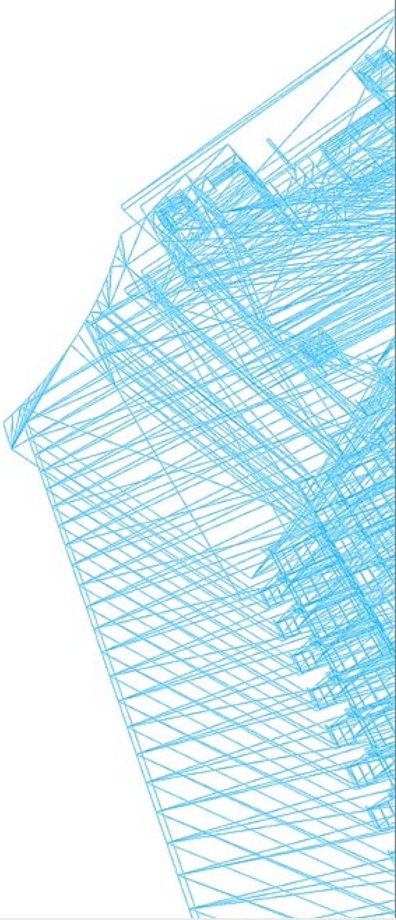
November 12, 2020

DESIGN, SIMULATION AND ANALYSIS OF A PASSIVE HOUSE AND ITS RENEWABLE ENERGY SYSTEM FOR NEWFOUNDLAND

MS Engineering Student:	Sabir Manzoor
Thesis Supervisor:	Dr. Tariq Iqbal

Memorial University of Newfoundland
Faculty of Engineering and Applied Science
www.mun.ca



Overview

- Introduction
- Research Objectives
- Passive House and background study
- Building performance modelling for the first house in Newfoundland built on PHIUS+2015 standards and design of renewable energy system
- Dynamic modelling and simulation of the rooftop P.V. system for the First Passive House in Newfoundland
- IoT based Renewable Energy Management and monitoring system for the First Passive House in Newfoundland
- Research Contributions
- Future Recommendations
- Acknowledgement
- Questions / Answers and References

Introduction

- 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.
- This climate change will put billions of people in danger and hundreds of millions at extreme risk from weather-related disasters.
- An energy-efficient and sustainable house design on a wide scale can play an essential role on a global scale.
- Researchers have made several attempts to build energy-efficient homes in the past.
- One of the first known energy-efficient houses named Saskatchewan Conservation House, built in the early 70s, which later became a pioneer of the modern Passive House model.
- This study has been dedicated
  - To promote research on energy efficient buildings and sustainable livings.
  - To spread awareness about sustainable solutions for energy management and renewable energy.
- Overall a house built based-on standards of Passive House Institute of United States (PHIUS+2015) has been analyzed and a prototype has been developed for both Renewable energy production and energy management system.

Research Objectives

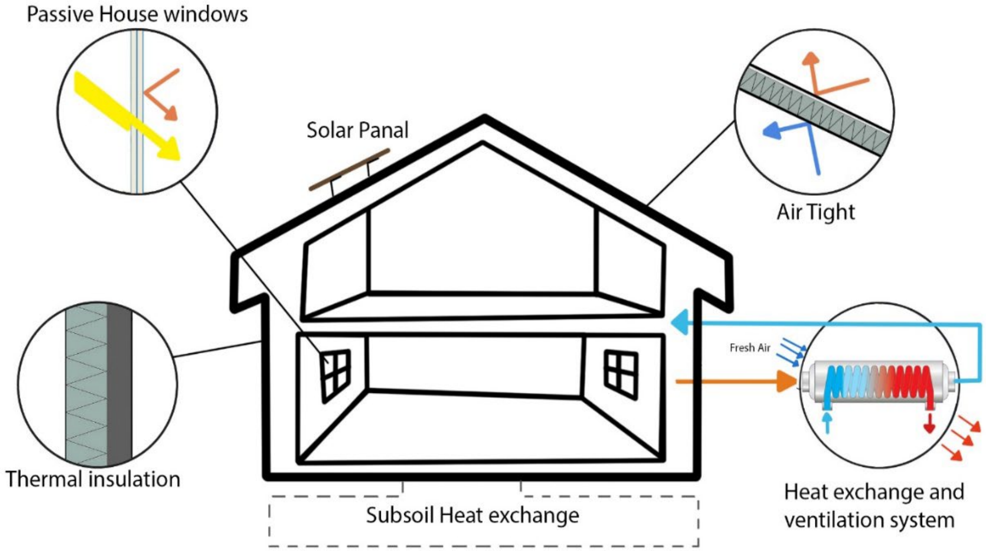
- Objective 1
  - ✓ A detailed study of Passive House design and standards as well as different Passive House literature review.
- Objective 2
  - ✓ Analyze and simulate the first Passive House in Newfoundland located at the location of Flat Rock using the advanced Passive House planning tools.
- Objective 3
  - ✓ 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 and suggest ways to optimize energy consumption. Also designing a renewable energy system to meet the energy needs of the house using Photovoltaic systems.
- Objective 4
  - ✓ Analyze energy management systems for water heating and design an energy management system using IoT based open-source SCADA system where users can monitor the energy consumption of the house and control the home appliances.

Passive House and background study

- Passive House is a building which is designed considering factors such as efficient energy, comfortable, affordable and ecological living environment.
- In the early 1990s, Dr. W. Feist built the first Passive House in Darmstadt, Germany, in a district named Kranichstein.
- The building has been continually being monitored and has an energy consumption demand of 9kWh/ m2 per year that stayed constant from the start until the present.
- There are many institutes and organizations founded to advance the research on the Passive House system, and low energy buildings.
- Some of the standards of low Energy Houses are ; PHI, PHIUS, CanPHI, LEED, Eco-home, Energy Plus house and Code built houses.
- Most of these standards are voluntarily followed throughout the world.

Passive House and background study

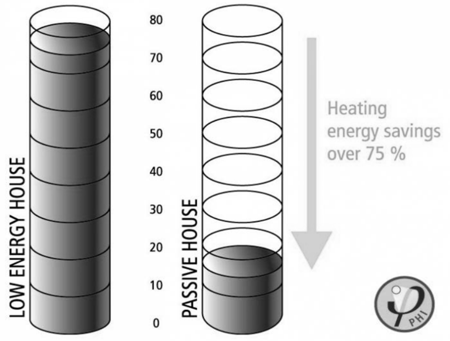
- The Passive House (Passivhaus) is defined as "a building designed to require minimal energy for comfort by having very good thermal insulation, excellent airtightness, and a ventilation system providing heating or cooling of the incoming air with mechanical ventilation with heat recovery (MVHR) of the warmer air.”



Passive House and background study

According to Passive House Institute PHI

- The energy required for space heating or cooling less than 15 kWh/ m2/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.
- With heat recovery with supplementary supply air heating in the ventilation to have controlled humidity, temperature, and quality of air.
- 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.
- Focusing Energy Performance and using energy-efficient appliances that demand ≤120 kWh/ m2 per year for domestic heating or cooling, ventilation, auxiliary electric consumption such as lighting and other domestic appliances.



Passive House and background study

Examples of Passive House

2. Sol Lux Alpha is an energy-efficient building, the winner of PHIUS 2018

1. The world's first multi-family Passive House, Darmstadt-Kranichstein, Germany 1990

3. The Marienlyst passive house school in Drammen

Passive House and background study

Passive House in different climates

- It is important to understand the fundamental differences of each Passive House built for a specific environment.
- Each type of environment and climate zone affects the overall design, passive heating or cooling techniques.
- Roughly climate zones can be divided into following categories.
    - Marine
    - Cold and Very Cold
    - Mixed-Dry and Hot-Dry
    - Mixed-Humid and Hot-Humid

Recap

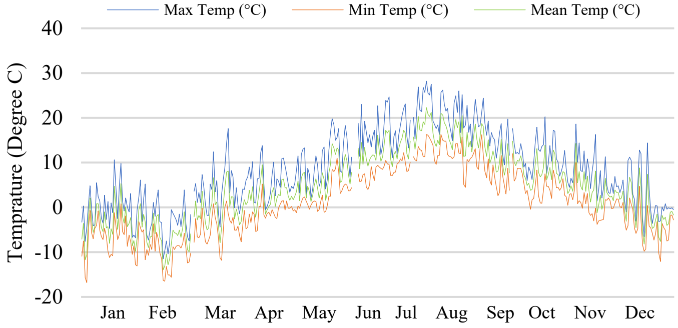
- ✓ Introduction
- ✓ Research Objectives
- ✓ Passive House and background study
- ➢ **Building performance modelling for the first house in Newfoundland built on PHIUS+2015 standards and design of renewable energy system**
- ■ Dynamic modelling and simulation of the rooftop P.V. system for the First Passive House in Newfoundland
- ■ IoT based Renewable Energy Management and monitoring system for the Frist Passive House in Newfoundland
- ■ Research Contributions
- ■ Future Recommendations
- ■ Acknowledgement
- ■ Questions / Answers and References

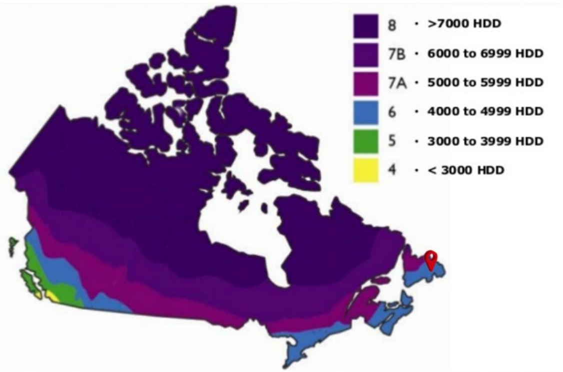
Synopsis

- Site analysis and weather conditions
- Passive House (PHIUS+2015) and Building envelop description
- Modelling methodology and Boundary conditions
- Energy analysis and building Performance simulation
- Load analysis and system sizing
- System Specification
- Optimization Results

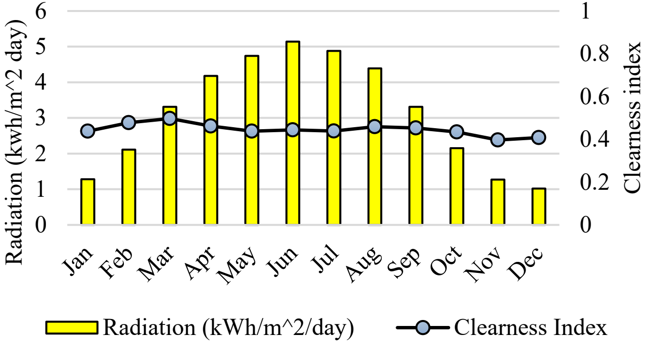
Site analysis and weather conditions

- In a cold climate, a substantial part of electrical energy is spent on heating loads in the residential buildings.
- Solar radiation reaches up to 5kWh/m^2.day with varying temperature.
- The site with red marker has shown which comes under zone six.





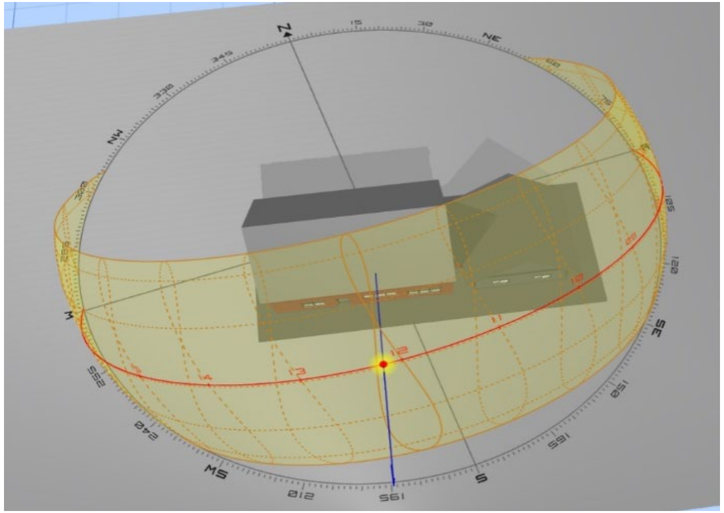
ASHRAE climate zone distribution



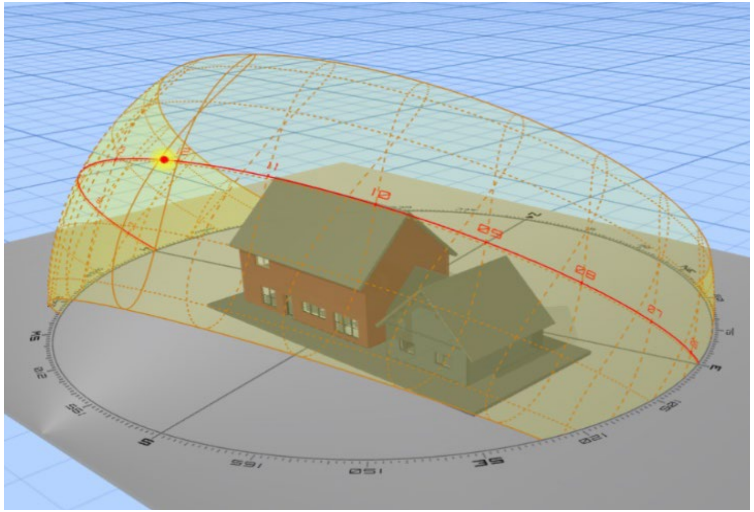
Solar energy potential for FlatRock Newfoundland.

Site analysis and weather conditions

- Renewable energy sources for the selected site can be biomass, geothermal, micro-hydroelectric, tidal, wind, solar thermal and solar photovoltaic. Below image shows perfect sun exposure for south façade.



Top view of the model of the house with the solar chart.



3D model with side view of the house with the solar chart.

Site analysis and weather conditions

- Newfoundland has a cold and humid climate which experience cold winter followed by a warm and humid summer with yearly snowfall can reach up to 250cm.
- Picture below shows the satellite view of the house that has challenging conditions for wind energy in spite of an average wind speed of 6.6 m/s.

A satellite location of the Passive House understudy

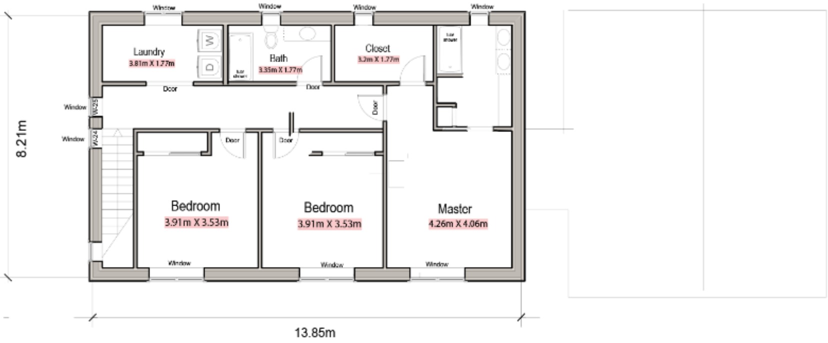
First house built on PHIUS+2015 standards in Newfoundland.

Passive House (PHIUS+2015) and Building envelop description

- PHIUS+2015 guidelines are said to have more personalized requirements tailored to climate and geolocation of the house rather than just having one guideline for every house.
- PHIUS+2015 designs constraints include but not limited to;
  - Heating demand should be less than 43.155W/m^2. K
  - Cooling demand 5.67-132.87kW/m^2.year
  - Airtightness should be less or equal to 0.05 cfm/sq. f.
  - Source Energy demand 6200kWh/person. year

Passive House(PHIUS+2015) and Building envelop description

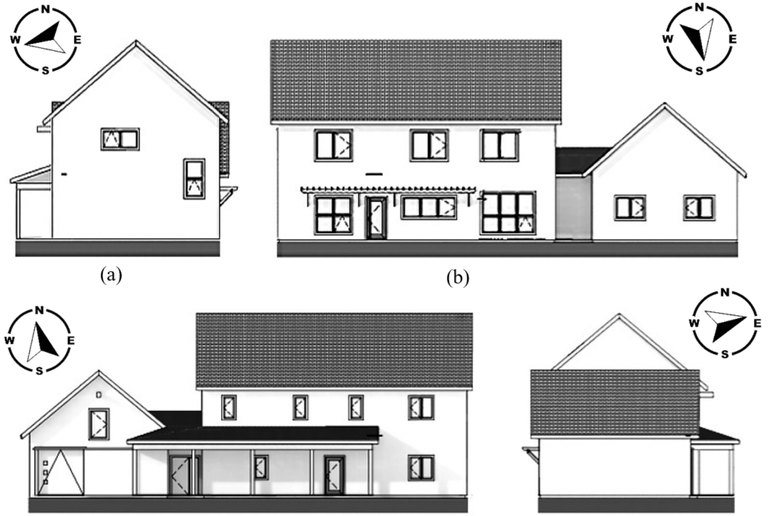
- The house design was completed after several rounds of renderings and plans with the input of the homeowner and the consultant.
- The house has a total of 185m^2 area out of which 113m^2 area has been designed, built and tested according to the PHIUS+2015 standards.
- The ground floor has a common living area, kitchen, dining room and small room for working space whereas top floor has bedrooms.

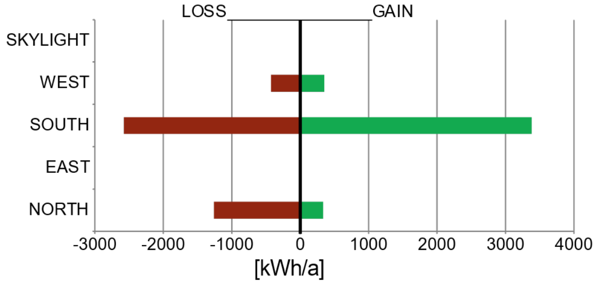


Passive House(PHIUS+2015) and Building envelop description

- The building site was selected to take advantage of solar radiation during the heating season.
- 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.

	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

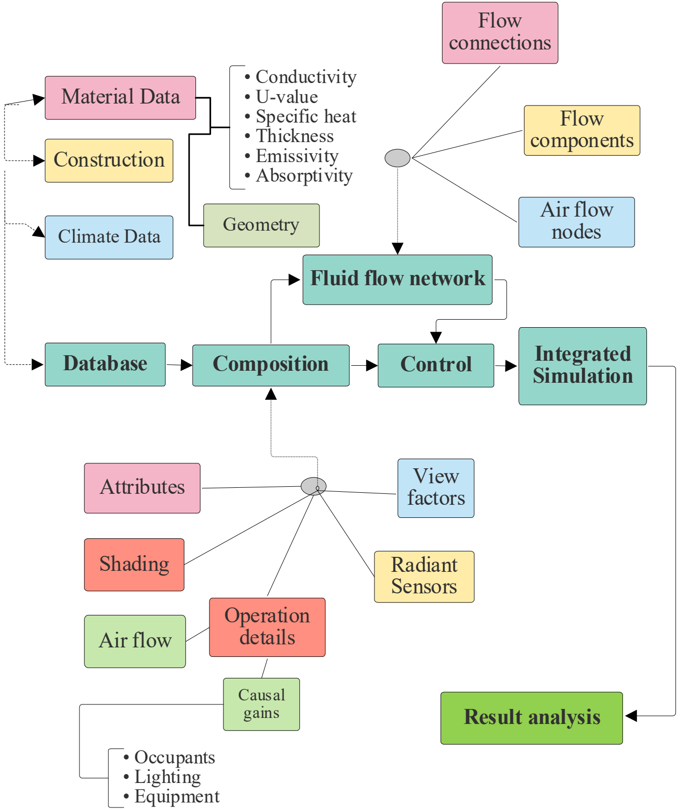




Building performance modelling for the first house in Newfoundland built on PHIUS+2015 standards and design of renewable energy system

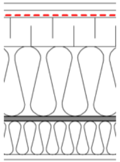
Modelling methodology and Boundary conditions

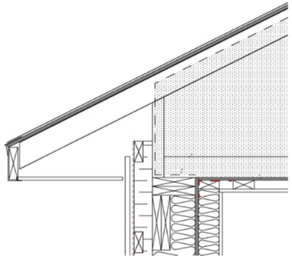
- There have been a number of tools developed for energy modelling and building simulation. Each of the software has its unique capability when it comes down to building simulation.
- There are mainly two types of simulation techniques when it comes down to Passive House; static and dynamic simulation.
  - In a **Static Stimulation**, data is assumed to be evenly distributed. (Two available tools, **designPH/PHPP** and **WUFI**, are most widely used for Passive House package planning.)
  - **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 simulations tools like IDE ICE, **EnergyPlus**, **OpenStudio**, **eQUEST** and **DesignBuilder** are available).



Modelling methodology and Boundary conditions

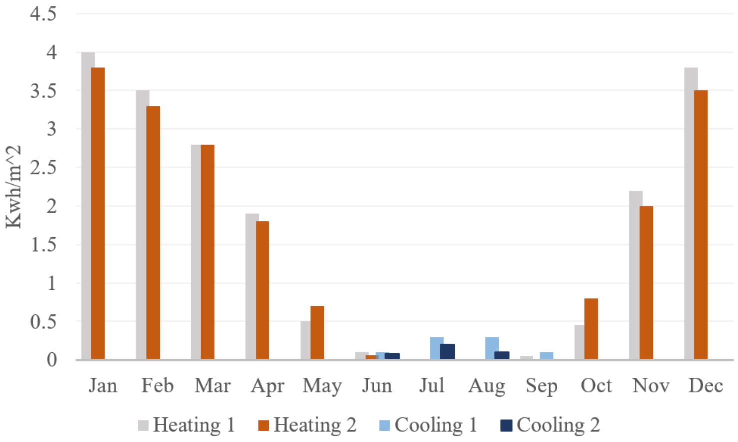
- Based on the principle of integral variation, the EnergyPlus engine is implemented using Openstudio to simulate the outdoor time-by-case and change of hourly thermal load on the enclosed structure of the envelope.

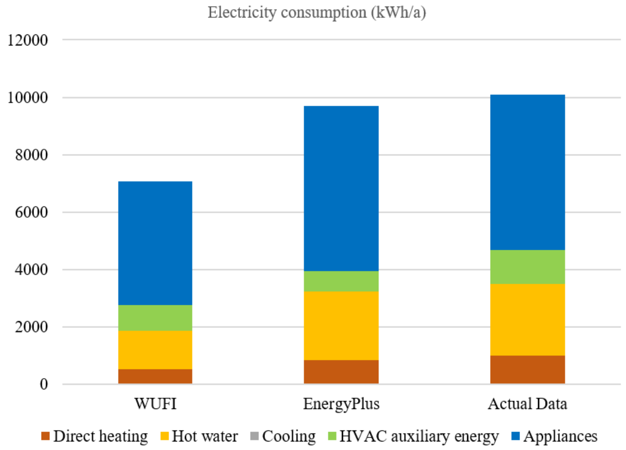
Boundary Conditions	Building specification
Building types	Optimized energy consumption
Floor area	113m^2
Glazing types	Triple glazed
Infiltration (ACH50)	0.45 /hour
External Walls RSI 10.1 m^2-K/W U-Value 0.099 W/m^2-K	
Source and composition of walls	1.58cm DRYWALL VAPOR BARRIER PAINT(<1 PERM) 2X4 STUD 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.

Boundary Conditions	Building specification
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 2X4 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 3X10cm T&G OSB SUB-FLOOR 1X4 STRAPPING 40.64cm O.C. 1.27cm DRYWALL Painted softwood flooring

Energy analysis and building Performance simulation

- Comparison of heating and cooling demand simulated with two different software (1 for dynamic modelling and 2 for WUFI modelling).
- Average Electricity consumption data comparison of a year is shown in the picture with comparison.





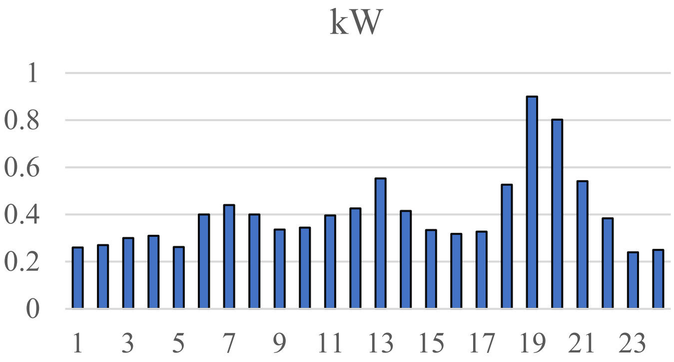
Load analysis and system sizing

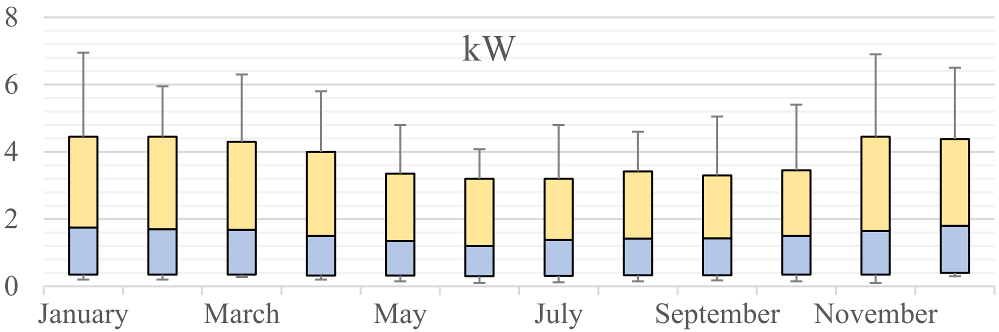
- An average of two years of energy consumption data of the house shows an average of around 1200kWh/month demand.
- The average solar potential of 3.15KWh/m^2/day. Whereas, the house selected for analysis has an area of 50m^2. So,

say η_PV=15%

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

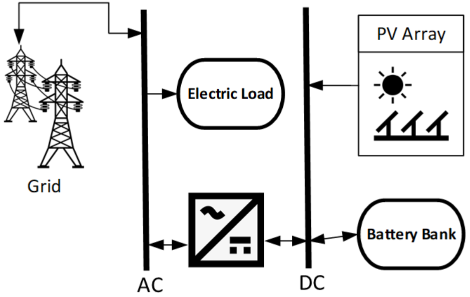
Panels can produce enough electricity to meet the requirement of an average day.

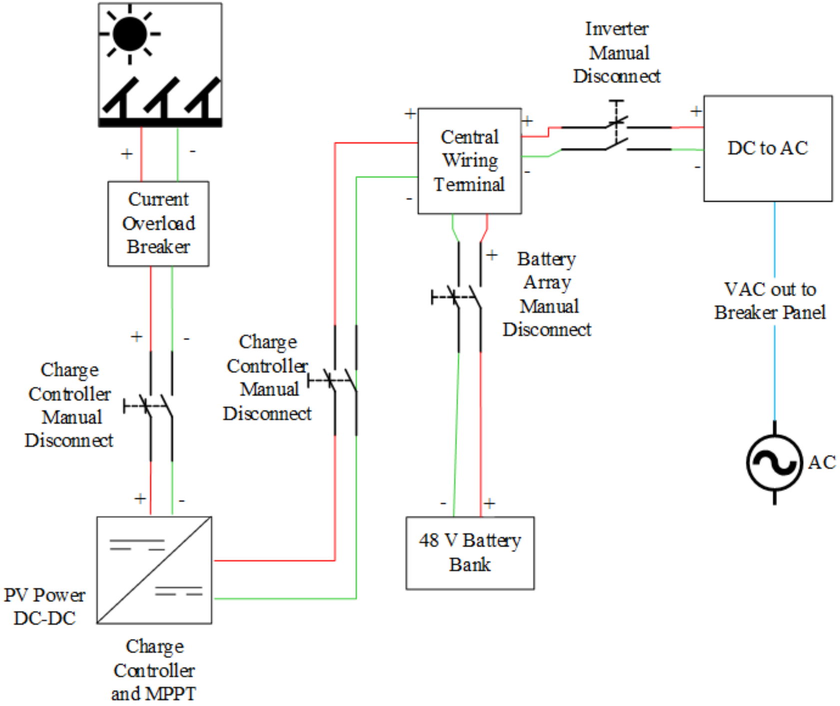




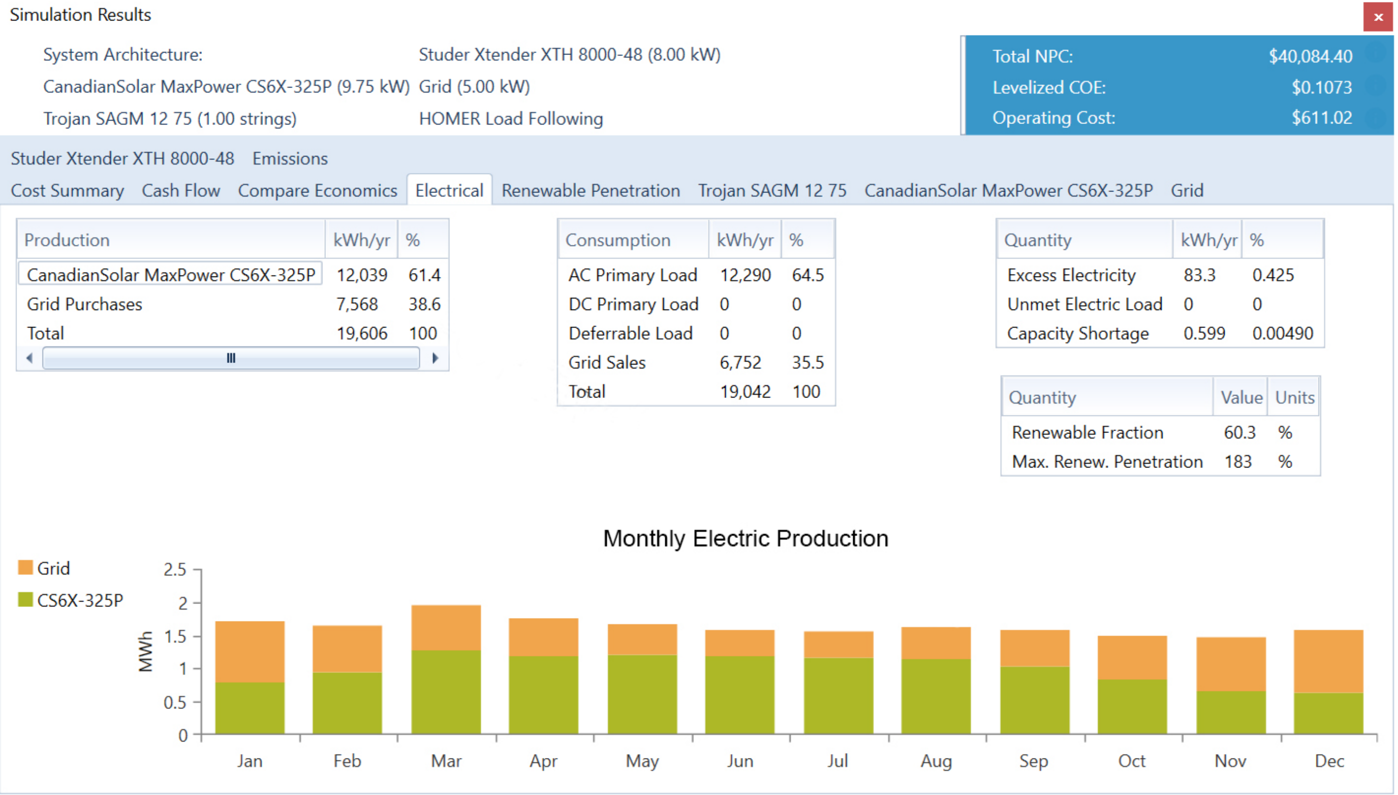
System Specification and Optimization

- Homer Pro Software has been used for optimization and System dynamics is shown below as considered for Homer Pro optimization.
- A detailed circuit flow of the optimized system can also be seen in the picture on the right.





Optimization Results



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	%

Monthly Electric Production

Dynamic modelling and simulation of the rooftop P.V. system for the First Passive House in Newfoundland

Synopsis

- Background and Site study
- Approach and methodology
- System modeling
- Detailed system description
- Results

Background and Site study

- Considering the extreme need for a low carbon footprint, a transition to efficient housing that uses renewable energy sources can make a considerable contribution.
- 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% .
- During winter months when the snowfall is at its peak, monthly PV production losses could reach up to 100%.
- This is alarming yet dependent on following factors;
    - The angle of a solar panel.
    - The outer surface of the PV plates.
    - PV plates frame to hold or allow snow slip from the plate.
    - Fluctuation in variables like temperature, wind and humidity to enable freezing rain or block the area of the plates.

Approach and methodology

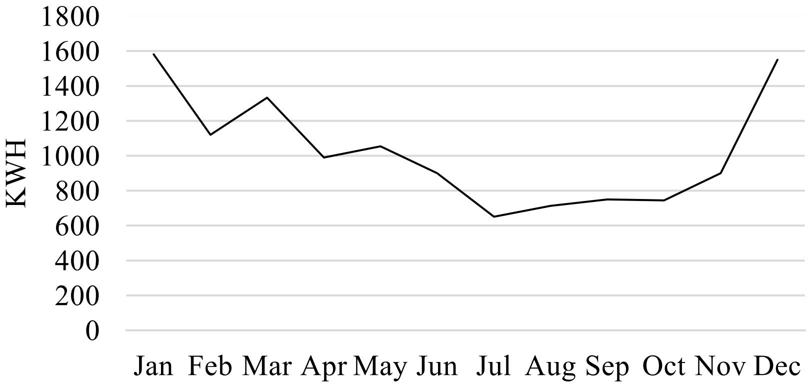
- A detailed site analysis and load analysis of the site had been performed. After that, historically collected load data was inserted into the Homer Pro software.

- The optimized system was then verified using PVsyst software, and cost analysis was performed.

- 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.

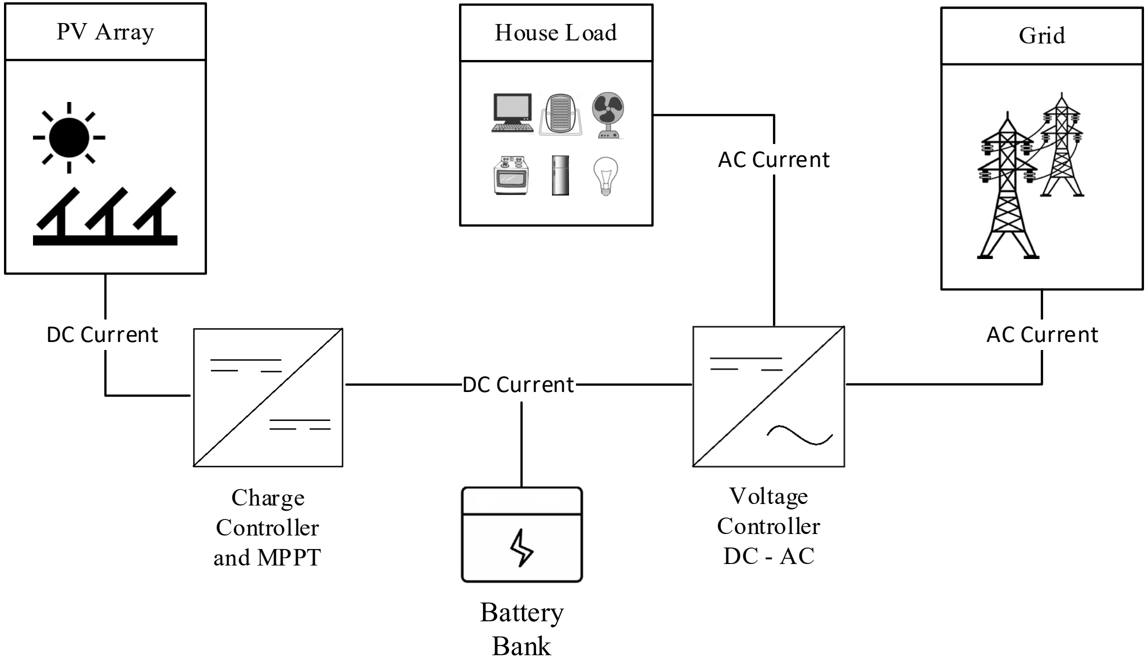
- There are three main types of photovoltaic power system :
  - ○ A grid-tied solar power unit
  - ○ Grid-tied solar power unit with battery backup
  - ○ Stand Alone or off-grid solar power unit

- Grid-tie inverter system is going to prove useful



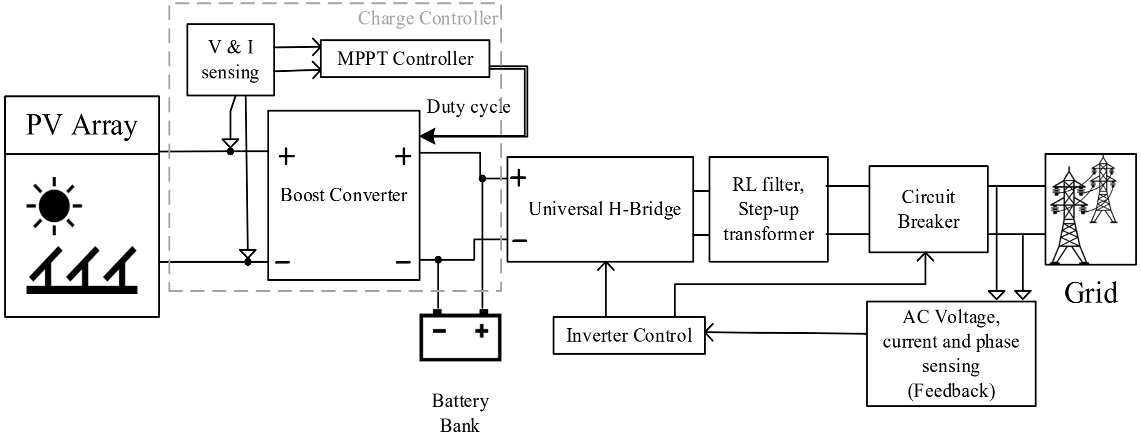
System modeling

- System dynamics of the proposed system



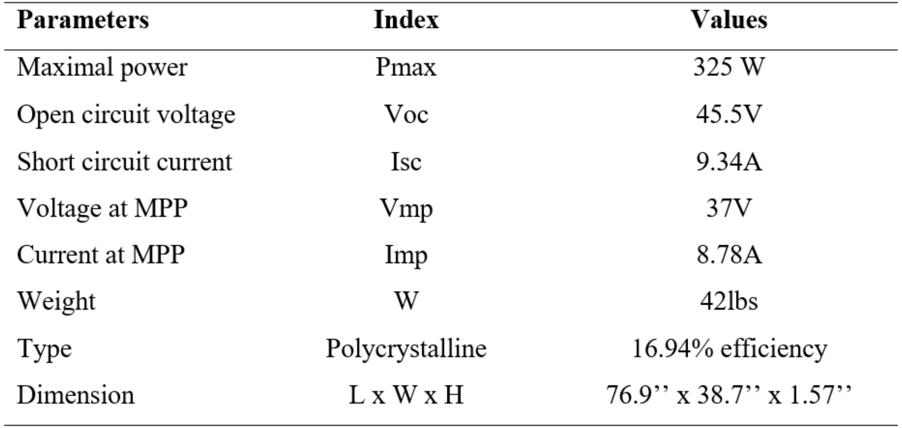
System modeling

- Canadian Solar (CS1H-325MS) PV module with the total available power to the maximum of 9.75kW as optimized in HomerPro.
- Boost converter system have been implemented 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.



Detailed system description – Solar Panel

- 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.
- Canadian Solar CS1H-325MS PV module with the parameters is shown in Table, is used for simulation for MATLAB.



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’’

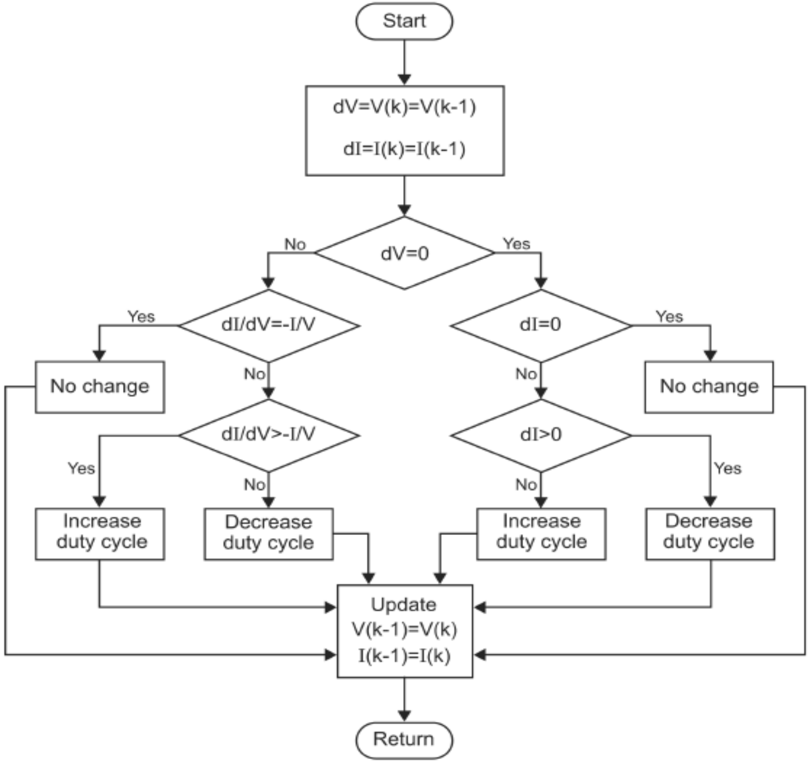
Detailed system description - MPPT

- To get maximum out of the panels, Incremental Conductance based **MPPT** algorithm has been implemented
- Flowchart of incremental conductance algorithm is shown in the figure
- Following is the quick explanation where the maximum power point is achieved when:

$$\frac{dP}{dV} = \frac{d(V * I)}{dV} = I + \frac{d(V)}{dV} = 0$$

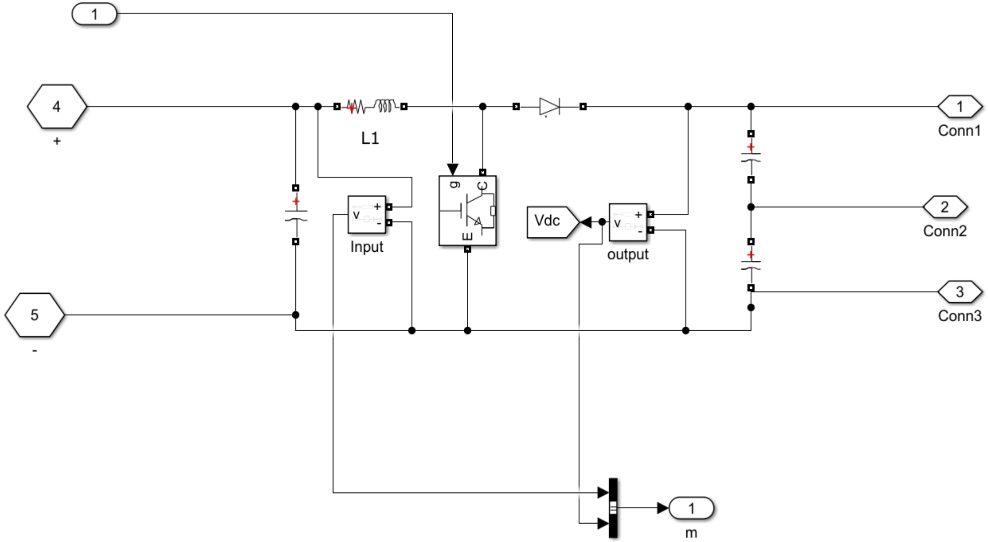
$$\frac{dI}{dV} = \frac{-I}{V}$$

- V, and I measured with a sliding time to supply the adjusted duty cycle to track maximum PowerPoint



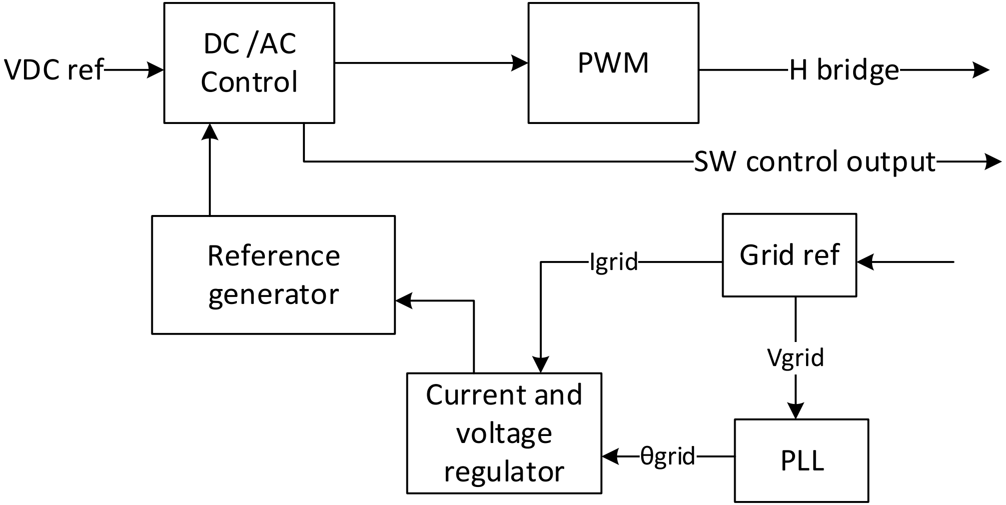
Detailed system description – Boost converter

- In **Boost converter**, diode and IGBT have been used for voltage setup.
- When the switch is on, the inductor starts to store the energy with the increasing flow through the inductor
- The stored energy is dispatched when the IGBT switch is closed.



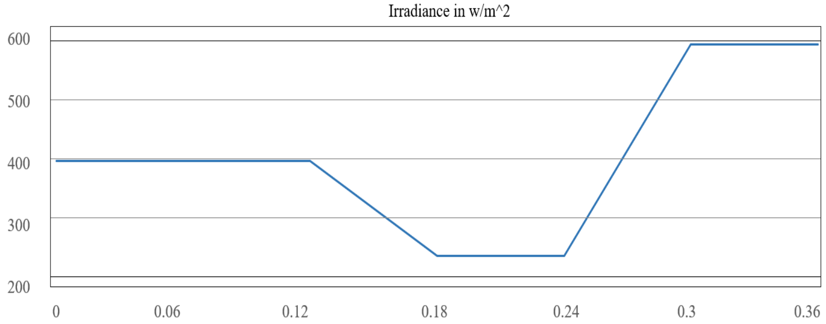
Detailed system description - DC-AC controller

- DC to AC converter aims to produce a sinusoidal wave AC output with controllable magnitude and frequency.
- The control system uses a sample time of 100 microseconds for voltage and current controllers.
- An external control loop that regulates DC link voltage to 48V bus.
- An internal control loop that regulates grid currents.

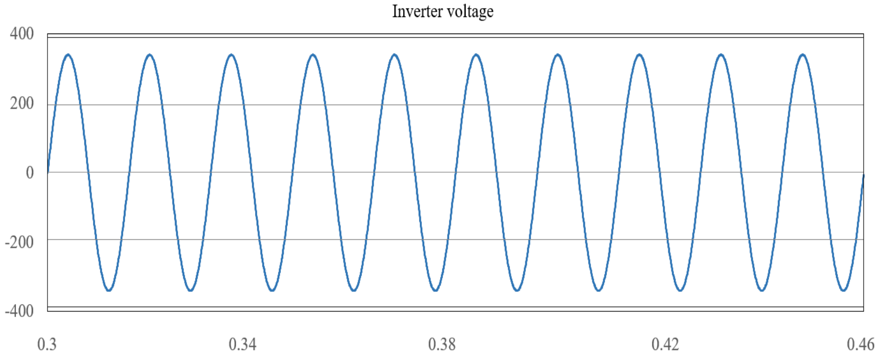


Dynamic modelling and simulation of the rooftop P.V. system for the First Passive House in Newfoundland

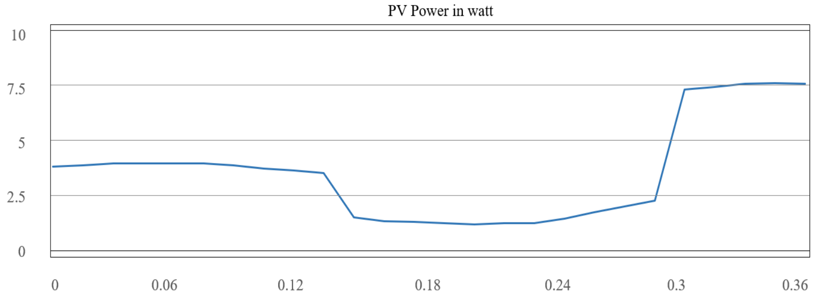
Results



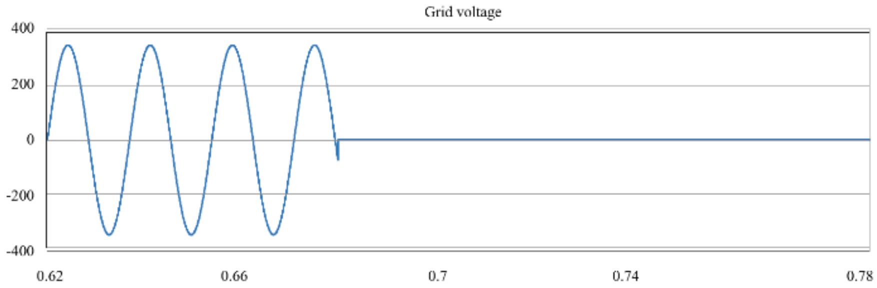
1. Solar irradiance input.



3. Voltage supplied to the grid.



2. Output power supplied from the PV array.



4. Voltage at the point of common coupling upon grid failure.

Synopsis

- Introduction
- Types of SCADA system / Literature Review
- Proposed SCADA system
- Working of SCADA system
- Detailed description of the system
- Approach and methodology
- Simulation results

Introduction

- Monitoring and Controlling energy produced from solar energy could be highly beneficial in both domestic and commercial environments.
- 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 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) - Master control for all components involved.
  - Remote Terminal Units (RTU) - Local collection points for gathering reports from sensors or actuators /FIDs
  - Human Machine Interface (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 for monitoring and controlling.

Types of SCADA system

- First Generation - Monolithic

  The original SCADA system was created during a time where networks did not exist. These first systems were not designed to connect to other systems.

- Second Generation - Distributed

  The second generation of SCADA was able to take advantage of LAN and were smaller and cheaper than its predecessor. In almost real-time, information was shared across stations that each had their own tasks..

- Third Generation - Networked

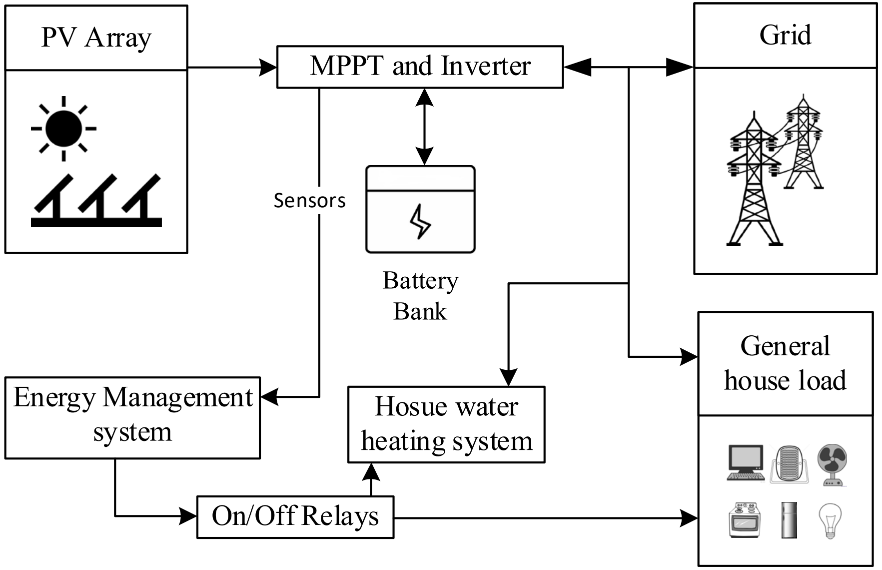
  Communication over WANs and utilizing PLCs for monitoring, this generation is much like the 2nd generation. However, it is able to connect to the internet and third-party peripherals..

- Fourth Generation - Internet of Things (IoT)

  Combining SCADA with the cloud, IoT provides SCADA systems with an alternative to PLCs and the use of data modeling and complex algorithms.

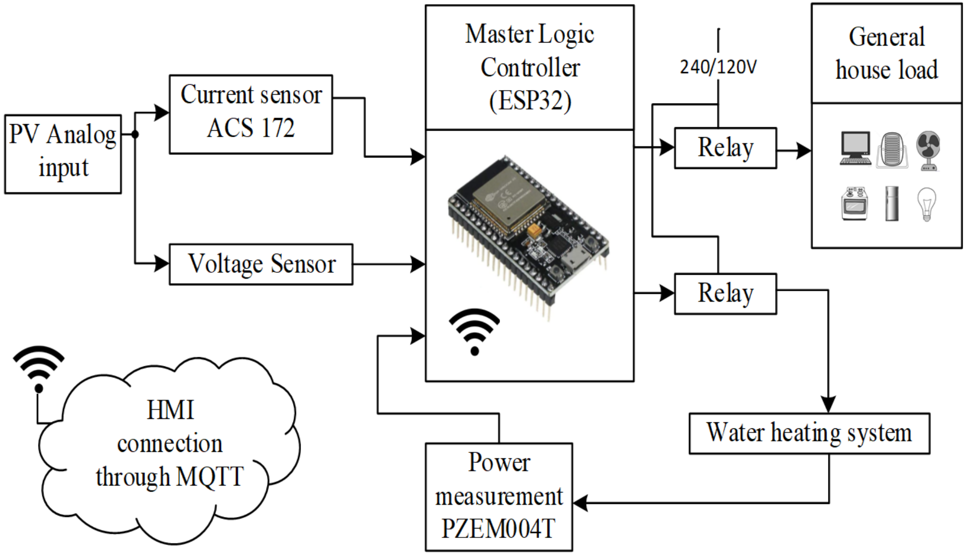
Proposed SCADA system

- 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.



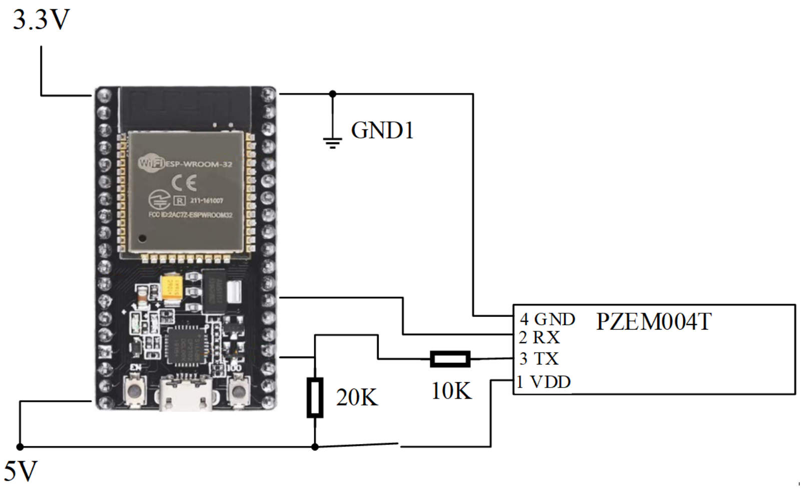
Working of SCADA system

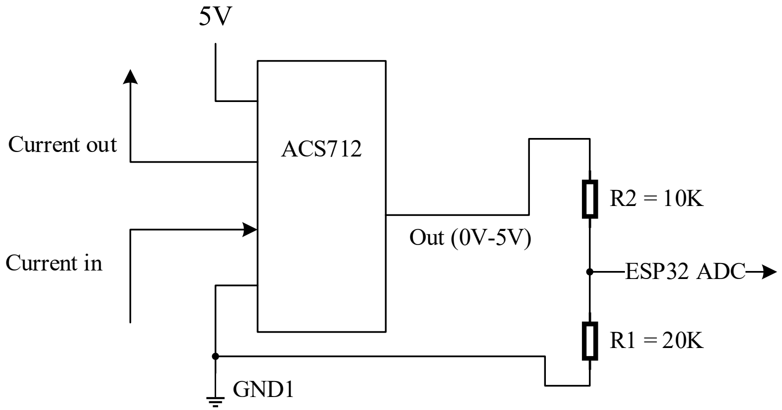
- PV input
- Master Logic Controller
- HMI system
- Water Heating system
- General House Load



Detailed description of the system

Figures below shows the circuit diagram of the power meter IC PZEM004T and current sensor for DC.

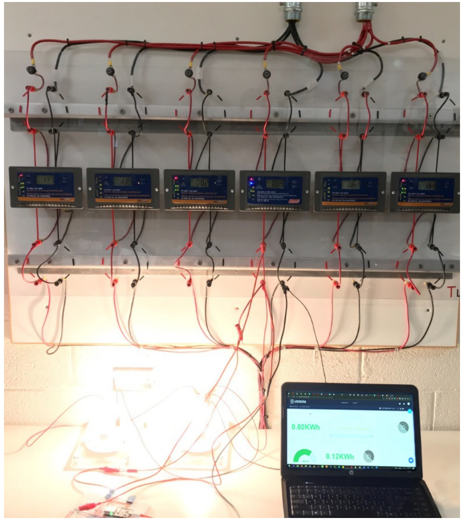


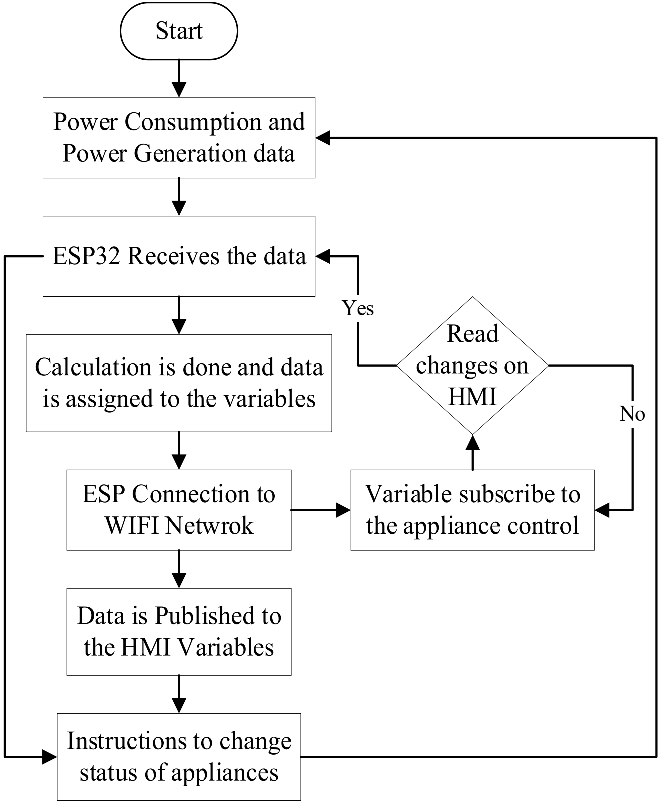


IoT based Renewable Energy Management and monitoring system for the Frist Passive House in Newfoundland

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.
- Flowchart describes the exact flow of the SCADA system's data and processes





IoT based Renewable Energy Management and monitoring system for the Frist Passive House in Newfoundland

Simulation results

Power Generation: Last Value 0.20KWh, Last updated: 10/20/2020 22:07

Total Load: 1,059.80

Water Heater: Last Value 0.50KWh, Last updated: 10/20/2020 22:07

Simulation results

- This idea comes in great help when there are multiple systems from different manufacturers that need centralized management and monitoring.
- The proposed system is scalable and, most importantly, affordable, with the overall cost of implementation to be below $300CAD.
- Acquiring real-time data from PV and water heater and remotely monitoring it on the Dashboard can improve the efficient usage of Photovoltaic electricity.
- the system also enables end-users to turn off home appliances with the ability to gain more control over the energy expenditure.

Research Contributions

- The first section presents a detailed literature review where the main requirements to build a Passive House has been discussed.
- Different climate zones and different styles of Passive House have been discussed with the main focus of discussion on sustainable living and renewable energy systems.
- 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 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.)
- Dynamic simulation of the renewable energy system using MATLAB / Simulink tool to show the system response.
- Designing and prototyping the overall Master Logic Controller and central Energy Monitoring and Management System using SCADA based open-source system.
- The proposed IoT based system is flexible and more features / RTU can be added for advanced monitoring and control.

Future Recommendations

- A smaller Passive House or a house retrofitting with 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.

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

- 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 system has a limited electricity storage system, which can only supply power to critical loads. A battery bank with 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.

Acknowledgments

Thank you all!!

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.

Questions / Answers

References

1. Saskatchewan Conservation House, Passipedia [Online] Available from: https://passipedia.org/ [accessed 01 November 2019].
2. W. J. Ripple, C. Wolf, and T. M. Newsome, “World Scientists ’ Warning of a Climate Emergency,” Biosci. Mag., vol. 2000, no. X, pp. 1–20, 2019.
3. J. Daily, C. News, and M. Vol, “Passive House Canada actively pursues Eastern Canada growth,” vol. 92, pp. 1–2, 2019.
4. S. Piraccini and K. Fabbri, “Building a passive house : the architect’s logbook.” 2018.
5. N. Jelley, A Dictionary of Energy Science. Oxford University Press, 2017.
6. iPHA [Online] Available from: https://passivehouse-international.org/upload/ipha-brochure/ [accessed 01 November 2019]
7. Passive House institute [Online] Available from: https://passiv.de/en/index.php [accessed 01 November 2019]
8. Zero Energy and Passivhaus Institute for Research [Online] Available from: https:// www.zephir.ph/ [accessed 01 November 2019]
9. M. G. Cook, “The Zero-Carbon House.”, The Crowood press, p. 74, 2011.
10. D. H. C. Toe, Sustainable Houses and Living in the Hot-Humid Climates of Asia. 2018.
11. Passive House Institute, “Criteria for the Passive House, EnerPHit and PHI Low Energy Building Standard,” Passiv. House Inst., pp. 1–25, 2016.
12. R. Charron, “PHPP V9 . 6 Validation using ANSI / ASHRAE Standard 140-2017,” p. 33, 2019.
13. M. T. Iqbal, "A feasibility study of a zero energy home in Newfoundland," Renewable Energy, vol. 29, no. 2, pp. 277–289, 2004.
14. Passive House Institute US [Online] Available from: https://www.phius.org/ [accessed 01 July 2020]
15. R. W. Andrews, A. Pollard, and J. M. Pearce, "The effects of snowfall on solar photovoltaic performance," Solar. Energy, vol. 92, pp. 84–97, 2013, doi: 10.1016/j.solener.2013.02.014.
16. R. E. Pawluk, Y. Chen, and Y. She, "Photovoltaic electricity generation loss due to snow – A literature review on influence factors, estimation, and mitigation," Renewable and Sustainable Energy Reviews, vol. 107, no. December 2018, pp. 171–182, 2019, doi: 10.1016/j.rser.2018.12.031.
17. M. J. Khan and M. T. Iqbal, "Pre-feasibility study of stand-alone hybrid energy systems for applications in Newfoundland," Renewable Energy, vol. 30, no. 6, pp. 835–854, 2005, doi: 10.1016/j.renene.2004.09.001.