132.87kW/m^2.year.

- Airtightness should be less or equal to 0.05 cfm/sf.
- Source Energy demand 6200kWh/person. year.

Also, the idea for Net-Zero Energy House has also been considered as one of the key solutions to improve upon the concept of the passive house [10]. To create an in-depth understanding of the working principle of the passive house model and retrofit its design to net-zero energy building, a recently built passive house in Newfoundland has been selected for the case study, which is shown in Figure 2-1. This house is located in a cold and humid environment of Newfoundland in Zone 6. According to the ASHRAE standard [11], and the house built on the guidelines of PHIUS+2015. The red colour envelope is the main living area of the passive house, and the gray colour envelop is the garage consist of a smaller portion of the house, as shown in Figure 2-1. All fenestrations in the envelope have been selected according to the recommendation to the passive house consultant, with most windows facing south to gain as much sunlight possible for heating.

Zone 6 in Newfoundland is a cold and humid climate which experience cold winter followed by a warm and humid summer with yearly snowfall can reach up to 250cm. One most important thing to consider is a high amount of wind experienced throughout the year, with an average wind speed of 6.6 m/s [12] which shows good signs for wind energy production. However, to implement an alternative energy solution, it is better to understand the demographics of the selected site. This section is going to discuss in detail, the weather data and possibilities of the other renewable energy resources available for the house. Renewable energy sources for the selected site can be biomass, geothermal, microhydroelectric, tidal, wind, solar thermal and solar photovoltaic. Figure 2-2 shows the satellite view of the house, which is surrounded by other houses, potentially limiting the option of using a wind turbine due to safety reasons because of the moving parts involved. A detailed study for a similar site, which is also the location in the vicinity of other residential houses, shows that only wind and solar resources can be utilized for the site [12]. Although the same study suggested that the micro-hydro project could have also be implemented if the site would have been in a remote area and need to have access to a potential hydro source. So, one of the best and practical sources to be used at the micro-level is solar photovoltaic because it is easy to install, has the flexibility of designing and cheaper than other sources and flexibility of extension [13]. Moreover, given the current site analysis, it is also possible to have a grid-connected renewable energy generation system, which, in our case, gives the ability to feed extra generated electricity to the grid.

Figure 2-1 First house built on PHIUS+2015 standards in Newfoundland.

Figure 2-2 . A satellite location of the passive house understudy taken from google map.

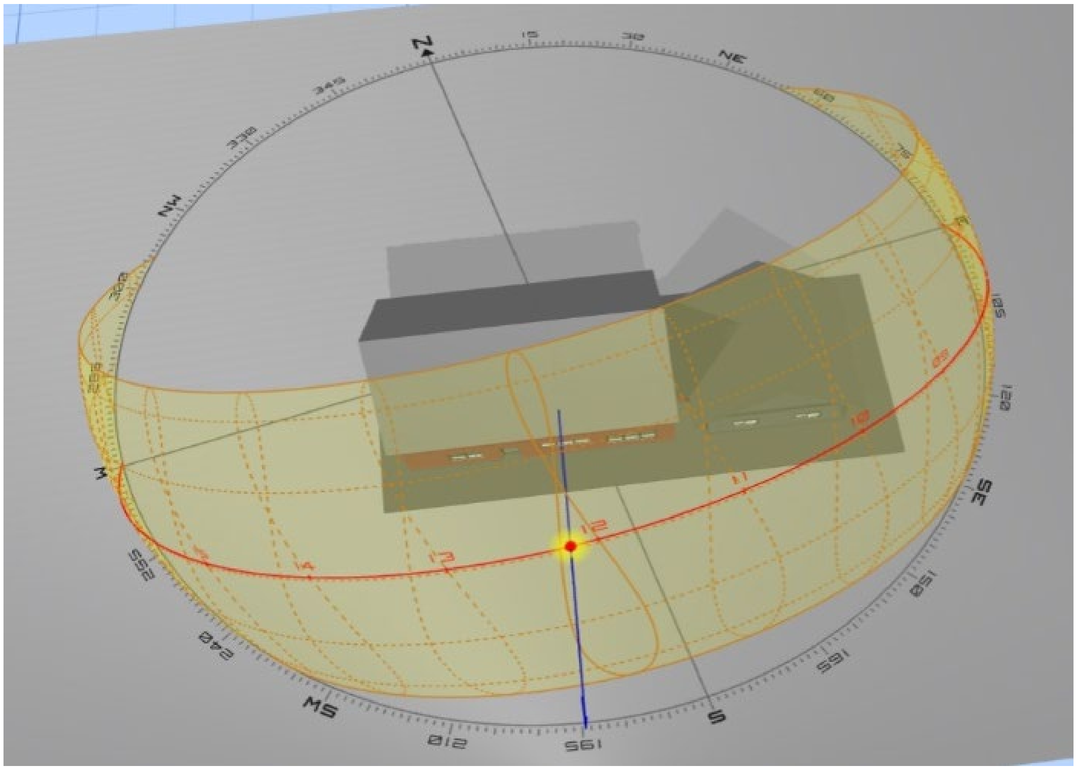


Figure 2-3 Top view of the model of the house with the solar chart.

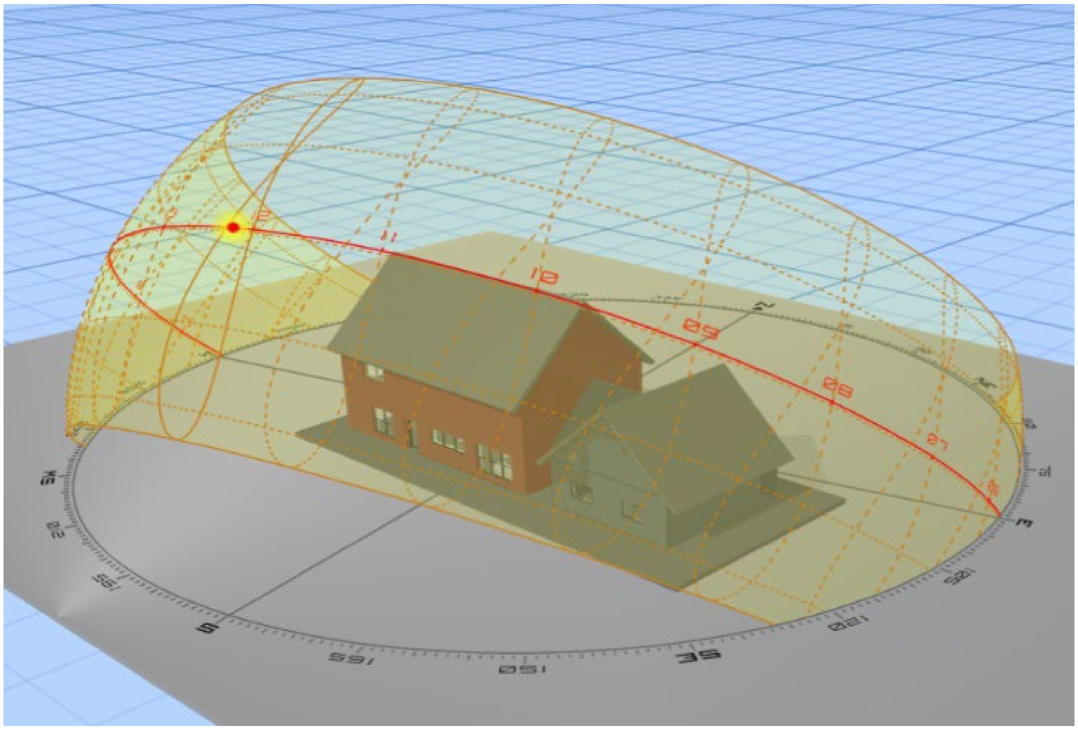


Figure 2-4 3D model of the house with the solar chart.

Figure 2-3 represents the top view of the house. It can be seen that the house has a roof facing south at an angle of 40 degrees, which gets maximum exposure from the sun. Also, Figure 2-4 represents the side view of the 3D house designed in SketchUp 3D initially and solar chart generated with Andrewmarsh's online web-based tool [14]. The area of the house selected for solar panel installation is 50 m^2. Initially, Homer Pro software was used for the sizing and optimization of the P.V. systems for the house, and finally, results were verified with PVsyst software. During summer, solar radiation reaches up to a fairly good amount of 5kWh/m^2.day and, irradiance gets lower in the winter, as represented in Figure 2-5. It can also be seen that the clearness index remains relatively constant throughout the year, with an average value of around 0.45. This data was obtained from a monthly average of 22 years under NASA surface meteorology and solar energy database [15]. Weather data has been downloaded from NASA solar energy database and used in Homer pro optimization [15].

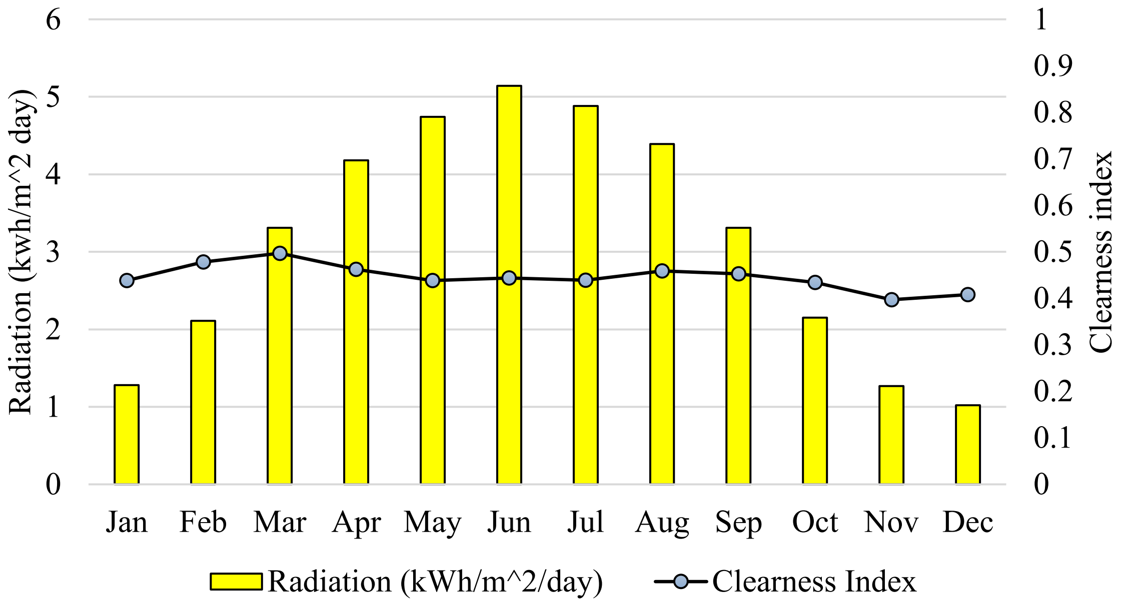


Figure 2-5 Solar energy potential for FlatRock Newfoundland (NASA).

2.1.2 Weather Condition

For the sake of dynamic simulation, EnergyPlus provides a lot of resources online from its website, and these resources are managed by National Renewable Energy Laboratory. For the first step, climate zone and accurate weather data input is a significant step for the simulation process. So, weather data from the EnergyPlus website has been downloaded. Figure 2-6 shows the heating degree day data of Canada, according to ASHRAE guideline, and the site with red marker has shown which comes under zone six [11]. The site has a lot of variation in temperature throughout the year, and the ASHRAE climate zone ranges from 2222-2777 heating degree day (HDD) when data from Figure 2-6 is converted from Fahrenheit HDD to Celsius HDD. Especially, consideration of outside temperature, humidity and sunlight hour is critical while planning for the house. Figure 2-7 represents the temperature graph for the site, and it shows a significant variation in temperature from winter to summer, where the temperature goes below zero and gets extremely cold. A similar study [16]-[18] indicates how important it is to keep all variables like moisture, fluctuating temperature, snow and gust into account while planning the house. Because of the humid nature of the climate, dehumidification is also required during certain times in the year to maintain an indoor comfortable living environment. Those times are mainly summers and shoulder seasons. All these variables can be more effectively stimulated with dynamic simulation tools where the properties of each device installed can be selected along with sudden changes of climate variables to achieve more accurate results.

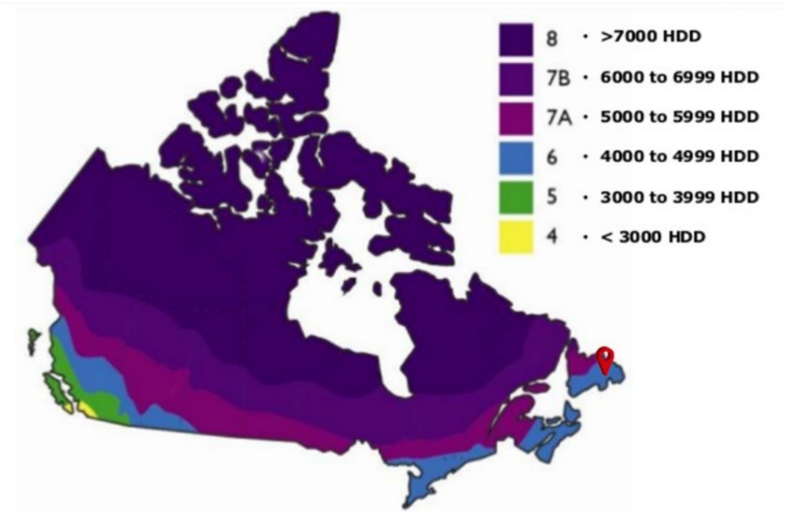


Figure 2-6 . ASHRAE climate zone distribution with respect to heating degree day (HDD) for Canada [11].

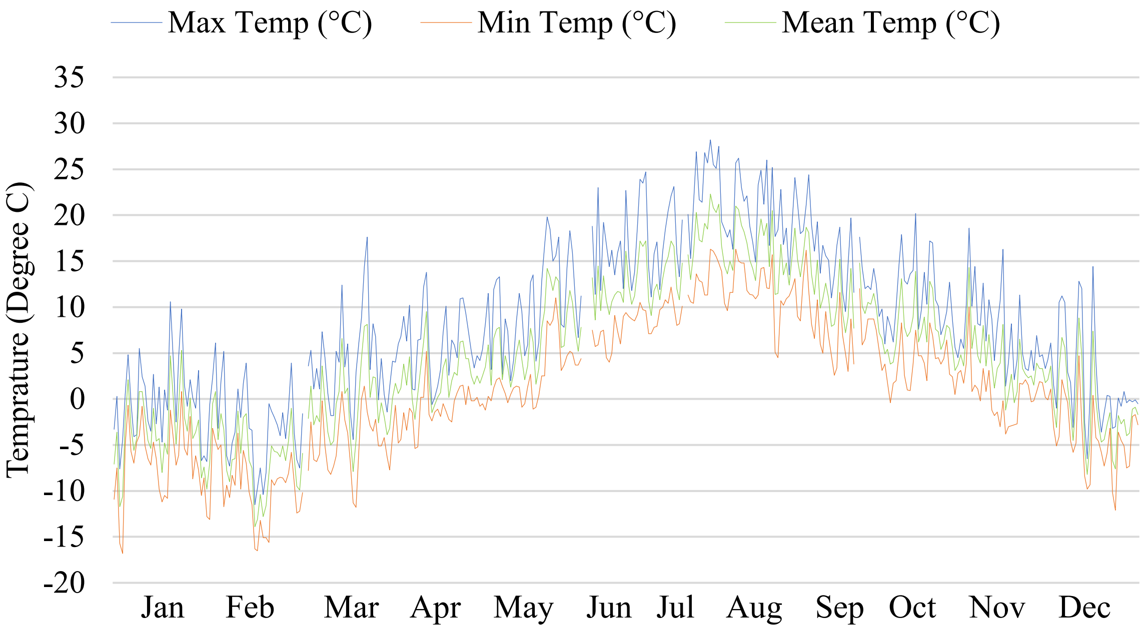


Figure 2-7 Temperature graph for the site of the year 2019 (NASA).

2.2 Building Envelop Description

The house design was completed after several rounds of renderings and plans with the input of the homeowner and the consultant. The final design of the house, as shown in Figure 2-1, has been constructed to captures traditional Newfoundland vernacular architectural style, locally known as the Saltbox style. This architecture style is simple and can be built to withstand the Newfoundland cold climate with a steeply pitched roof to protect from snow accumulation and wind-driven rain [19]. The ground floor has a common living area, kitchen, dining room and small room for working space, which is also deemed as a fourth bedroom. A detailed floor plan for the first floor can be seen in Figure 2-8 for visualization. The floor plan of the second floor of the envelope is also shown in Figure 2-9. It has three bedrooms, and the total area of the second floor is the same as the first-floor build on a similar layout as of the first floor. The house has a total of 185 m^2 area, out of which 113m^2 area has been designed, built and tested according to the PHIUS+2015 standards. The remainder of the house (garage) is less insulated and not built according to the PHIUS+2015 standard, and hence it is left out of the scope of the study.

Figure 2-8 Floor plan of the passive house (first floor).

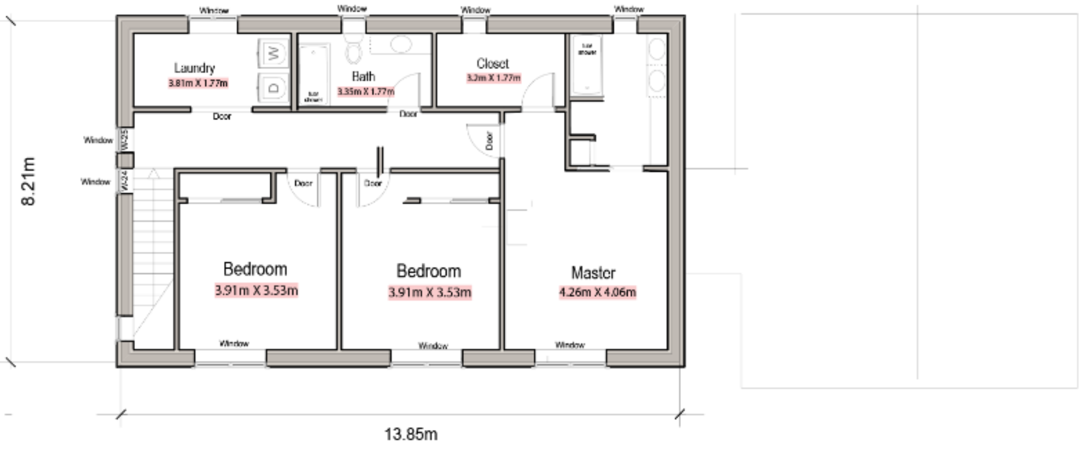
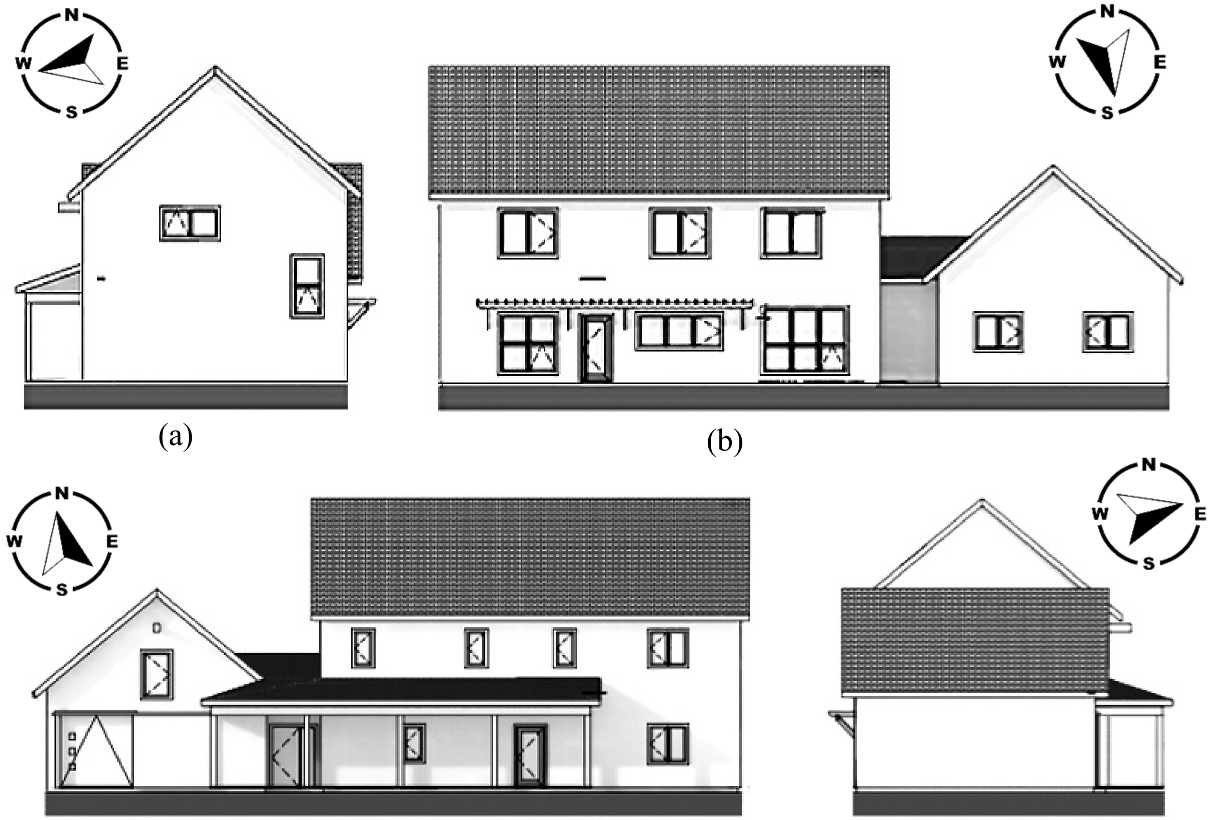


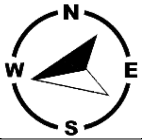
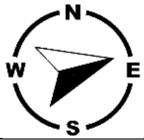
Figure 2-9 . Floor plan of the passive house (second floor).



(a) (b) (c) (d)

Figure 2-10 House elevations from different viewing directions.

Table 2-1 window-wall ratio of the model.

	Total				
Wall Area m^2	271.8	86.4	54.3	75.4	55.7
Glazing area m^2	26.41	5.68	2.78	17.95	0
Window to wall ratio R %	9.71	6.57	5.11	23.8	0

The building site was selected to take advantage of solar radiation during the heating season. Table 2-1 shows the area of each façade, and the global percentage of the glazing is about 19% of the total opaque façade area. As can be seen in the Table 2-1, and also in Figure 2-10(b), the maximum amount of glazing is located in south façade which accounts for 23.8% of the wall. The rest of the façades have 5.1% facing west, 6.57% facing north and zero percent glazing facing east, as shown in Figure 2-10(a), Figure 2-10(c) and Figure 2-10(d), respectively. Triple glazed windows have been deployed to maximize efficiency and reduce heat loss during the winter season. The windows on the south facades were chosen to have a higher Solar Heat Gain Coefficient (SHGC) than the rest of the building to maximize solar gain. The results of different thermal simulations were tested using EnergyPlus with various configurations of windows and areas.

Furthermore, optimized results can be calculated using simulation analysis [20], with the desired glazing characteristics or specifying known specific heat and conductivity of glazing windows installed and wall insulation specifications. It has been verified that the high-performance windows make a considerable difference in the heat loss or gain for the envelope [21]. In this case study, SHGC of the south-facing windows is 0.58, a total of around 4900kWh/year energy in the form of heat has been lost from the windows and doors, as shown in Figure 2-11. Moreover, it has been discovered that larger windows lead to higher heat loss and lesser heat gain for the heating season. A detailed study can be explored to analyze the different ratios of the windows with walls; however, overall energy gain and energy loss depends on many other factors, not only the glazing area of the walls [21], [22].

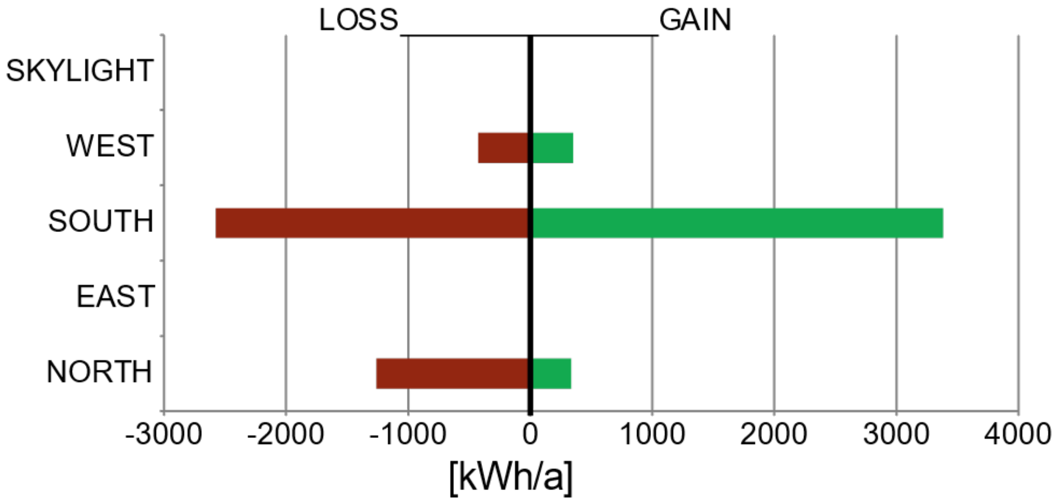


Figure 2-11 Energy Loss/Gain from glazing area in kWh/year.

2.3 Modelling Methodology and Boundary Conditions:

Building simulation tools are essential for the analysis phase of the build information modelling. Over a period of time, there have been a number of tools developed for energy modelling and building simulation. Each of the software has its unique capability when it comes down to building simulation. There are mainly two types of simulation techniques when it comes down to a passive house; static and dynamic simulation. In a static stimulation, data is assumed to be evenly distributed. Two available tools, designPH/PHPP and WUFI, are most widely used for the Passive House package planning [2]-[4]. On the other hand, dynamic simulation allows robust and advanced techniques where time-dependent changes along with other factors like Heating, Ventilation, and Air Conditioning (HVAC), heat sources, moisture effect etc. are also taken into account. A lot of building energy simulation tools like IDE ICE, EnergyPlus, OpenStudio, eQUEST and

DesignBuilder are available and mentioned in the studies which promise high accuracy level for a comprehensive simulation of building design [20]-[26]. In this study, the EnergyPlus engine and open-studio is used to compare the results with WUFI, which is a Passive House planning tool. Final results are compared with the actual energy consumption data logged from the recently build a passive house.

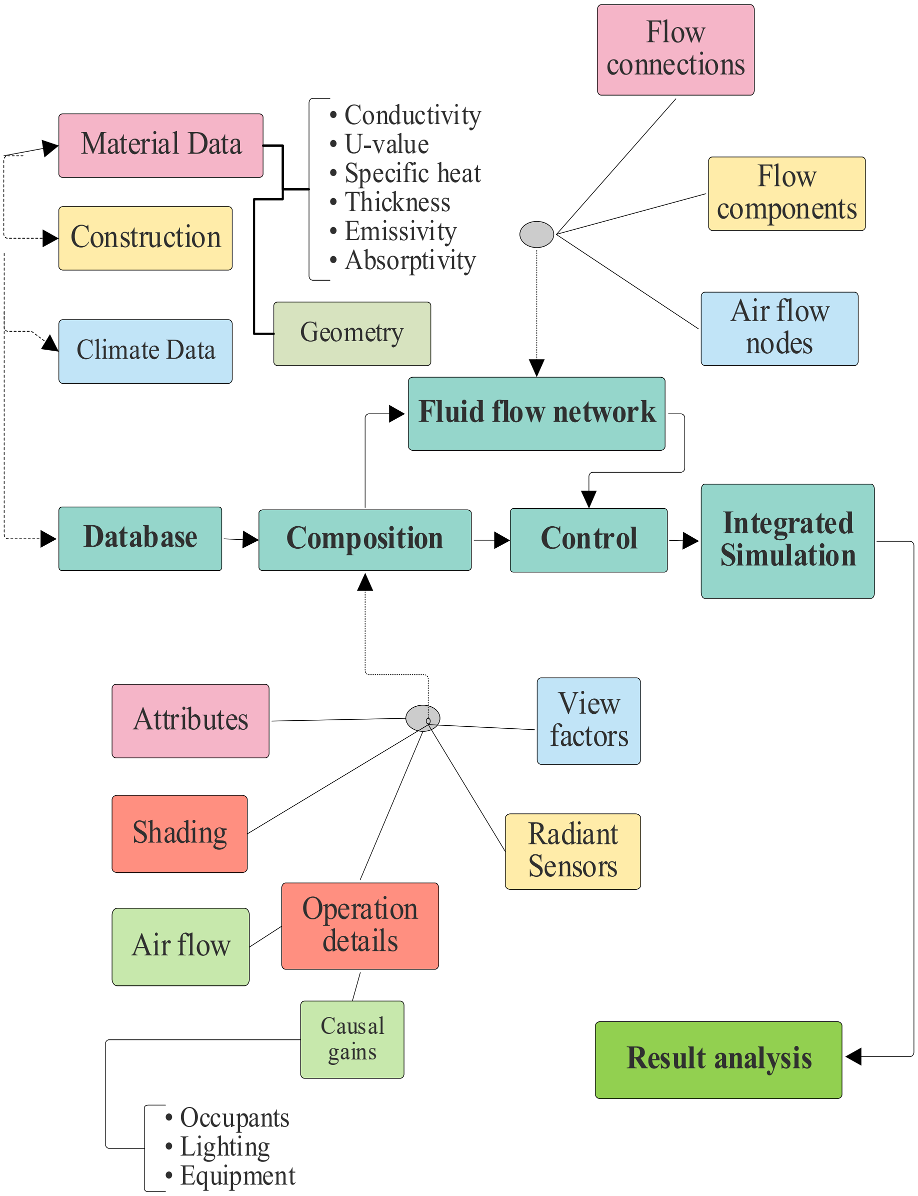


Figure 2-12 Typical steps involved in building energy simulation.

Inputting exact parameters for building energy simulation needs careful consideration of components involved, including but not limited to division of thermal zones, geometric modelling, software selection that matches the requirement and finally, the selection of meteorological data [27], [28]. Geometric modelling represents the first stage of the simulation [29], which consumes typically requires exact measurements and knowledge of the site in the process of energy modelling [30]. Moreover, other parameters, like material data, shading, glazing, construction attributes, etc. Figure 2-12 represents the overall methodology adopted for simulation modelling using OpenStudio with the EnergyPlus engine and WUFI planning tool. This methodology represents typical building information and energy modelling with some extra steps involved for more complex high-rise buildings. Starting from the selection of climate data and construction parameters, all the composition data has been selected according to the specifications, and later zone connections added for temperature and air flows calculations [31]-[33].

2.3.1 Design and Specification

As shown in Figure 2-12, after 3D modelling and creating a database of material and construction data, the next step is to input the characteristics like shading, causal gains like occupants, lighting, equipment etc. and airflow of the house accurately. Table 2-2 represents the boundary conditions for the house, which is to be analyzed and Figure 2-13 represents the 3D model of the house used for simulation. The model uses a concrete slab as the base, and then one top floor plate has been constructed. It is favourable by passive house standards to have a concrete slab-on-grade to control heat loss from the house to the ground. With added extra insulation in the concrete slab reduces the amount of concrete being used hence reduces overall embodied energy. Additional insulation under the slab can be added in order to decouple the slab for the thermal losses to the ground. The roof of the house has loose-fill cellulose insulation that gives the building overall excellent thermal inertia and an overall U-value of $0.058 W/m^2K$.

Figure 2-13 Designed model in sketch-up for visualization.

The thermal envelope is directly in contact with the external environment; therefore, it acts as the dominant medium through which heat or energy moves between outside and inside of the Passive building. In the enclosure structure, external walls work as the primary constituent and significant area, where all part of the thermal maintenance system contacts. Outer walls account for more than 40% of the whole building energy consumption, so it is important to minimize thermal bridging to the enclosure structure of the envelope [29]. Figure 2-14 shows the intersection point of the roof and the wall where an extra bit of insulation added the structure to reduce the thermal bridging effect that overall plays an essential role in avoiding energy leakage, mould or moisture accumulation. A detailed Computational Fluid Dynamics (CFD) analysis can be explored with the DesignBuilder tool [33].

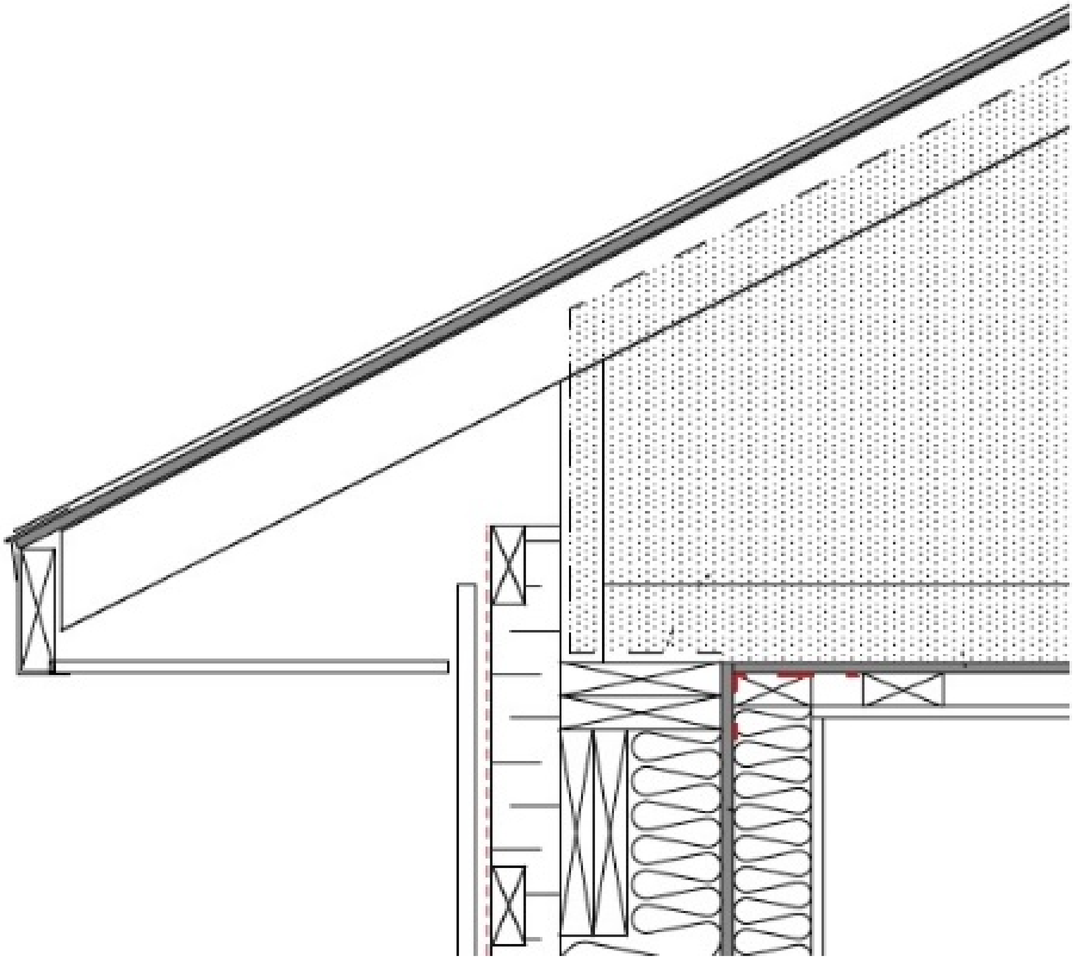
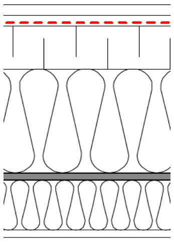
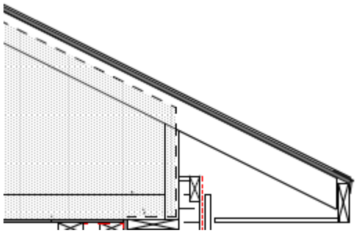


Figure 2-14 Representation of roof and wall intersection to avoid the thermal bridging.

Table 2-2 Design specifications for the simulations.

Boundary Conditions	**Building specification**
Building types	Optimized energy consumption
Floor area	$113m^2$
Glazing types	Triple glazed
Infiltration (ACH50)	0.45 /hour
Outer side → External Walls RSI 10.1 m^2-K/W U-Value 0.099 W/m^2-K Inner side →	
Source and composition of walls	1.58cm DRYWALL VAPOR BARRIER PAINT(<1 PERM) 2*4 STUD WALL W/ TIGHT-FITTING FIBERGLASS BATT INSULATION, 60.96cm O.C. 1.11 cm OSB WALL SHEATHING AND AIR/VAPOR BARRIER, ALL JOINTS SEALED AND TAPED 2X8 STRUCTURAL STUD WALL W/ TIGHT-FITTING FIBERGLASS BATT INSULATION, 60.96cm O.C. WIND BRACING 7.62cm EPS TYPE 2 CROSS STRAPPED 60cm 26O.C.
Roof RSI 17.24 m^2-K/W U-Value 0.058 W/m^2-K	
Source and composition of the roof	1.27cm DRYWALL 2*4 STRAPPING, 40.64cm O.C. 1.11cm OSB AIR/VAPOR BARRIER, all joints caulked and taped engineered wood trusses, slopes and overhang 45.72cm RAISED HEEL 66cm LOOSE FILL CELLULOSE- SETTLED DEPTH 5/8" OSB ROOF SHEATHING W/ H-CLIPS
Source and composition of the floor slab and floor plate	10cm POLISHED CONCRETE SLAB 15 MIL POLY RADON/VAPOR BARRIER 25cm TYPE 2 EPS FOAM 15cm GRAVEL 3*10cm T&G OSB SUB-FLOOR 1*4 STRAPPING 40.64cm O.C. 1.27cm DRYWALL Painted softwood flooring

The ceiling of the house also occupies a large area and can lead to significant heat loss [34], contributing to increased energy consumption overall. In this house, like any other passive house [35], the insulation layer of the ceiling structure is specially designed thicker and highly insulated with higher resistance (R-value) than the external wall structure. Moreover, it is crucial to minimize the transport of the moisture in the envelope, so an extra sealing layer and vapour retarder layer can be added to the walls [36], which in this case, the strand board (OSB) wall sheathing (air barrier and vapour retarder) has been used. So, taking the house boundary conditions as a paradigm, a three dimensional model of the house in SketchUp with spatial zoning and spatial tagging is established by relative design parameters for heat transfer environment and overall envelope, as shown in Table 2-2 and Figure 2-13. Having a garage with the design has been ignored while designing the house in WUFI. However, the analysis of different possible structural combinations with varying properties of zoning is possible in the OpenStudio. This software comes with a massive amount of preloaded libraries, and custom libraries have been created, and all reference characteristics for materials have been mentioned in Table 2-2. Based on the principle of integral variation, the EnergyPlus engine is implemented to simulate the outdoor time-by-case and change of hourly thermal load on the enclosed structure of the envelope. Also, according to the American National Standards Institute / American Society of Heating, Refrigerating and Air-Conditioning Engineers (ANSI/ASHRAE) 90.1 [37], multiple spaces can be represented as one thermal zone with the same heating and air conditioning system applied to have the same orientation of the exterior walls.

2.3.2 Energy Analysis

Table 2-3 and Table 2-4 show a comparison of different energy expenditure components involved in the house. As can be seen, that all components of the house and their electricity and non-electric energy demands. Since a passive house has ultra-low energy consumption [36], [38], to serve this purpose of energy saving, the heat recovery ventilation system (X24ERV model from Venmar) has been adopted, which is fully programable and ventilates according to ASHRAE standards. R-values mentioned in Table 2-2 exclude the effect of surface resistance and are calculated by the EnergyPlus software after inputting data for each layer in the wall. Since the outer surface resistance depends on the exposure to wind and the site data, the final result of the simulation is calculated by the algorithms of the EnergyPlus engine.

Table 2-3 Total electricity consumption of the passive house.

Types	**Electricity (kWh/year)**
Direct heating	832
Hot water	2394
Cooling	0
HVAC auxiliary energy	704
Appliances	5770
Current renewable generation	0
Total	9700

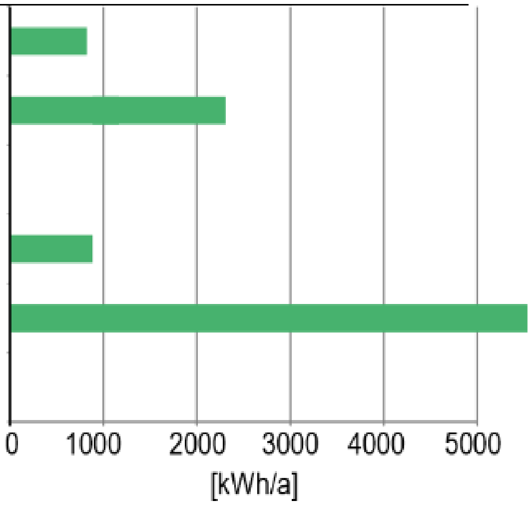


Table 2-4 A detailed breakdown of the energy demand of the house.

Type	Electric demand (kWh/year)
Kitchen dishwasher	143
Laundry (Washer only)	137.9
Energy consumed by evaporation	0
Kitchen fridge/freezer combo	452.6
Misc Electric loads	4137.3
Interior Lighting	845.1
Exterior Lighting	54.1
Total	5770

2.4 Building Performance Simulation and Results

To calculate energy consumption by each separate boundary condition and each separate room, the EnergyPlus engine is of great help. To understand the energy requirements of each section of the house, Table 2-5 is shown with heating demand to maintain comfort level and 20^0C of indoor temperature with the extreme external condition and dry bulb temperature to be -20^0C. Overall, the comparison of the heating and cooling demand for yearly data shows results on par with the static simulation results. As can be seen in Figure 2-15, Heating1 and Cooling1 are the results produced with the simulation of dynamic modelling while Heating2 and Cooling2 are the pre-construction simulation results with the help of WUFI modelling tool. Passive House Institute United States (PHIUS) has slightly different criteria when it comes to heating/cooling demand and airtightness. As mentioned in the literature review and also on the PHIUS website, criteria are specific to the climate zone where the construction is being done. For PHIUS+ 2015 standard [4] under which target of yearly heating demand has been set to 15kWh/m^2.

Table 2-5 Total heating load of the passive house.

Space	**Area (m^2)**	**Heating Load (W)**	**Overall (W/m^2)**
Office	17	185	10.88
Kitchen	39.2	538	13.7
Living Room	39.3	360	9.16
Bath	9	80	8.88
Laundary	10.4	165.5	15.91
Main Bath	8.2	67	8.2
Master Bedroom	22.9	183.2	7.9
Bedroom 1	18.2	135.2	7.42
Bedroom 2	18.2	135.2	7.42
Master Closest	7.5	59	7.8
Upstairs Hall	9.7	22	2.26

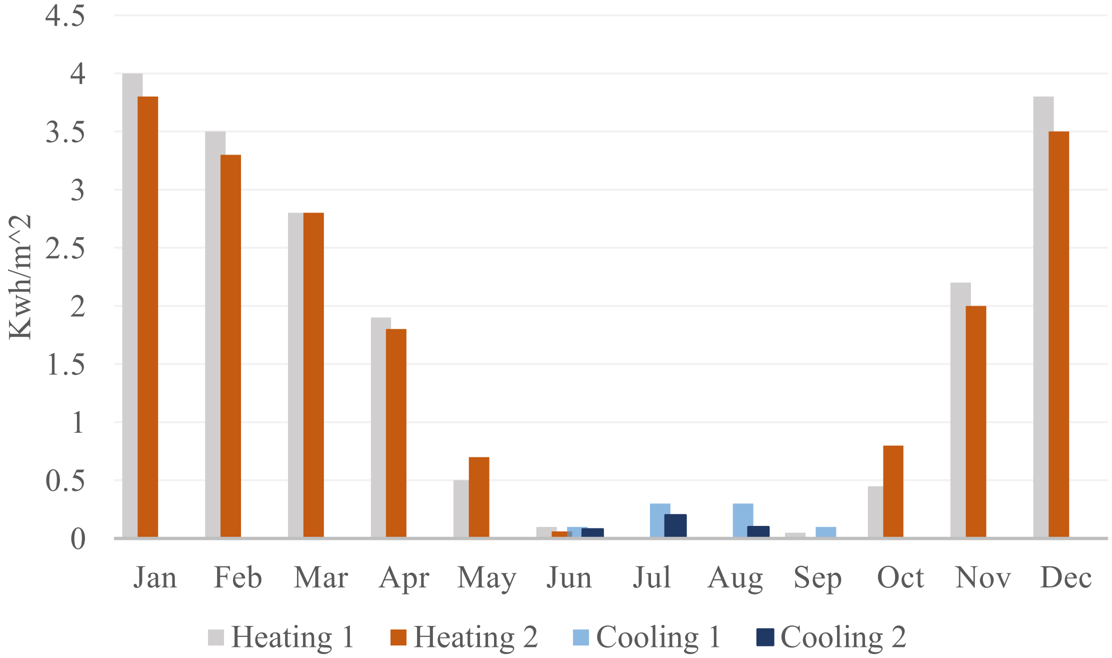


Figure 2-15 Comparison of heating and cooling demand simulated with two different software (1 for dynamic modelling and 2 for WUFI modelling).

Although, results for the heating and cooling demand have been on par with the static analysis of the house simulation for the house in the study with the results from dynamic modelling through EnergyPlus. As shown in Figure 2-16, there has been a slight variation in the results of the electricity consumption of the house from the actual predicted results. EnergyPlus tool gave more realistic and closer results to the real data. There could be other factors affecting the accuracy of the final simulation results as well. One of the most critical factors in hot water consumption, and it is being used as a space heating element that appeared to be ignored in the initial simulation. Moreover, there has been fairly tight fitted fiberglass has been placed in the external walls, which could end up creating a variation in the actual results from the simulation. Also, there has been the involvement of the garage, which has different properties, and individual simulation is quite tricky. Overall results, for ambience temperature and humidity and heating/cooling load, has been on par with the simulation.

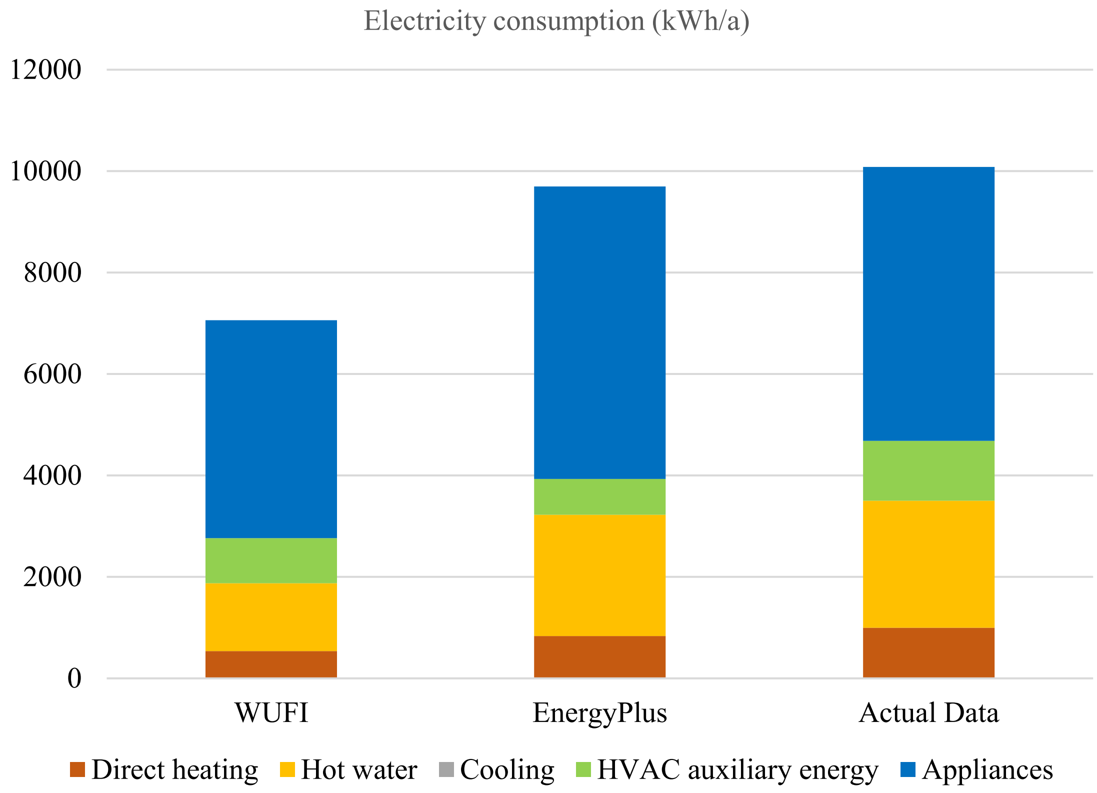


Figure 2-16 Average Electricity consumption data comparison of a year.

2.5 Load Analysis and System Sizing

This section focuses on system sizing and Photovoltaic system optimization for the house. In Figure 2-17, an average of two years of energy consumption data of the house shows an average of around 1200kWh/month demand. Figure 2-5 shows the lowest amount of solar radiation during the winter season when the house has the highest energy consumption.

While electricity production is going to increase in summer due to higher solar irradiance shown in Figure 2-5, load consumption is also going to decrease, as shown in Figure 2-17. Figure 2-18 shows that during peak production hours, total electricity consumption is no more than 60% of the peak load, which is mostly during the evenings. An hourly profile throughout the week, which was scaled later to have overall energy consumption in a day, was in the range of ±10%, which is to be noted at 33.66KWh/day. Furthermore, hourly seasonal load data was approximated using reports generated by the home's smart meter and, Figure 2-19 shows that during peak hours in winter, load reaches to maximum rated consumption of 7kW.

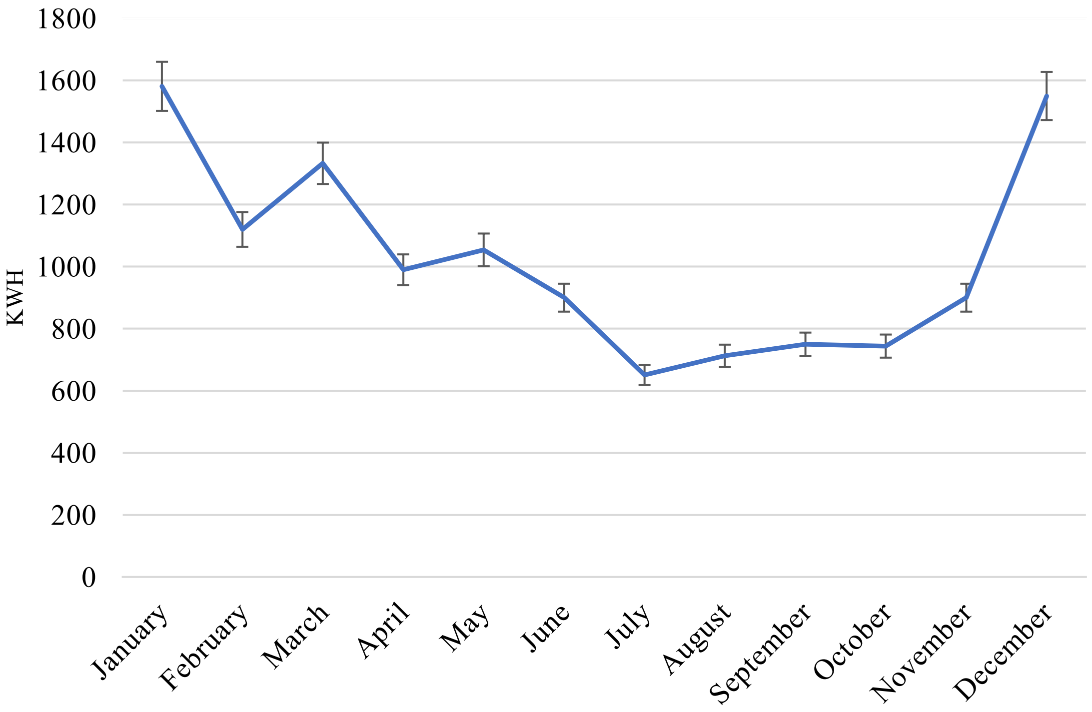


Figure 2-17 Average monthly power consumption of the selected site.

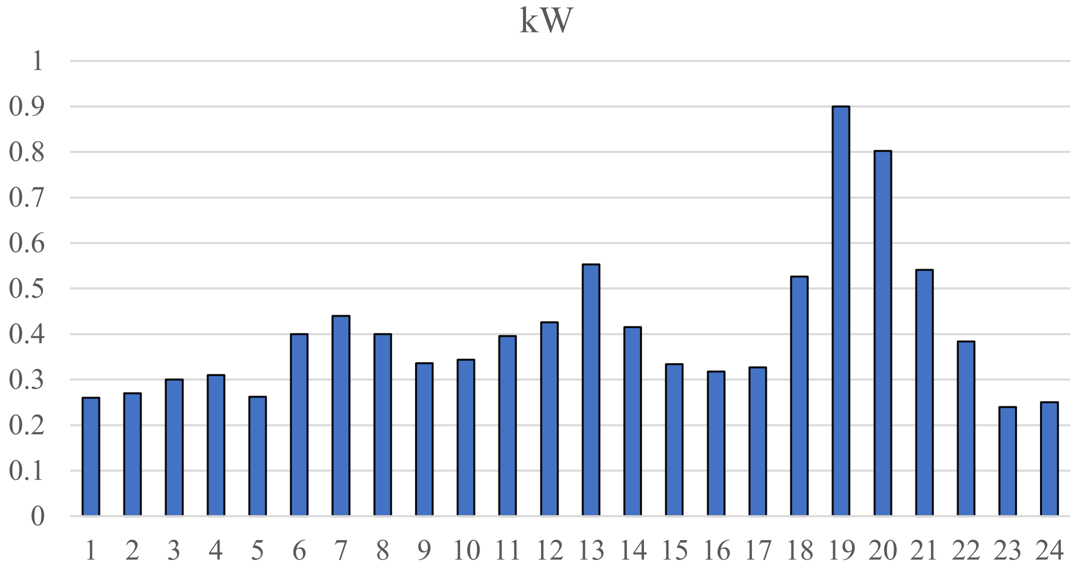


Figure 2-18 Average hourly profile of load in a day (scaled to 1kW).

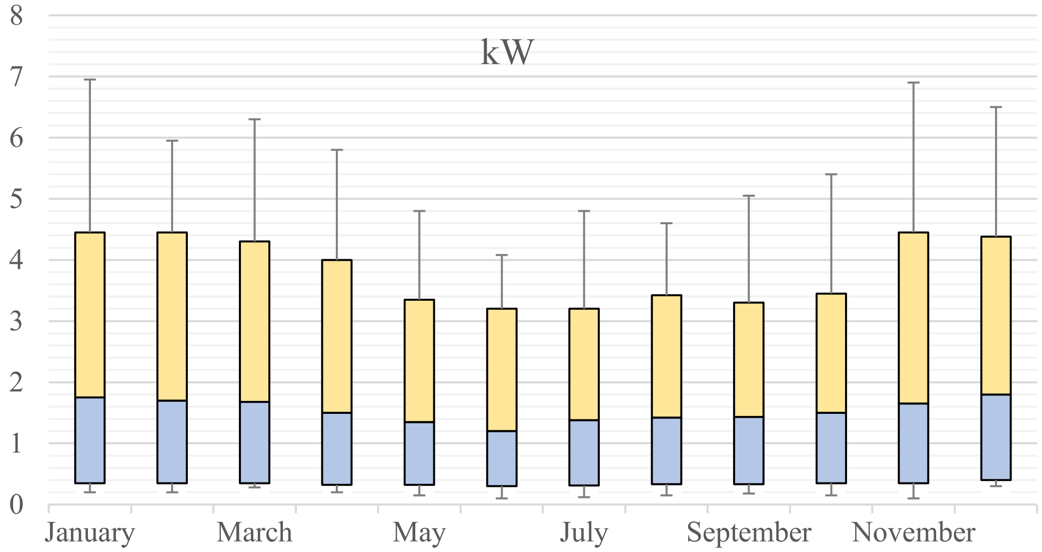


Figure 2-19 Approximated seasonal load data for the house.

Considering the data given in Figure 2-5, which shows the average solar potential of 3.15KWh/m^2/day. Whereas, the house selected for analysis has an area of $50m^2$. So, say η_PV=15%

$$Available\ energy = \frac{3.15\ KWh}{m^2 day}\ X\ 0.15\ X\ 50.1m^2 = 32.064\ \frac{KWh}{day} \qquad (1)$$

Equation (1) shows that the designed P.V. panels can produce enough electricity to meet the requirement of an average day. This methodology gives a rough estimation ignoring other losses involved in the system. To completely meet the load of the house, solar park has to be created to increase the capacity of the P.V. generation. An entirely different study needs to be completed on how a maximum area of a building and the characteristics of P.V. installation. Finally, after simulation of the system in PVsyst, and estimation, the sizing results are further verified using the Homer Pro tool.

2.5.1 System Specification and Optimization

For steady-state system analysis and optimized solutions, Homer pro software has been used. It allows the user to do sensitivity analysis with all the possible scenarios and gives the user the flexibility to quickly see the impact of on final results with a modified system to get desired optimized results. Now, considering a Grid-connected system structure as shown in Figure 2-20, integrated blocks selected in the Homer Pro software for simulation and optimization, where sensitivity analysis has been performed, generates over 1000 different combinations were analyzed. Finally, the best possible solution considering capital cost, operating cost, power rating, deterring factor and other variables.

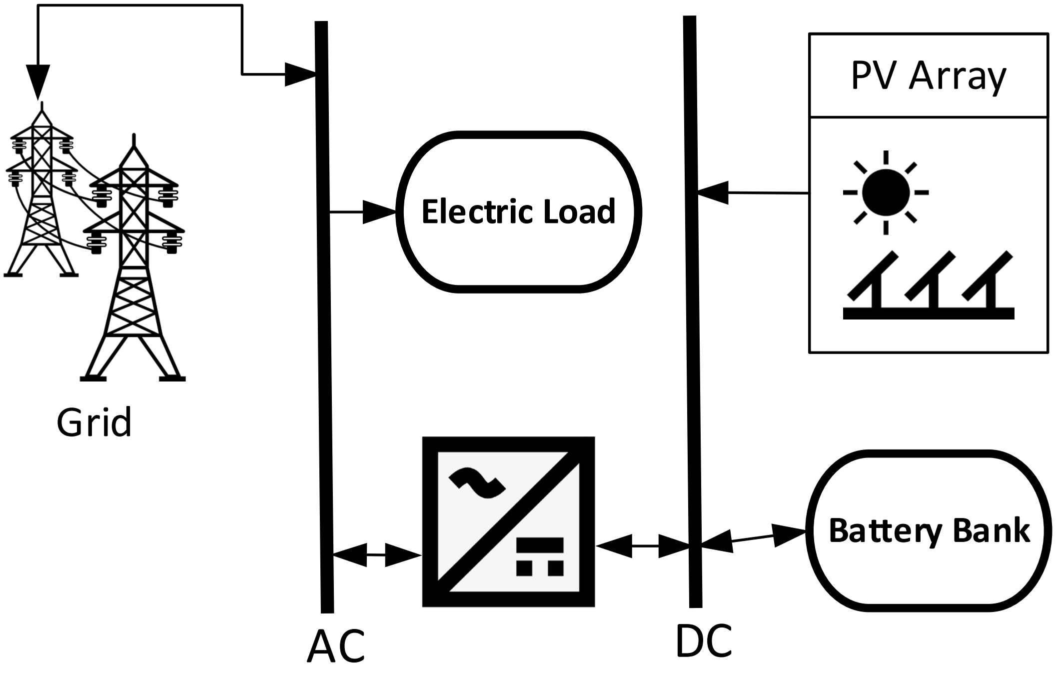


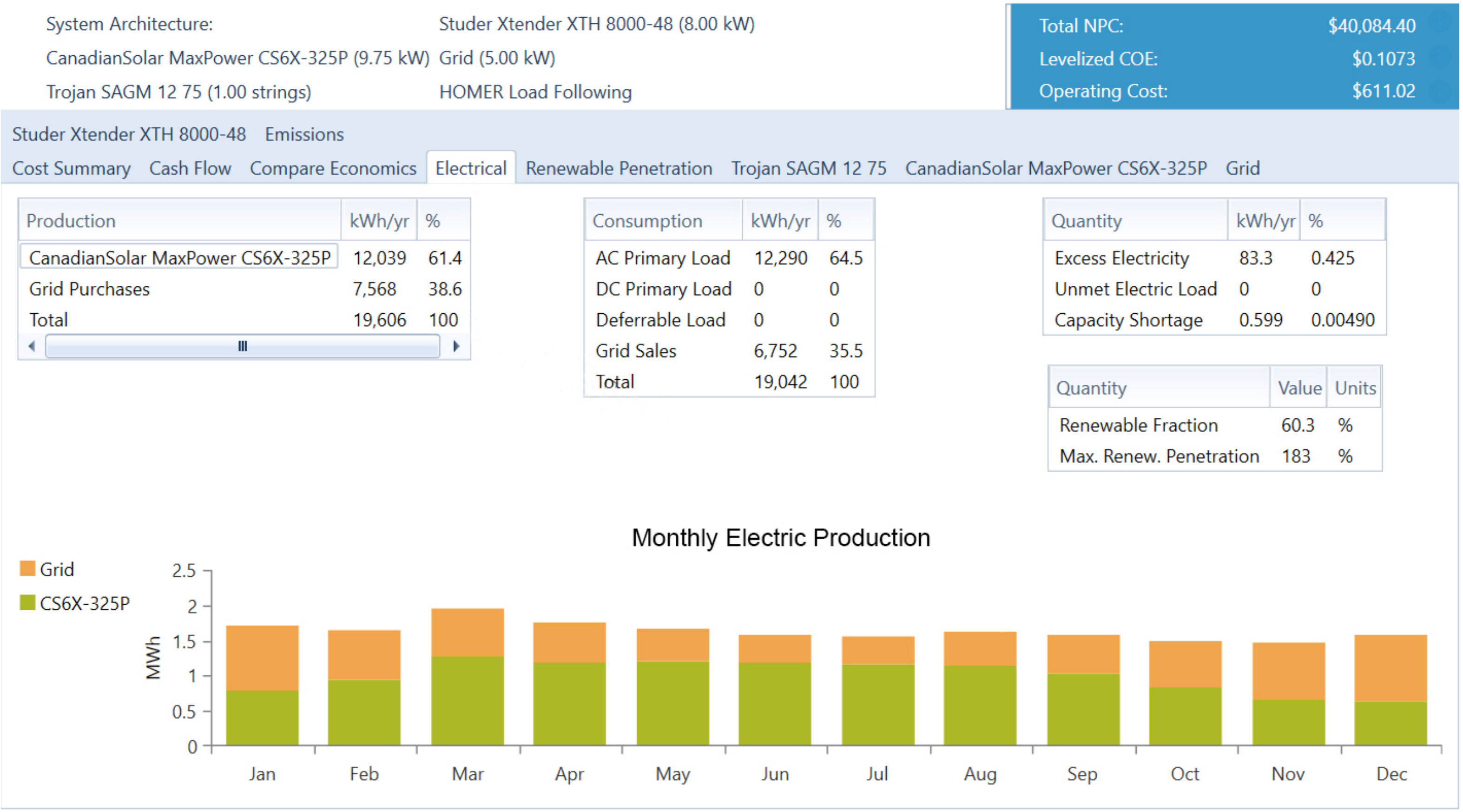
Figure 2-20 System dynamics considered for Homer pro optimization.

2.5.2 System Presentation

The selection of a solar panel mostly depends on the quality, price and availability in the local market. This module is 17% efficient with IEC 61215, IEC 61730, TÜV-Rheinland, UL 1703, IEC 61701 and IEC 62716 certificates. For simulation purposes, CanadianSolar (CS6X-325P) has been selected where an estimated one plate costs C$450, including installation cost. The detailed specification has been shown in Table 2-6. Figure 2-21 presents a detailed overview of the final result from optimization. Considering the urban setup, evolving load profile, calculation of shades of nearby buildings or trees and tilt properties of P.V. panel, other software like PVSyst, Solar Pro and SketchPro helps in optimization to calculate the closest estimate to practical values. Finally, the overall circuit diagram has been presented in Figure 2-22. The system has been tested and simulated according to the circuit flow and this Figure 2-22 represents the actual wiring diagram to be installed for the system.

Table 2-6 . System specifications.

Components	**P.V.**	**Converter**	**Battery**
Rating of each components	325W	8kW	SAGM 12V, 220Ah
Required number	30	1	4
Final rating	9.75kW	8kW	48V, 220Ah
Per Unit installation cost	$433	$11,500	$900
Total Cost	$12,990	$11,500	$3,600



System Architecture: Studer Xtender XTH 8000-48 (8.00 kW)
CanadianSolar MaxPower CS6X-325P (9.75 kW) Grid (5.00 kW)
Trojan SAGM 12 75 (1.00 strings) HOMER Load Following

Total NPC: $40,084.40
Levelized COE: $0.1073
Operating Cost: $611.02

Production	kWh/yr	%
CanadianSolar MaxPower CS6X-325P	12,039	61.4
Grid Purchases	7,568	38.6
Total	19,606	100

Consumption	kWh/yr	%
AC Primary Load	12,290	64.5
DC Primary Load	0	0
Deferrable Load	0	0
Grid Sales	6,752	35.5
Total	19,042	100

Quantity	kWh/yr	%
Excess Electricity	83.3	0.425
Unmet Electric Load	0	0
Capacity Shortage	0.599	0.00490

Quantity	Value	Units
Renewable Fraction	60.3	%
Max. Renew. Penetration	183	%

Figure 2-21 Hommer optimized results and parameters.

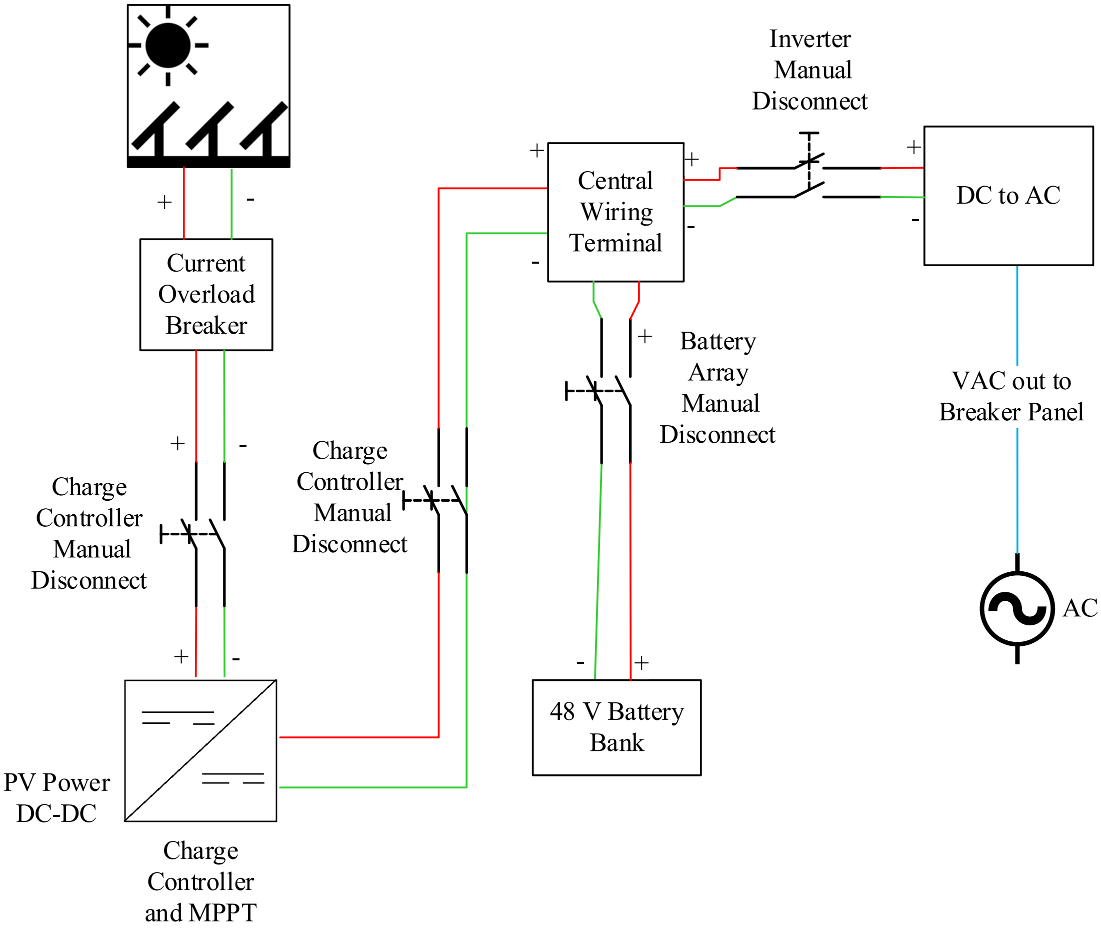


Figure 2-22 Proposed system circuit flow.

2.6 Conclusion and Future Work

A detailed analysis of the construction process and energy modelling of the first house in Newfoundland built on PHIUS+2015 guidelines has been performed. It has been discovered that the house does not only focus on cutting down carbon emission by extremely low heating and cooling demand, but also provides a sustainable solution for the environment of Newfoundland. This style of the house constructed with wood overall has a minimum amount of embodied energy [37], [38], overall, less carbon footprint over the period.

1. Comparing this house with a standard code build house in Newfoundland, there have been some materials like insulation, framing, attic, windows, and tape has been added extra that makes this house different than a standard house. After the cost analysis of the material and labour involved in the construction process, it was determined that additional material costs around \$46,500, which is 12% of the total cost of the house, including labour. So, it has been concluded that comparing the amount of energy saved for heating, this house will payback in less than 25 years and will contribute towards a sustainable living style.

2. Simulation analysis of the house was done using both static and dynamic simulation. After review of the simulation results for the house and results, it can be concluded that both types of tools provide their own unique capabilities. While dynamic simulation using the EnergyPlus engine requires detailed pre-planning of the house with a lot of parameters pre-defined and well known. Moreover, this type of simulation provides more accurate results, but it takes a considerable amount of time and tedious amount of work for setting up the simulation environment. On the other hand, WUFI provides more easy to follow approach to a small house in retrofitting with passive house standards.

3. The proposed renewable system for the house understudy is going to add a lot of value

in terms of sustainable living and solar resource consumption for a low carbon footprint. Considering the Net-Metering rules for Newfoundland, this system has the benefit of producing around 64% of electricity on its own. From the Homer Pro optimization tool, it has been seen that the system has a payback period of approximately 22 years, which includes the estimated maintenance cost and estimated quotation of the pricing and installation cost. Overall, despite having fewer solar resources and other limitations, this system is a feasible and essential part of the modern standards of future sustainable models of the house. Furthermore, for future work, effect of humidity and wind speed on production can be studied [39] and, for a similar house at a remote location; a hybrid system [40] with improved wind turbine system [41] and intelligent optimization system [42] can provide more promising alternative energy solutions.

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Chapter 3

Dynamic Modelling and Simulation of the Rooftop Photovoltaic System for the First Passive House in Newfoundland

Preface

A version of this manuscript has been peer-reviewed, accepted and presented in the conference proceeding of the ***International Conference on Enhanced Research and Industrial Application (2020).*** *I am the lead author who conducted literature reviews, planned, modelled, and simulated the method and evaluated the findings. I have written the manuscript's first iteration and then revised the final manuscript based on the co-author's input and the peer-review process. Dr. M. Tariq Iqbal, as a co-author, directed the study, revised and corrected the manuscript, and contributed to the actualization of the manuscript with research ideas.*

Abstract

This paper presents the design and modelling of a photovoltaic (PV) system for the first house in Newfoundland built under the guidelines of the Passive House Institute United States (PHIUS+2015). The proposed PV system is optimized with the use of HomerPro software to get 9.75kW of PV panels with a battery storage system. Detailed modelling of the system is finally completed in MATLAB/Simulink with the implementation of a charge controller, MPPT controller, and 8kW of single-phase D.C. to A.C. converter. The simulation results show the stability of the system and the advantage of the Grid-connected PV system with a battery backup. System design, detailed modelling and some simulation results are included in the paper. Finally, The cost of the designed system has been compared with the electricity bills considering saving and using Homer optimized results; the feasibility of the proposed system is presented.

3.1 Introduction

With the gradual improvements in renewable energy technologies and increasing concerns related to climate change, there is increasing interest in renewable energy production solutions for the cold climate like Canada. Especially with a considerable amount of wind resources, it is possible to implement a wind generation system to meet the energy needs of a house in Newfoundland [1]. A micro-hydropower generation system could also be an option depending on the location. The usage of solar resources as a renewable energy generation with the help of the Photovoltaic (PV) systems is also of interest. In this study, all possible solutions for renewable energy production with the focus towards the photovoltaic and effects of snow have been explored and discussed in detail for the first passive house built in the cold climate of Newfoundland, Canada. Load analysis and site analysis for the passive house, along with an appropriate grid-connected renewable electricity generation system, have been performed using computer simulation tools for sizing and optimization.

Considering the extreme need for a low carbon footprint, a transition to efficient housing that uses renewable energy sources can make a considerable contribution. The idea of a substantial reduction of residential energy consumption was developed in 1990, where the first passive house was built [2], and this idea has been voluntarily followed throughout the world. Although local building code for the selected site offers considerable energy savings but following strict standards of PHIUS can prove to be a vital step towards sustainable living. Furthermore, it is not uncommon for the installation of a PV generation system in cold climates. In some cases, the performance gets better than extremely hot climates [3] because drawing current from solar panels increases temperature hence reduces efficiency [4]. Generally, in cold climates, snow is a big issue for PV energy generation systems, but overall yearly production losses from the snow covering the panels have been found to less than 35% [5]. It has also been known that during winter months when the snowfall is at its peak, monthly PV production losses could reach up to 100% [5], which is alarming yet dependent on many factors like:

1. The angle of a solar panel.

2. The outer surface of the PV plates.
3. PV plates frame to hold or allow snow slip from the plate.
4. Fluctuation in variables like temperature, wind and humidity to enable freezing rain or block the area of the plates.

The efficiency of PV panels can be enhanced by either following the principles of self-consumption [6] and manual snow clearing from the PV panels or by implementing snow removal technologies with active heating and snow melting [7], [8]. There are few related examples which use a similar bottom-up approach and comparison with the simulation of the computer-aided model [9], to visualize the overall consumption of a unit throughout the year to build on Net-Zero-Energy-House [10] and also the strategies of retrofitting efficient energy consumption techniques where the climate get hostile and extremely cold [11]. Still, detailed system design and modelling are required that shows easy steps of designing a complete model.

3.1.1 Approach and Methodology:

Firstly, a detailed site analysis and load analysis of the site had been performed. After that, historically collected load data was inserted into the Homer Pro software, and the sizing of the optimized system was completed with sensitive analysis among the thousands of possible combinations. The optimized system was then verified using PVsyst software, and cost analysis was performed. Finally, the control system for the selected system was designed with MPPT, charge controller, DC boost converter, and tested using MATLAB /

Simulink tool with the requirement of according to the Newfoundland powers guideline. Finally, the system was verified by creating a fault in the grid and tested for islanding mode. In other words, the system should not produce any electricity if the gird was shutdown.

3.2 Site Analysis

This study focuses on cold climate areas like Newfoundland winter gets extremely cold, and yearly snowfall reaches more than 250cm [12]. The first step is to study the options for alternative energy, and only micro-hydro, wind, and solar energy have been found to be feasible [13]. Occasional high winds in the area increase the risk factor and public safety concerns in the residential area [13]. So, one of the most suitable alternative energy production options is the PV system due to its affordability and ease of use. There are three main types of photovoltaic power system for residential electricity generation:

1. A grid-tied solar power unit
2. Grid-tied solar power unit with battery backup
3. Stand Alone or off-grid solar power unit

All solar power systems are designed as per the requirement of the user. A grid-connected system is designed with battery backup to make it failsafe against local grid failure [14]. Furthermore, a modular system has been designed and presented [15], which can be expanded later on. This system is also tested according to the guideline of the local grid-tie handbook.

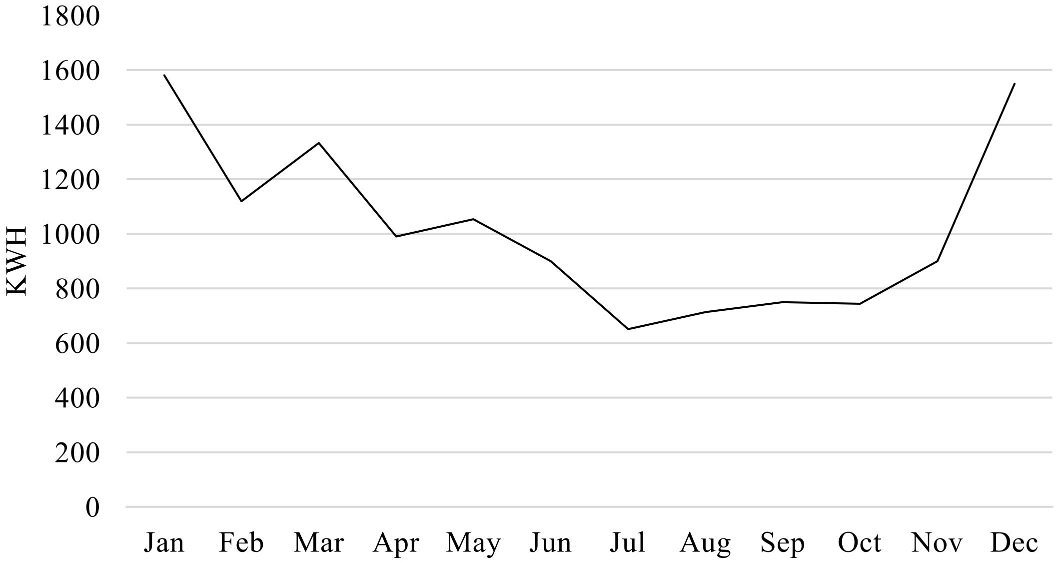

Figure 3-1 . Average monthly power consumption of selected site.

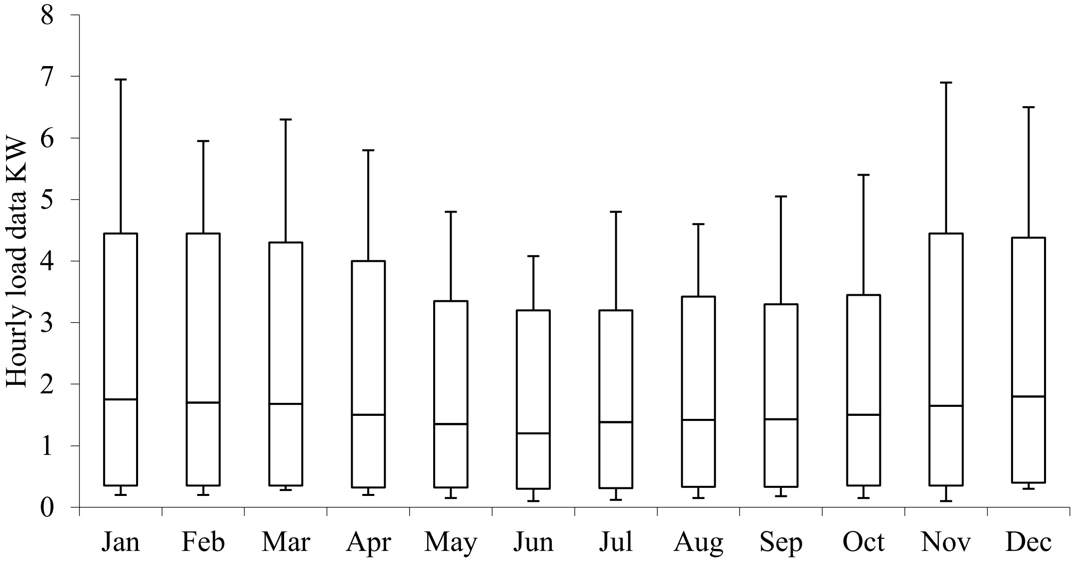

Figure 3-2 Approximated seasonal load data for the apartment.

3.2.1 Load Analysis

By looking at the average of the last two years' energy consumption data for the selected site, as shown in Figure 3-1, it is visible that the peak months are January and December. Figure 3-2 shows the hourly seasonal load data approximated using the reports generated by the smart meter. It also shows similar trends in peak load values in the winter season when solar irradiance is lower than the yearly average [1]. For this reason, the Grid-tie inverter system is going to prove useful where excess energy can be sold back to the grid in summer. The main consumption of electricity is for water heating and other home appliances. Currently, a combination of wood and electric heating system is being used for the passive house. A separate study can be completed for solar water heating systems or sub-soil heating for more sustainable living.

3.2.2 System Optimization and Cost Analysis

For the first step towards the system sizing, HomerPro software has been used for steady-state system optimization and analysis. This software gives the user the flexibility to have multiple sensitivity analyses at the same time while the ability to quickly see the impact of each variable for all possible scenarios. Figure 3-3 shows the overall proposed system. For simulation purposes, CanadianSolar (CS1H-325MS) has been selected, where an estimated cost of solar panels has been selected to be $12,990. For Battery backup, one string of 4 batteries with 12V-220Ah rating has been used with an average cost of $3,600. Overall converter cost with installation has been selected $11,500 in HomerPro for optimization, and Studer Xtender XTH 8000-48 has been selected for the HomerPro optimization. After adding up all the costs, average operation/maintenance costs and replacement costs in the HomerPro, a final price of $40,084 has been estimated with yearly operating costs around $611. Now, by selecting an optimized system cost and dividing it with the estimated electricity bill saved. The payback period of the system is calculated to be 21.5 years, while the system can meet 64.5% of electricity needs. The expected life of the system is 25 years, and the cost estimates include operation and maintenance costs also replacement costs.

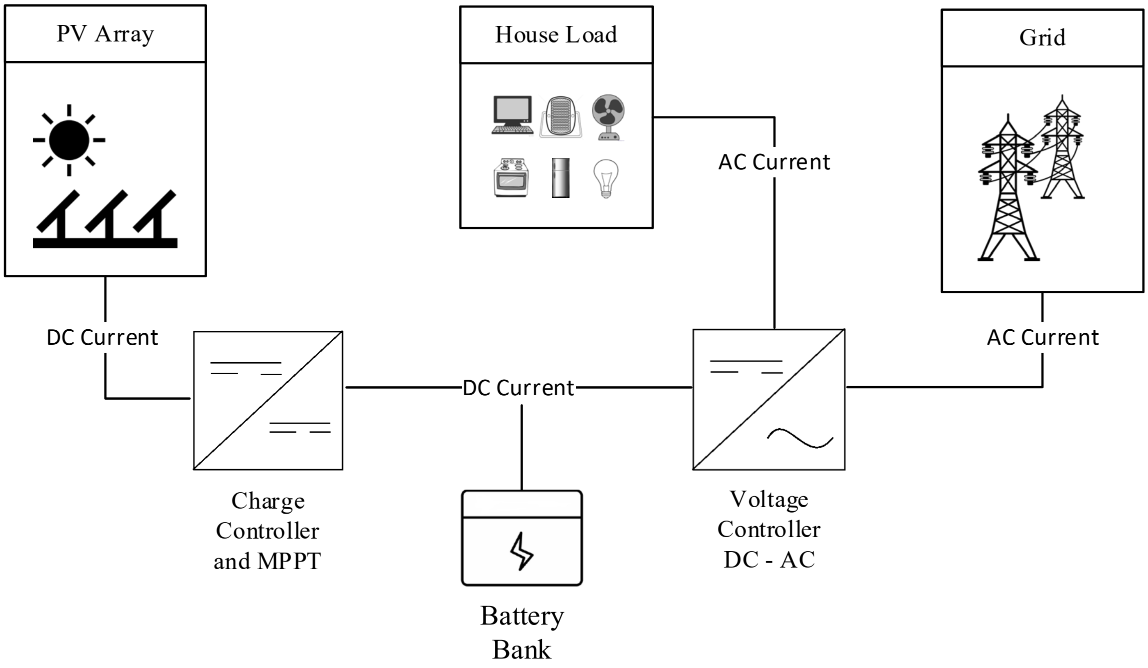

Figure 3-3 System dynamics of the proposed system.

3.3 Detailed System Design

After a detailed analysis of the system, analyzing similar system dynamics [16]-[18], a controller has been designed similar to [19], also shown in Figure 3-3. Previously, it has been concluded that the most optimized solution, as shown in Figure 3-4, is to have a Grid-Tie system with MPPT and battery controller. The system is connected to the grid, and the most challenging part is to have a controller designed to match the frequency of the grid; THD should be less than 0.1%, so, for this purpose, a generalized study helps implement ways to reduce error and to reduce harmonics[20]. Conclusively, a hybrid PV inverter, is going to feed the local load and the grid. As the system used an AC circuit breaker for anti-islanding protection. This system can be further integrated for DC coupling if the grid has turned off, eventually using the leftover energy for the critical loads.

3.3.1 System Presentation

The presented system model of PV solution, composed by:

- CS1H-325MS PV module with the parameters is shown in Table 3-1, and the total available power to the maximum of 9.75kW as optimized in HomerPro.
- Boost converter system has been presented to step-up the voltage of the PV system to 48VDC, which makes the system scalable for future usage with multiple sub-systems and loads.
- Feedback and Phase-locked loop system with self-filter output.
- A single-phase coupling system with anti-islanding protection.
- Controller blocks have been used to track maximum power point and to control the magnitude, frequency, and total harmonics disturbance with VLL = 240Vrms

and the grid frequency to be 60Hz.

Figure 3-4 represents the flow that has been simulated in Matlab/ Simulink. The system has all the blocks mentioned above, with the flow of each block representing the respective module explained below. Table 3-1. Provides some PV specifications.

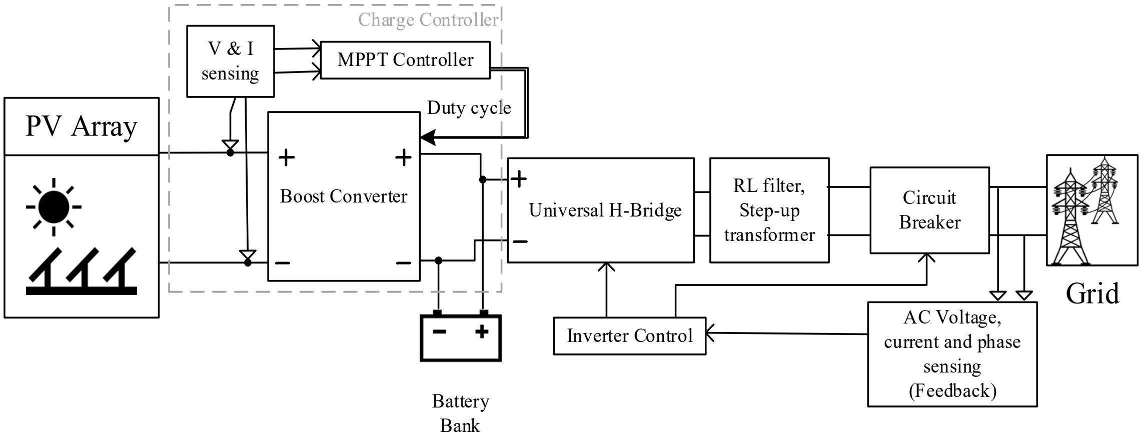

Figure 3-4 Complete model of proposed system as simulated in Simulink.

Table 3-1 Canadian Solar (CS1H-325MS)

Parameters	**Index**	**Values**
Maximal power	Pmax	325 W
Open circuit voltage	Voc	45.5V
Short circuit current	Isc	9.34A
Voltage at MPP	Vmp	37V
Current at MPP	Imp	8.78A
Weight	W	42lbs
Type	Polycrystalline	16.94% efficiency
Dimension	L x W x H	76.9’’ x 38.7’’ x 1.57’’

3.3.2 The PV System Modelling and Maximum Power Utilization

Photovoltaic panels are inherently a DC power source and composed of a lot of small PV cells that assemble up to become a PV panel. The equivalent circuit of a single photovoltaic module is shown below in Figure 3-5. This power source can be indicated by a current source in anti-parallel with a diode, and other non-idealities, as shown in Figure 3-5, are indicated by Rs and Rsh. PV arrays are composed of several PV modules to produce the desired level output. Equation 1 shows the I-V characteristics of the PV panel [21].

$$I = I_{pv} - I_0 \left[exp \left(\frac{qv}{akT} \right) - 1 \right] \qquad (1)$$

PV array has been represented in Figure 3-4, and the MPPT controller has been represented, giving duty cycle signals. At only one-point PV panel is supplying maximum output power, which is dependent on the load and current and voltage sensing going to help determine that. To get maximum out of the panels, Incremental Conductance based MPPT algorithm has been implemented, which provides robust power point tracking. The algorithm is illustrated in Figure 3-6, which basis on dI/dV at Maximum Power Point (MPP) should be zero. Voltage and Current are sampled and plus width modulation is regulated to calculated dI and dV. The MPPT regulates the duty cycle and PWM for the control signal until the condition dI/dV + (I/V) = 0 is satisfied [21].

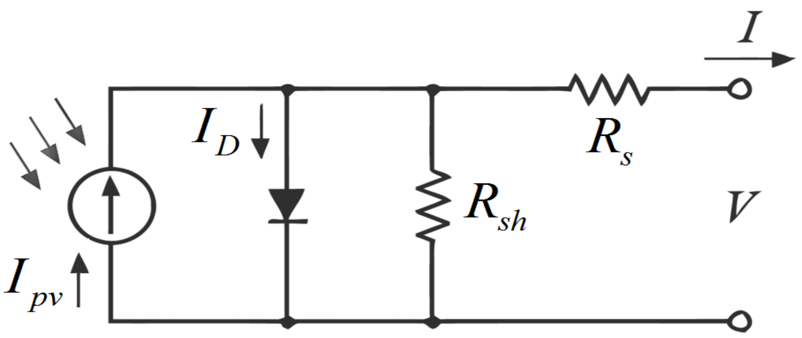

Figure 3-5 Photovoltaic module equivalent circuit.

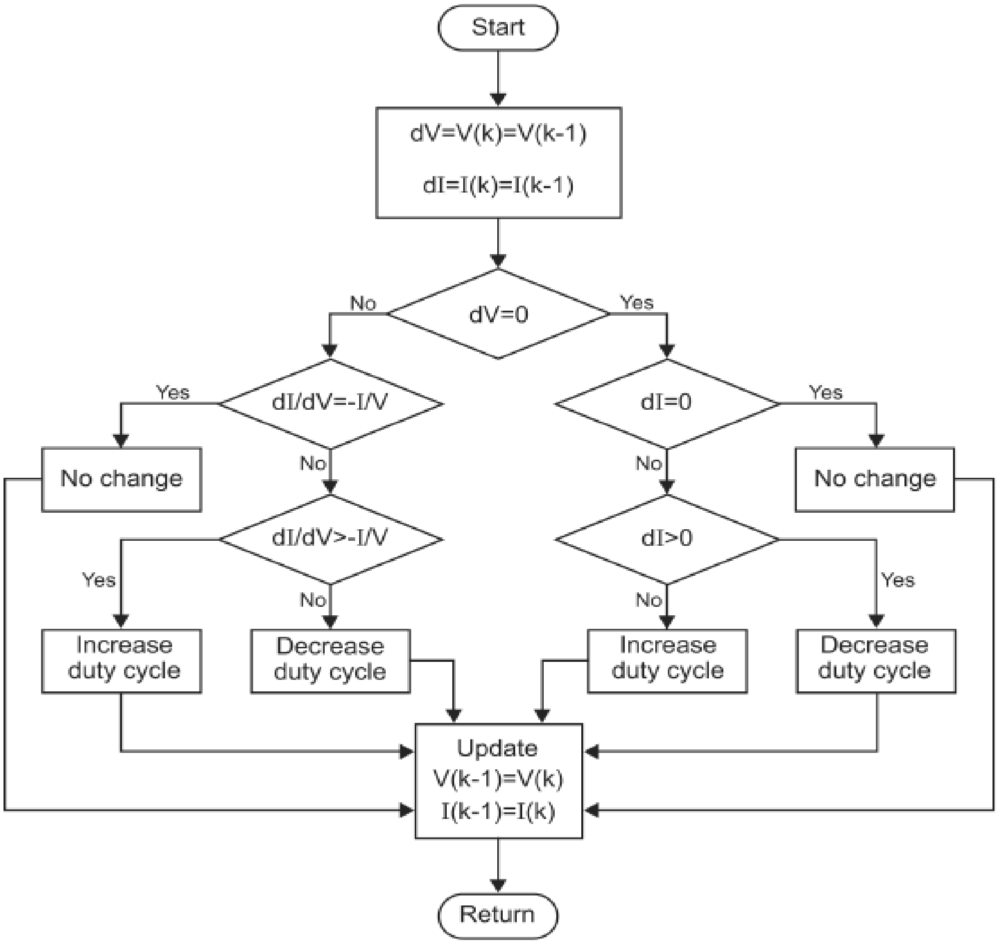

Figure 3-6 Flowchart of incremental conductance algorithm [21].

Following is the quick explanation where the maximum power point is achieved when:

$$\frac{\mathrm{d}P}{\mathrm{d}V} = \frac{\mathrm{d}(V * I)}{\mathrm{d}V} = I \tag{2}$$

$$\frac{\mathrm{d}I}{\mathrm{d}V} = \frac{-I}{V} \tag{3}$$

where P = V*I

dI, dV = components of I and V ripples measured with respect to time and I , V = mean values of V, and I measured with a sliding time to supply the adjusted duty cycle to track maximum PowerPoint.

3.3.3 Boost Converter:

In this system, diode and IGBT have been used for voltage setup. The average inductor current is higher than the average output current in boost converter [22]. When the switch is on, the inductor starts to store the energy with the increasing flow through the inductor, and the stored energy is dispatched when the IGBT switch is closed. Consequently, the average voltage across the load is higher than the supplied input voltage. Figure 3-7 shows a diagram of the boost converter implemented.

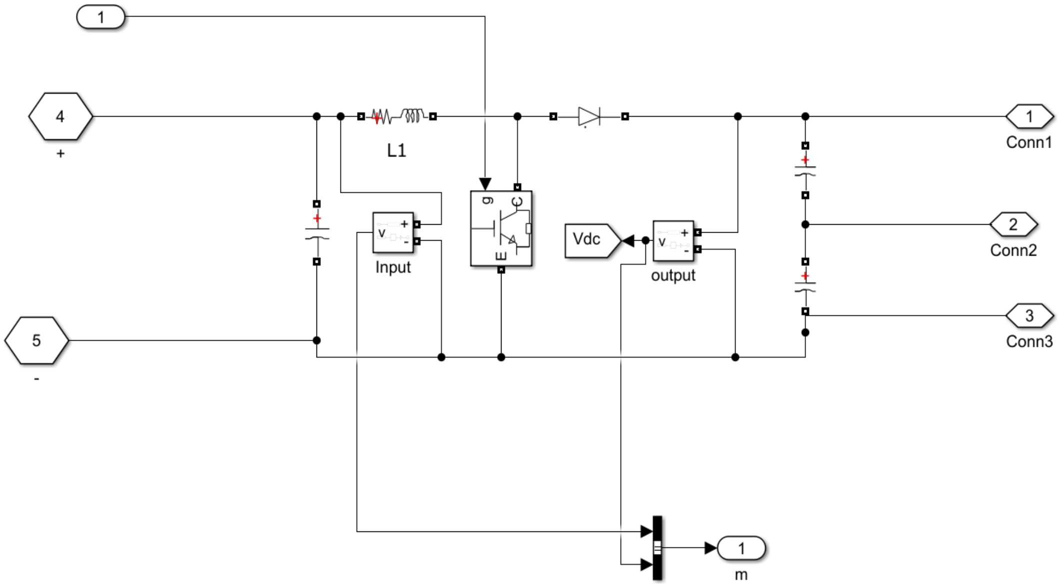

Figure 3-7 Boost converter as simulated in Simulink.

3.3.4 DC-AC Controller:

To feed current to the grid, DC current supplied by the PV system is to be converted into Vac that must have exact parameters as the grid. Vac converts 48 VDC into AC pure sine wave. It consists of two feedback control loops:

- An external control loop that regulates DC link voltage to 48V bus.
- An internal control loop that regulates grid currents.
- The control system uses a sample time of 100 microseconds for voltage and current controllers.

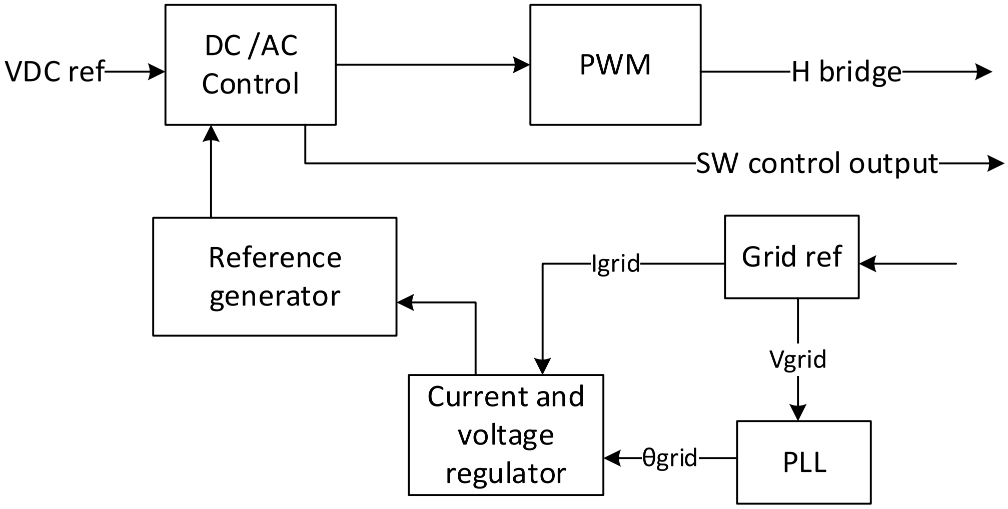

Figure 3-8 Block Diagram of inverter control.

DC to AC converter aims to produce a sinusoidal wave AC output with controllable magnitude and frequency. As can be seen in Figure 3-8, inverter control takes input from VDC reference and reference signal generator and generates a pulse width modulation (PWM) to control H-bridge. It also takes feedback from the grid to match the phase and regulates voltage and current. Finally, it generates the corrected PWM, which eventually contributes to synchronizing the inverter to the connection of the main grid.

Boost converter and Vac converters use pulse width modulation, and fast sample time to achieve appropriate resolution of PWM waveforms [24]; on the other hand, islanding is a phenomenon when PV generated, and grid-connected inverter system delivers power to the load and the grid even the grid has been shut down after failure. This power injection to the grid may cause harm to the workers working on-site [25]. So, according to Canadian and European standards (VDE 0126-1-1) [26], the detection of the Islanding and PV system is expected to disconnect from the grid in case of grid lost the power. High-speed AC circuit breakers [27] are capable of disconnecting circuit PV generation systems from the main grid [28].

3.4 Simulation Results and Discussion

As represented in Figure 3-4, the simulation of the system has been performed through MATLAB / Simulink softwareR2020a. PV panels consist of 15 parallel and two plates in series, which is then stabilized at 48V with battery array. This PV energy produced is fed to closed-loop controller sync up with the grid eventually. Figure 3-10 and Figure 3-11 shows the power being supplied to the grid with the 3kW of the load as a standard operating condition. Figure 3-9 shows the variable solar irradiance provided and a constant operating temperature of 15^0C is feed to the PV array. Figure 3-10 shows the maximum power supplied to the grid at the conditions mentioned.

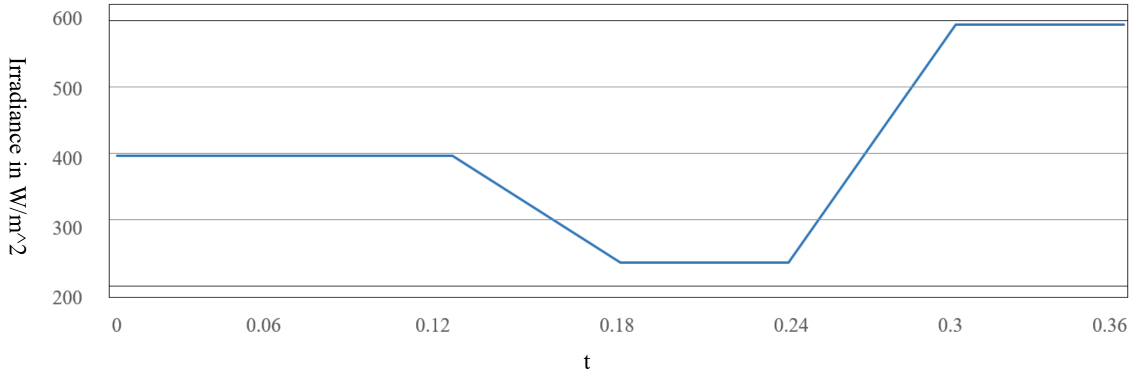

Figure 3-9 Solar irradiance input.

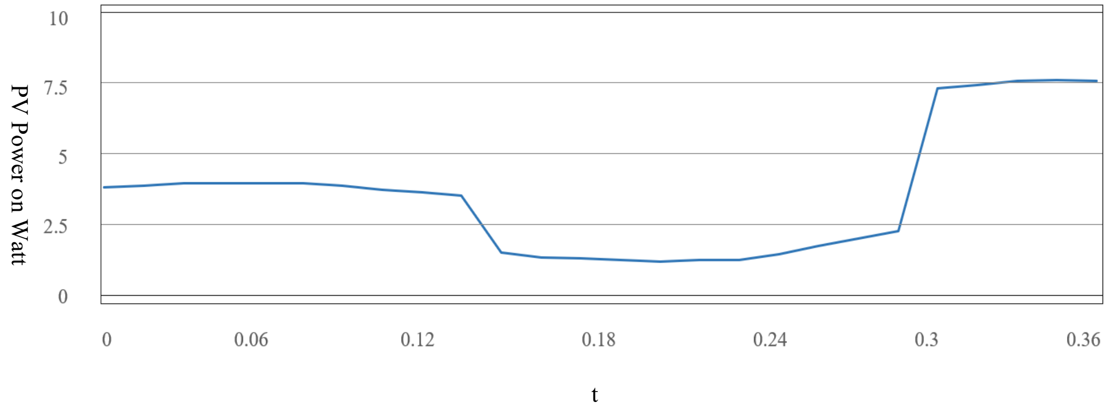

Figure 3-10 Output power supplied from the PV array.

Figure 3-11 shows the output sinusoidal waveform of the inverter output. After there is a fault in the grid, and the switch control output is activated with the help of Active Frequency Drift [25], and power flow is controlled with the use of a responsive circuit breaker; hence the inverter is disconnected. Figure 3-12, shows the dynamic response and the output at the point of common coupling.

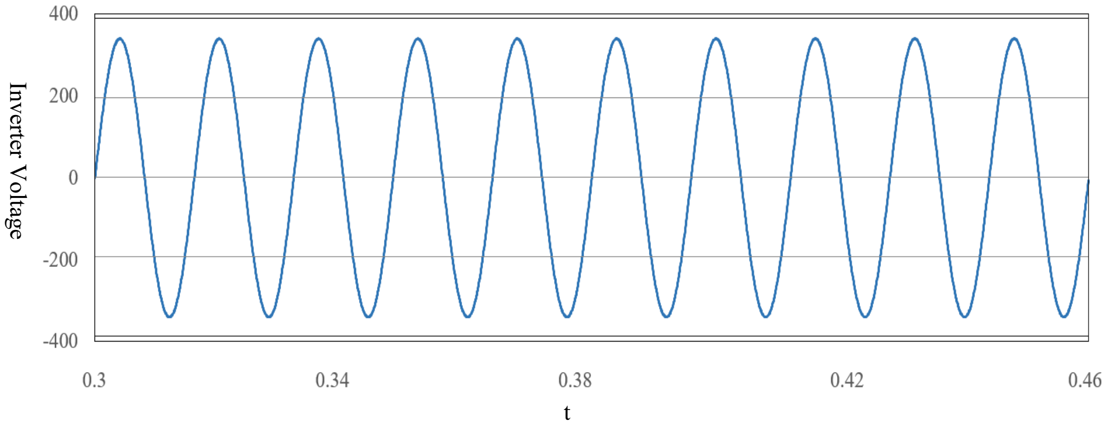

Figure 3-11 Voltage supplied to the grid.

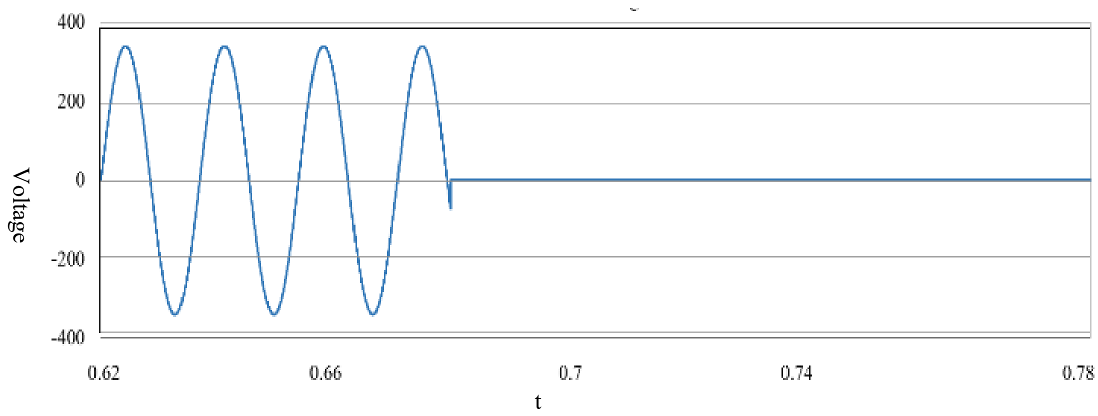

Figure 3-12 Voltage at the point of common coupling upon a grid failure.

3.5 Conclusion and Future Work

For the passive house understudy, this renewable system is going to add exceptional value in terms of sustainable living. As the net-metering rules for Newfoundland in place and being able to use solar resources for low carbon footprint, this system can self-produce up to 64% electricity as an added advantage. The payback period is going to be 21.5 years, including operation cost as optimized in HomerPro. This system is an essential part of the modern standards of futuristic sustainable house models despite having some limitations, including snow clearing and uncertain solar resources.

This study gives detailed dynamic modelling, load analysis, sizing and optimization of a single-phase, grid-tie, and islanding protected PV electricity generation system. This unique feature can be utilized with distributed generation systems as well as coupling with stand-alone systems. After disconnecting from the grid, this system has a battery bank, which can be used to power up critical loads. In the given case study, reach up to high value and battery bank is not enough to provide long term backup. So, either a backup generator or a larger battery bank can be added with this, which may add an extra cost to the system.

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Chapter 4

IoT Based Renewable Energy Management and Monitoring System for the Frist Passive House in Newfoundland

Preface

A version of this manuscript has been reviewed, accepted and presented in the conference proceeding of the ***The 29th Annual Newfoundland Electrical and Computer Engineering Conference, IEEE.*** *I am the lead author who conducted literature reviews, planned, modelled, and simulated the method and evaluated the findings. I have written the manuscript's first iteration and then revised the final manuscript based on the co-author's input and the peer-review process. Dr. M. Tariq Iqbal, as a co-author, directed the study, revised and corrected the manuscript, and contributed to the actualization of the manuscript with research ideas.*

Abstract

This paper presents a prototype of an Energy Management and Monitoring System (EMMS) for the first house in Newfoundland built under PHIUS+2015 standards. The

proposed Supervisory Control and Data Acquisition (SCADA) system is based on the Internet of things (IOT) and is designed to minimize electricity usage through self-consumption. It comprises of PZEM004T current and voltage sensor with ESP32 as the first layer controller. The controller also has control relays and a web-based monitoring and controlling platform using Ubidots development platform. The overall system can be controlled and monitored remotely with advanced web-based systems powered by Ubidots and set up triggers for excess usage of electricity by the boiler system. The user can then manually load the wood into the boiler to reduce electricity consumption. Overall, this system is scalable and can be implemented to transform the house into a smart home, which will eventually generate cost savings and promote sustainable living.

4.1 Introduction

Electricity is the most useful form of energy, and the current lifestyle has been dependent on electricity. Recent trends have shown that solar electricity generation, with the help of a Photovoltaic (PV) system, is one of the most economical sources of alternative energy. PV Self-consumption methods have proven to be the only way to efficiently utilize electricity produced from solar energy [1]. Not only this, but there are multiple other reasons why monitoring and controlling energy produced from solar energy could be highly beneficial in both domestic and commercial environments. Several data acquisition and monitoring systems have already been developed, which are either expensive or not customizable. To address this problem, a low-cost Supervisory Control and Data Acquisition (SCADA) has been designed and produced, which can take input from multiple things (sensors, controllers, etc.) and present on a dashboard to analyze and perform specific tasks according to the requirement.

Supervisory Control and Data Acquisition (SCADA) is a technology that provides users with real-time data exchange in a control center and things/devices working in the field. The proposed SCADA system has been implemented to monitor and control components of the already designed renewable energy system. So, this proposed system can be considered as a master controller to the existing renewable energy generation grid-tie system. The design of the system mainly consists of an examination, collection and processing of data in real-time and the overall energy management system consists of three main components;

- The Master Logic Controller (MLC)
- Remote Terminal Units (RTU)
- Human Machine Interface (HMI)

The logic controller can also be considered as a master control for all components involved. This controller also helps create a bridge between the FID and RTU. FID consists of sensors, actuators and intelligent signal processing modules, and there can be multiple FIDs communicating with the central controller, which is ESP32 development kit in this case. These FIDs can include but are not limited to sensors such as power measurement, in this case, relays acting as actuators, and other switches/devices installed. RTU can also be a part of each device and has its own Human Machine Interface (HMI) system to give control to the user. All these devices send data to MLC, and then data is communicated to the SCADA system through a secure SCADA communication channel and stored on the cloud and used by the central HMI system, which is powered by Ubidots in this study. Eventually, the user can use this SCADA system to monitor and control all connected devices remotely using either a computer or mobile app using an HMI platform where all the variables and controls are displayed in real-time and chart can also be observed to view the history of the data. This HMI sends instructions back to the MLC to either turn on or off.

4.2 Literature Review

SCADA systems are one of the most important parts of solar energy and renewable energy production systems.[2] The main problem with the advanced SCADA system is the associated high price tag and compatibility issues, which makes it difficult for small-scale users and research communities all over the world to strive to develop more accessible and advance SCADA solutions [3] with each having different functionalities and varying cost. For a low-cost, open-source SCADA system using the Arduino Uno controller with the Zigbee radio module to transfer the data has been studied. The data is collected from different devices such as temperature sensors, flow sensors, pumps and control valves and software developed in java. This data is used to generate reports with an overall system that is not compatible with a number of low power controllers. Another study [4] uses a slightly different approach by using a system developed in Python. This system uses three layers approach similar to our proposed system but using Python Open Platform Communication Unified Architecture and MySQL database language. Raspberry Pi3 and PLC are also added for control and supervision layers, respectively. This system design has greater power consumption than the proposed system. There have also been attempts to use low power electronics ESP32 boards to develop the SCADA system [5]. This study uses a subscription-based HMI system that limits the number of devices for free users, and pricing depends on the number of devices added to the system. Other studies using SCADA technology for devices/things connected through the Internet have been found to have a similar concept with implementation using Honeypots [6]. Cloud-based Amazon Web Services (AWS) have also been reviewed [7] in comparison to the private network-based system [8], which does not give a whole lot of flexibility to the end-user for IoT management.

Studies have also been reviewed, which are using artificial intelligence for automated control of all the devices connected in a house, which can also be called the Internet of Things (IoT). In this methodology, less control to the end-user is given for manual control of the devices [9], which can be programed afterward using hybrid simulation system prototypes that has been studied [10]. Transferred data of the daily usage and patterns can be stored in huge databases to train and optimized machine learning algorithms [11] for high accuracy and automated control to save energy expenditure for cost saving in an IoT based smart home system.

An advance approach seen in the previous study [8], which has also adopted in our project, is to combine different small scale RTUs to communicate to a central SCADA system [12] and using an open-source SCADA system can save cost and time for development and gives flexibility to the end-user to add more functionality on the later run. Mayur et al. [13] and Ikhsan et al. [14] has proposed an open-source system using micro-controller AtMEGA 2560 with SCADA Vijeo Citect and ArchestrA System Management Console, respectively. As the RTU operates independently operated with either own controller collects data from sensors and using the Modbus protocol as the communication channel between the MLC and the RTU. Similarly, authors in recent studies [15], [16] have developed a low-cost SCADA system based on IoT technology, where RTU is communicating through TCP/IP to the field devices, which eventually is managed by a data traffic management system process. The major problem with these types of designs is as the system gets complex with multiple devices, it would be difficult for an end-user to troubleshoot.

4.3 Proposed SCADA Design

The system proposed system architecture is based on a SCADA system that incorporates IoT using a low-cost ESP32 microcontroller and implementing recent research SCADA architecture discussed earlier [5], [8], [12], [15]. For a general understanding of the system, Figure 4-1 presents a high-level description of where the proposed approach is represented as an Energy Management System (EMS). PV array inputs the inverter MPPT, which is then converted into pure sine wave AC to supply to the grid as well as house load, including a water heating system. There is a gird-tie inverter that supplies excessive energy to the grid as well as takes the energy from the grid when there is not enough solar irradiance to produce enough power for the connected load. This DC generated power is fed to the battery bank and also provided to the energy management system. There are current sensor and voltage sensor, which gives the analogue signal to the Master Logic Controller (MLC) with a built-in analogue to digital converter. MLC consists of KeeYees development board 2.4GHz Dual Core with WLAN WiFi capabilities with Microcontroller ESP-WROOM-32 Chip CP2102 for ESP32.

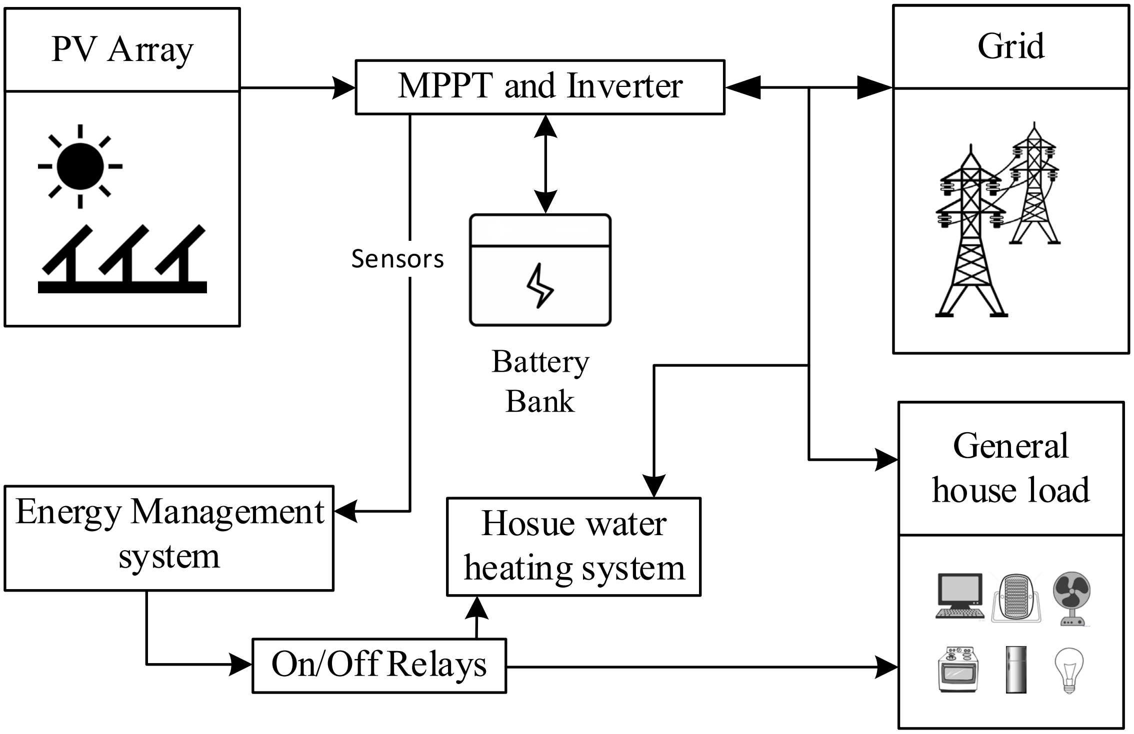

Figure 4-1 High-level design of the complete system.

The other task for the MLC is to get energy consumption data for the water heating system and display it on the HMI system. Part of this HMI system consists of a dashboard board powered by the Ubidots IoT platform and free for educational use. This HMI system will let the user see the historical data and control specific home appliances which are categorized under non-critical load for the house. The overall approach is explained in the following section.

4.3.1 Working of the SCADA System

To understand more in-depth, EMS shown in Figure 4-1 can further be expanded into Figure 4-2, which represents a more detailed version of the proposed system. Here it can be seen that power consumption from PV is monitored with ACS172 current sensor and voltage divider circuit for a level of voltage. This parameter is later used to monitor the power supplied by the grid. If there is a significant drop in power while it is still daytime, it is clear that there is snow blocking the PV panels, and the manual process of snow clearing is initiated by sending an email to the house owner. This HMI system is flexible enough to give freedom to an end-user with other ways of notification since the data is already being monitored.

Secondly, power consumption by the water heater is also monitored by the MLC with the help of PZEM-004T 3.0 version TTL Modbus-RTU power meter. This power meter has a measurement accuracy of 0.5% and can measure AC current up to 100A with other variables like voltage, power and frequency. This water heater uses both wood and electricity for water heating, so there is a potential to monitor and save electricity if it is being used more than usual. Also, other house loads can be controlled and monitored from the Dashboard of the SCADA system. Instead of publishing the value on the Dashboard, Ubidots and Arduino library for ESP32 let you subscribe to the variable for continuous monitoring and control of the variable. As this variable changes values from the Dashboard when the user decides to turn off/on a switch remotely, ESP32 fetches the value of the respective variable, and an immediate signal is sent out to the output pin of the ESP32 controller. This whole process activates the relay to turn on/off the appliance.

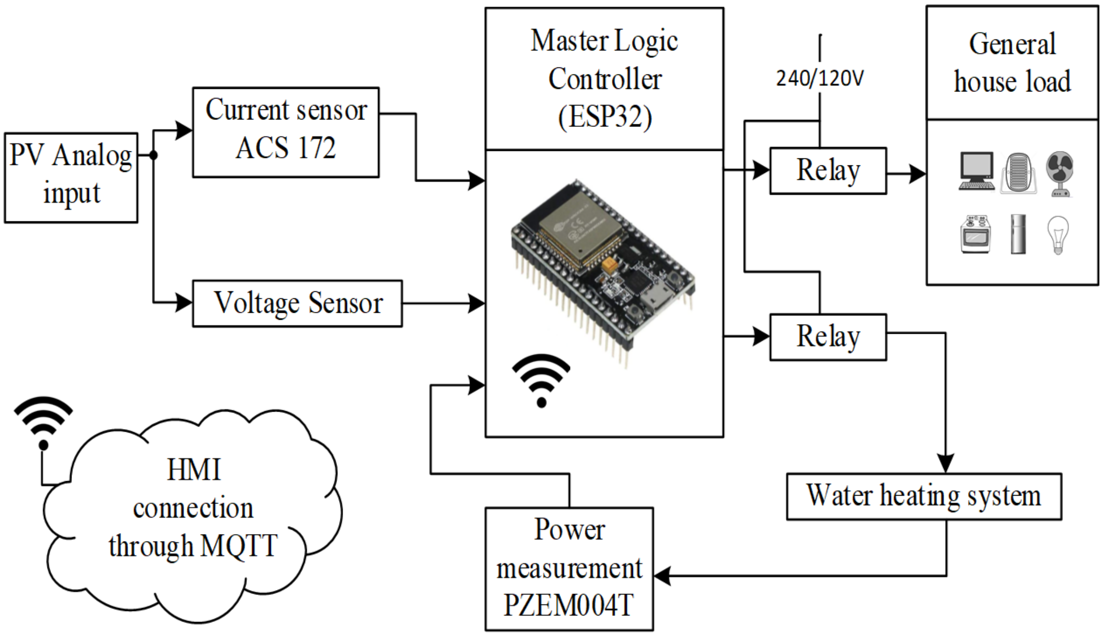

Figure 4-2 Detailed structure of the Energy Management System (EMS).

4.3.2 Description of SCADA

Sensors feeding information to the SCADA system are the FIDs for the RTUs to get real-time data for users which can be remote to monitor and control the system. The EMS follows a three-layer SCADA system [17], where the current and voltage sensors are at the base layer. There can be temperature or humidity sensors added to the system using a similar framework.

For analogue signals coming out from the PV generation system, a step-down resistor arrangement has been used, which can be seen in Figure 4-3. Equation 1 is used to calculate the voltage, which uses a voltage divider circuit. A similar circuit is used for voltage sensing. ACS712 takes 5V input to operate and uses series connect for power in and power out to generate the voltage ratio accordingly.

$$V_{out} = \frac{R_1}{R_1 + R_2} \times V_{in} \tag{1}$$

Figure 4-4 shows the circuit diagram of the power meter IC PZEM004T. There is a potential divider logic shifter circuit that has been used to shift the voltage from 5V to 3.3V. PZEM004T provides output in the form of 5V and 0V during serial communication, and ESP32 has a standard operating voltage of 3.3V. All inputs to ESP32 should be 3.3V; for that purpose, equation 1 has been used, which gives 3.3V when there is 5V applied.

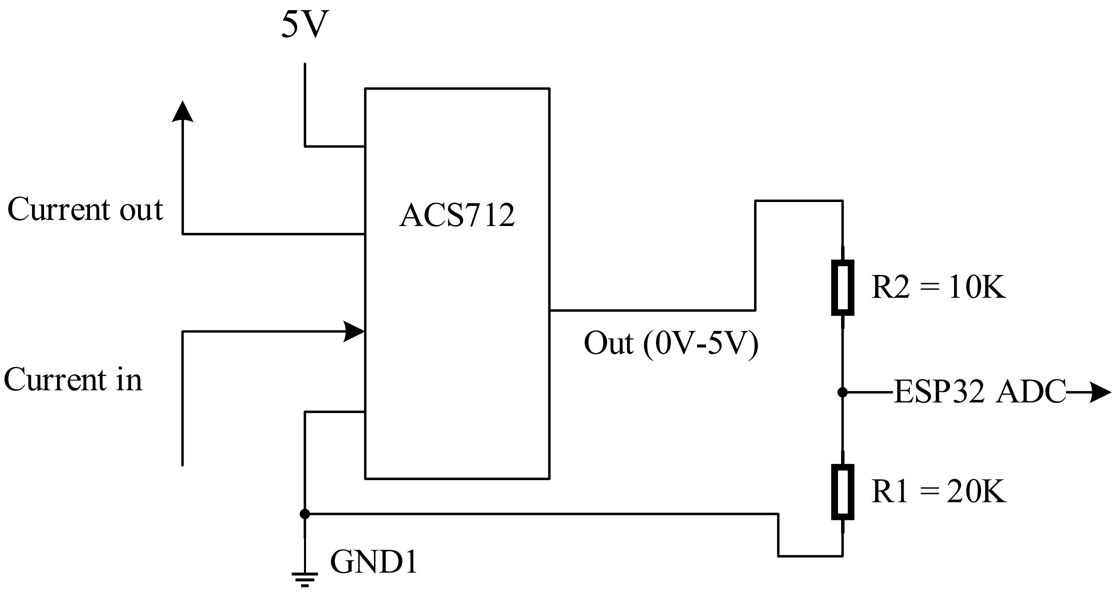

Figure 4-3 ACS 712 Pin configuration.

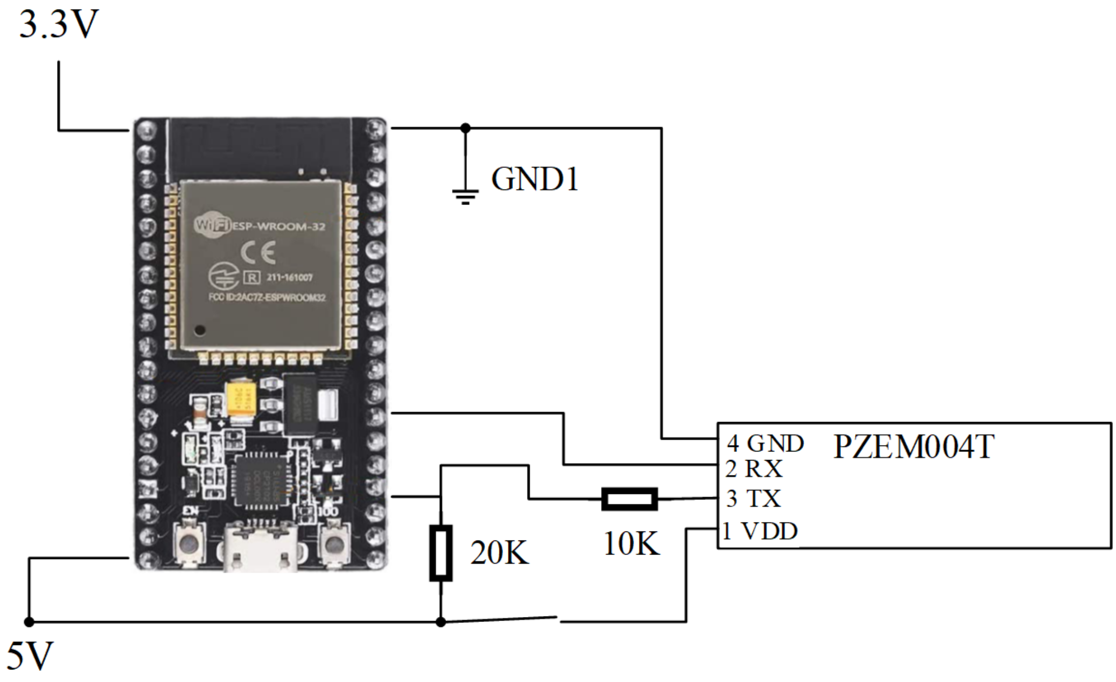

Figure 4-4 PZEM004T Pin Configuration.

4.3.3 Approach and methodology

After a clear understanding of the system requirement and architecture, it is time to understand the programming approach and what is going on behind the scene. Figure 4-5 describes the exact flow of the SCADA system's data and processes, as explained earlier.

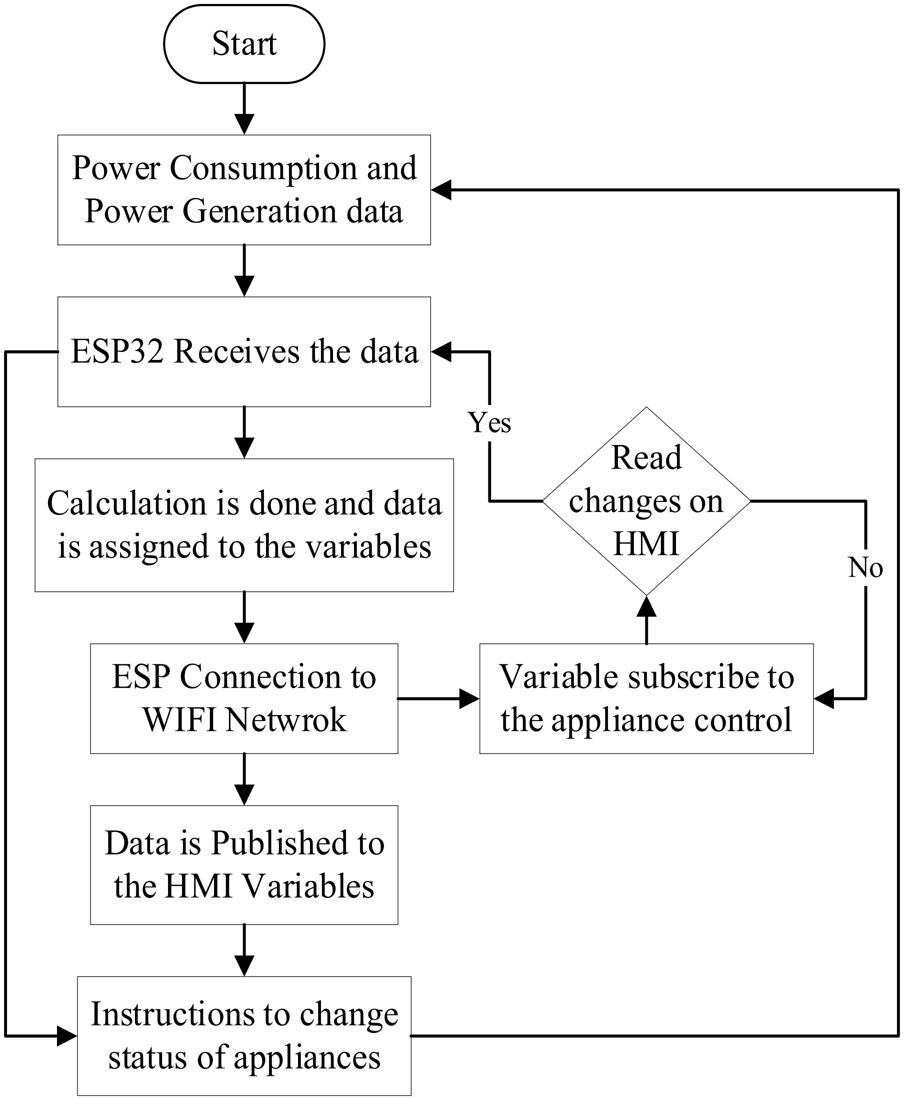

Figure 4-5 Flow chart of the SCADA system

Firstly, analog and digital sensor data is read, which is collected from the PV system and water heater. ESP32 reads the sensor values on analog pin 26 and 25 for the calculation of the value of power supplied by the solar system. 27 Pin is connected to the PZEM-004T for serial communication to get the power value for later to show on Dashboard. ESP32 then connects to the WiFi, which is local TCP/IP, using a unique WiFi name and password that throughout remains unchanged. ESP32 uses the MQTT protocol to connect to the Ubidots platform, where similar variable names take the value to publish on the Dashboard. MQTT client identifies the MLC with a unique ID referred to as a Token number. The HMI system provides this Token number for security and authentication purposes and remains unchanged for the account.

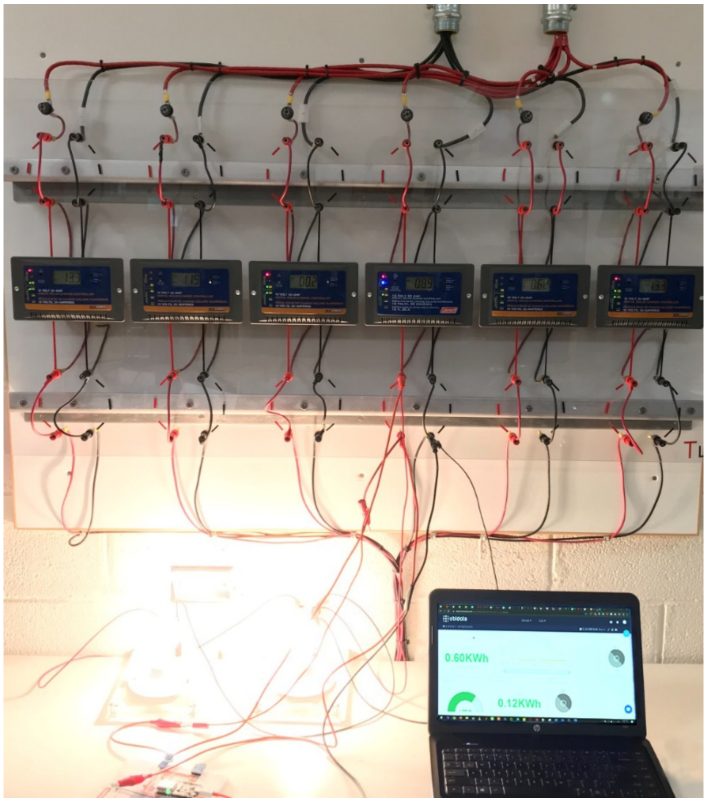

Figure 4-6 Experimental setup for the SCADA system testing.

As the user interacts with the Dashboard and values change for the on/off control of the appliances, these values are then sent out automatically to the variables subscribed for the values. Pin 12 and 13 send a signal that activates relays to turn on/off sequence for respective appliances. Figure 4-6 shows the prototype testing setup for the SCADA system. Two electric bulbs are being used.

4.4 Simulation and Results

Ubidots IoT platform provides a user-friendly Dashboard where real-time data can be seen, and charts can be accessed remotely. Figure 4-7 shows a screenshot of the Dashboard for the prototype of the proposed SCADA system using Ubidots IoT platform. As can be seen, a real-time graph can be seen, which shows the historical data stored in the cloud as well. There is a demo of real-time power consumption data for the water heating system. Users can create multiple kinds of real-time visualization, and all this can be done remotely using an internet connection and an online Dashboard. Ubidots also have an android as well as an iOS app to support all kinds of environments and provide accessibility to the end-user. Finally, there can be seen two switches in a gray circle that can give live feedback to ESP32 controller's variables subscribed to these switches. An operator can also initiate automated supervisory checks and control actions where a particular script or task can be performed at the given condition. An email is sent out to the user, reminding them to clear the snow if solar power generation is less than a threshold of 0.1kWh. This alert can be changed to a text message with the option provided by the HMI system.

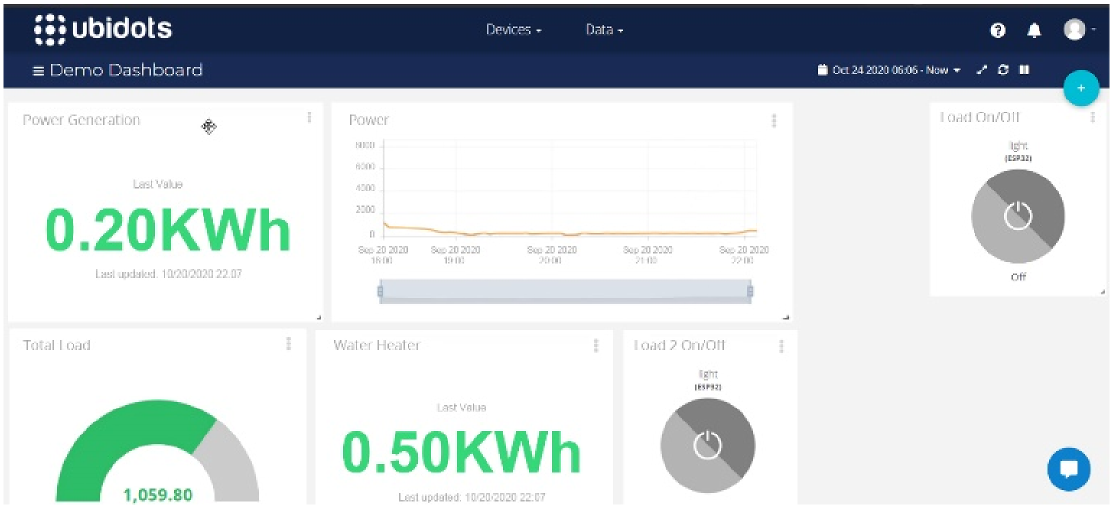

Figure 4-7 Ubidots Dashboard prototype for the proposed SCADA system.

4.5 Conclusion

The idea of the SCADA systems have revolutionized the industrial systems for complex automation control, visual inspection and monitoring. This idea comes in great help when there are multiple systems from different manufacturers that need centralized management and monitoring. For a futuristic house design where various appliances are connected from different manufacturers, and there is a need for efficient control and monitor of energy expenditure. The proposed system is scalable and, most importantly, affordable, with the overall cost of implementation to be below $300CAD. Moreover, acquiring real-time data from PV and water heater and remotely monitoring it on the Dashboard can improve the efficient usage of Photovoltaic electricity. Not only that, but the system also enables end-users to turn off home appliances with the ability to gain more control over the energy expenditure. This is going to be another step closer towards sustainable living.

4.6 Future work

This system has been designed as a prototype with the ability to add more devices in the future. This will enable the user to gain full control of the house and make it more smarter with an automated check and conditional algorithms. Multiple devices can be turned off when they are not being used, or multiple houses can be connected and monitored simultaneously. Most importantly, this idea is not only limited to an energy management system for a house. A lot of industries like pharmacies, traffic control systems, data centers and small businesses can implement this system with added security using encrypted communication between HMI and MLC.

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Chapter 5

Conclusion and Future Work

Research Contributions and Conclusion

This thesis presents a study of an efficient energy building built in FlatRock, Newfoundland, Canada. This building has been constructed according to the PHIUS+2015 standards with respect to the cold climate of Canada ASHRAE climate Zone 6. This study presents essential information that can be used in the future for all the buildings that will be built in Newfoundland under similar guidelines of passive house construction style. As shown through the results of a dynamic simulation that the energy consumption of the passive house can be simulated close to actual results. Overall, the main idea is to reduce the energy consumption of the house as well as reducing its impact on the environment when the occupants are using the house. PHIUS standards provide guidelines that are climate-specific and does not only focus on adding an extra layer of insulation to the envelope. Overall cost comparison shows that the house costs not more than 12% extra for construction, and it pays off in less than 25 years in terms of energy savings on space heating and cooling. Even in the climate zone where the winter gets extremely cold, as shown in the study, it is possible to improve a typical house's indoor conditions and lower energy consumption to maintain a comfortable living environment for the people living in the house.

The first chapter presents a detailed literature review where the main requirements to build a passive house has been discussed. Other than that, different climate zones and different styles of the passive house have been discussed with the main focus of discussion on sustainable living and renewable energy systems. Overall, it has been established that there is a strong need to change the mindset of modern construction techniques to focus on sensible energy usage by a house envelope.

The second chapter has a detailed discussion on the steps involved in constructing the passive house, calculation of energy consumption of the house and designing a renewable energy production system to support the energy expenditure. The initial focus during construction of the house is to find ways to reduce the house's energy consumption. Dynamic simulation and comparing the results with the actual data collected from the house showed that the results could be pretty accurate, so dynamic simulation can help the planning phase to construct a house that is efficient and has a low carbon footprint. This research work, along with detailed site analysis, renewable energy system design and optimization along with results, have been published in the International Journal of Renewable Energy. The proposed system can provide about 65% of the yearly electricity consumption of the house. These results are estimated without considering the effects of snow covering the solar panels. As discussed in the chapter, snow can cause up to 90% of the reduction of electricity production during wintertime and overall up to 35% in a year if it is not cleared.

Chapter three acts as an extension to chapter two with a more detailed design and dynamic simulation of the renewable energy system using MATLAB / Simulink tool to show the system response. Overall, the proposed renewable system has shown to add a lot of value in terms of sustainable living as the system can reliably produce electricity for the house. The battery bank is also there to supply back-up power for the system.

Chapter four focuses on designing and prototyping the overall Master Logic Controller and central Energy Monitoring and Management System using SCADA based open-source system. Usually available SCADA system solutions for this similar situation cost a lot with substantial initial purchasing and installation fees. Moreover, as the renewable power generation system's components like PV panels, power electronics converters, energy storage systems, and other critical components, including house loads, are from different manufacturers, there are sometimes compatibility and interoperability issues. These types of setup sometimes require the entire infrastructure to be redesigned or modified to accommodate SCADA system installation, which may lead to more cost and downtime. Hence, the proposed system provides a low-cost open-source solution to the proprietary SCADA system. The proposed IoT based system is flexible and more features / RTU can be added for advanced monitoring and control.

Future Work

This work is mainly published to spread awareness to adopt more energy-efficient ways of housing and manage its electricity expenditure. However, there have been several knowledge gaps discovered which can further be addressed. Some of these points are mentioned below in the form of recommendations:

- A smaller passive house or a house retrofitting with the passive house standards with a less complicated structure can be studied for more accuracy by observing the effect of humidity and wind speed in the simulation and planning phase.

- A hybrid system can be studied in detail for more cost-effective ways of renewable energy production. Moreover, a study of a combination of wind-turbine and solar can be studied for similar houses located at remote locations.

- The proposed Photovoltaic system's simulation technique can be utilized with distributed generation systems as well as coupling with a standalone system.

- The current study had proposed a renewable energy system that can support less than 65% of the electrical load through solar energy. Small scale solar farm can be created after a detailed site analysis to produce all the required electricity from the renewable energy source.

- The proposed system has a limited electricity storage system, which can only supply power to critical loads. A battery bank with a higher capacity can be simulated and optimized to support peak load in case if there is a power outage.
- The master logic controller and HMI system communicate without any encryption in the proposed approach. For increased security in each of the SCADA systems, data encryption can be implemented on the controller level.

List of Publications

- S. Manzoor, M. T. Iqbal, and D. Goodyear, “Building Performance Modelling for the First House in Newfoundland Built on PHIUS+2015 Standards and Design of Renewable Energy System,” Int. J. Renew. Energy Res., vol. 10, no. 3, pp. 1234–1245, 2020.
- S. Manzoor and M. T. Iqbal, “Dynamic Modelling and Simulation of the Rooftop P.V. System for the First Passive House in Newfoundland” International Conference on Enhanced Research and Industrial Application, 2020.

- S. Manzoor and M. T. Iqbal, “IoT based Renewable Energy Management and Monitoring System for the Frist Passive House in Newfoundland ” The 29th Annual Newfoundland Electrical and Computer Engineering Conference, IEEE, 2020.

- A. K. Sran, S. Y. X. Komiak, and S. Manzoor, *Mobile Based Agricultural Management System for Indian Farmers*, vol. 12202 LNCS, no. 2019. Springer International Publishing, 2020.

- S. Manzoor and M. T. Iqbal, “Design and Analysis of a PV System to Meet all its Energy Requirements of an Apartment in Abu Dhabi” The 28th Annual Newfoundland Electrical and Computer Engineering Conference, IEEE, 2019.