ENERGY CONSUMPTION ANALYSIS AND FUTURE TRENDS FOR NEWFOUNDLAND

by

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Dedicated to my

Parents for making me who I am, and my husband for his unconditional love and support.

ABSTRACT

This thesis presents energy consumption analysis of Newfoundland. A detailed data analysis indicated that energy consumption per person in Newfoundland is 185.34 kWh/day. To analyze the energy consumption in houses, a data logger is designed and implemented, which can measure and record inside, outside house temperature and electricity consumption. Similar data loggers were installed in two houses in Newfoundland and data was logged for more than a year. A detailed analysis of the logged houses energy consumption is presented in the thesis. A Thermal model of two houses is developed in the Building Energy optimization (BEopt) software and Newfoundland power logged data is used to validate the houses BEopt model. For long-range energy consumption analysis in Newfoundland, the EnergyPLAN and Long-range Energy Alternative Planning (LEAP) software is used to analyze the Newfoundland existing energy consumption. EnergyPLAN software is considered to show the future energy model scenario with additional wind energy integration to the system. On the other hand, long-term energy consumption, production system and forecast up to year 2030 are presented using LEAP software. Three possible future energy system scenarios are proposed and analyzed to understand the Newfoundland energy demand and supply system.

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Chapter-1

Introduction and Literature Review

1.1 Energy consumption in Newfoundland

Newfoundland and Labrador is a province of Canada, which is located in the eastern part with a total area of 405,212 km^2. The Labrador portion is connected to main land Canada whereas Newfoundland is an Island in the Atlantic Ocean. Total population of the province in 2014 was 526,977 [1] and 92 % of the provinces total population lives on the island of Newfoundland.

In the province, electricity generation and distribution is done by two utility companies; Newfoundland Hydro and Newfoundland Power. Newfoundland Powers total generating units consists of 23 hydro generating plants, two diesel plants and three gas turbines. Almost 93% of its electricity is purchased from Newfoundland and Labrador Hydro. On the other hand, installed generating capacity for Newfoundland hydro in the province is 1637 MW, with six hydroelectric plants, one thermal generating station, two combustion turbines, and two diesel plants. Most of the hydro's electricity generation is from hydro electric generation. Hydro also purchases power from some non-utility generators and installed wind farms. The main generation sources in Newfoundland island system are hydro, wind and oil. Presently installed wind farm capacity is only 54.7 MW, but wind power potential is great in the province. Newfoundland has long winter months with strong wind speed. Figure 1.1 shows that 78% of the total generation capacity in the island

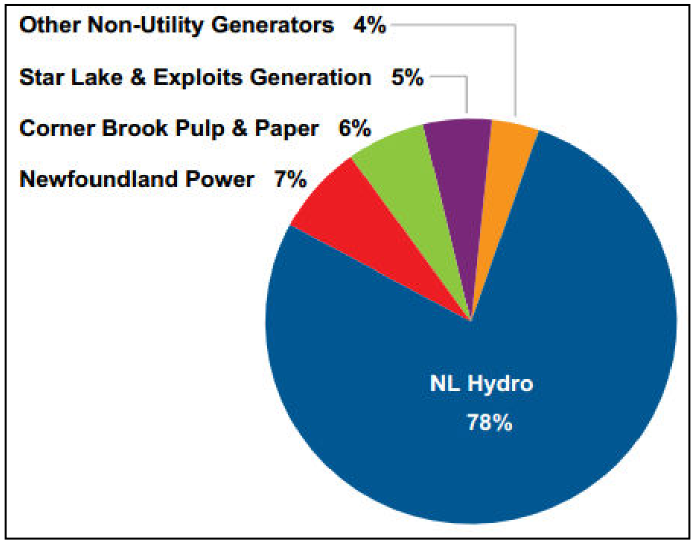


Figure 1.1 Newfoundland (island) generating capacity [2]

portion is supplied by NL Hydro; 7% and 6% is taken care of by Newfoundland Power and pulp & paper mills respectively. Finally, 5% and 4% come from star lake & exploits hydroelectric generation and some non utility generators, respectively.

In Newfoundland & Labrador, 14% of total energy is consumed by residential sector (Figure 1.2). There are approximately 250,000 residential electricity customers. Again 40% of the electricity use by the island portion is by Business. In conventional residential houses, 69% of total energy is used for heating purposes (Figure 1.3). Most of the houses in Newfoundland use electric baseboard heater for space heating. Of the total energy, various appliances need 16.3%, water heating needs 10.3% and lights requires 4.3% of the total energy need as given in Figure 1.3.

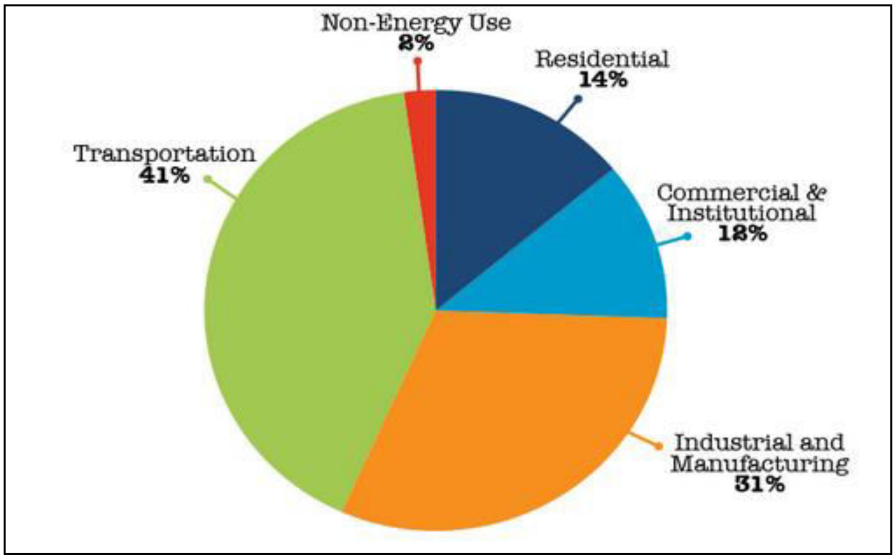


Figure 1.2 Energy consumption by sector in Newfoundland and Labrador [3]

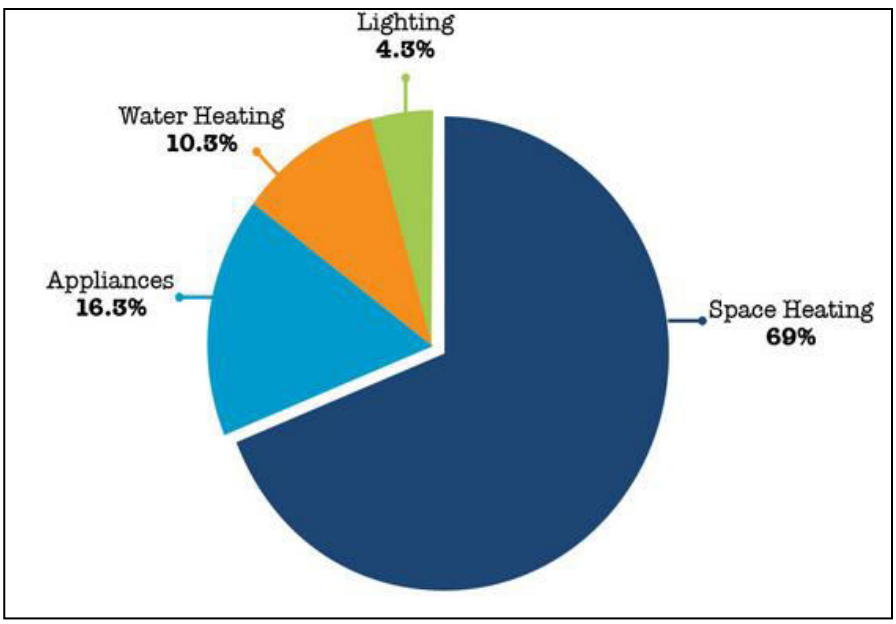


Figure 1.3 Residential energy use [3]

1.2 Literature Review on Energy Data Collection and Analysis

1.2.1 Various Data Logger Designs

Data loggers are used to record different type of measurements at set intervals over a period of time. A data logger is installed in a house to measure house parameters like temperature, humidity, AC/DC current or voltage etc of the house. Any analysis can be completed easily using the data, recorded in small intervals of time. A number of data logger designs have been published in the literature. For example, in [4] multiple parameters (temperature, pH) of green houses are logged using sensors which is transferred to a PC using NI-DAQ cards for analysis in LabVIEW. Rosiek [5] proposed a microcontroller based data acquisition system which collects data from different meteorological stations using eight sensors. To test the functionality of the designed system, results were compared with two commercial data acquisition systems. Ameur [6] designed a data acquisition system to monitor growth of bananas in a greenhouse. They also used a temperature regulation card to keep the greenhouse temperature around 25^{o} C for better production of bananas. Commercial data loggers do not reveal their design and provide a limited functionality. Data loggers have been used for energy analysis of houses. Shuqin [7] investigated residential house energy consumption patterns in summer in seven cities in China. It was observed that Hong Kong uses the highest amount of household electricity compared to other cities. Dutta [8] designed and implemented a better resolution Data Acquisition System (DAS) using Atmega8 microcontroller. This DAS system measures temperature using LM35 temperature sensor. Mahzan and others

[9], presented a data logger design with multiple inputs and large memory space. Four analog signals were tested and sampling interval for the data to be saved was set to 1 second. A case is also observed when one SD card is full and failed. Finally the paper concluded that a 4 GB of SD card can store 3 years of data, coming from four analog signals. Rajesh [10] in his work presented the design of a microcontroller based data acquisition system for recording physiological data. The designed device is portable with dimension 18x9x3 cm, having 16 MB of storage capacity with a high sampling rate up to 16 kHz. The paper also presented a data compression algorithm in the software design to increase the storage capacity of the data logger by up to 3.9 times. Ning [11] designed a high speed data logger using a S3C2440A microprocessor and µC/OS- II operating system. The paper also gave the solution of signal disturbance in sampling and storage using AD7899. Data is stored in the NAND Flash chips with every channel's sampling frequency at 10kHz. Folea and others [12] designed a data logger to measure temperature and humidity based on programmable system-on-chip, which can display and save data using a thermal printer or an USB flash drive. Lindberg [13] analyzed 5 year building energy consumption data, collected from a data acquisition system which used almost 520 sensors in each of 6 buildings. For different exterior wall material the data was collected for analysis. They showed that for reducing building heating and cooling energy load, use of thermal mass of a house has significant effect. The authors of [14] and [15] presented an energy and economic analysis of a zero energy house with solar application and a conventional house. Among several conclusions it was observed that an air conditioner with a water-cooled air condenser saves noticeable electricity. Full design of a data logger and energy analysis of electrically heated houses is missing in the literature. A design of a

low cost data logger and energy analysis of two houses is presented in Chapter 3 of this thesis.

1.2.2 Examples of House Energy Analysis in Literature

A number of house energy analysis techniques and software have been published in the literature. Christopher [16] in his paper used software HOT2000 to analyze the annual energy consumption of an existing house in the city of Thessaloniki, Greece and compared the simulation result with the actual data from the annual utility bills. They concluded that on energy saving, climatic conditions and the type of building materials have noticeable impact on energy efficiency of a single family house. Miloroad [17] presented the results of his research on optimization in the thickness of its thermal insulation layer in low energy residential houses in Serbia. The optimization is done using EnergyPlus software and Hooke–Jeeves direct search method. It was concluded that the use of polystyrene results in highest primary energy consumption. Also the optimized thickness of the thermal insulation layer of45 cm for mineral wool and 20 cm for polystyrene was found. According to the paper, the ultimate solution for lowest primary energy consumption in residential houses is achieved using mineral wood as thermal insulation because the saved energy per unit of material energy is as high as 9–14 times. Gustavsson and Joelsson [18] completed a study of primary energy use and CO_2 emission for the production and operation of conventional and low-energy residential buildings. The result showed that for residential and ordinary buildings, the primary energy use for production can be up to 45% and 60%. The energy use depends on the type of house construction material and the study concluded that wood-framed constructions results in low energy use and CO_2 emission from production than for concrete-framed constructions. The analysis is completed mainly with five different type of buildings modified in various ways. The large part of energy is consumed for domestic hot water and house electricity. Author [19] studied yearly house energy consumption and analyzed thermal behavior of a house using Energyplus software. Actual consumption is compared with simulated result and found that simulation overestimated the heating and cooling consumption due to less use of air conditioning. An improved model of the house with lightweight walls is simulated for a year, which resulted in increased heating energy consumption and decreased cooling consumption. The study concluded that heavy walls save energy up to 25% compared to the light weight walls in the Argentinean Northwest.

Miha [20] introduced a calculation model which uses different quality parameters of a house, depending on their availability. The statistical samples for the evaluation process were taken from a Slovenian single-family house. Floridesa [21] used the TRNSYS program to study a typical house heating and cooling load variation for different building constructions used in Cyprus. It was concluded that better roof insulation results in a reduction of cooling load up to 45.5% and heating load up to 75%. Promoting a house as zero energy and saying that it is energy efficient are not enough to convince customers to choose this type of house. The purpose of André Stephan’s [22] study was to detect barriers to and opportunities for promoting nearly zero-energy houses. They surveyed on the basis of end user satisfaction with zero energy houses. End users appreciate comfort in passive houses mainly because of better winter thermal comfort and better indoor air quality. The study indicates that energy costs are an important aspect to choose a nearly zero-energy dwelling. A barrier to select zero energy houses might be a perception of insufficient summer comfort and air quality. From [23], it can be concluded that the extra cost of the low-energy house is 4% and of the passive house is 16% in comparison with the standard house. Insulation material and ventilation are the main reasons for this extra cost. Low energy house is recommended than the passive house and even when energy prices increase significantly. Detailed house energy simulation and a comparison of data with the logged data are missing in the literature. Chapter four presents simulation results of two houses in newly developed software and compares results with simulation outputs.

1.2.3 Review of Energy Planning Softwares

Several system analysis and designs have been done using free EnergyPLAN software [available at http://www.energyplan.eu/] Bjeli and others [24] introduced wind integration and evaluated with the existing Serbian energy system using EnergyPLAN software, to reduce energy imbalances. Liliana [25] analyzed three scenarios with reference to the existing Portuguese electricity system and ultimately proposed and analyzed a 100% renewable energy source scenario with EnergyPLAN. Hagos and others [26] evaluated and validated two energy system scenarios in EnergyPLAN with bio-heat and heat pumps in individual and district heating systems, with a reference to energy model of Norway. They concluded that adding solar, wind and bioenergy in the current energy system it is possible to reduce import of electricity and primary energy consumption. Boris [27] proposed a future energy plan of Macedonia for 2030 and 2050 with the use of EnergyPLAN software. A 50% and 100% renewable energy system is created for the year 2030 and 2050 respectively and importance is given to storage technologies. A 100% plan has also been proposed by Lund [28] for Ireland, three scenarios with different renewable energy sources for each is designed to get the optimum energy system design.

Madeleine [29] presented Panamas current electricity generation sector design by LEAP. Four future scenarios had been designed and analyzed for this study. The first scenario is climate subsidence without adding new technologies. In Scenario 2, resource diversity is maximized and scenario 3 reduces the possibility of global warming. These three scenarios are compared with the current electricity generation scenario. The study found that mixing renewable sources to the existing electricity generation system reduces the global warming effect. This study also concluded that with existing technologies and costs, Panama can attain a sustainable grid.

Qureshi and others [30] modeled and analyzed a baseline model for Pakistan in LEAP. An energy demand is forecasted from year 2005 to 2030 for the country. Three scenarios are designed to compare with the baseline case. The first scenario adds renewable sources to the system, the second scenario shows high contribution of hydro resources and in the third scenario, use of coal is decreased increasing renewable and nuclear resources. The result concluded that all the new scenarios are better than the baseline case although the baseline case is the lowest cost option. The study suggested the second scenario rather than the baseline scenario, due to its low GHG emission and low costs in comparison to the other scenarios.

Supachart and Ahsan [31] presented rural electricity demand forecast for Bangladesh in LEAP from year 2010 to 2030. The study showed that total electricity demand for rural areas of Bangladesh by 2030 will be 27 TWh, and this demand can be met by solar and biomass energy together with national grid electricity. The paper also studies the increasing potential of solar and biomass energy in Bangladesh.

Rajesh and Sanjay [32] presented demand forecast and energy resource mix for year 2030 using LEAP for Maharashtra with a baseline year 2012. The study concluded that the industrial demand will be 34.5 % of the total electricity demand in the future. Also for year 2030, the electricity demand will be 212.7 billion kWh. The paper proposed a resource mix to fulfill the demand with 76% coal plant, 9.8% hydro plant, 9% renewable plant and 5% gas power plant.

Huang [33] used LEAP models to compare future energy demand and GHG emission of the existing system with several alternative energy systems for Taiwan. In the study, the first scenario was by improving energy efficiency by 2% yearly through 2025 where demand side energy use totals 805.2 trillion kcal by 2030, which is 327.8 trillion kcal less than in the base case. Second scenario assumes financial tsunami’s long term negative effect on Taiwan’s economic growth, in which total energy demand in 2030 is 1062.8 trillion kcal, which is 70.3 trillion kcal decrease when compared with the base case. Third scenario assumes retirement of existing nuclear power planst where energy demand in 2030 totals 755.3 trillion kcal, which is a decrease of 377.8 trillion kcal as compared to 2030 base case demand. The fourth scenario combines all the three scenarios case where energy demand in 2030 totals 755.3 trillion kcal, which is a decrease of 377.8 trillion kcal as compared to 2030 base case demand. But the third scenario will have a negative impact by increasing CO_2 emission. Also the second case has less effect on energy consumption than the first or fourth case.

Yusnan [34] modeled and forecasted energy conditions in Yogyakarta from base year 2008 to 2025. This study used LEAP to design an energy system with renewable energy. With the base case, two more scenarios were designed for comparison. The study concluded that, In the National Energy Policy scenario, renewable energy can reach 17% of the total energy mix. Whereas in the Regional Energy Policy scenario, renewable energy can penetrate only 9.28% of the total system. The study also found that the transportation sector and the household sector use the highest energy in Yogyakarta.

1.3 Thesis Overview

In this research, energy use data for different sectors is collected to calculate energy consumption per person per year in Newfoundland. A data logger has been designed to store and log house energy consumption data and show inside & outside house temperature. Energy analysis and thermal simulation is completed for two houses in St.

John's, NL. Finally, Newfoundland Island's present energy system and demand forecast is presented with collected energy data. In the following sections a brief description of the work as well as motivation is described.

Energy is needed everywhere in every step of daily life. Total energy demand according to Statistics Canada for Newfoundland and Labrador is 32.32 TWh in year 2011. But to know how much energy is needed per person would be helpful to predict the demand per person for future. In the thesis energy data is collected and annual average energy consumption per capita is found, which is 185.34 kWh/person/year.

In every country, monthly energy consumption of every household or office is calculated and sent to the users as bill at the end of each month. Newfoundland is not different than the other countries. In Newfoundland and Labrador, Newfoundland Power and NL Hydro operates the transmission, distribution and generation system throughout the island portion. Newfoundland Power and Hydro calculates the monthly energy consumption of each month. In most parts of the province, meters are read by meter readers. The data are read and stored on a handheld pc which is later transferred to the main utility computer system and monthly bills are produced. But for a better picture of energy consumption hourly, daily, weekly data are useful. Data loggers are a low cost and quick solution to log house data. This house data can be temperature, humidity, voltage, current etc. Data loggers are needed to be installed in a house and it needs no monitoring to give accurate results 24 hours a day. A simple, low cost data logger has been designed in this thesis which can measure inside and outside house temperature along with the measurement of current, being used by appliances. All the data are stored in an sd card with a time interval of 2 seconds. With the stored data, a detailed picture of the house energy consumption can be observed.

The present environmental situation requires increased research in energy efficiency and energy savings. No matter the size or age of a house, there are options to reduce the energy use and costs. But to reduce the energy use one needs to know which parts of the house consumes the most energy. Energy analysis is the first step to make a house more energy efficient. Using the type of data logger that is designed, house energy analysis is done for two houses in St. John's, NL. The actual monthly house energy consumption data is compared with the consumption data stored by the data logger. Final energy analysis concluded that both the measured data and the collected data from Newfoundland Power follow a similar pattern.

The analysis of energy consumption and indoor thermal simulation of buildings has experienced a fast growing need in the last few years. Again a thermal simulation of a house helps to determine which purchases and improvements will save the most money and energy. Thermal simulation suggests improvements for the house to increase energy efficiency, lower utility bills, and increase comfort. A thermal house energy analysis is important to make the house more energy efficient. For a more comfortable and less expensive heating and cooling system thermal simulation is needed. In this thesis thermal simulation of two houses in St. John's is shown using Building Energy optimization (BEopt) software, which calculates yearly house energy consumption. The analysis gives promising output that the actual house energy consumption matches with the simulation results.

For enough generation and distribution of energy to the consumers, better planning is necessary. Planning is done according to the demand forecast. If demand can be projected correctly, future need of energy can be met by sufficient capacity expansion planning. The energy resource in Newfoundland and Labrador is significant. With proper planning and implementation, Newfoundland and Labradors future needs can easily be fulfilled from its own energy warehouse. In this thesis, present energy data of Newfoundland Island interconnected system are collected from reliable sources to use in planning softwares. At first, the existing energy sector is designed and analyzed in EnergyPLAN software to get a true picture of the Newfoundland energy system. The analysis is presented in hourly steps over a period of one year. Also a future plan with more wind energy integration in the existing system is proposed. Finally an energy plan is proposed, with demand forecasted up to year 2030 in LEAP (Long range Energy Alternatives Planning system). Three scenarios are designed to compare with the present scenario with actual growth rate.

Detailed energy consumption data and analysis of Newfoundland is missing in the literature. Design of a data logger to log house energy consumption is also missing. The actual plan by Nalcor does not consider more wind integration in the existing system. In the thesis, a scenario with added wind energy to the system is presented. Again the Newfoundland energy plan does not talk about excess hydro generation and how that could be used in different energy system scenarios. This thesis presented three possible scenarios with proposed mixes of energy sources to fulfill the future demand.

1.4 Organization of the Thesis

The thesis consists of six chapters. Along with introduction, Chapter Includes detailed literature review.

Chapter 2 consists of some collected data and energy consumption analysis per person per day in Newfoundland. Different types of energy are used by the people of Newfoundland. The consumption data for different energies are collected for analysis. All the data are summed up in MATLAB to get the per person energy demand. It is found that energy consumed is 185.34 kWh/person/day. This value matches reasonably with 168.93 kWh/person/day data, found from Statistics Canada website.

Chapter 3 presents design and implementation of a low cost house energy data logger. Two temperature sensors, four current sensors and a 40 pin microcontroller are used in the design. Mikrobasic compiler is used to program the microcontroller. The designed data logger can measure the inside & outside temperature of a house and also the total current coming into the house with good accuracy. Both measured temperature values are displayed on a 2x16 LCD. The data logger logs every data in every two seconds to a 2 GB sd card. Separate files are created in the sd card to store all the sensor data. The design of this data logger has been published in the conference proceedings and presented in the *International Conference on Electrical and Computer Engineering 2014, Dhaka, Bangladesh.*

Chapter 4 consists of design and energy consumption analysis of two houses in St John's, Newfoundland. Power consumption data for both the houses is collected from utility company and then compared with the measured values from data logger installed in the houses. It was observed that collected and measured values of energy consumption follow a similar pattern. For detailed analysis, two houses are designed and simulated in BEopt to get the yearly energy consumption of both the houses. The simulation results in BEopt showed that the output of energy consumption for one year is almost equal to the measured energy consumption of both the houses. This design and energy consumption analysis has been published in *BSME International Conference on Thermal Engineering, 2014, Dhaka, Bangladesh.*

Chapter 5 presents the Newfoundland energy plan design in EnergyPLAN and LEAP (Long range energy alternatives planning) software. For the designs detailed data are collected for Newfoundland Island. In EnergyPLAN existing energy system is designed and later a model is designed by increasing the wind energy to 300 MW which shows a step toward the future energy model of NL. Similarly in LEAP NL island energy system is designed but it works with growth rate. So an energy plan up to year 2030 is presented with analysis of three scenarios and comparison with base case. The energy system design in EnergyPLAN software has been presented and published in *Newfoundland Electrical* *and Computer Engineering Conference 2014, St. John's, Newfoundland and Labrador, Canada.*

Another paper titled 'Design of a 3-bed passive house for St. John's using BEOPT software' was published and presented in *Newfoundland Electrical and Computer Engineering Conference 2013, St. John's, Newfoundland and Labrador, Canada.*

Summary of the research work, results, limitations and future work is included in the last chapter.

Chapter-2

Analysis of Newfoundland's energy consumption data

2.1 Introduction

Energy is the most important part of todays everyday life and its significance will continue to grow untill the end of world. Newfoundland has ample amount of resources which can be used with proper planning for the benefit of future generations. Newfoundland and Labrador's energy resources include mainly crude oil, natural gas hydropower and wind power. With a proper and wise energy plan it can be ensured that the people of Newfoundland get the most benefits of its resources. Newfoundland with its present potential, can not only meet its own demand but also can export significant amount of energy to other places where needed. The different energy activites of the province consists of electricity generation and distribution, crude oil production/refining and petroleum product distribution. Canadian houses are entirely dependent on various types of energy to heat, cook, run appliances, lighting, water heating etc. But the mainly used energy sources by the people of NL are electricity, natural gas, petroleum products etc.

According to Canada-Newfoundland and Labrador Offshore Petroleum Board, the Newfoundland and Labrador offshore contains 2.9 billion barrels of oil, 479 million barrels of natural gas liquids and 10.86 trillion cubic feet of natural gas [35]. It is also estimated by the goverment that there are 6 billion barrels of oil and 60 trillion cubic feet of natural gas offshore, which is not discovered yet.

The province of Newfoundland & Labrador generates electricity from hydropower, wind power, oil and natural gas. Newfoundland Power (NP) and Newfoundland & Labrador Hydro (Hydro) are the two companies who are responsible for the generation and distribution of electricity in the province. Island interconnected system and Labrador system are the two electric power system in the province. Some diesel generators operated by hydro are used to distribute energy for customers of rural and isolated island. On the island part of the province the main distributor of electricity is Newfoundland Power (NP) with nearly 240,000 customers. NP purchases 92% of the island's customer's demand from hydro, and the rest of the demand is managed by 23 small hydroelectric generating plants [36] operated by NP. Total generation and transmission process of the province is taken care of by Nalcor energy, which is the parent company of hydro. In this thesis the data analysis has been done primarily for the island portion of the province. The total electricity generation of Newfoundland Island is dependent on hydro power, supplemented by wind power and thermal station, where total installed capacity of wind energy on the island is 54.7 MW [37] and capacity of the thermal station is 613 MW. The thermal plant consists of three turbines with a total capacity of 490 MW. Recently in year 2014 a new unit of 123 MW [38] has been installed on the Holyrood generating site. Figure 2.1 shows the generation and transmission map of the province of NL.

Figure 2.1 Newfoundland and Labrador's electricity generation and transmission map [39]

2.2 Electricity consumption data

Different types of energy are used every day in Newfoundland. But among all, electricity is the major source of energy used for residential, industrial and other purposes. It is already mentioned that Newfoundland and Labrador Hydro is the principle supplier of electricity in the province. The total generating capacity of only Newfoundland Hydro is 1637 MW, which does not include any power purchase. On the island the electricity generation process comprises of six hydroelectric plants (located at Bay d'Espoir, Cat Arm, Granite Canal, Hinds Lake, Paradise River, and Upper Salmon), the Holyrood Thermal Generating Station, two combustion turbines (St. John's and Stephenville), two diesel plants (Hawke's Bay and St. Anthony) and some power purchase from non-utility generators and wind farms [40].

Every day the province is producing the electricity needed by the customers. Customer demand is at its peak during the winter months. Also in Figure 2.2 [41] it can be seen that, throughout the year the demand increases in the morning and evening time. The dotted yellow line indicates the maximum available supply and plain yellow line indicates the demand. Table 2.1 shows total residential electricity consumption for year 2011, which was 5,421,942 MWh. Since NL power takes the responsibility of the residential section electricity supply, by subtracting the residential use from the total use we can get the industrial and Labrador side consumption which is mainly maintained by NL hydro. The monthly data of residential electricity consumption has been collected from NL power [42] through e-mail. The total island consumption data is collected from statistics Canada website [43]. From Table 2.2 we can conclude that Labrador & industrial sector consumption is 5,488,754,000 kWh, where the total electricity consumption in the province is 10.91 TWh. The actual picture of Newfoundland energy consumption is

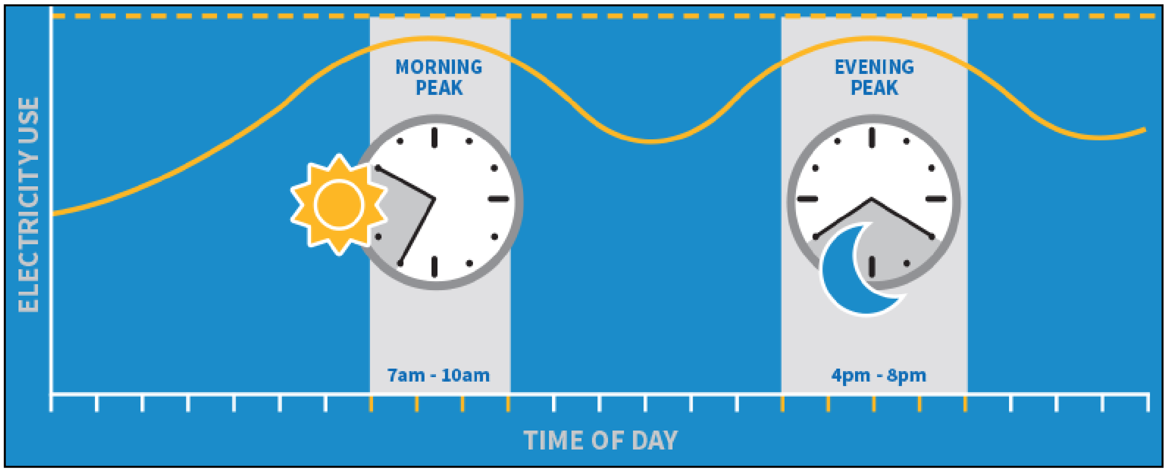


Figure 2.2 Electricity demand peak

Table 2.1 Monthly residential electricity consumption data of NL

Year 2011, Actual energy sales of NL	
Month	MWh
January	570,842
February	617,604
March	591,511
April	538,236
May	465,045
June	386,108
July	339,782
August	317,563
September	286,441
October	337,848
November	451,640
December	519,322
Total	5,421,942

Table 2.2 Total electricity consumption data of NL

Electricity consumption data, year 2011				
Month	Total electricity available to use(a)		residential consumption in NL(b)	Labrador & industrial sector consumption=(a)-(b)
	MWh	kWh	kWh	kWh
January	1,162,168	1,162,168,000	570,842,000	591,326,000
February	1,086,754	1,086,754,000	617,604,000	469,150,000
March	1,133,656	1,133,656,000	591,511,000	542,145,000
April	963,552	963,552,000	538,236,000	425,316,000
May	842,054	842,054,000	465,045,000	377,009,000
June	697,683	697,683,000	386,108,000	311,575,000
July	663,721	663,721,000	339,782,000	323,939,000
August	700,996	700,996,000	317,563,000	383,433,000
September	695,747	695,747,000	286,441,000	409,306,000
October	817,132	817,132,000	337,848,000	479,284,000
November	987,361	987,361,000	451,640,000	535,721,000
December	1,159,872	1,159,872,000	519,322,000	640,550,000
Total	**10,910,696**	10,910,696,000	5,421,942,000	5,488,754,000

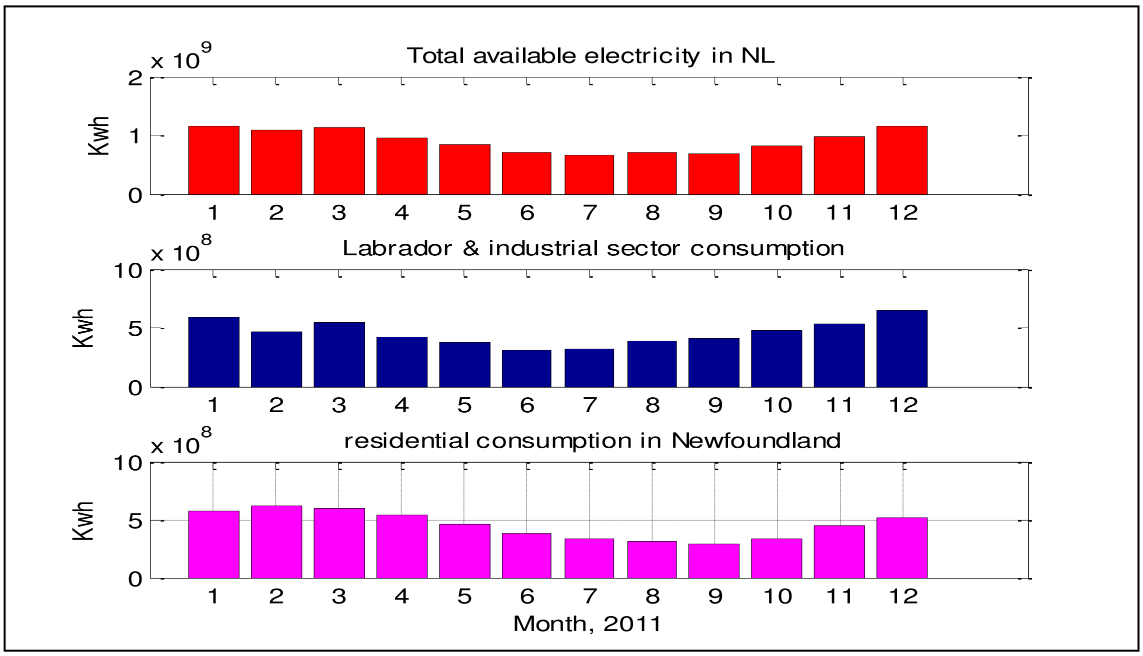


Figure 2.3 Total availability and consumption of electricity in NL.

presented by plotting the data using MATLAB in Figure 2.3. The red bar shows total available electricity in NL, the blue bar indicates Labrador & industrial sector consumption and the pink bar shows the residential consumption only. In Figure 2.3., month 1 indicates January and so on.

2.3 Use of Natural Gas

Natural gas is one of the safest and cleanest source of energy. Though natural gas reserve and potential is significant in NL, but no natural gas is currently being produced in the province of NL. Due to some industrial and financial issues, harsh environment etc. offshore development of natural gas is not effective yet. Government is working to overcome the challenges.

The Canada Newfoundland and Labrador Offshore Petroleum Board estimate that there are over 10 trillion cubic feet of natural gas offshore [44]. Mostly the natural gas used in Canada comes from Alberta and other western provinces. Natural gas can be used for heating, to fuel appliances etc. Table 2.3 shows the net withdrawal of Natural gas in year 2011 [43]. Here net withdrawal is same as the total available gas to use. Unit conversion from cubic meter to kWh is done using $1m^3$=10.365 kWh [45]. The aqua colour bar in Figure 2.4 shows the total available gas to use in NL in year 2011.

Table 2.3 Total available Natural gas for use

Natural gas (net withdrawal), year 2011		
Month	Million m^3	Million kWh
January	33.4	346.191
February	31.5	326.4975
March	34.5	357.5925
April	37.2	385.578
May	36.3	376.2495
June	30.4	315.096
July	33.8	350.337
August	33.5	347.2275
September	30	310.95
October	29.5	305.7675
November	30.2	313.023
December	34	352.41
Total		4086.9195

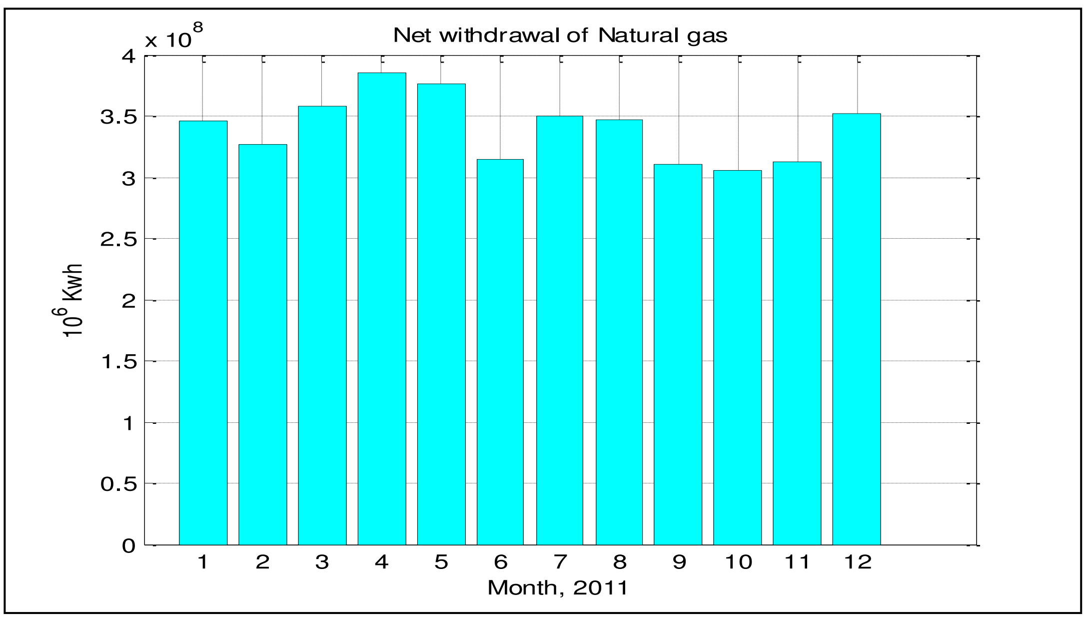


Figure 2.4 Total available natural gas to use, year 2011

2.4 Use of Petroleum products

Petroleum is a naturally formed, inflammable liquid which is found beneath the earth's surface. Petroleum products are products which are derived from crude oil after refining the oil in refinery. In the refinery the majority of crude oil breaks into various type of petroleum product like gasoline, fuel oil, jet fuel, diesel fuel, heating oil, kerosene, and

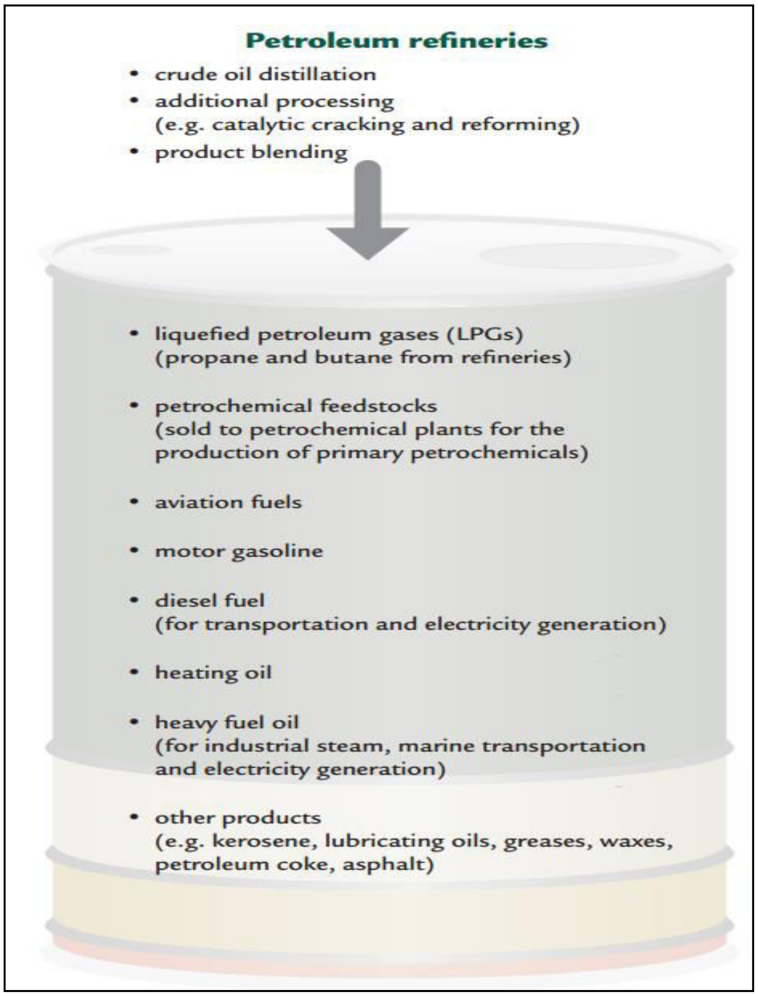


Figure 2.5 Petroleum products [46]

heavier fuel oils. In Figure 2.5 the total process and the final petroleum products are shown[46]. Newfoundland and Labrador produces approximately 300,000 barrels of oil per day. And there are three producing offshore oil projects: Hibernia, Terra Nova and White Rose. The fourth Hebron oil development project is expected to begin in 2017 [35]. Table 2.4 lists the use of different class of fuel used in Newfoundland and Labrador in year 2012. Year 2012 data is collected because demand of the petroleum in year 2011 and 2012 are close. In the table, diesel fuel oil includes all grades of distillate fuel sold for diesel engine use including low sulphur content. Light fuel oil includes all distillate type fuels for power burners, fuel oil number 2, fuel oil number 3, furnace fuel oil, gas oils and light industrial fuel. And the heavy fuel oil includes low sulphur, Bunker B and Bunker C,

Table 2.4 Total use of refined petroleum products [47].

Refined petroleum products, 2012	
Fuel type	1000 m^3
Propane and propane mixes	30.5
Aviation gasoline	0.8
Motor gasoline	871.1
Aviation turbo fuel, kerosene type	85.5
Stove oil, kerosene	301.5
Diesel fuel oil	468.2
Light fuel oil	199.5
Heavy fuel oil	139.4
Asphalt	12
Lubricating oils and greases	10.4
Other petroleum products	25.6
Total refined petroleum products	**2,144.50**

and Bunker C, fuel oils numbers 4, 5 and 6, and residual fuel oil.

The units in Table 2.4 are given in cubic meters, so 1 m^3=10693 kWh conversion factor is used [48] [49] for further description. Figure 2.6 plots different types of refined petroleum products in different colours. Which colour of bar indicates which fuel is defined in the right side of the picture. Like the navy blue indicates propane, yellow bar indicates light fuel oil, light green bar indicates diesel oil, and so on.

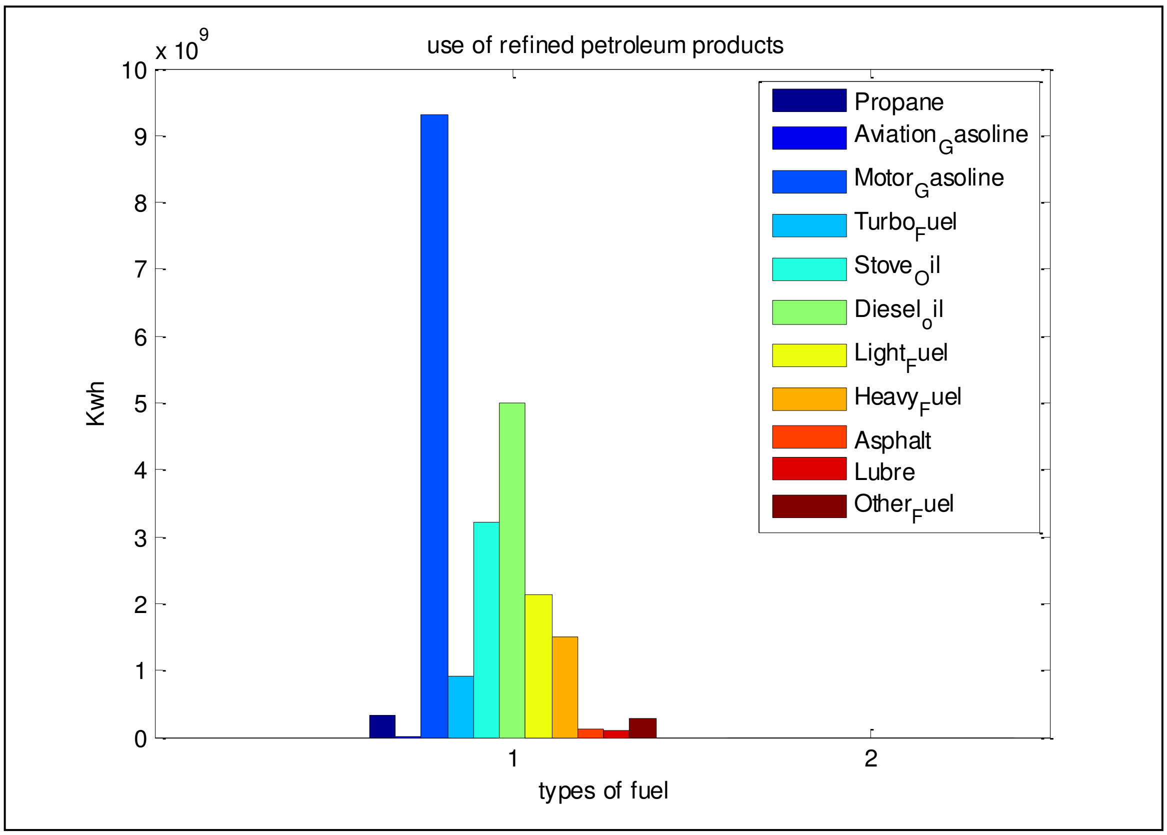


Figure 2.6 Total use of different types of refined petroleum product.

2.5 Use of Bunker-C oil

Another name of Bunker-C is number 6 fuel oil, which is a high viscosity residual oil. Number 6 fuel oil is used to run the Holyrood Thermal Plant, which generates 15 to 25 % of the island's annual electricity demand, with a total capacity of 490 MW. In the summer months, the plant does not need to operate, but it operates in winter months when the demand is in its peak. Figure 2.7 shows the hours of operation from beginning of the year where it can be seen, for some noticeable amount of time in summer the plant remains off.

At peak production, the plant needs 18,000 barrels of oil/day [50]. If it operates 250 days in a year the plant needs 4,500,000 barrels of oil per year. In a year the plant produces 2.42 TWh electricity. The data of the thermal plant production is collected from one of the plant employee.

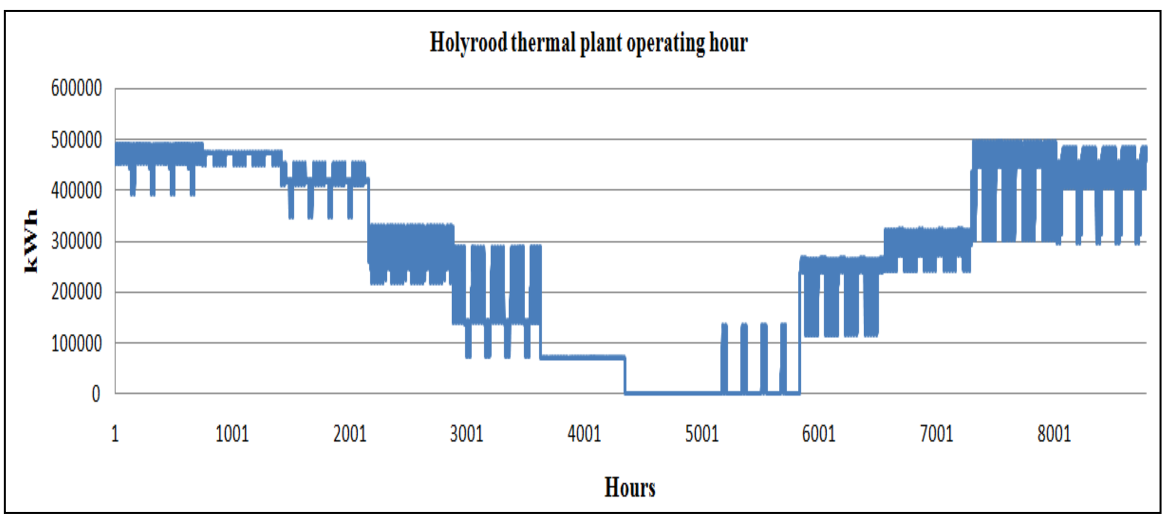


Figure 2.7 Operating hour of Holyrood thermal station

2.6 Biomass

Any plant element that can be turned into fuel is known as biomass. In the province of NL wood is mainly used for heating purpose of the house. Newfoundland had three pulp mills with a total capacity of 60,000 tonnes but recently only one is running. And now the pallet market of Newfoundland is only 3000 tonnes [51]. So the total demand of energy is 14400000 kWh (figure 2.8), using conversion factor, 1ton=4800 kWh [52].

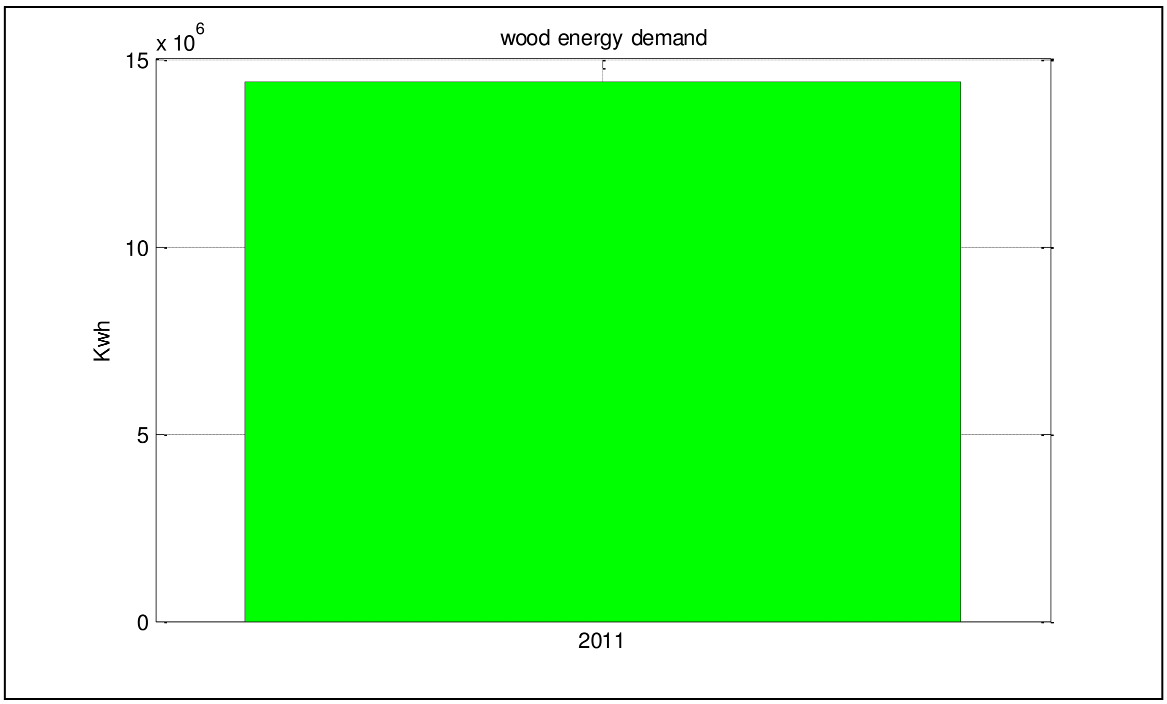


Figure 2.8 Wood energy demand, year 2011

2.7 Energy demand per person

The total population of Newfoundland and Labrador was 525,037 [53], in year 2011. On the other hand the final energy demand used by mining, manufacturing, forestry, construction, transportation, agriculture, residential, public administration, commercial and other institutional sectors is 116,546 TJ, in year 2011. Table 2.5 shows the total energy demand in Tera-Joule (TJ) for Newfoundland and Labrador in year 2011.

Table 2.5 Total energy demand, year 2011

Total primary and secondary energy consumption,2011 [54]	
Sectors	**TJ**
Total industrial	24,643
Total transportation	53,439
Agriculture	483
Residential	20,529
Public administration	6,004
Commercial and other institutional	11,448
Total energy consumption	**116,546**

Total demand = 116546 TJ

=116546*277777.778 kWh

=32373888900 kWh

=32.32TWh [55]

So the final demand according to the statistics Canada per person/day is,

$$\frac{32373888900}{525037*365} = 168.93 \text{ kWh/person/day}$$

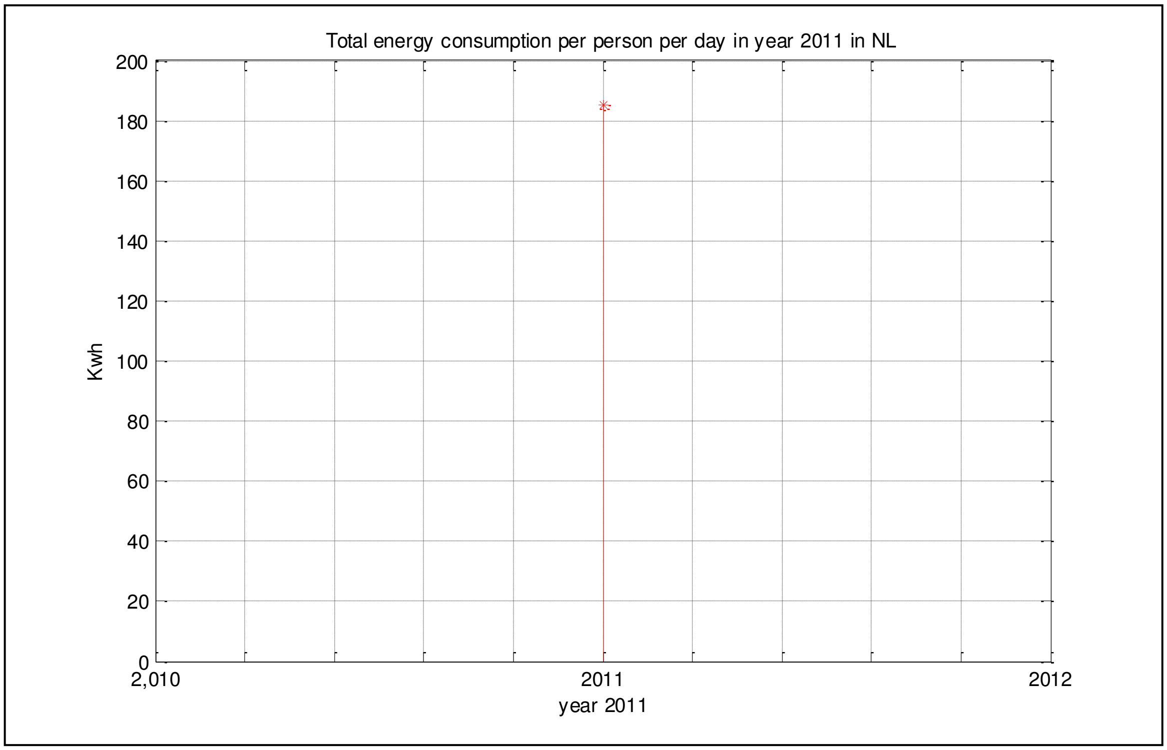


Figure 2.9 Total energy consumption per person per day in year 2011.

After collecting all the data and running the MATLAB code we found that, the total energy per person per day is approximately 185.34 kWh/person/day which is close enough to 168.93 kWh/person/day reported by Statistics Canada.

Calculation were done in MATLAB using the collected data, with the calculation below,

Demand = (E+N+W+RP-H)/ (P*365)

Here,

E= Total electricity consumption of year 2011

N= Total natural gas consumption of year 2011

W= wood Demand

RP= Total refined petroleum product demand of a year

H= Electricity produced in Holyrood thermal plant

P= Population of Newfoundland

The data is plotted using Matlab which is shown in Figure 2.9. Matlab code is provided in Appendix 4.

2.8 Conclusion

Energy consumption per person per day for NL in year 2011 is calculated in this chapter. Energy data from reliable sources is collected to find how much energy is used by the people of NL. The energy data is collected and summed up using MATLAB to get the per person energy demand. In this chapter Bunker-C oil demand is collected separately to show the thermal plant use of the oil. But in petroleum demand the Bunker-C oil is included in heavy fuel oil. Since we are already calculating the energy of oil for that reason the electricity generated by the thermal plant using this oil, which is 2.42 TWh is deducted from the total electricity consumption. The actual demand 168.93 kwh/person/day is close with data reported by Statistics Canada which is 185.34 kWh/person/day.

Chapter-3

Design and development of a house energy data logger

3.1 Introduction

According to statistics Canada [56] the total population of *Newfoundland* & Labrador is approximately 526,896 till January 2014. Many houses in NL are electrically heated. Energy consumption in each house is logged and recorded once a month by the utility company. The total electricity consumption of each house varies with type and size of the house, number of occupants etc. A much frequent data logging is required to determine energy consumption pattern in a house. An energy data logger design is presented in this chapter that is capable of logging house input currents and temperatures at a much higher rate. The designed data logger can sense and record the inside and outside temperature of the house and total current coming into the house.

A data logger is an electronic instrument that measures and records different physical or electrical parameters such as temperature, humidity, wind speed, current through an appliance over time. A common temperature data logger is shown in Figure 3.1. Data loggers are based on a computer connected to a number of sensors and data storage. Sensors are devices which are placed in contact with the component being measured. Figure 3.2 shows a block diagram of a commercial data logging system, which consists of sensors, an interface, sd card and computer device. Sensors sense data from surroundings and produce an analog electrical signal. Most computers cannot work with analog data so

Figure 3.1 Commercial temperature data loggers

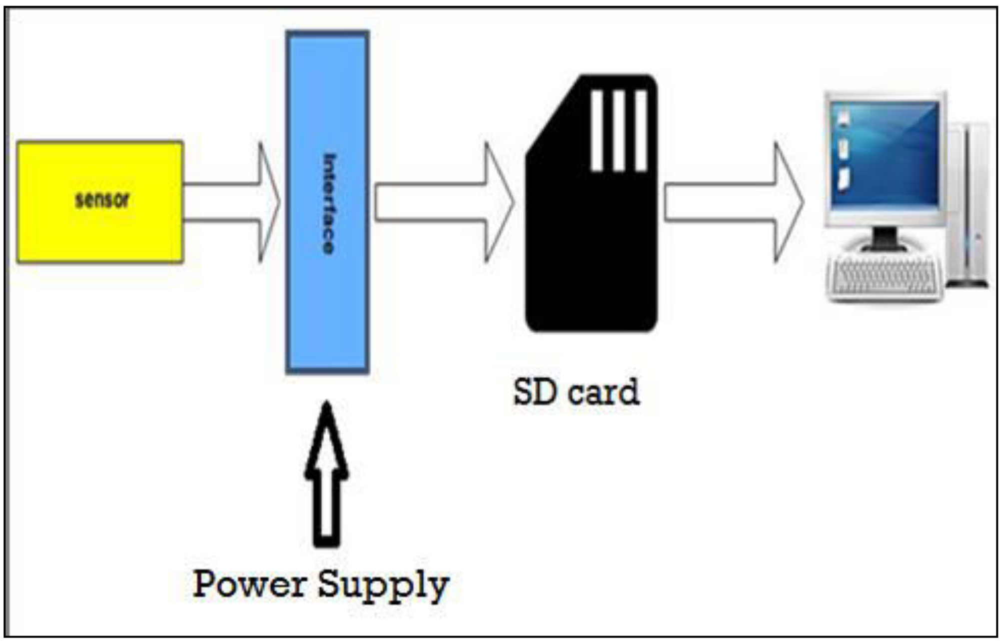


Figure 3.2 Basic data logger system block diagram

the analog signal needs to be converted into digital signal. The interface converts the analog electrical signal into digital signal or numbers which is stored in recording device. Finally the data goes to the computer for further analysis. But power consumption in computers is high and data is lost in case of a power failure. Recent availability of low cost and low power microcontrollers allowed new design of data loggers.

3.2 Data Logger Design

In this section a data logger design is introduced which records total current consumption in a house and both inside and outside temperature of the house. The designed data logger mainly consists of the following components.

1. Temperature sensor (LM35)
2. Current sensor (L18P003D15)
3. Microcontroller unit (PIC18F4550)
4. 2 GB sd card
5. 2x16 LCD module
6. Operational amplifier
7. Resistors
8. Rms to Dc converter (AD737)
9. Ac & Dc power supply
10. Voltage regulator etc.

Four current sensors and two temperature sensors have been used in the design. Data logger circuit diagram is shown in Figure 3.3. Figure 3.8 shows photos of designed data logger. A 2x16 LCD is used to display required measurements. A Microchip microcontroller PIC18F4550 is used for recording the data from the sensors. Data taken from the temperature sensor is displayed on a 2x16 LCD. And data taken from current

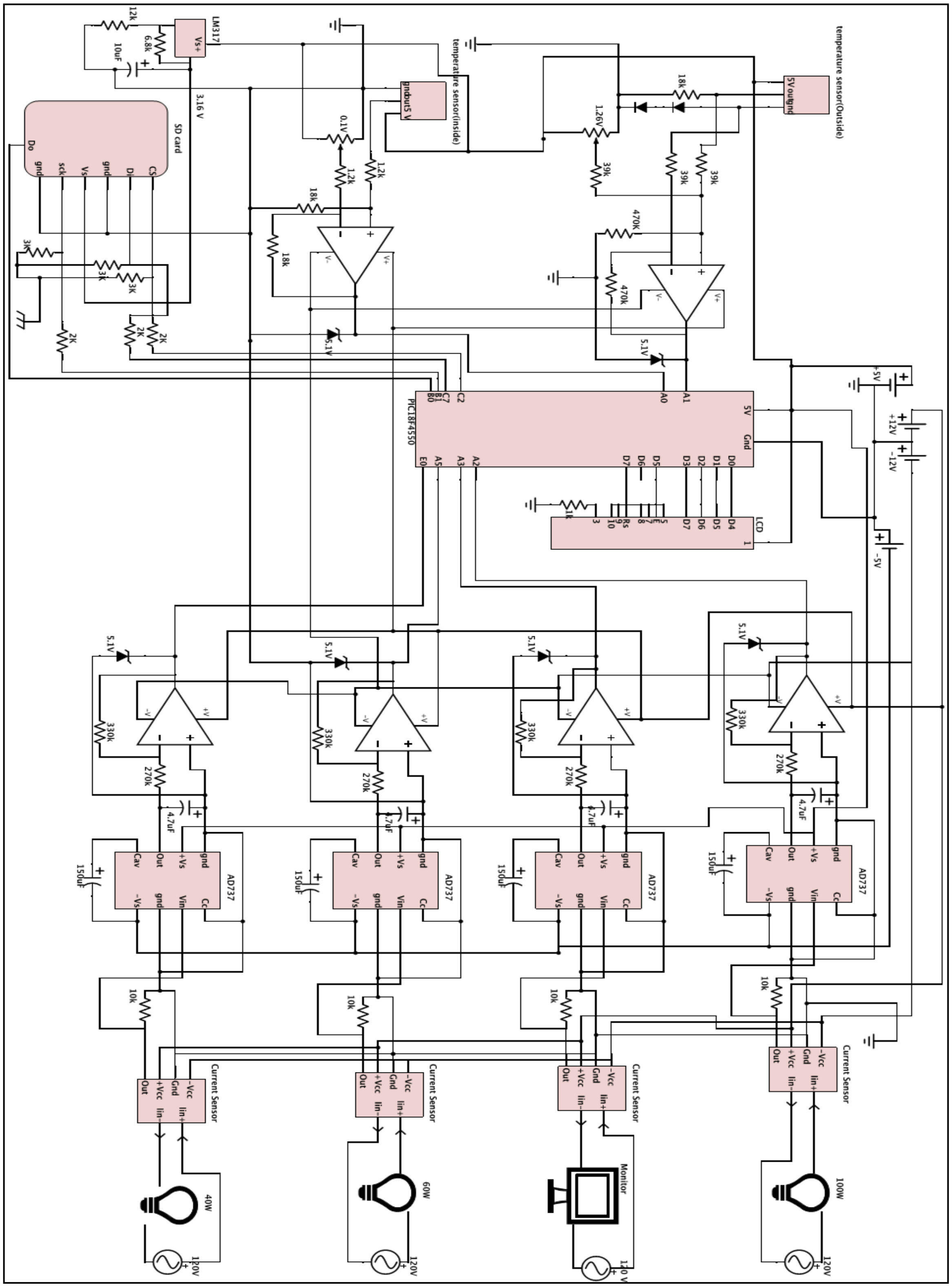


Figure 3.3 Data logger circuit diagram with test load

sensors are directly saved in separate files on the sd card. For further analysis the data from sd card can easily be transferred to a computer.

3.2.1 Temperature sensor

Temperature sensor is a device that senses the temperature from the environment and gives the output in terms of voltage. In the design LM35 series temperature sensors have been used whose output voltage is linearly proportional to the Centigrade temperature. Scaling factor of LM35 is +10mV/◦C, which means for every degree Celsius changes in temperature it gives 10mV analogue output voltage. Two temperature sensors are used, one for the inside and another for the outside house temperature. Temperature range selected for the inside house temperature is $(+10\ \text{to}+40)^{o}$ C and for the outside temperature is $(-30\ \text{to}+40)^{o}$ C. Outputs of LM35 are amplified to 0-5V for input to microcontroller. Zener diodes (5.1V) are used for circuit protection. Figure 3.4 shows LM35 temperature sensor which has three pins. 5V voltage is supplied to pin 1, Pin 2 gives the output and pin 3 is grounded.

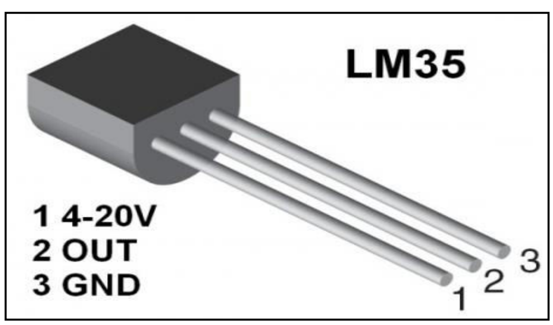
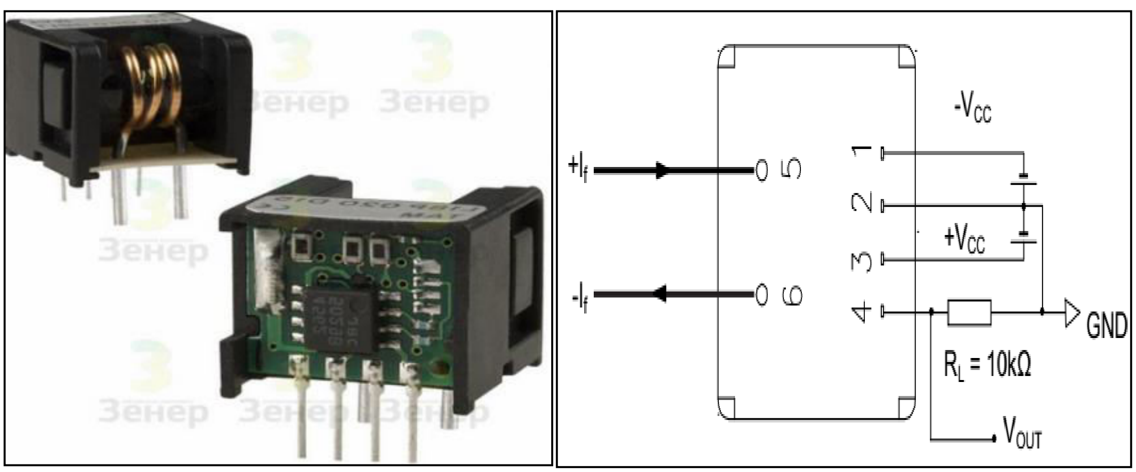


Figure 3.4 LM35 temperature sensor

3.2.2 Current sensor

A current sensor is a device that senses electric current in a wire, and generates a signal proportional to it. Current sensors are connected around incoming current wires to a house in the main panel. Hall sensor based current sensors generate small ac voltage proportional to input current, Rated current for which is ±3A and maximum current is ±9A. Pin configuration and basic connection of the current sensor is given in Figure 3.5 Current sensor AC output voltage is converted to DC using an rms to dc converter (AD737). Amplifiers are used to amplify the output of rms to dc converter to 0-5V for PIC microcontroller. Four identical circuits are used for four current sensors.



(a) (b)

Figure 3.5 Current sensor (L18P003D15)

3.2.3 Microcontroller & SD card Connection

A PIC18F4550 microcontroller is used in the data logger design, which is the most important element in the whole circuit and needs a 5V to operate. There are 13 analog to digital (A/D) input pins which allow conversion of analog input signal to corresponding 10 bit digital number. The A/D module has five registers which are ADRESH, ADRESL, ADCON0, ADCON1, ADCON2. This microcontroller uses a 10 bit resolution ADC converter. Both the current and temperature sensors give analog output which goes to the ADC (analog to digital conversion) port of the microcontroller. Thus analog value is converted to digital value to be displayed on the LCD correctly. Conversion from analog to digital value is done using equation (1).

$$\text{Voltage} = (5 * 10\ bit\ value\ read\ by\ microcontroller)/1024 \qquad (1)$$

A 2GB micro sd card of class 2 is used for the system design. The card is formatted with FAT16 file system. Operating voltage of sd card is 2.7V-3.6V. A voltage regulator LM317 is used to supply 3.16 V to the sd card in the design. In basic connection 2K and 3K resistors are used on pin 1, 2 & 5 (see circuit in Figure 3.3). Resistors are used to lower the input voltage of the sd card. Pin-out diagram for the sd card is shown in Figure 3.6. The chip select pin is necessary to indicate which chip is being communicated with. Serial clock of sd card is directly connected to PIC clock. Pin2 is digital input, connected to PIC's output and Pin7 is digital output, connected to PIC's input.

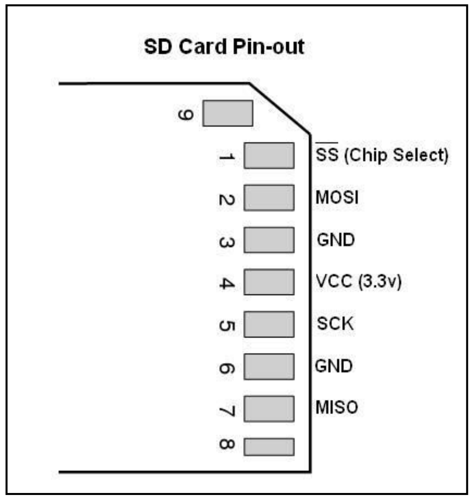


Figure 3.6 SD card pin-out diagram.

3.2.4 2x16 LCD Display

A 2x16 LCD module is interfaced to the Microcontroller to display the inside and outside house temperature. A 2x16 LCD means it can display 16 characters per line and there are 2 such lines. There are 16 pins in the lcd but last two pins are not used. The basic pin connection diagram is given in Figure 3.7. A 1k resistor is connected with VEE to ground which fix the screen contrast of the LCD.

3.2.5 Circuit design

The designed data logger circuit is given in Figure 3.8. In the test circuit, different range of bulbs and a computer monitor was connected as the test load to measure the currents using current sensors.

As mentioned before, for inside house temperature measurement the range is selected

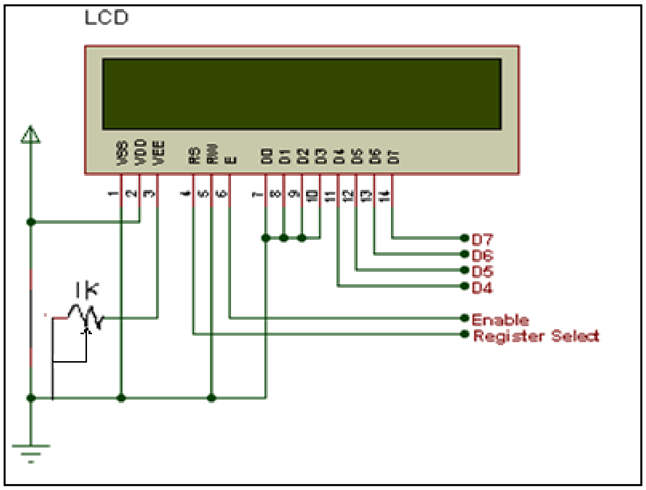
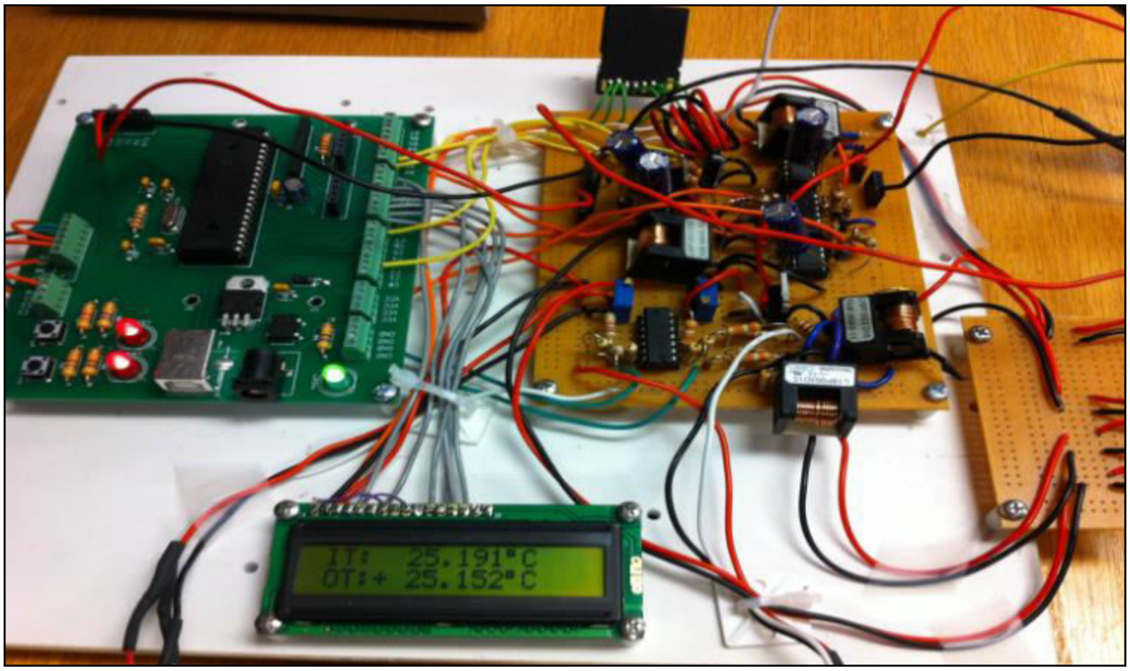
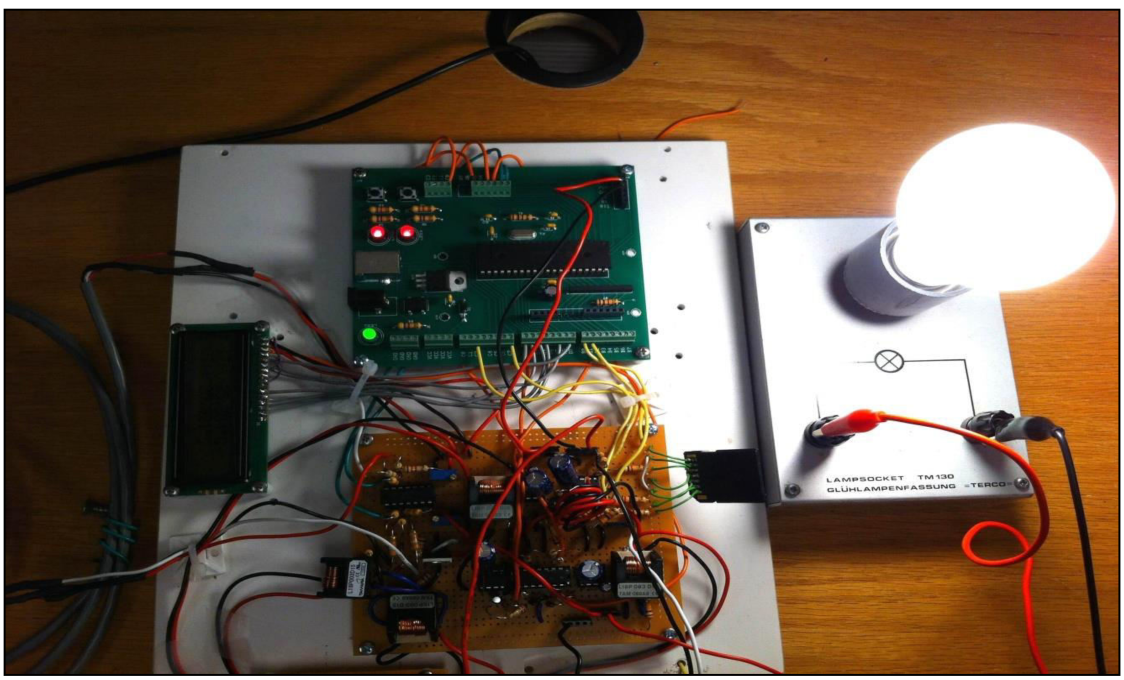


Figure 3.7 2x16 LCD (CM162-4) pin diagram and connection

from +10° C to +40° C. Pin 1 of the temperature sensor is connected to 5 V and the output is connected with an op-amp through a resistor. Here the gain is R2/R1=18k/1.2k=15. For temperature measurement outside of the house, the range is selected from -30° C to +40° C. The offset is required for negative temperature measurement, instead of connecting the temperature sensor to ground; it is connected to an offset voltage. Thus when temperature is negative it will not produce negative voltage. In this design offset voltage is generated by two diodes. In the output pin there is a 18k resistor connected to ground and a 39k resistor connected with op-amps's positive pin. Another resistor of 39k from positive pin of op-amps goes to a POT which is set to 1.26V. Here the gain is R2/R1=470k/39k=12.05. The gain of the op-amp is selected as such, so that the for the selected temperature range the output voltage remain within 0-5V. The temperature sensor senses the temperature and generates a voltage signal which is received by the microcontroller A/D pin A1 and A0. And then by internal calculation and programming both the temperatures are shown in LCD screen. Calculation for inside house temperature



(a)



(b)

Figure 3.8 Designed data logger circuit testing in the lab

reading is shown in equation 2 where 10 ^{o}C is the offset voltage.

$$PIC\ output\ to\ LCD = \left(ADC\ read * \frac{5}{1023}\right)V + (40-10)^{\circ}C/4.5\ V + 10^{\circ}C \qquad (2)$$

Again calculation for outside house temperature reading is shown in equation 3. A temperature difference of 70 ^{o}C varies between 4.37 V, so 4.37/70=0.062 V/^{o}C.

$$PIC\ output = (\left(ADC\ read * \frac{5}{1023}\right) + 1.26)/0.062 \qquad (3)$$

But for LCD display, in case of positive temperature the final PIC output is subtracted from 61 and in case of negative temperature, PIC output is subtracted from 60 to get the correct measurement (Details are given in appendix 5).

For current measurements, from the current sensors saturation characteristic multiplication factors are chosen which is used to get the correct results up to ±3A. Current passes through the current sensor and the generated output is AC voltage. But microcontroller's operating voltage is 0-5V DC. An rms to DC converter is used to convert the AC output voltage of the current sensor to DC voltage. The output of the converter is negative. The negative voltage is then passed through an inverting op-amp with gain of 1.22 (R2/R1=330/270), so that the input voltage in PIC remains within the range of (0-5) V. The output of the op-amp is connected to PIC's analog input port. A clock signal of 20MHz is applied to the microcontroller. Microcontroller's SCK (serial clock) pin is connected to the SD cards SCK pin 5. SD card's input pin in connected to PIC's SD out (SD0) pin & sd card's output pin is connected to PIC's SD input (SDI) pin. All the values from the sensors enter through the analog port and get stored in the SD card with assigned time interval. A 2 GB sd card can be used up to7 days to store data, with 2 sec interval. Once the card is full with stored data, SD card can be removed from the adapter and can be inserted into a PC for further data analysis.

For programming of PIC18F4550, mikrobasic compiler is used which is downloaded from http://www.mikroe.com/mikrobasic/pic/ .The written program is given in Appendix 5. Once a programme is written and compiled it generates a hex file which is loaded to the PIC using a device programmer. In Figure 3.8 the constructed data logger circuit is shown. When the picture was taken both temperature sensors were inside of the house. So in the LCD it is showing same temperature (25 ^{o}C) for inside and outside of the house. And the current readings are saved in the sd card in separate files (Figure 3.9) with both the temperatures. Figures 3.10 and 3.11 display how the data are stored in the SD card. A delay of 2 seconds is used between the data storage. Some actual value readings from the sensors and saved on the sd card are shown in Table-1. Both the inside and outside temperature are shown and both the sensors were inside of the house while the data was being logged. Outside temperature value is higher because that sensor was close to a light bulb. Value of only one current sensor is shown using a 100 W bulb as the load.

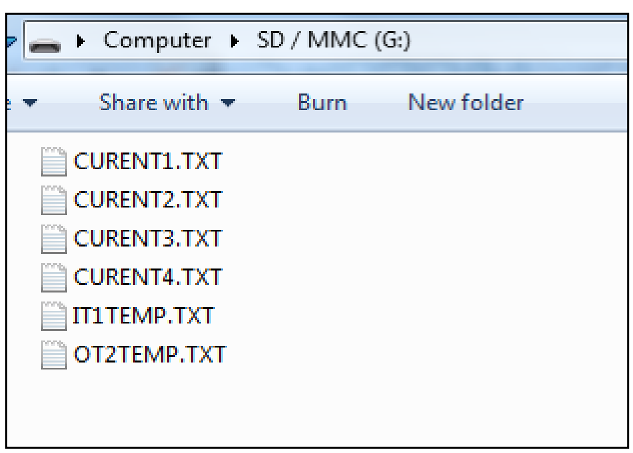
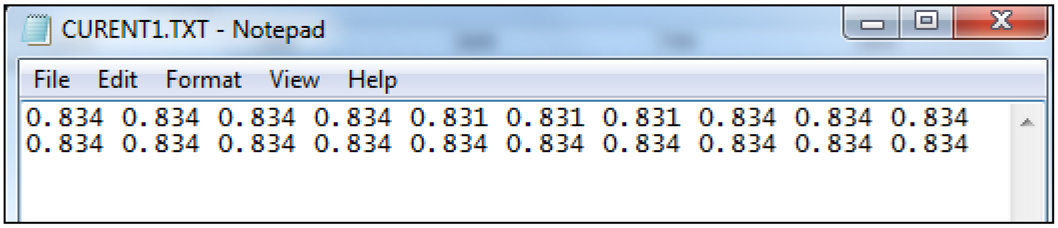


Figure 3.9 Folders in SD card

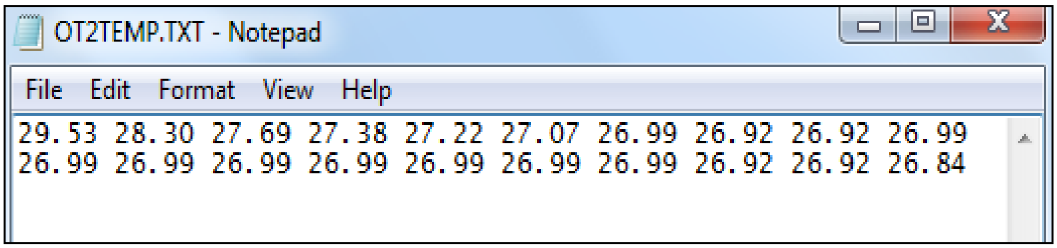


CURENT1.TXT - Notepad

File Edit Format View Help

0.834 0.834 0.834 0.834 0.831 0.831 0.831 0.834 0.834 0.834
0.834 0.834 0.834 0.834 0.834 0.834 0.834 0.834 0.834 0.834

Figure 3.10 Stored current readings in the SD card



OT2TEMP.TXT - Notepad

File Edit Format View Help

29.53 28.30 27.69 27.38 27.22 27.07 26.99 26.92 26.92 26.99
26.99 26.99 26.99 26.99 26.99 26.99 26.99 26.92 26.92 26.84

Figure 3.11 Stored temperature readings in the SD card

Table 3.1 Actual sensor readings

Date	**inside temperature C**	**outside temperature C**	**current(A)**
13/6/14	25.64	26.99	0.834
13/6/14	25.77	27.07	0.834
13/6/14	25.81	27.38	0.834
13/6/14	25.84	29.53	0.834

3.3 Conclusion

A simple data logger design has been developed using several sensors. This type of data logger can be used in almost every household to get different parameters of a house within a certain interval. Daily, monthly and yearly data can be analyzed to understand the exact power consumption nature of the houses. The main idea was to make a new design and construct a cost effective data logging system. There are 13 analog input ports in PIC18F4550. Six ports (AN0-AN5) have been used for the design but more sensors could have been added to the remaining ports. In the next chapter energy data of houses is presented and analyzed.

Chapter-4

Thermal Simulation and Energy Consumption Analysis of Two Houses in NL

4.1 Introduction

In Newfoundland houses need heating for more than 6 months a year due to long winter. Most of the new houses are electrically heated and the rest are oil heated. Power consumption is high in winter months. Power consumption depends on the number of occupants in a house. Power consumption data of each house is logged and recorded by utility company (Newfoundland Power) every month. Data loggers can be used in houses to measure and record the data at higher sampling frequency. In this chapter, yearlong electricity consumption data collected by Newfoundland Power and measured data from the data logger of two houses are studied to complete a detailed analysis of house electricity consumption. Thermal simulation results of two typical houses in St. John's are also presented using BEopt (Building Energy optimization) software. Simulation results and logged data is compared and analyzed for both the houses.

4.2 House Energy Analysis

4.2.1 House Selection

Two typical electrically heated houses in St. John's are selected for the energy analysis.

Figure 4.1 House#1

Figure 4.2 House#2

Figure 4.3 Garage of house#2

First one (Figure 4.1. house#1) is a two storey building with a semi-finished basement. Other house (Figure 4.2. house#2) is a two storey house with a separate garage (Figure 4.3) attached to it. From the utility company and using a data logger the total energy consumption data was logged for more than a year for both the houses.

4.2.2 Energy Analysis

4.2.2.1 House#2 Energy Analysis

From the utility company the total monthly energy consumption of both the houses is collected. The collected data for house#2 is given in Table 4.1 and the chart for electricity consumption of year 2012 is plotted in Figure 4.4. According to utility company total

Table 4.1 Monthly electricity consumption by Newfoundland power for house#2

Monthly electricity consumption of house#2, 2012	
Month	kWh Used
January	3660
February	1920
March	1260
April	780
May	960
June	1080
July	1500
August	1500
September	2220
October	3780
November	4080
December	4560
Total	**27300**

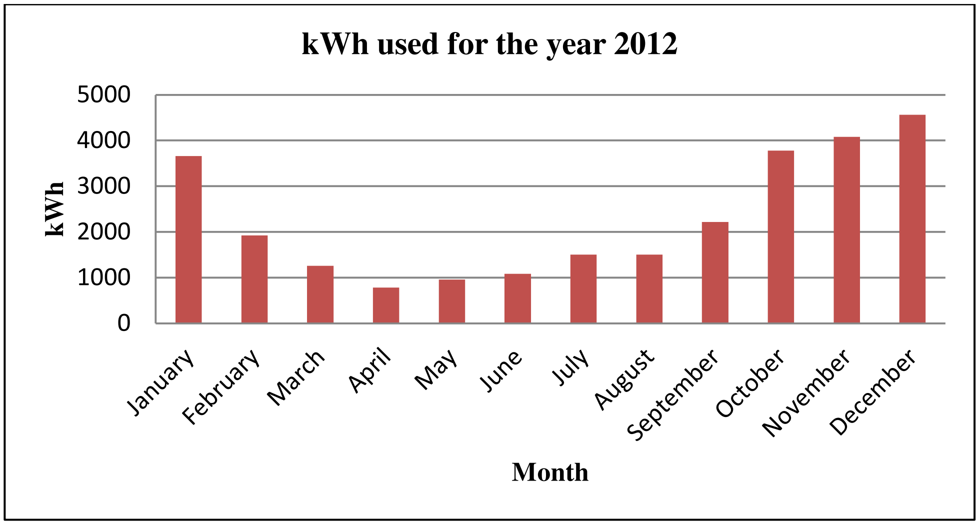


Figure 4.4 Energy consumption by the utility company in year 2012, of house#2

electricity consumption for house#2 was 27300 kWh in the year 2012. Again using a data logger, data of a whole year has been logged for both the houses. Sampling was done once every 2 minutes. The measured monthly value of energy consumption from the data logger is listed in Table 4.2 and the chart (Figure 4.5) is drawn for the measured value of energy consumption. From those measured value we can conclude that the highest consumption is in January and lowest is in September. We can observe that the measured and actual consumption chart follows a common pattern. In Figure 4.4 and Figure 4.5 we can see there is a mismatch between the measured and collected data by the utility company. It is because some data logger values were missing, but the main reason of mismatch is that utility company do not measure energy consumption for 3 to 4 winter months in a year (meter access is limited due to snow). Utility send an estimated bill and correct that later when all snow has melted away. Also the year-long data is adjusted using year 2012 and 2013 power consumption data. Energy consumption from some plugs was not logged (data logger limit), that resulted in measured data 4000 kWh less than reported by the utility. Figure 4.6 shows power consumption on a typical winter day in house#2. The start time of the data is 12.01 am at night. We can see that the main

Table 4.2 Monthly electricity consumption from data logger for house#2

Monthly electricity consumption data of house#2	
Month	Total kWh Used
January	4127.28
February	3820.63
March	3890.73
April	1751.31
May	1224.97
June	1041.58
July	748.52
August	628.19
September	505.76
October	646.93
November	1618.20
December	3111.99
Total	**23116.09**

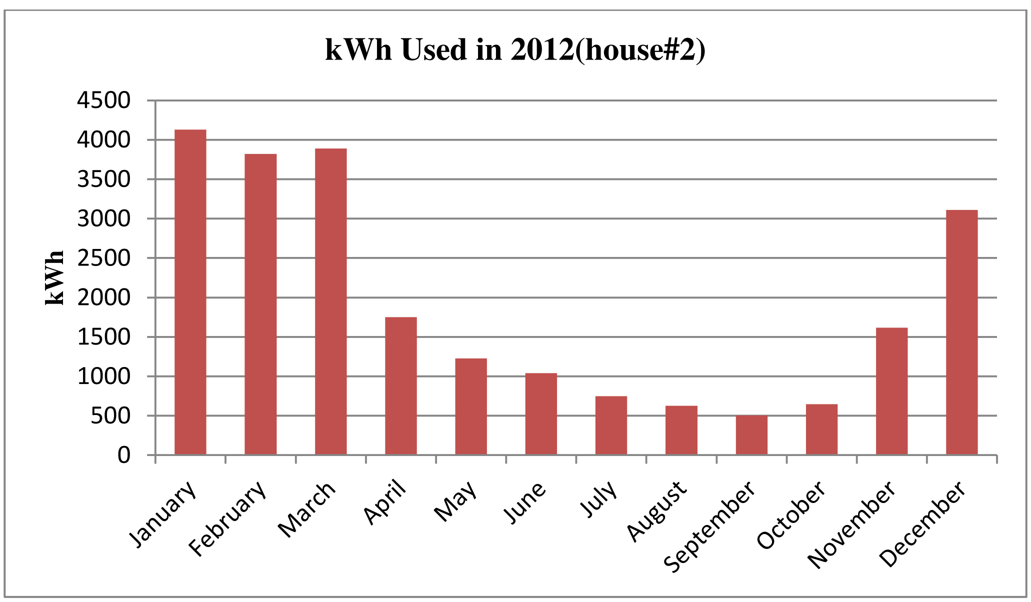


Figure 4.5 Measured electricity consumption in year 2012, of house#2

power consumption is due to heating. It is indicated that most heating was done during night and late evening. Similarly Power consumption for the same house on a typical summer day is shown in Figure 4.7. We can see there is no house heating power for that day. Another major electrical load was electric water heater. In Figure 4.8 hourly averages for a day in winter is shown using bar chart. We can conclude from this chart that consumption is high at night, late evening and in early morning. Similarly hourly average of a day in summer is shown in Figure 4.9 where it can be noticed that the consu-

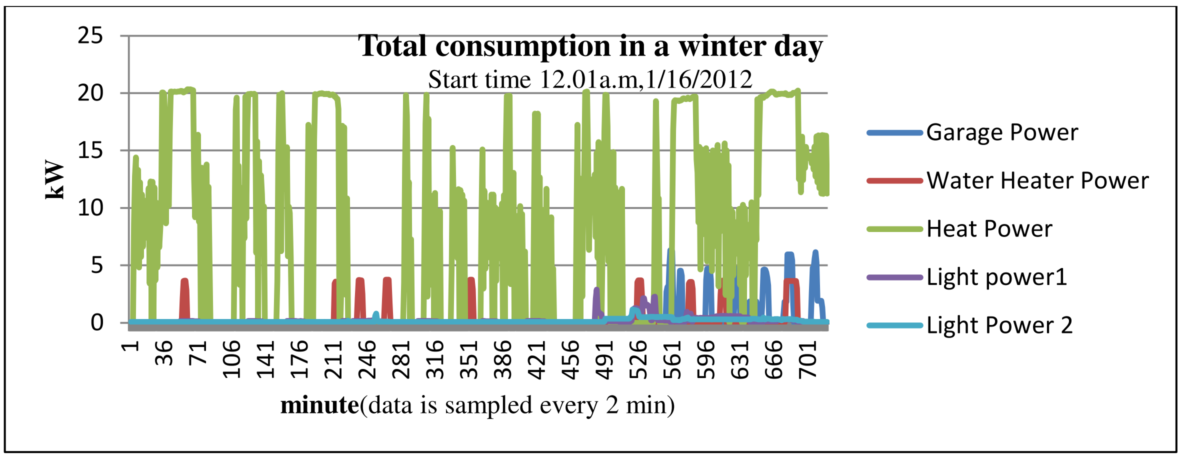


Figure 4.6 Power consumption in a typical winter day of year 2012

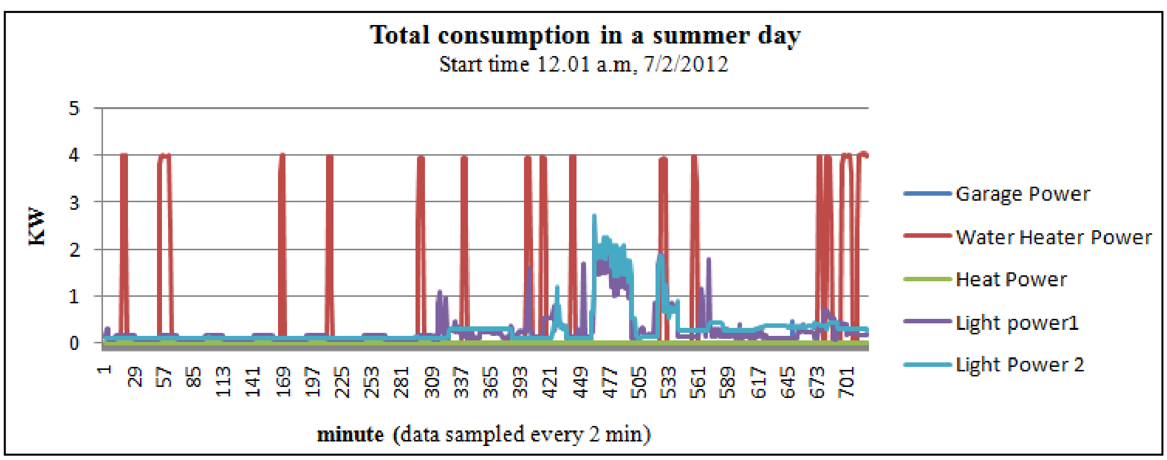


Figure 4.7 Power consumption in a typical summer day of year 2012.

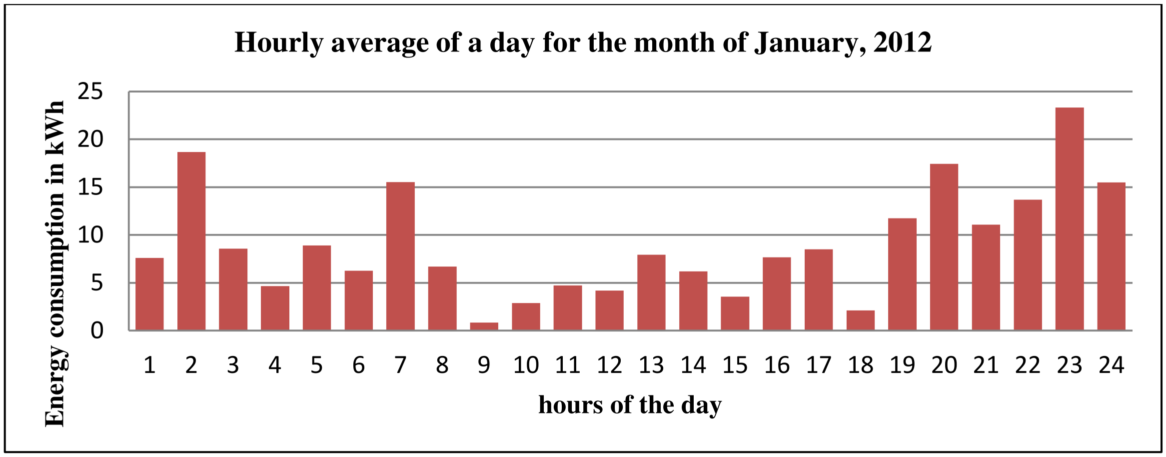


Figure 4.8 Hourly average of a day for the month of January, 2012

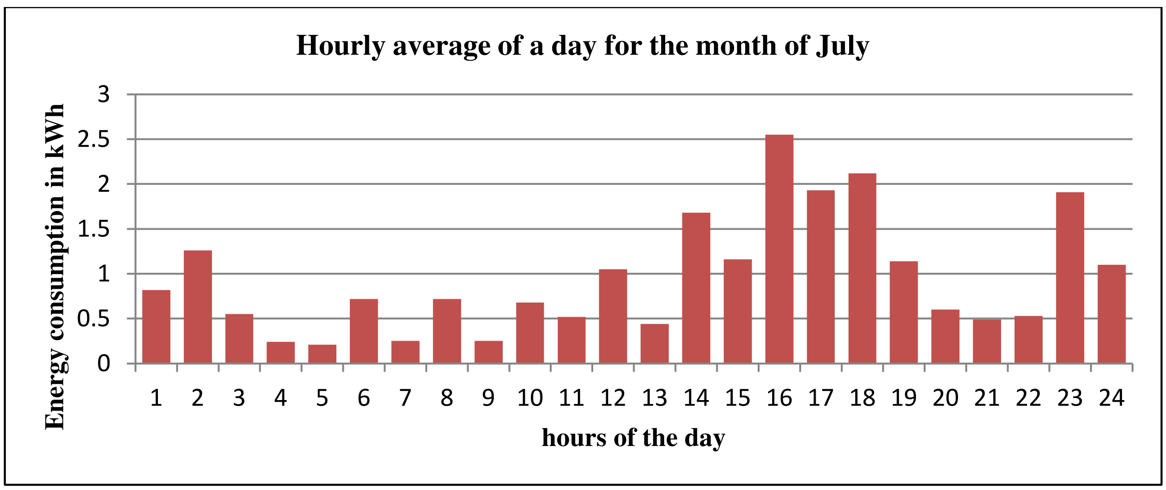
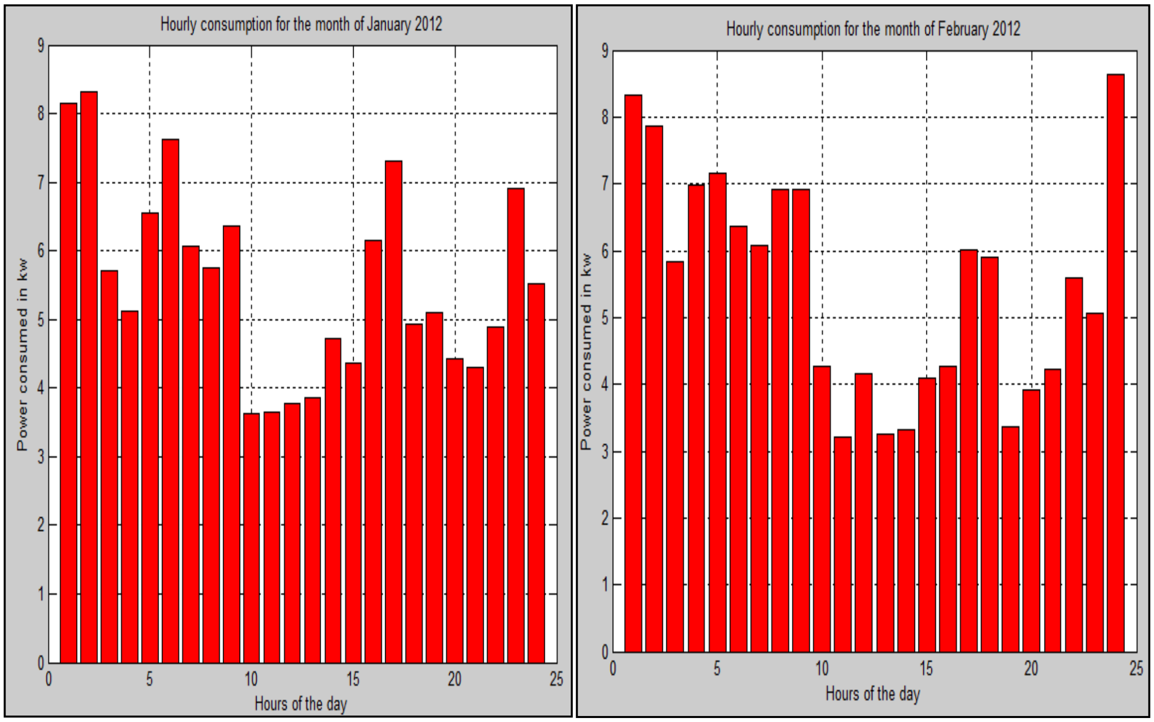


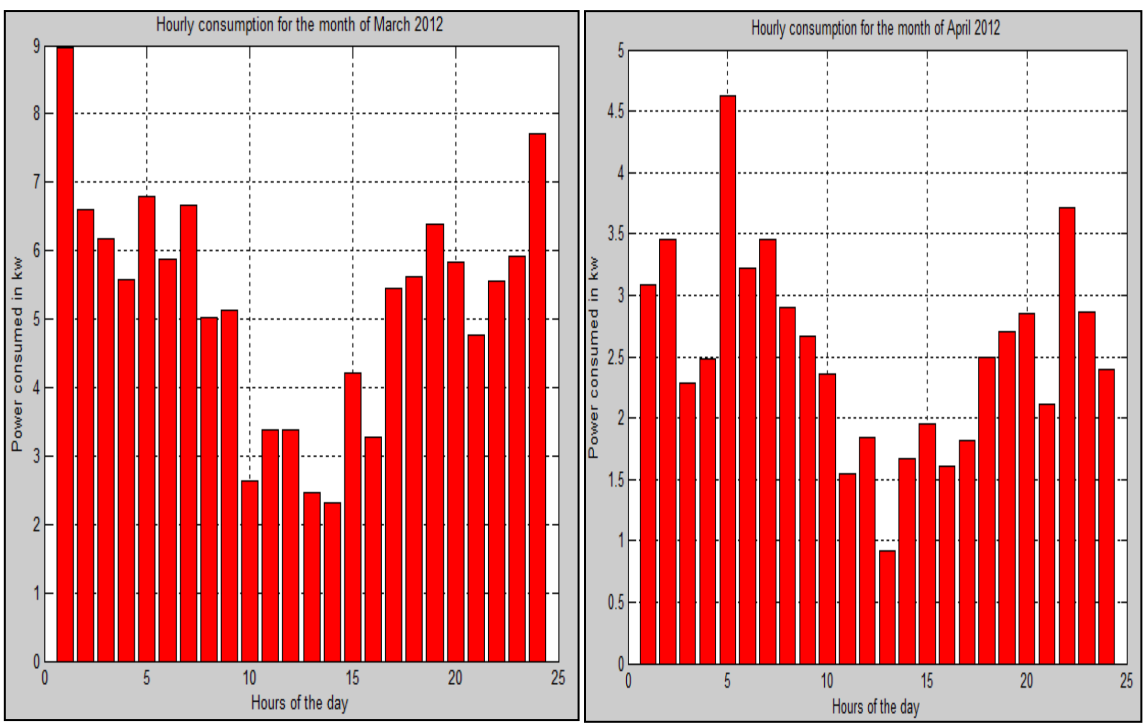
Figure 4.9 Hourly average of a day for the month of July, 2012

mption is high in the afternoon hours. Data analysis of Figure 4.8 & Figure 4.9 was done using Excel. In Figure 4.10 to 4.15 hourly average power consumption of house#2 for one year is shown. Again for house#2, from Figure 4.11(c) & 4.14(i) we observe minimum hourly power consumption was below 1.5 kW in September whereas the maximum hourly consumption was 9 kW in the beginning of March in year 2012.



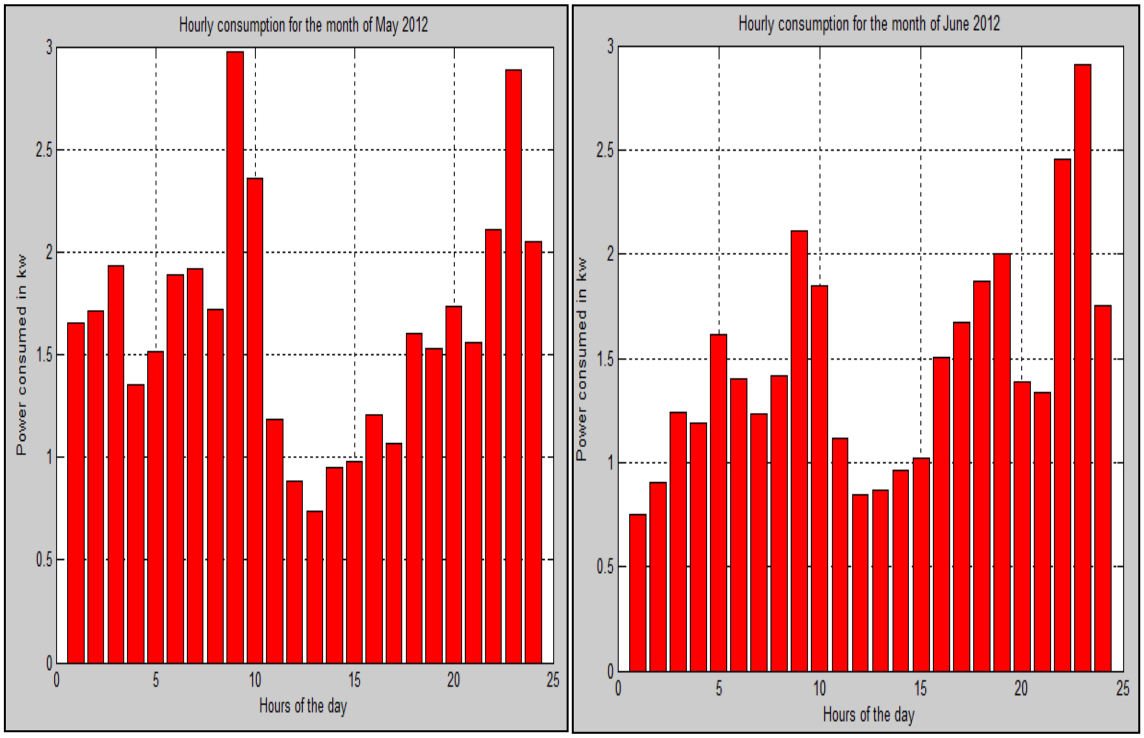
(a) (b)

Figure 4.10 Hourly average power consumption in January & February, 2012



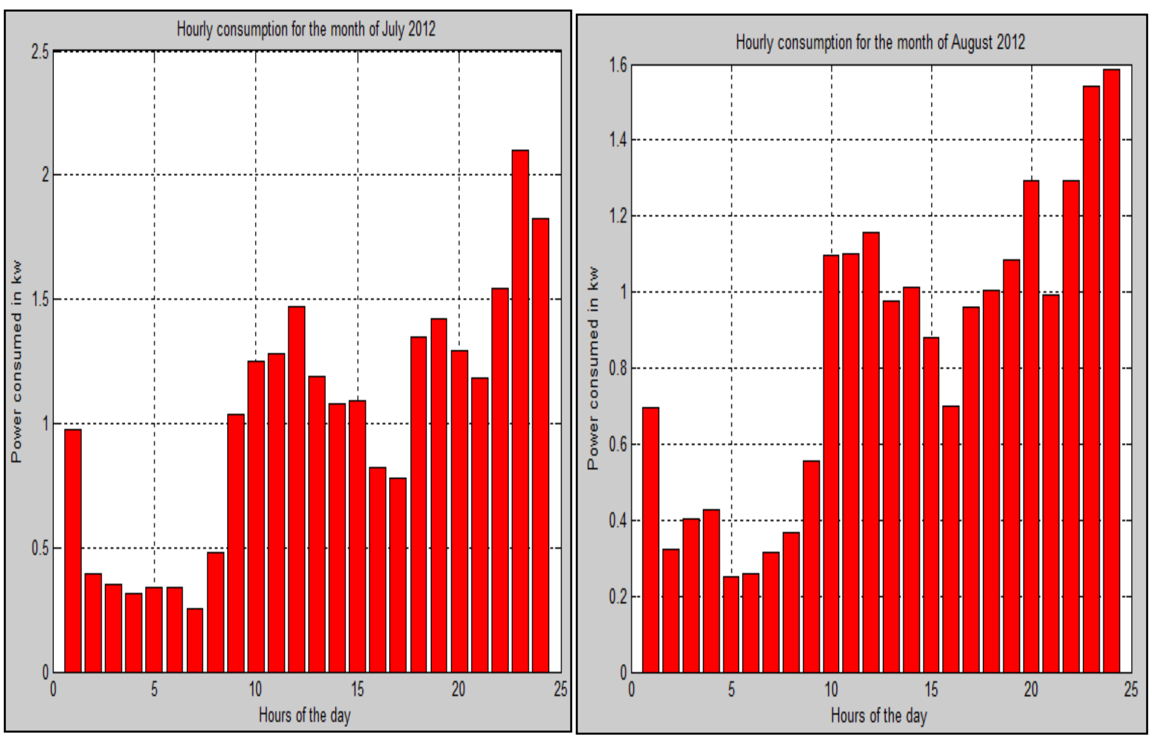
(b) (d)

Figure 4.11 Hourly average power consumption in March & April, 2012



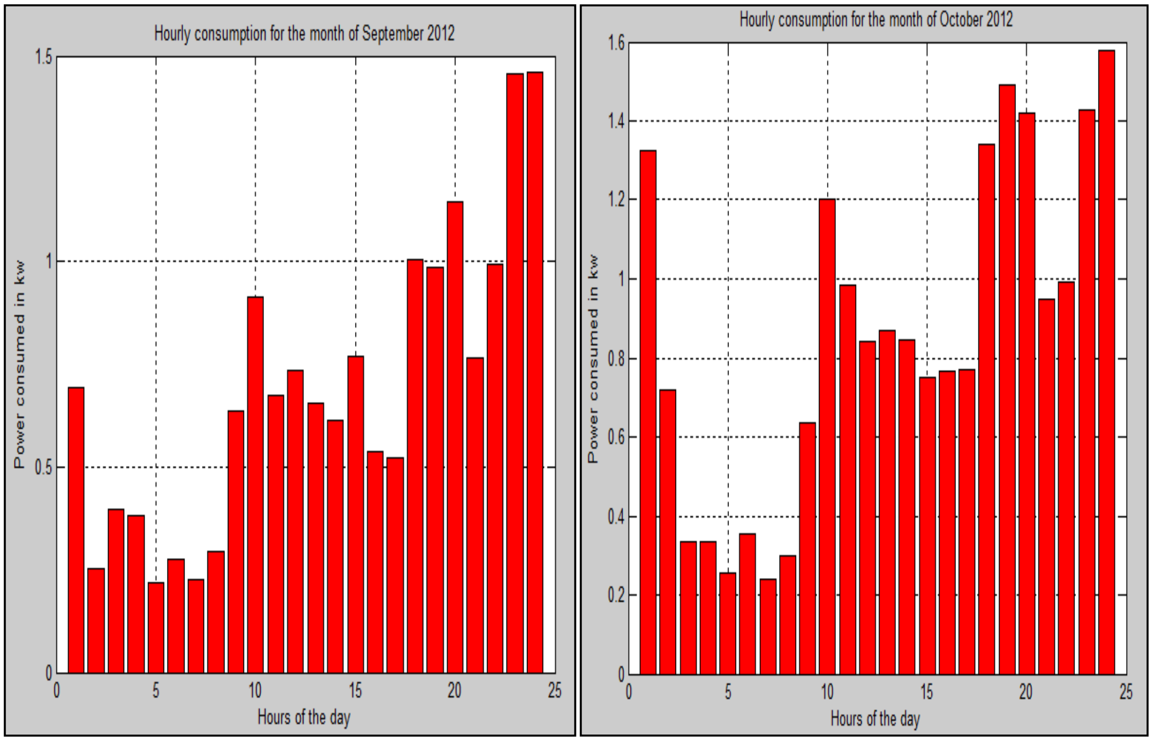
(e) (f)

Figure 4.12 Hourly average power consumption in May & June, 2012



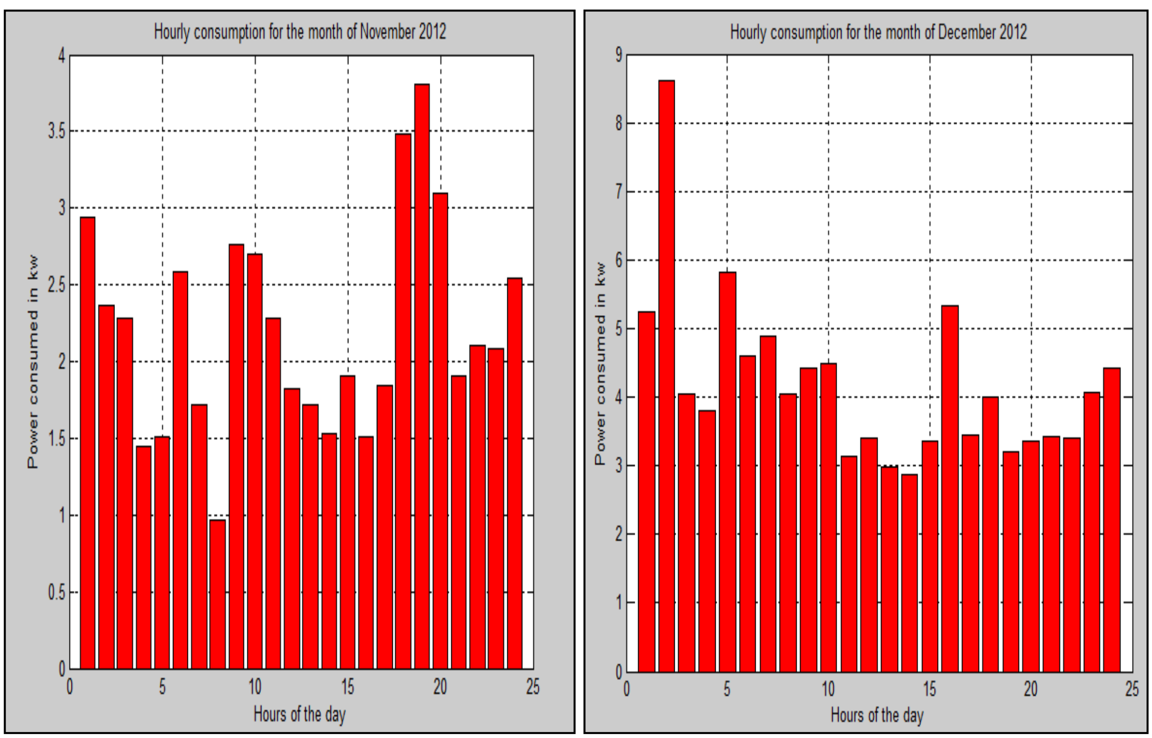
(g) (h)

Figure 4.13 Hourly average power consumption in July & August, 2012



(i) (j)

Figure 4.14 Hourly average power consumption in September & October, 2012



(k) (l)

Figure 4.15 Hourly average power consumption in November & December, 2012

4.2.2.2 House#1 Energy Analysis

Figure 4.16 & 4.17 show monthly energy consumption of house#1 (smaller house) from August 2003 to August 2004, as reported by the utility company. On the other hand Figure 4.18 shows the measured energy consumption for the year 2003-2004. Energy consumption in the year 2003-2004 was maximum in January 2004 (2084kWhr), while it was minimum in April 2004 (only 237 kWhr) [57]. It is clear from this data that measurements were not done at a regular interval and it also includes few estimated values. In other words utility reported measurements are not a good indication of actual energy consumed in the house during winter months when their meter is not accessible. If we compare data in Figure 4.17 and with measured value in Figure 4.18 we find similarity in pattern but energy consumption value reported by the Newfoundland power

Date (Y/M/D)	Read / Estimate	kWh Used	Days	Usage Per Day
2004-08-19	Read	827	29	29
2004-07-21	Read	1209	33	37
2004-06-18	Read	739	30	25
2004-05-19	Read	877	29	30
2004-04-20	Read	237	32	7
2004-03-19	Estimated	1955	30	65
2004-02-18	Estimated	2045	30	68
2004-01-19	Estimated	2085	32	65
2003-12-18	Read	1360	28	49
2003-11-20	Read	1074	29	37
2003-10-22	Read	730	30	24
2003-09-22	Read	747	31	24
2003-08-22	Read	718	31	23

Figure 4.16 Energy usage in the house#1 year 2003-2004 by the utility co.

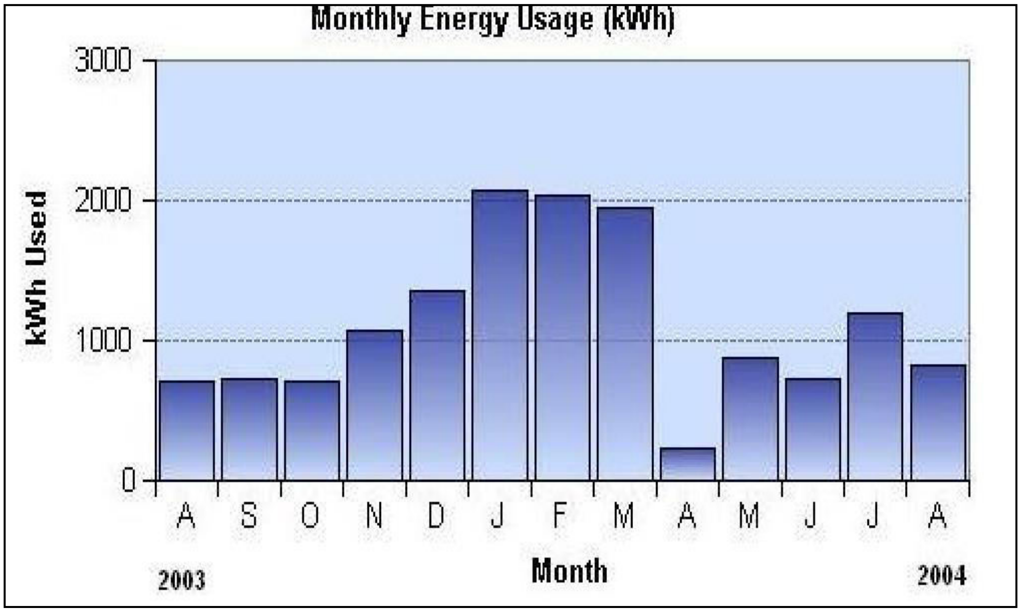


Figure 4.17 Consumption provided by the utility co. (2003-2004) for house#1.

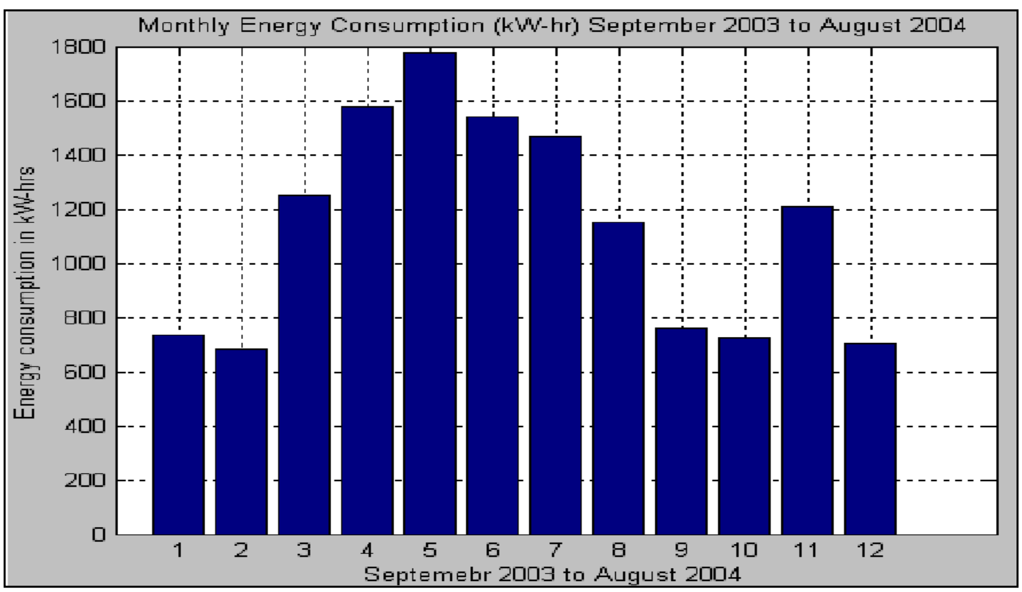


Figure 4.18 Measured monthly energy consumption from Sep 2003 to august 2004 for house#1.

(Figure 4.17) and measured value (Figure 4.18) for the month of April 2004 do not match. This mismatch is because of adjustment done by the Newfoundland power during that month. Figure 4.19 shows power consumption data on a typical summer day in September. Minimum power consumption was 56W while maximum power consumption for a short while was 10.6kW. The maximum consumption shown by the shaded area is

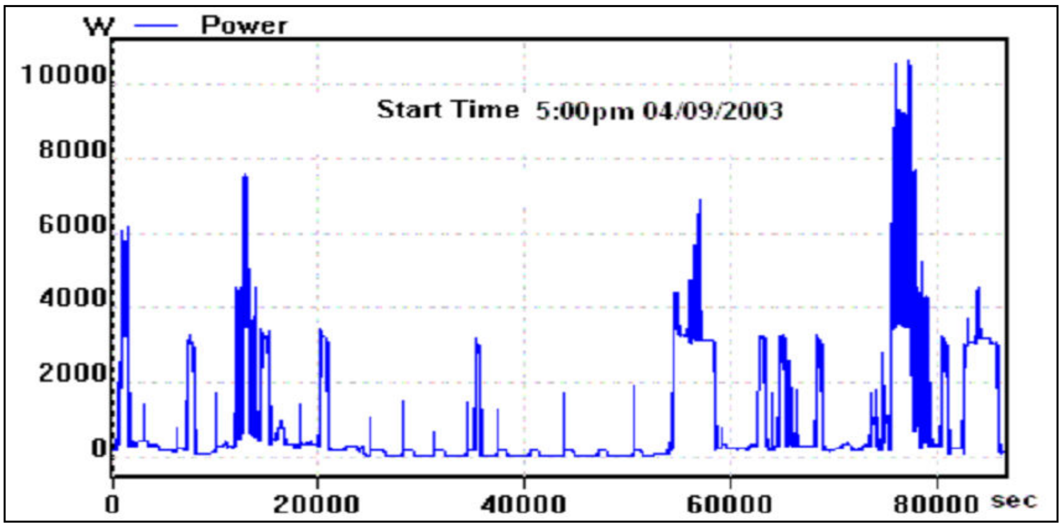


Figure 4.19 Power consumption in a summer day

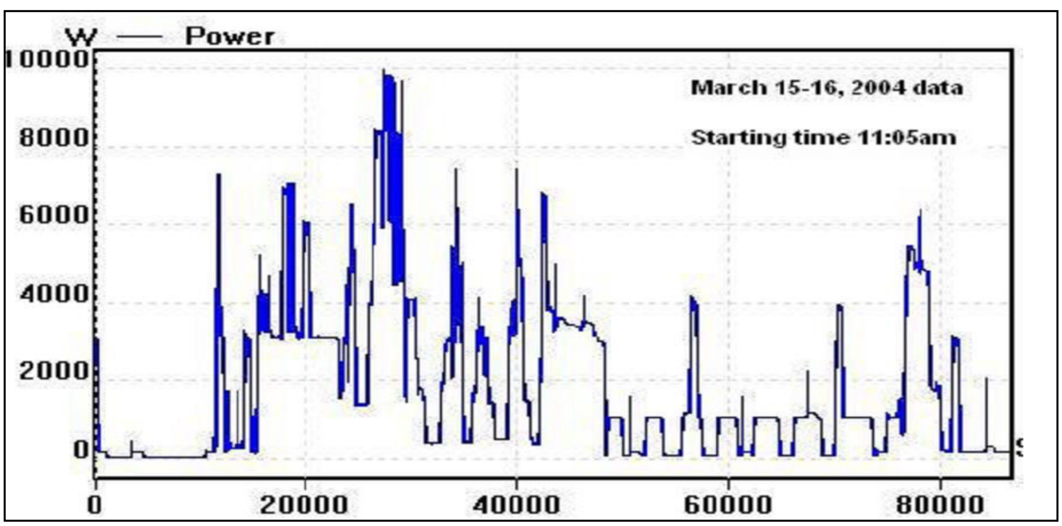
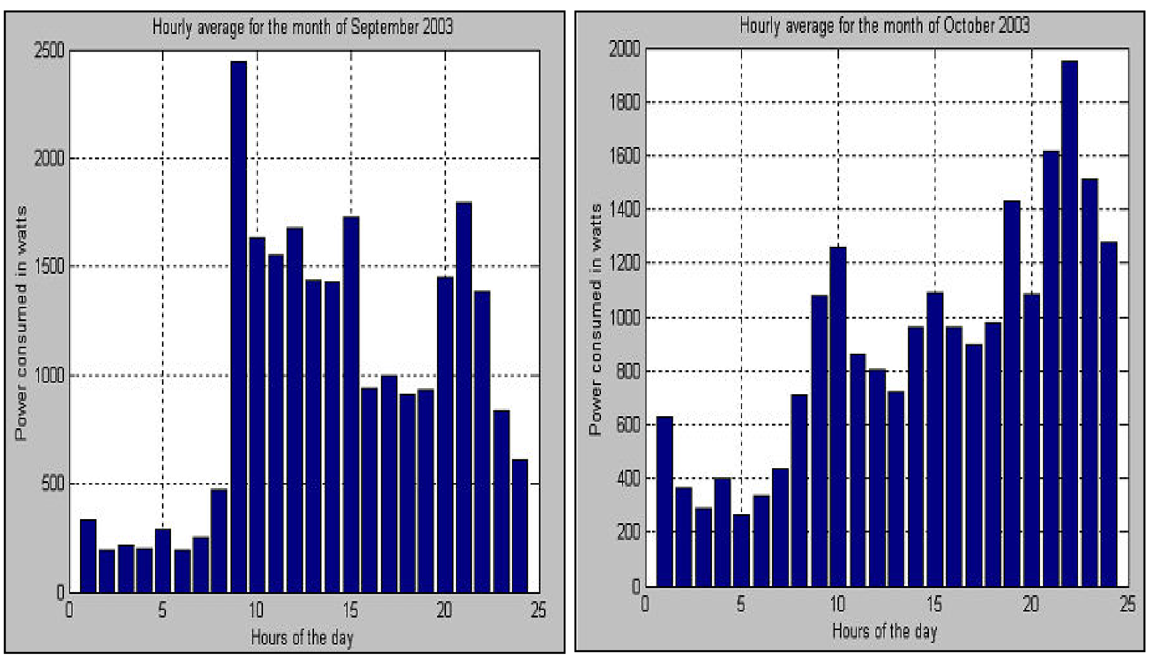


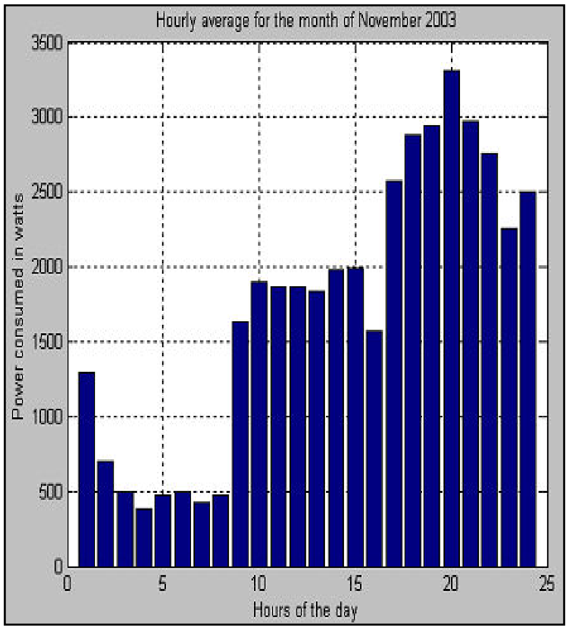
Figure 4.20 Power consumption in a winter day in 2004

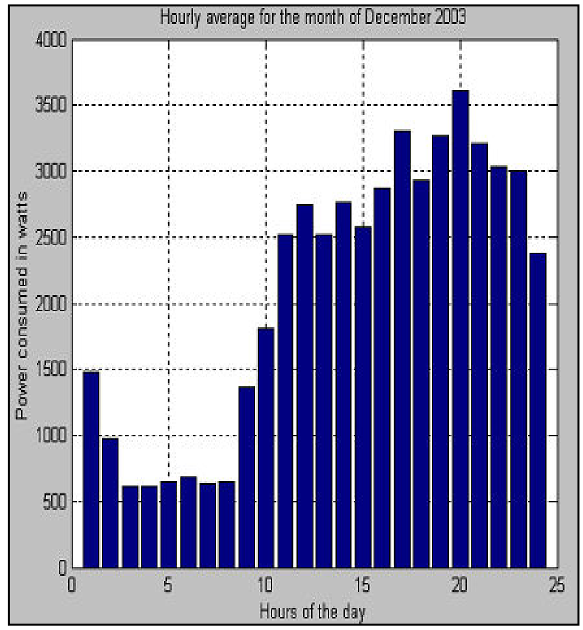
due to the operation of oven. Small pulses near the base level are due to the refrigerator operation at the night. During that day no heating was required therefore the major electrical load was electric water heater (3000W). Average load in September 2003 was 990W. Figure 4.20 shows power consumption on a typical winter day. It indicated that most heating was done during the afternoon and early evening. During the night only one heater was in use. Single early morning peak is due to the water heater. Figure 4.21 to Figure 4.26 shows hourly average power consumption pattern for each month starting from September 2003. From all the monthly figures it is noticed that Power consumption is lowest during the day and it increases in the afternoon, peaking late in the afternoon. It is observed from Figure 4.23 (e) that the maximum average hourly power consumption was in January 2004, which exceeded 5000W level. Similarly from Figure 4.26 (i) the minimum hourly power consumption was 250W in



(a) (b)

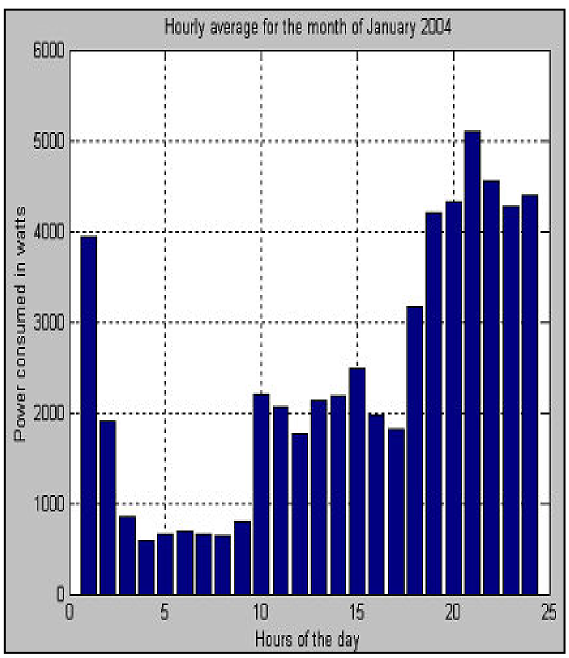
Figure 4.21 Hourly average power consumption in (a) September & (b) October, 2003

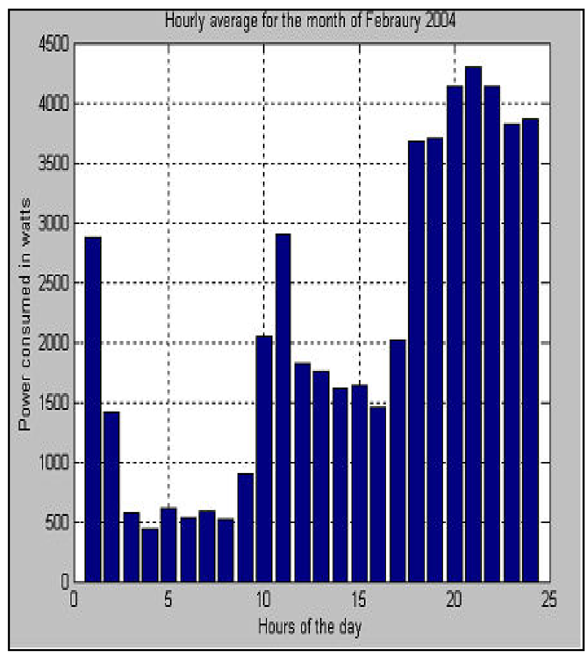




(c) (d)

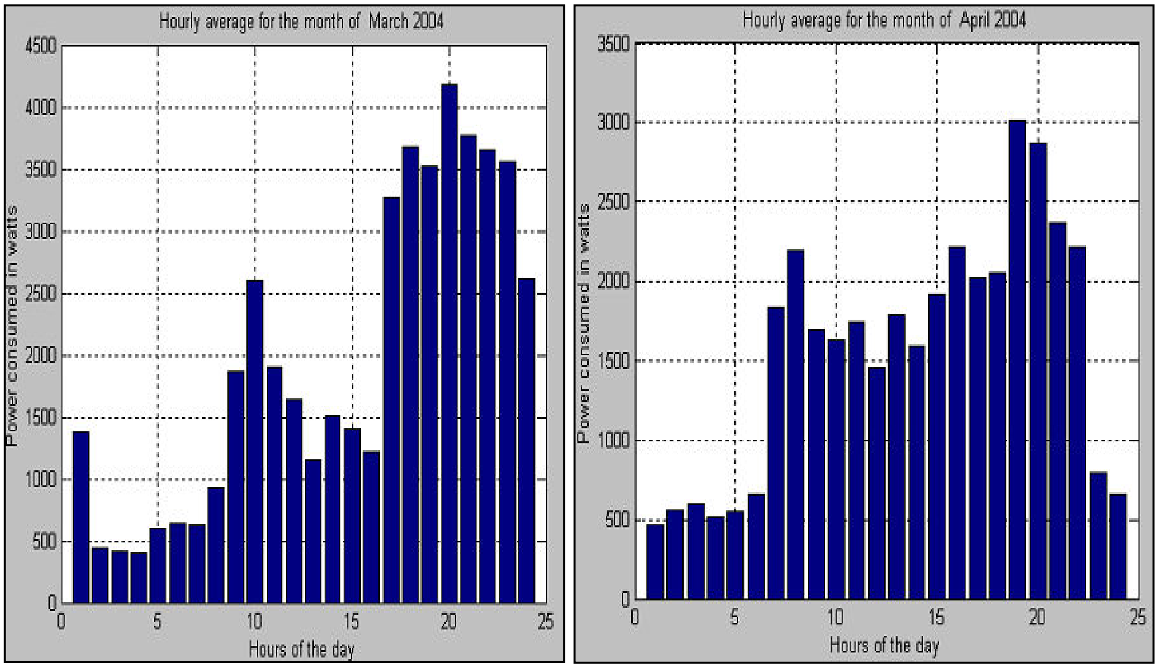
Figure 4.22 Hourly average power consumption in (c) November & (d) December, 2003





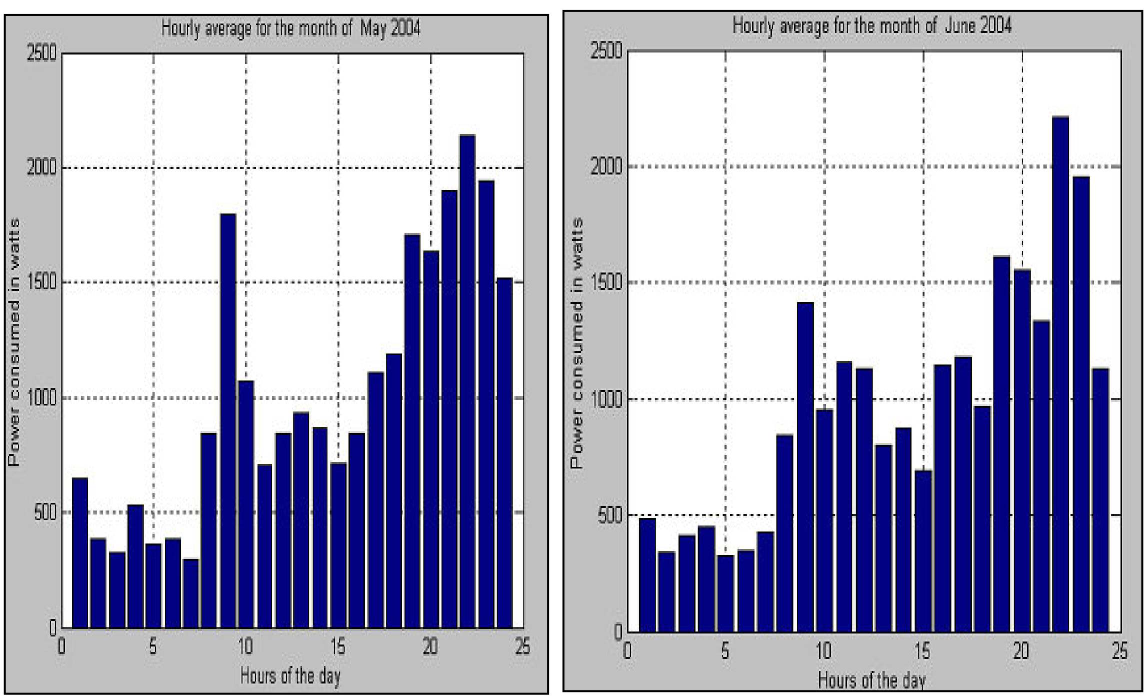
(e) (f)

Figure 4.23 Hourly average power consumption in (e) January & (f) February, 2004



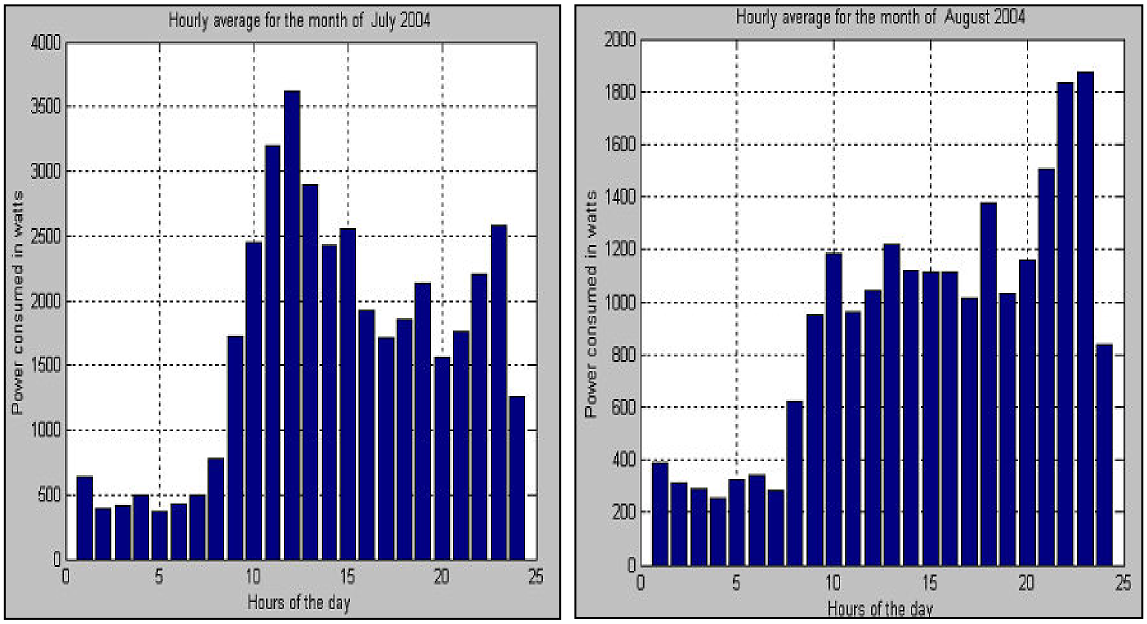
(g) (h)

Figure 4.24 Hourly average power consumption in (g) March & (h) April, 2004



(i) (j)

Figure 4.25 Hourly average power consumption in (i) May & (j) June, 2004



(k) (l)

Figure 4.26 Hourly average power consumption in (k) July & (l) August, 2004

early hours of the day in August 2004. The hourly power consumption graphs are generated using Matlab code (Appendix 6) and using all the collected data, sampled every 2 min by the data logger.

4.3. Houses Energy Simulation in BEopt

BEopt has been developed by the National Renewable Energy Laboratory in support of the U. S. Department of Energy Building America program. The BEopt™ (Building Energy Optimization) software provides capabilities to evaluate residential building designs. It calculates the maximum energy saving case or minimum cost case according to the user's requirement. BEopt can be used to analyze both new construction and existing home retrofits, through evaluation of single building designs, parametric sweeps, and cost-based optimizations [58].

For house simulation in BEopt there are three input screens.

i. Geometry screen- Here the house is drawn following the correct house measurements and actual orientation of the house.

ii. Site screen- The location of the house is selected and the weather data is downloaded.

iii. Input screen-Main inputs, like the house material, appliances, temperature set point etc are chosen from this screen. New inputs can be inserted according to the house requirement.

4.3.1 Input Parameters

For simulation in BEopt there are three screens. At first the house is designed in the geometry screen. Figure 4.27 shows the design of house#1 in BEopt. Similarly Figure 4.28 & Figure 4.29 shows the design of house#2 with front and back view. This house is attached with a separate garage. For better analysis of consumption, garage and main house is designed and simulated separately instead of in a single design. The input parameters for both the houses are given in Table 4.3 which are used in input screen. The actual area of the house windows is calculated and then used as input. The actual measurements for the window area were done using house photos and BEopt assigns windows based on input area. Every input in garage is same as the main house input, except that there are no major appliances or water heater in the garage. For lighting the consumption is assumed (based on the actual house use) 596kWh/yr. The window area ratio is also different for garage building. Weather data [59] for St John's is used in site

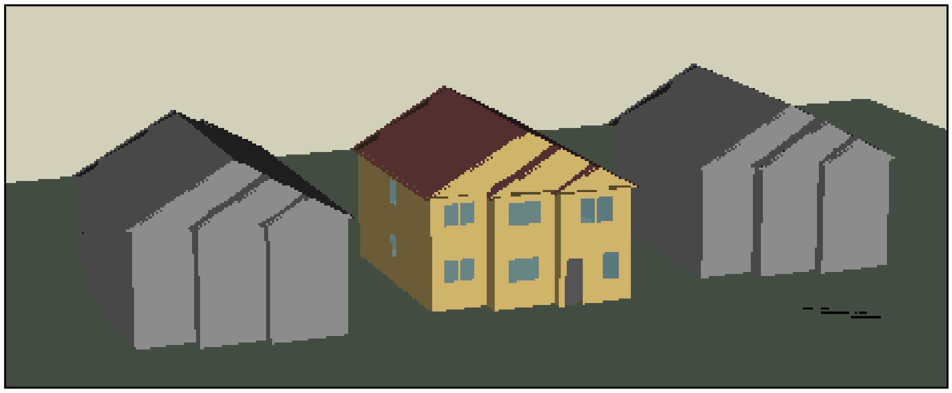


Figure 4.27 Geometry screen in BEopt for house#1

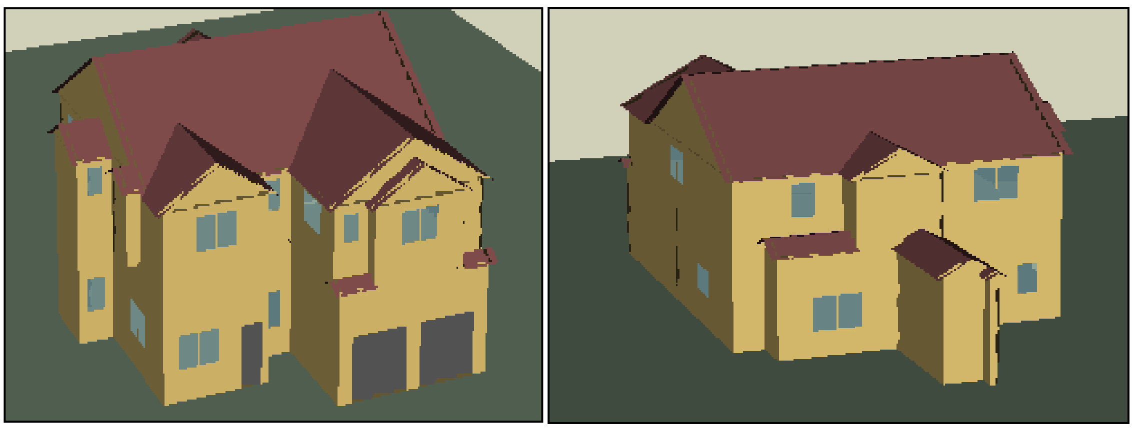


Figure 4.28 (a) House#2 -Front side (b) House#2-back side

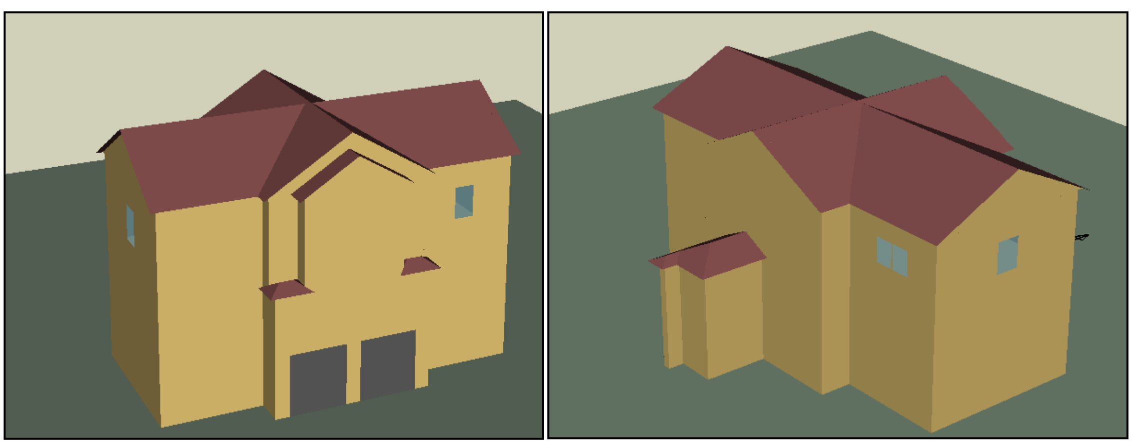


Figure 4.29 (a) House#2 Garage -Front side (b) House#2 Garage -back side

Table 4.3 Input parameters used in BEopt for both the houses

	Option screen	House#1	House#2
1	**Operation**		
	Heating set point	60F, at night time it remains off	
	Cooling set point	100 F	
	Humidity set point	65% RH	
	Misc electrical load	0.25	
	Misc hot water load	12.5 gal/day	
	Natural ventilation	Cooling months only	None.
2	**Walls**		
	Wood stud	R-21 Fiberglass batt, gr-1, 2*6, 24 in o.c	
	Wall sheathing	OSB	
	Exterior finish	Vinyl, light	Vinyl, medium/dark
3	**Ceiling/Roofs**		
	Unfinished attic	Ceiling R-44 Fiberglass, vented	
	Roof Material	Asphalt shingles, dark	
4	**Foundation/Floors**		
	Slab	4ft R-5 perimeter, R-5 gap	2ft R-10 perimeter, R-5 gap
	Interzonal floor	None	R-13 fiberglass batt
5	**Thermal Mass**		
	Floor mass	wood surface	
	Exterior wall mass	½ inch drywall	
	Partition wall mass	½ inch drywall	
	Ceiling mass	1/2 inch drywall	
5	**Windows & Doors:**		
	Window areas	A new input window to the software	
	Windows	Double pane, medium gain, low e, non- metal frame, Air fill.	
	Eaves	1 ft	
6	**Air flow**		
	Air leakage	4 ACH50	2 ACH50
	Mechanical ventilation	HRV 70%	
7	**Major Appliances**		
	Refrigerator	18 cu ft, EF=21.9, top freezer	
	Cooking range	Electric	
	Dish washer	290 annual kwh	
	Clothes washer	Energy star, cold only	
	Clothes dryer	Electric	
8	**Lighting**	80% fluorescent hardwired plugin.	
9	**Space conditioning**		
	Electric baseboard	100% efficiency	
	Duct	7.5% leakage, R-8	
10	**Water heating**		
	Water heater	Electric standard	
	Distribution	Uninsulated, Homerun, PEX	

screen and other parameters such as house interest rate values [60] in site screen are inserted from a Bank website.

4.3.2 BEopt Simulation Results Analysis

The output results analysis can be done in three different modes in BEopt, with three different references.

Output modes are,

i. Design mode-Output comes according to the user's defined inputs.

ii. Optimization mode-Multiple options can be selected. For each and every input an output comes from which best result can be chosen.

iii. Parametric mode

References are,

i. 1st selected option-From the multiple chosen options the very first option is taken as the reference for that particular case.

ii. B10 benchmark-House Standards which is followed in USA.

iii. User defined-Reference set by the user.

In this section, design mode is used for energy consumption analysis of one year for the two houses. The inputs are given same as the actual house. BEopt simulation produce yearly energy consumption result. As shown in Figure 4.30, the energy consumption of house#1 for one year came as 16849 kWh/yr, whereas the actual consumption for the house is 15747 kWh/yr which is very close. For house#2, the actual consumption of the house reported by utility co. is 27300 kWh/yr. But the simulation shows the total house consumption as 31029 kWh/yr (Figure 4.31), BEopt energy estimation is higher. Reason is that only three occupants live in this big house but BEopt Software considers more occupants for such a large house. As a result the output shows higher electricity

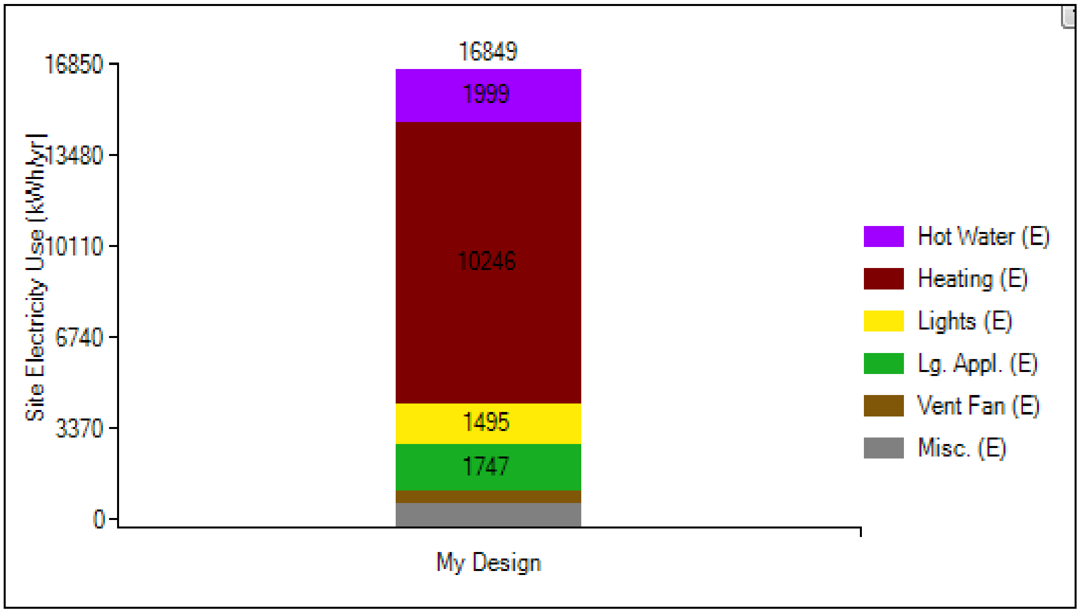


Figure 4.30 Electricity consumption of one year for house#1(BEopt simulation)

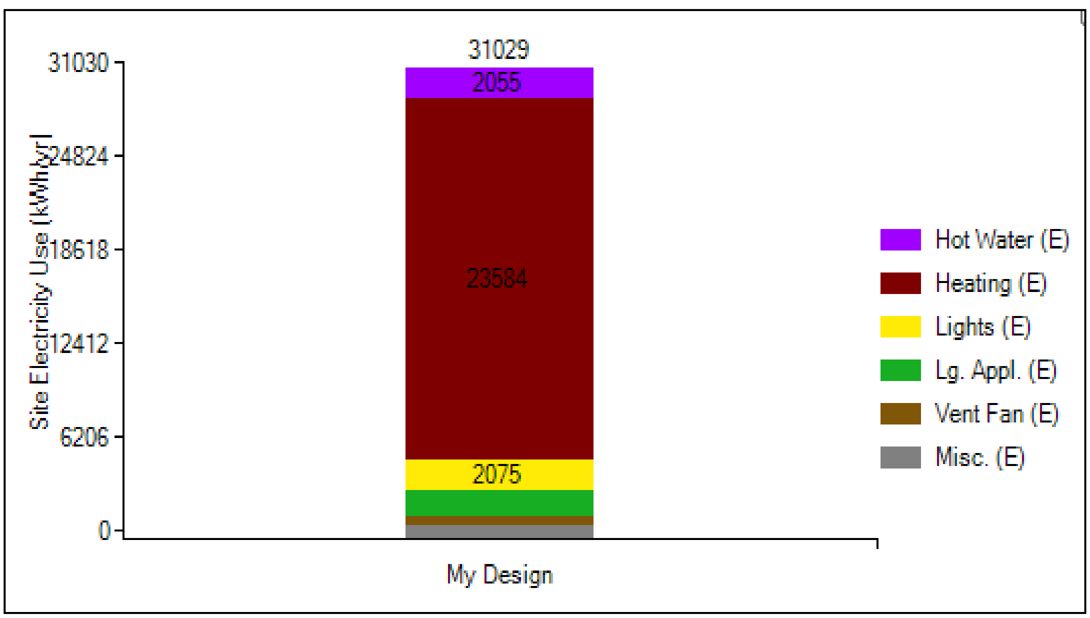


Figure 4.31 Electricity consumption of one year for house#2 (BEopt simulation)

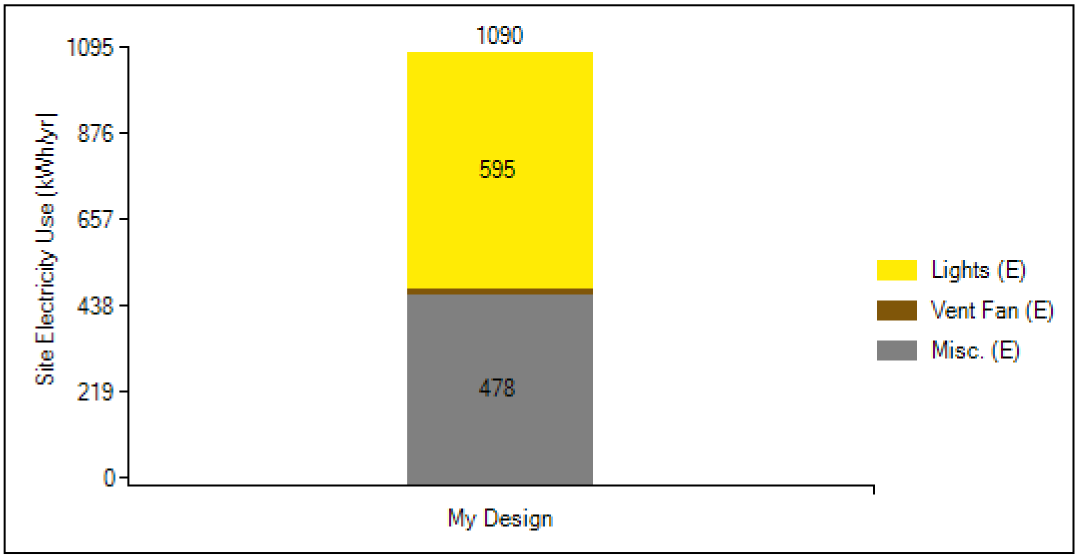


Figure 4.32 Electricity consumption of one year for house#2 garage

consumption than the actual house consumption. Energy consumption of the garage for one year came as 1090 kWh/yr (Figure 4.32), whereas the actual consumption is 1190.56 kWh/yr, which is very close to 1090 kwh/yr. So for both the houses simulation results match with the measured data. House simulation in BEOpt can be used to optimize insulation and energy saving. BEopt energy simulation also shows energy distribution in each house.

4.4 Conclusion

Two houses in St. John's, Newfoundland have been considered to analyze the total power consumption for one year. Power consumption data for both the houses is collected from utility company and then compared with the measured values from data logger. For the data logging, designed data logger in Chapter 3 was not used even though it was capable to log the house data. Since recent power consumption data for house#1 was unavailable, logged data for both the houses was used for two different years. The data loggers were installed inside of the main floor of both houses. Collected and measured values of energy consumption follow a similar pattern. Data acquisition systems were installed in each home to give a true picture of energy consumption. For a detailed analysis, houses are simulated in BEopt and the simulation results showed that the output for energy consumption for one year is almost equal to the measured energy consumption of both the houses. Simulation is done using one-year weather data, typical thermostat settings and occupation of the houses. Daily, monthly and yearly data can be analyzed to understand the exact power consumption nature of the houses. Hourly averages of each month and energy consumption in a winter day and in a summer day are shown by a time series plots. Such plots are necessary to design a renewable energy system for a house, manage demand side and also to study human behavior and energy usage.

Chapter-5

Analysis of NL Energy System using EnergyPLAN & LEAP

5.1 Introduction

Electricity demand is increasing with every passing day and to fulfill the demand future planning has to be done. Two plans are proposed by Nalcor to the government to meet the future need of the island of Newfoundland. One is island interconnected option and another is isolated island option. In the isolated island system the entire load would be supplied by additional generation in Newfoundland mostly by adding thermal plant, mini hydroelectric station and wind farm to the existing system. But for the island interconnected system large portion would come from muskrat falls hydroelectric station through a HVdc transmission system and use of thermal plant would decrease to zero.

The capacity of the Muskrat Falls hydroelectric plant is 824 MW with average annual production of 4.9 terawatt hours. Muskrat Falls is being built to meet the island's growing electricity needs. Right away, the island will need 40 per cent of the energy from Muskrat Falls to displace the Holyrood Thermal Generating Plant, with that need growing over time. Even though the plant is being developed to meet the demand of the province of NL, it is also analyzed that there will be sufficient excess power to export.

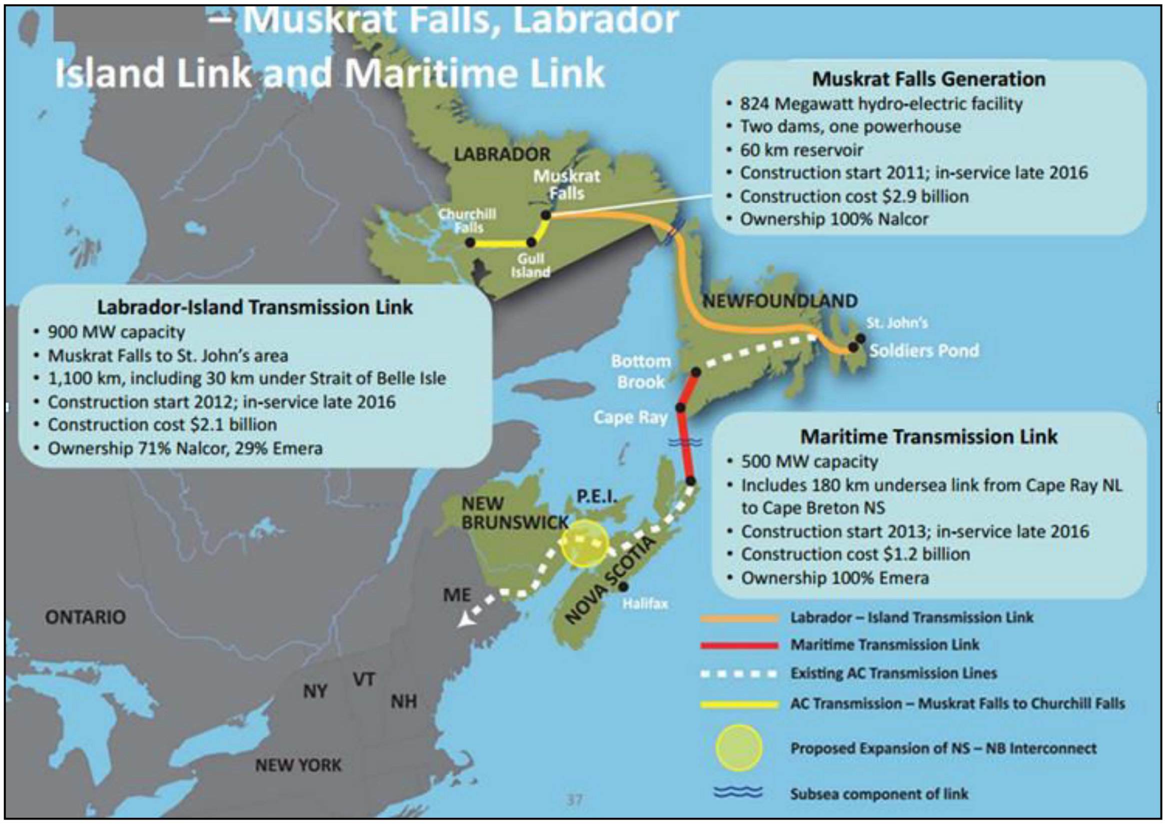


Figure 5.1 Muskrat falls generation with Labrador island link and Maritime link

Rather than letting the extra water go over the dam Nalcor plan to capture the possible maximum power for the people of Newfoundland and Labrador. According to the agreement between Nalcor and Emera in Nova Scotia, Emera will purchase 20 per cent of the energy from Muskrat Falls for 20 per cent of the project costs. Figure 5.1 shows both the 900 MW capacity Labrador island transmission link and 500 MW capacity Maritime transmission link. Approximately $1.58 billion Maritime Link is being financed and constructed by Emera Inc.. Due to the contract with Emera, Nalcor will have transmission access to Nova Scotia and beyond to New Brunswick and into New England. Excess energy not needed in the province will be sold outside of the province and revenue will be returned to Newfoundland and Labrador. The Muskrat Falls Project will create remarkable opportunity of cash flows in the province – around $30 billion over the life of the project [61]. From 824 MW, the contracted amount to Nova Scotia is around 165 MW 7 days/week over the 16 peak hours per day. The remaining amount, which is 824 MW - 165 MW = 659 MW, is available to meet the load in Newfoundland and Labrador at all times.

However, because of the daily and seasonal variances in load in NL the full plant capacity is not needed to meet load in NL. Based on Nalcor's projections 2 TWh of energy which is approximately 40% of energy capability of the plant, will be used to meet load in NL. The remainder of the energy will be available for export and it will be exported during times that the capacity is not needed to meet domestic load in NL. All above information of muskrat fall development has been collected from NL hydro and Nalcor energy.

Newfoundland and Labrador (NL) is blessed with natural resources where the sources of energy are hydro, wind, solar, oil, gas etc. Figure 5.2 [62] shows the energy potential in the province of NL. All new developments are focused on Large Hydro and Oil. The undiscovered hydro and Oil resources are respectively 6000MW & 6 Billion barrels of oil. Again, Figure 5.3 [62] shows the potential for natural gas and petroleum production up to year 2060. On the other hand, witnessing the windy season in Newfoundland it can be easily said that wind power has great potential for the Province. But even though having great wind resource, wind energy is most underdeveloped in NL. As per Figure 5.2 the undeveloped wind energy is 5000 MW. The following Figure 5.4 [62] from that energy plan indicates that government focus will be mainly large hydro generation. Other

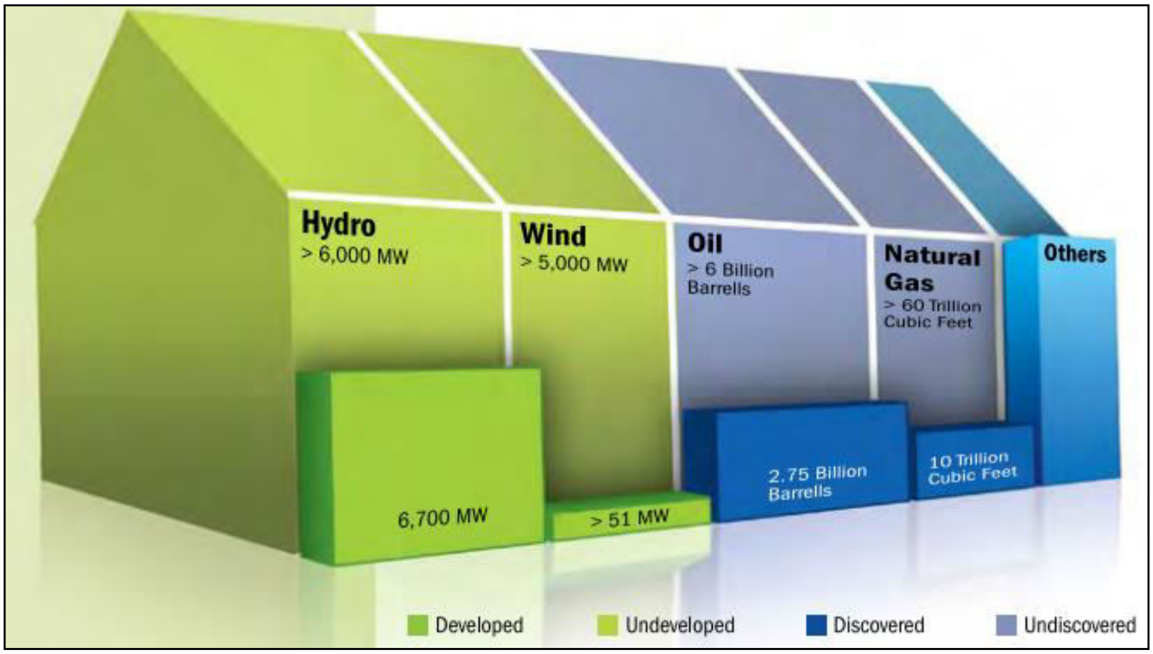


Figure 5.2 Newfoundland and Labrador's energy potential

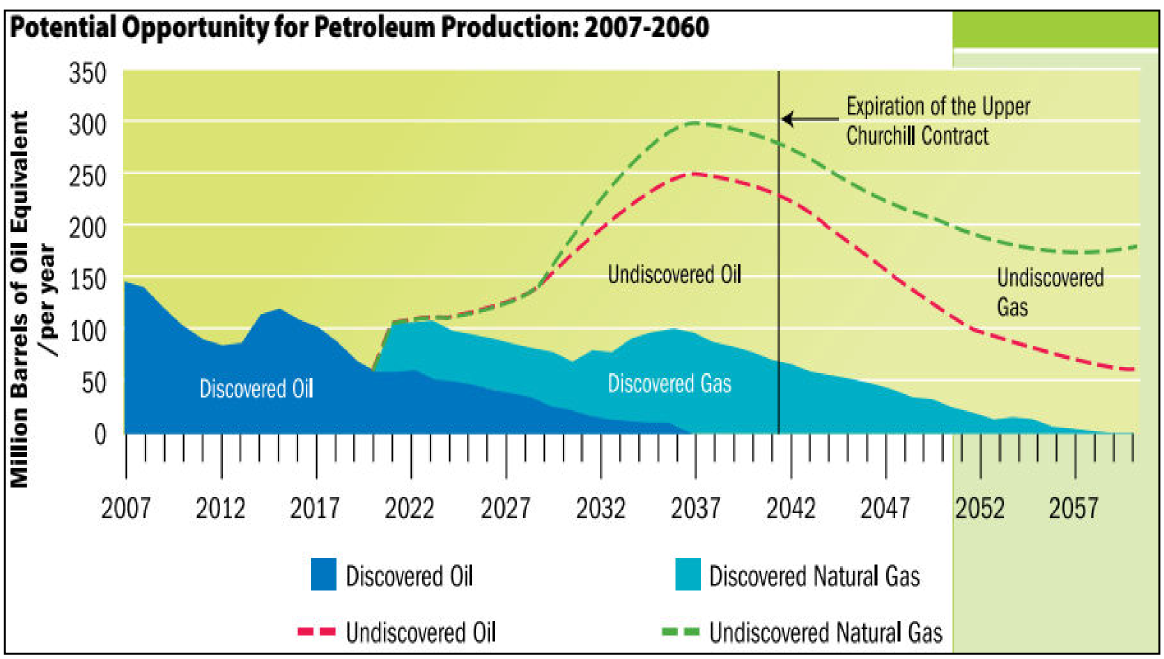


Figure 5.3 Petroleum production Potential in NL

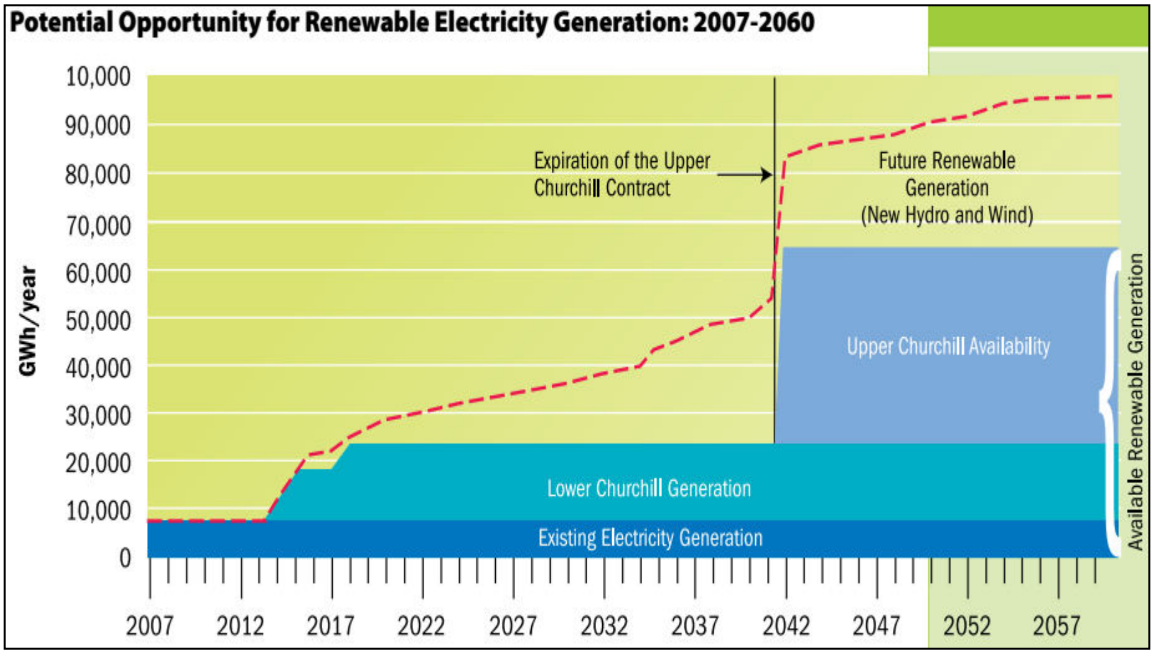


Figure 5.4 NL energy plan from 2007 to 2060.

renewable energy options are not considered. Government has no plan to use existing immense renewable small hydro and wind potential.

In Newfoundland and Labrador, the generation and distribution of electricity is provided by Newfoundland Power (NP) and Newfoundland & Labrador Hydro (Hydro). The total generating assets operated by the individual companies are listed below.

- *Newfoundland Hydro*
    - 6 Hydroelectric plants
    - Thermal plant
    - 50MW Gas turbines (St. John's and Stephenville)
    - diesel plants in Hawke's Bay (5MW) and St. Anthony (9.7 MW)

- *Newfoundland power*
  - operates 23 hydro generating plants
  - two diesel plants
  - three gas turbine facilities (4.7MW)

The main energy source for NL is hydro. Total hydroelectric capacity of Newfoundland island portion is 1265 MW. Plants operated by Newfoundland power and Newfoundland hydro are listed in Table 5.1. On the other hand, The Holyrood Thermal Generating Station is a major source of electrical energy supply to the Island energy system. The generating station consists of three turbines, two of 170 MW and one of 150 MW capacity. The plant can produce electricity over 3000 GWh per year and supplies 20% of the island's annual electricity demand [63]. The thermal plant operates in winter months when demand is in peak, but in summer time the plant does not run. When in case of peak production the plant burns approximately 18,000 barrels of oil per day. So if it runs 250 days in a year the energy required would be approximately 7.3 TWh/ year. A new 123 MW turbine unit was installed at holyrood location in 2014 to meet needs of the province's main power grid at peak demand periods. According to Hydro, the new unit will use about 31,600 litres of diesel fuel an hour to operate. Since the unit will operate during the peak times only, the new plant will run less than 500 hours a year [64]. The total installed capacity of wind farm is 54.7 MW. The first wind farm was developed in St. Lawrence with 27 MW capacity in 2008. And the other 27 MW capacity wind farm started to operate in year 2009 in Farmeuse. Both the wind farms have nine Vestas V90, 3 MW turbines. In Ramea, another wind-hydrogen-Diesel energy system installed wind

Table 5.1 Hydroelectric stations in Newfoundland Island

Hydroelectric generating station in Newfoundland Island	
Hydro Plant operated by Newfoundland hydro	**Plant capacity(MW)**
bay d espoir	605
Cat arm	128
Upper Salmon	84
Hinds Lake	75
Granite canal	41
Paradise River	8
Snooks Arm and Venams Bight	1
Roddickton	0.4
Grand falls	76
star lake	18.4
Non utility generator	
rattle brook	11.2
Deer lake	130
Hydro Plant operated by Newfoundland power	
Pierrs's Brook	3.4
Morris	1.08
Mobile	10.13
Rocky Pond	3.1
Torris Cove	6.36
Horsechops	7.52
Cape Broyle	5.3
Petty Harbour	4.35
Topsail Pond	2.25
Seal Cove	3.18
hearts content	2.1
Pittman's Pond	0.61
New Chealsea	3.4
Victoria	0.42
Fall Pond	0.32
West Brook	0.545
Lawn	0.6
Lockston	3
Port Union	0.6
Rattling Brook	13.41
Sandy Brook	5.7
Lookout Brook	5
Rose Blanche	5.22
Total capacity	**1265.595**

capacity is 300 KW. The system uses three wind turbines to supplement the diesel requirements of the community. Newfoundland hydro purchases power from the two 27 MW wind farms, and in 2010 Hydro purchased 183,252 MWh of energy to meet the province's demand. NL hydro operates two gas turbines one in Stephenville and the other one in hardwoods. These turbines are placed in standby mode for emergency electricity generation during unplanned outages. Again the total existing biomass market of NL is just 3000ton/yr or 0.0144 TWh/yr [65], but it has a potential of producing 750,000 Ton/yr [66]. The energy supply sectors in Newfoundland and Labrador consists of crude oil extraction, petroleum refining and electricity generation. But in the island portion the only petroleum refinery is located in come by chance. All petroleum refining in Newfoundland island occurs at the refining plant with maximum capacity of 115,000 barrels per day. In this chapter Energy system of Newfoundland is analyzed with two softwares. The first software that is used is EnergyPLAN and second one is LEAP. Leap is a long term energy planning tool whereas EnergyPLAN is a design tool that analyzes annual result. For predicting the future demand LEAP is used later. A detailed discussion about the softwares and designs are given in the following sections.

5.2 Analysis in EnergyPLAN

To understand Newfoundland's current energy system we need to collect energy data and model the system. There are several designing tools to use but for this thesis we have chosen EnergyPLAN software for the first analysis. The model was first developed at

Aalborg University in Denmark and free downloads are available at www.energyplan.eu. EnergyPLAN is a computer model that helps to design and analyze a national energy system. It considers electricity, transport and heat demand sectors of a national energy system and the analysis is presented in hourly steps over a period of one year.

It is an input-output model where main inputs are demand, capacity, renewable sources, fuel cost, investment cost, regulation strategies; and outputs are annual, monthly, hourly values of consumption/production of different energy sources, export, import, Hydro power, RES electricity etc. This model is specialized in integration of renewable energy sources. Schematic diagram of the EnergyPLAN model is presented in Figure 5.5. Hourly

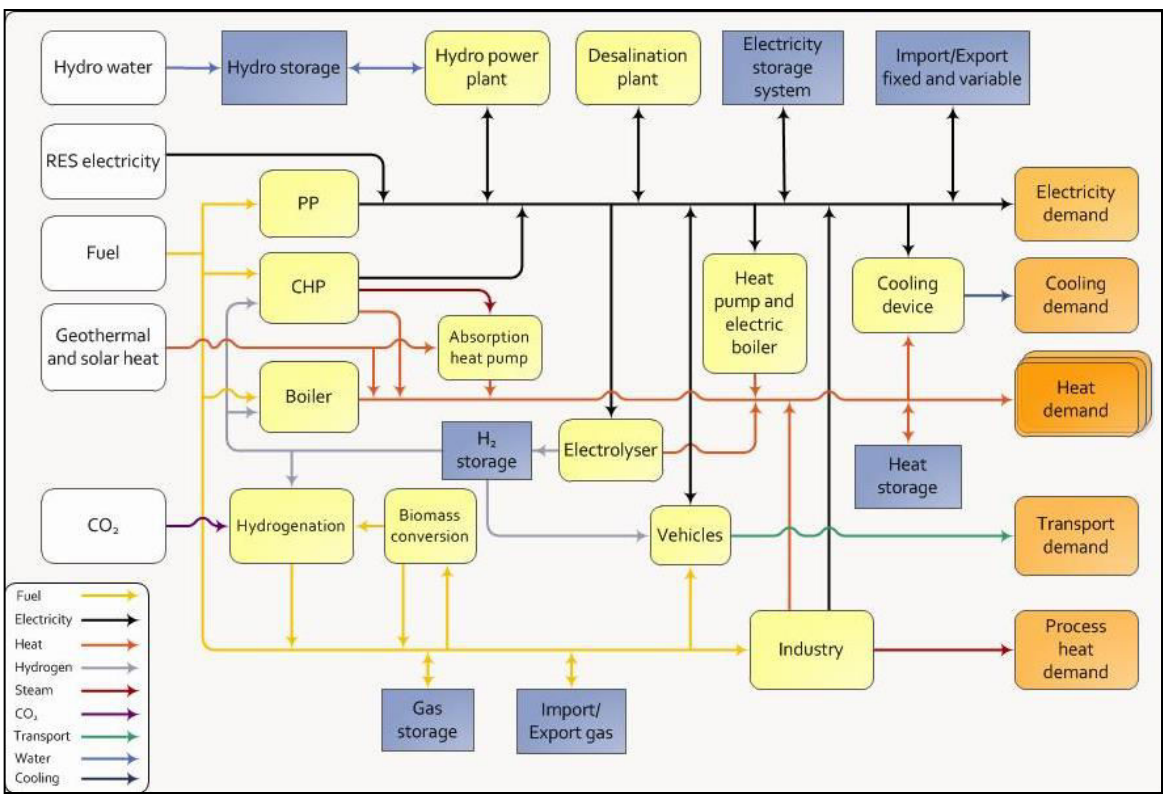


Figure 5.5 Schematic diagram of EnergyPLAN model

distribution data with 8784 data points is required for the simulation and hourly analysis. Depending on four criteria's user can compare and identify the better energy model: Critical excess electricity production (CEEP), Share of Renewable energy in the supply, Emission of CO_2 and Annual generation cost to meet the demand. In our work we are not concerned about Emission of $CO_{2.}$ EnergyPLAN has two optimization strategies, technical and market economic. Reduction of excess electricity and fuel consumption are analysis concern in technical regulation. There are four options in technical regulation, from which user can choose one according to the design. The available strategies for the analysis are given below:

1. Technical regulation strategy: balancing heat demands.
2. Technical regulation strategy: balancing both heat and electricity demand.
3. Technical regulation strategy: balancing both heat and electricity demand (Reducing CHP when needed).
4. Technical regulation strategy: balancing heat demands using triple tariff.

There is no combined heat and power production used in Newfoundland and also no district heating is used. So balancing both heat and electricity demand regulation strategy has been used in design of Newfoundland energy system.

5.2.1 Inputs in EnergyPLAN

The current existing scenario for Newfoundland is modeled by EnergyPLAN software. Electricity consumption for NL for year 2013 was 8.15 TWh/yr [67]. Figure 5.6 shows the hourly load in MW of Newfoundland in year 2013. This hourly distribution data file is

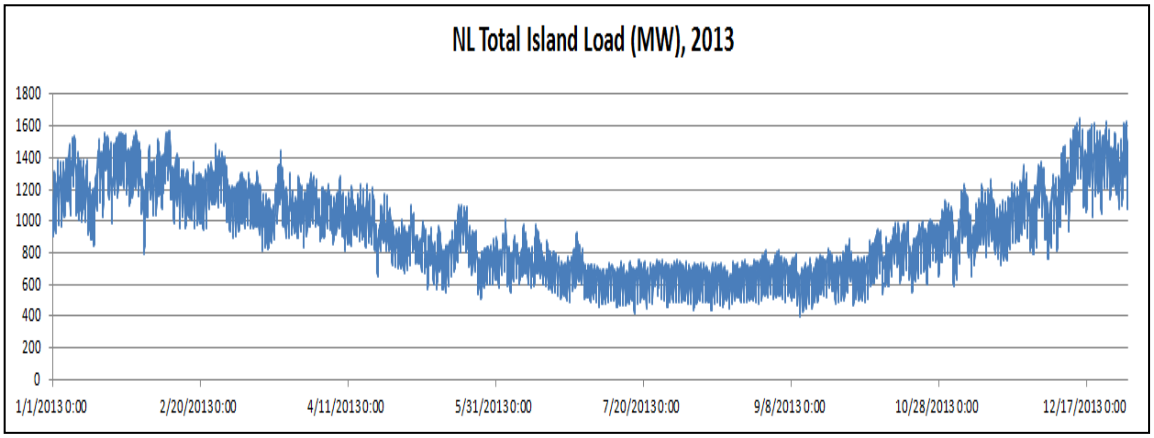


Figure 5.6 Hourly load for Newfoundland in 2013

used in demand window of Energy plan software. There is no district heating but all houses are individually heated, so about 70% of the total consumption has been assumed as heat demand. Heat demand per house is calculated as about 5981 kWh/yr [68]. The heat demand is included in the total demand. The distribution of water data and wind data are downloaded from water office [69] and weather office [70] respectively. Since the proposed design is for NL island so there is no export or import and also no storage system is used. (Proposed link to Nova Scotia is not considered).

All the collected data that has been used in EnergyPLAN software are given in the table-5.2. Since the population is remarkably low in Labrador, so we have used fuel consumption data in the model that is used in the total province. Fuel cost, operation and maintenance cost are inserted from appropriate sites [71] [72] [73]. There is a window for fuel prices in USD/GJ which values are given in table 5.2. Operation & maintenance cost

Table 5.2 Data used in the energy model of NL in EnergyPLAN.

Energy sectors	**MW**	**energy source** [74]	**USD/GJ**
Holyrood thermal plant	490	Fuel oil	34.21
Hydro power plant	1265	Diesel	34.21
Wind turbine	54.7	Petrol	31
	TWh/yr	Natural gas	4.38
NL electricity demand	8.15	LPG	25.2
Industry [75]	**TWh/yr**	Biomass	0.26
Coal	1.123		
Oil	1.4		
Natural gas	21.005		
Biomass [76]	0.0144		
various	10.405		
Transport [77] [75]	**TWh/yr**		
Jet fuel	0.36		
Petrol	18.51		

for hydro plant and electricity are used 270 USD/MWh & 123 USD/MWh respectively in a different window. Wind energy is set to 54.7 MW with stabilization share of 0.8 and correction factor of 0.8. In the industry and transport sector the amount of different type of fuel value is inserted as given in Table 5.2. There is no desalination unit, nuclear plant, carbon capture or cooling system, so all those windows input are kept zero. In the cost window fuel cost, investment cost for the plants, operation and maintenance cost are inserted as per requirement. The optimization strategy chosen is technical regulation to simulate the model.

5.2.2 Future Energy Model

Climate change is now a worldwide concern and use of renewable energy system is encouraged everywhere. In the current NL energy system only wind energy of 54.7 MW is used, whereas the potential is much higher than this. Newfoundland has the strongest winds of any Canadian Province, with annual average speed greater than 20km/h. On the other hand solar energy is another option to consider but if we think about generation throughout the year then wind energy integration to the system is probably more feasible.

In a wind integration study for year 2020 and 2035 by hydro system planning department [78], they concluded that theoretically 500MW of wind generation can be installed on the island isolated system with no voltage or overloading concerns. But practically it is recommended that wind energy integration of 225MW to 300MW can be added to the existing system during the extreme light load conditions. An energy model for near future is created with increased wind energy from 54.7 MW to 300 MW. In EnrgyPLAN software in the RES (renewable energy source) window, wind capacity is changed to 300MW from 54.7MW with stabilization share 0.8. Keeping other values same as the existing model; we get the result presented in figure 5.8. This model indicates a small step towards an energy model of Newfoundland with possible wind energy integration.

5.2.4 Analysis of Results

The simulation of both the model has been done using Technical optimization strategy by balancing both heat and electricity demand. Figure 5.7 and Figure 5.8 shows the output in

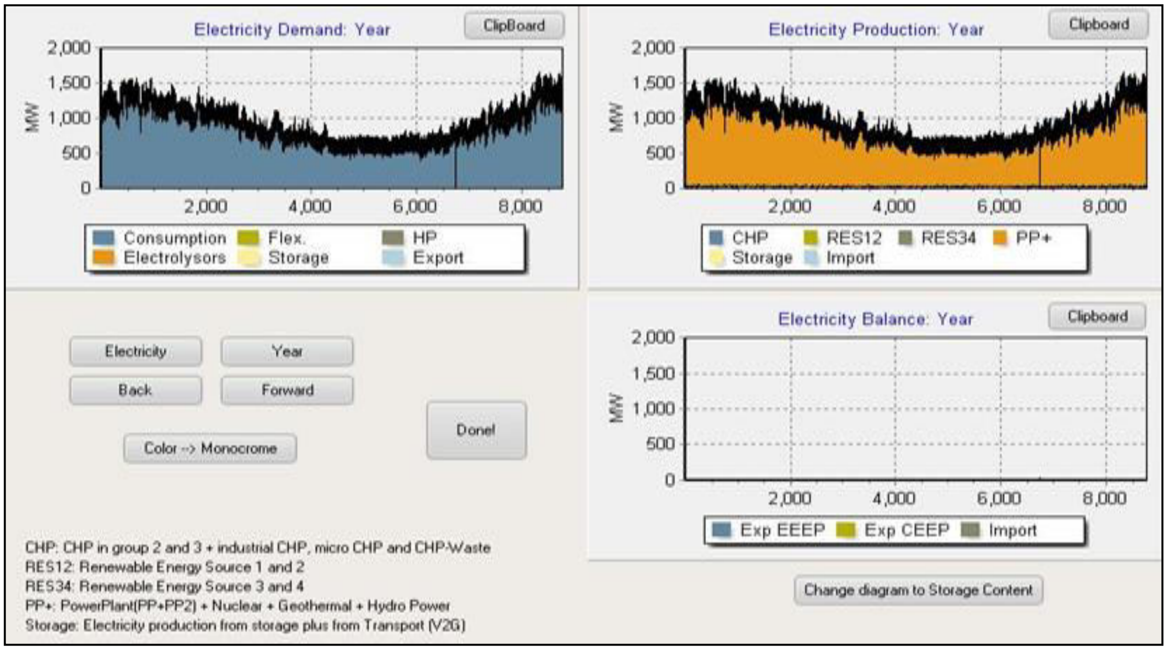


Figure 5.7 NL energy model, 2013.

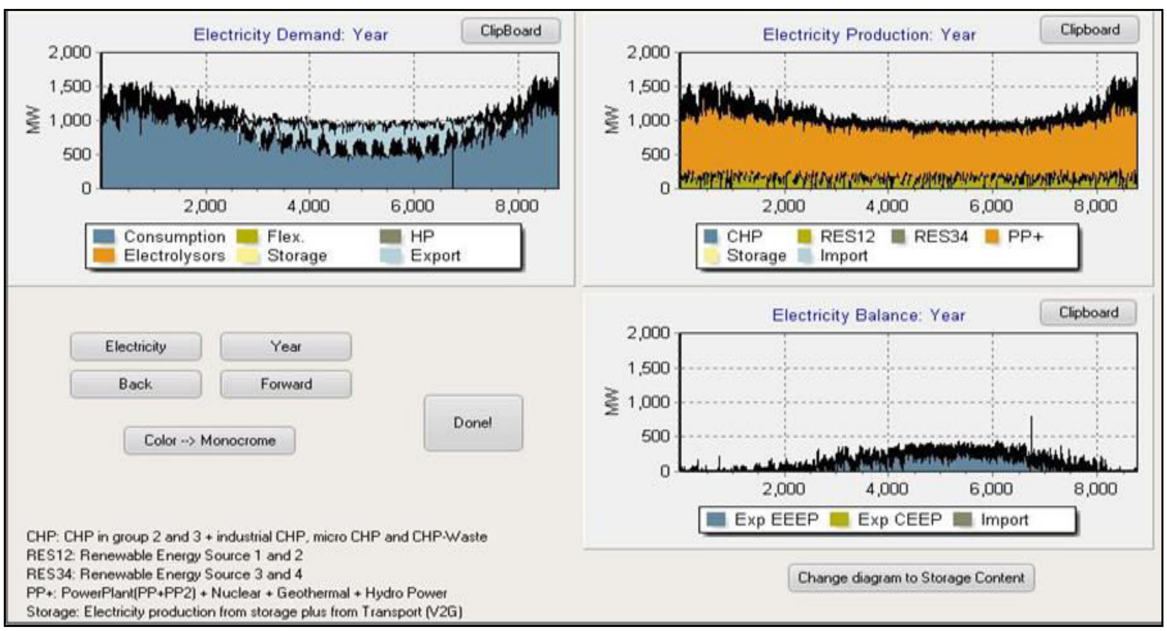


Figure 5.8 NL future energy model with 300 MW wind

graph for the existing model of NL and future energy model respectively. We can see the electricity production (yellow) meets with the demand (blue) for year 2013, and there is no Exportable excess electricity production (EEEP) or critical excess electricity production (CEEP). Critical excess production is not expected as it cause breakdown to the entire supply system. From the simulation result it can be noticed that the average annual energy consumption from wind is 35 MW and the highest production is in December, January and February month. For hydro the annual average is 862 MW with highest production in December.

The annual CO_2 emission for the current energy model is 13.248 Mt but for the future model with added wind energy CO_2 emission reduces to 12.392 Mt. Renewable energy source (RES) electricity production is 7.88 TWh/yr for NL existing system. And with increasing wind energy the total RES production reaches to 9.26 TWh/yr. Figure 5.8 shows the output for the future model with integration of wind energy in the system. For the future model only the wind energy is increased and it is noticed that the average wind energy production reaches to 192 MW. The Electricity production from the wind energy (brown) is noticeable in the graph and in electricity balance graph EEEP is 1.12 TWh/yr.

5.3 Analysis in LEAP

LEAP, the Long range Energy Alternatives Planning System is a software tool that can model electric sector generation and plan future capacity expansion of a region or country for an unlimited number of years. The software was developed at the Stockholm

Environment Institute [79]. LEAP has been used in more than 190 countries by academic institution, government sector, energy companies etc. It calculates energy consumption, production and resource extraction in all sectors of an economy. Besides resource planning it can also be used to analyze green house gas emission, optimization for least cost model etc. The calculation in LEAP happens on an annual time step and time frame can be set to the desired number of years. For calculating the data and showing the output LEAP requires less initial data as input.

In LEAP there are mainly four sectors where input and output can be shown. The sectors are,

I. Analysis view, the desired model is constructed here with data input.

II. Diagram View, shows the designed energy system with input resources and outputs which finally reaches to the end user.

III. Result view, here outputs are assessed as graphs and tables for designed scenario.

IV. Energy balance shows the detailed final energy calculations up to the forecasted year. Energy balance view displays a summary of energy consumption, conversion and production for the designed scenario. The energy balance table is divided into 3 sections. The resource section shows primary resource requirements and includes three rows: production, imports and exports. The Transformation section shows the energy consumed and produced during the conversion of primary resources into secondary fuels, as well as the energy lost during the transportation and distribution of fuels. Energy inputs are shown as negative values, outputs are shown as positive values. Demand section shows final demands in the Area.

5.3.1 Base Case Input in LEAP

In this thesis NL island energy system and demand are forecasted from year 2013 to 2030 using LEAP. With the data which are same as used in EnergyPLAN software, LEAP needs some basic data with growth rate to predict the demand up to year 2030.

The total population in Newfoundland & Labrador in year 2013 was 528,194 [80]. The Conference Board of Canada predicts the province's population will fall from present population to 482,000 by 2035. So the growth rate will be negative, 8.74% [81]. There are almost 200 thousand houses in the province with assuming 3 persons per household on average [82]. Per capita income in the province of NL, in year 2013 was $39,668 [83]. And the income growth rate is 3.4% per year. For NL, GDP per capita in 2013 was 67,838 CAD [84] and Department of Finance indicates GDP growth of 1.6 per cent annually for the next 20 years [85]. The electricity demand will increase 1.4% annually between year 2011 to 2030 [85]. All the demand data of Petroleum, Natural gas, Biomass are used from chapter-2. There will be a decrease in petroleum production by 2030, which is 0.6% per year [86]. Figure 5.9 shows the main data structure tree in LEAP, to input all the data including supply, demand and available resources. According to Canada-Newfoundland and Labrador Offshore Petroleum Board, Newfoundland's offshore energy reserves contain 2.9 billion barrels of oil, 479 million barrels of natural gas liquids, and 10.9 trillion cubic feet of natural gas [87].

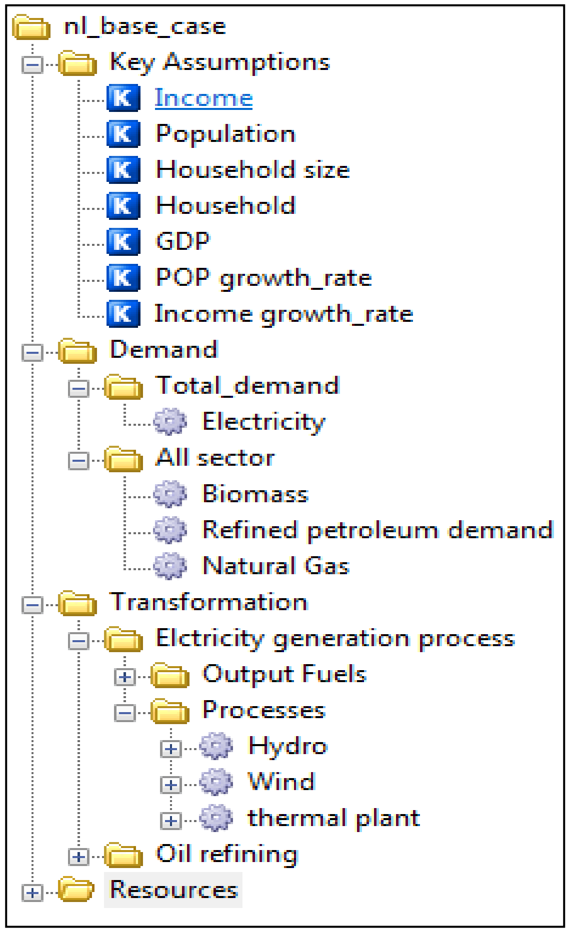


Figure 5.9 Data structure in LEAP

The electricity generation sources in Newfoundland Island are Hydro plant, thermal plant and wind farm. The efficiency of wind, thermal plant and hydro are assumed to be 30%, 30% & 90% respectively in LEAP [88] [89] [90]. According to the document (based on Nalcor & Manitoba hydro report) submitted to government by Public Utility Board, among the two generation expansion plans Muskrat falls and transmission link between Labrador & the island is the lowest cost option to meet the electricity demands in the province of NL [91]. Figure 5.10 shows the plan up to year 2030 prepared by Manitoba

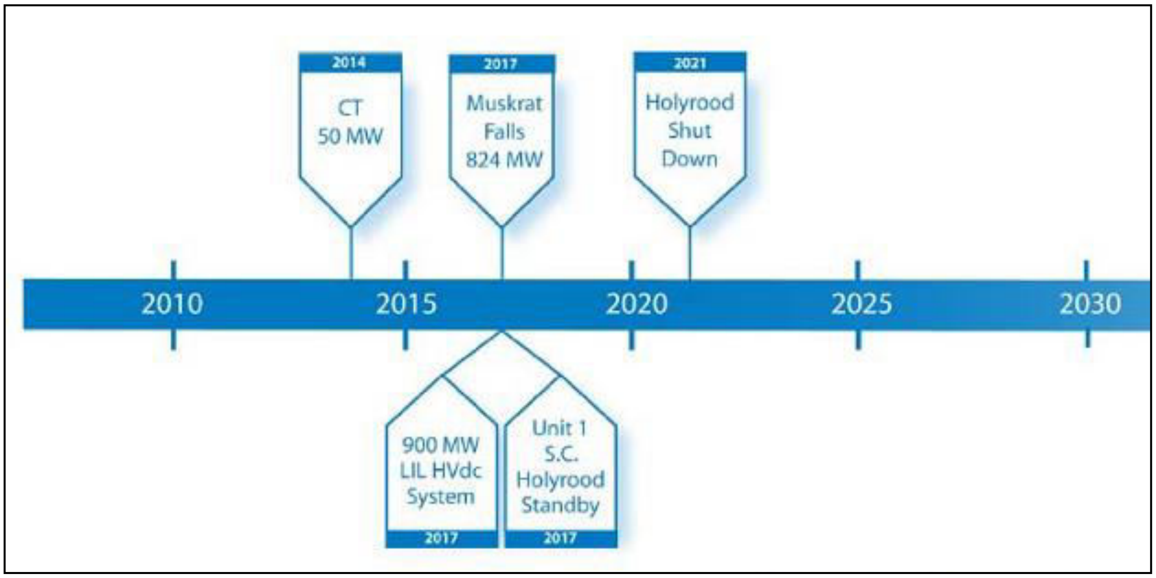


Figure 5.10 NL energy plan up to year 2030 by Manitoba hydro.

hydro international (MHI). Though it planned 50 MW of combustion turbine in year 2014 but actually 123 MW was installed in Holyrood in 2014, which started to operate as needed in the beginning of 2015. With the addition of electricity from Muskrat falls in year 2017, Holyrood units would remain in standby status available for generation until 2021. But in 2021 Holyrood thermal plant will shut down. The analysis and forecast in LEAP is based on this plan.

5.3.2 Base Case Output

Figure 5.11 shows the energy supply system modelled in LEAP after inputting all the required data. It clearly shows the sources of energy in NL are Natural gas, Crude oil, wind, hydro and biomass. Figure 5.12 shows the different energy sources transformed

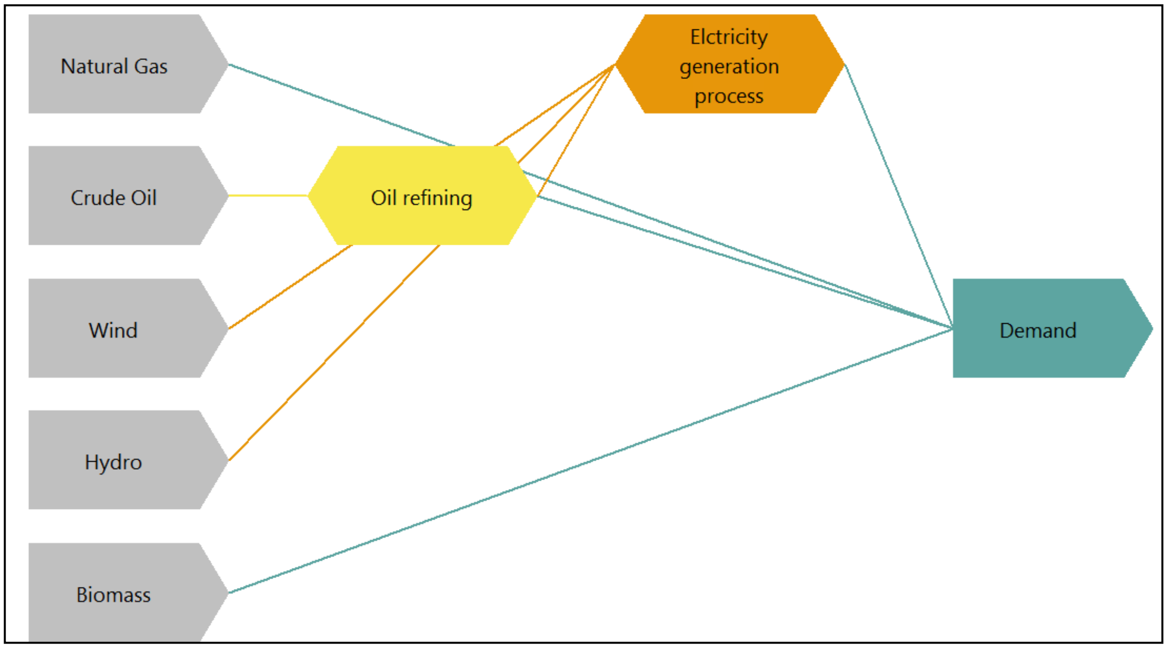
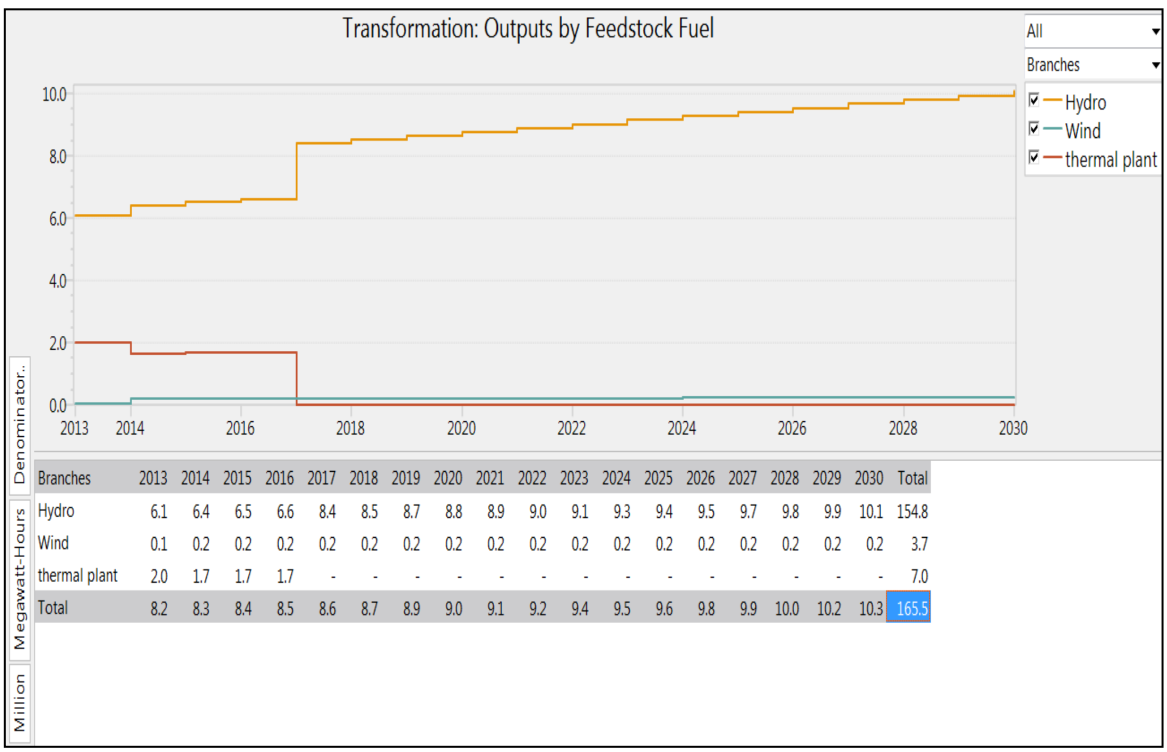


Figure 5.11 Energy supply system of NL island system



Branches	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Total
Hydro	6.1	6.4	6.5	6.6	8.4	8.5	8.7	8.8	8.9	9.0	9.1	9.3	9.4	9.5	9.7	9.8	9.9	10.1	154.8
Wind	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	3.7
thermal plant	2.0	1.7	1.7	1.7	-	-	-	-	-	-	-	-	-	-	-	-	-	-	7.0
Total	8.2	8.3	8.4	8.5	8.6	8.7	8.9	9.0	9.1	9.2	9.4	9.5	9.6	9.8	9.9	10.0	10.2	10.3	165.5

Figure 5.12 Transformation output by energy sources

Energy Balance for nl_base_case

Scenario: NL_future, Units: Million Megawatt-Hour

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Production	33.7	32.8	32.8	32.9	33.0	33.1	33.1	33.2	29.3	29.3	29.3	29.4	29.4	29.4	29.5	29.5	29.6	29.6
Imports	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Exports	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Primary Supply	33.6	32.8	32.8	32.9	33.0	33.1	33.1	33.2	29.3	29.3	29.3	29.4	29.4	29.4	29.5	29.5	29.6	29.6
Oil refining	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Elctricity generation process	-5.4	-4.6	-4.7	-4.7	-4.8	-4.9	-4.9	-5.0	-1.0	-1.0	-1.0	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1
Total Transformation	-5.4	-4.6	-4.7	-4.7	-4.8	-4.9	-4.9	-5.0	-1.0	-1.0	-1.0	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1	-1.1
Total_demand	8.2	8.3	8.4	8.5	8.6	8.7	8.9	9.0	9.1	9.2	9.4	9.5	9.6	9.8	9.9	10.0	10.2	10.3
Electricity	8.2	8.3	8.4	8.5	8.6	8.7	8.9	9.0	9.1	9.2	9.4	9.5	9.6	9.8	9.9	10.0	10.2	10.3
All sector	20.0	19.9	19.8	19.7	19.6	19.5	19.4	19.2	19.1	19.0	18.9	18.8	18.7	18.6	18.5	18.4	18.3	18.2
Biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Refined petroleum demand	19.4	19.3	19.2	19.1	19.0	18.9	18.7	18.6	18.5	18.4	18.3	18.2	18.1	18.0	17.9	17.8	17.6	17.5
Natural Gas	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Total Demand	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.2	28.3	28.3	28.3	28.3	28.3	28.4	28.4	28.4	28.5

Figure 5.13 Energy balance of NL island system up to year 2030 (base case)

into electricity. Both in the chart and table (Figure 5.12) it can be seen that thermal plant produces around 20-25% of total energy in the province until the addition of electricity from Muskrat Falls hydro plant. In 2017 Muskrat fall will start to operate and NL will be benefitted by 329 MW of electricity to fulfill the demand. Again Figure 5.13 shows the total energy balance of the province up to year 2030. And it is clear from the output of figure 5.12 that the province can meet all its demand from the generation expansion plan. The total demand in year 2030 is 28.5 TWh and no import is required.

With the base case scenario three scenarios have been designed in LEAP to compare. All the scenarios are discussed in the next page.

5.3.3 Scenario-1: Higher growth rate

In this scenario with all other value kept the same, electricity demand is increased from 1.4% to 2% annually. In the output it is observed that up to year 2028 existing system can supply the demand but after that import of electricity is needed. Figure 5.14 shows in year 2030, 200000 MWh energy needs to be imported which is considerable.

Scenario: NL_future, Year: 2030, Units: Million Megawatt-Hour

	Electricity	Natural Gas	Oil	Crude Oil	Wind	Hydro	Biomass	Total
Production	-	0.6	-	17.5	0.7	12.3	0.0	31.1
Imports	0.1	-	-	-	0.1	-	-	0.2
Exports	-	-	-	-	-	-	-	-
Total Primary Supply	0.1	0.6	-	17.5	0.8	12.3	0.0	31.3
Oil refining	-	-	17.5	-17.5	-	-	-	-
Elctricity generation process	11.3	-	-	-	-0.8	-12.3	-	-1.7
Total Transformation	11.3	-	17.5	-17.5	-0.8	-12.3	-	-1.7
Total_demand	11.4	-	-	-	-	-	-	11.4
Electricity	11.4	-	-	-	-	-	-	11.4
All sector	-	0.6	17.5	-	-	-	0.0	18.2
Biomass	-	-	-	-	-	-	0.0	0.0
Refined petroleum demand	-	-	17.5	-	-	-	-	17.5
Natural Gas	-	0.6	-	-	-	-	-	0.6
Total Demand	11.4	0.6	17.5	-	-	-	0.0	29.6

Figure 5.14 Energy balance of NL island system for year 2030 (Scenario-1)

5.3.4 Scenario-2: Encourage and use electric vehicle

In this case it is assumed that by year 2030, 20% vehicle will be using gasoline for transportation and the rest will use electricity, with 2% growth rate. So using the data from chapter-2,

Total (gasoline) energy used by Motor vehicle was 871100 m^3 or 9314672300 kWh.

20% Motor energy= 9.3*0.2=1.86 TWh

Remaining vehicles, 9.3-1.86=7.44 TWh

So by 2030, 20% of the vehicles will use 1.86 TWh energy and the remaining (7.44 Twh) transportation will be dependent on electricity. With 2% growth rate the electricity demand reaches to 11.4 TWh from 8.13 TWh. Similarly petroleum demand decreases to 20.7 TWh with negative 0.6% rate. So by year 2030 electricity demand will be 18.84 TWh and petroleum demand would decrease to 13.26 TWh. Using all these assumptions in LEAP the output is generated. Figure 5.15 shows the process capacity that is entered in LEAP to meet the maximum demand. Wind and thermal plant capacity will remain the same as base case. But hydro capacity will increase from 1265 to 1595MW in 2017 and again to 1894 MW in year 2021 to meet the increasing demand. Figure 5.16 shows the energy balance chart. In 2030 the electricity import needed is 2.2 TWh. Wind energy can be added to the system up to 225 MW; but since we already have additional electricity coming from muskrat falls, wind energy is not increased in the system considering the

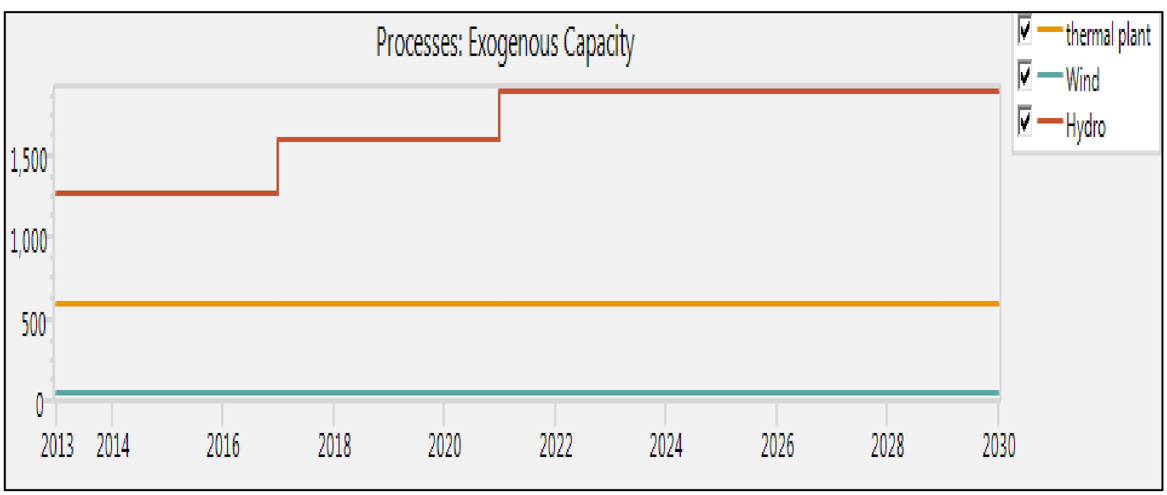


Figure 5.15 Active process capacity till year 2030 (Scenario-2)

Energy Balance for nl_scenario2 Scenario: NL_future, Units: Terawatt-hour	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Production	33.7	33.2	33.7	34.1	34.6	35.0	35.3	35.6	36.0	36.3	36.6	36.8	37.0	37.0	37.0	37.0	36.9	36.7
Imports	-	0.4	0.4	0.5	0.4	0.4	0.5	0.5	0.4	0.5	0.5	0.6	0.7	0.9	1.2	1.5	1.8	2.2
Exports	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Primary Supply	33.6	33.6	34.1	34.6	35.0	35.4	35.8	36.2	36.4	36.8	37.1	37.4	37.7	38.0	38.2	38.4	38.6	38.9
Oil refining	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Elctricity generation process	-5.4	-5.2	-5.6	-6.0	-6.2	-6.5	-6.7	-6.9	-7.0	-7.2	-7.4	-7.6	-7.7	-7.8	-7.9	-8.0	-8.1	-8.2
Total Transformation	-5.4	-5.2	-5.6	-6.0	-6.2	-6.5	-6.7	-6.9	-7.0	-7.2	-7.4	-7.6	-7.7	-7.8	-7.9	-8.0	-8.1	-8.2
Total_demand	8.1	8.8	9.4	10.0	10.7	11.3	11.9	12.6	13.2	13.8	14.4	15.1	15.7	16.3	17.0	17.6	18.2	18.8
Electricity	8.1	8.8	9.4	10.0	10.7	11.3	11.9	12.6	13.2	13.8	14.4	15.1	15.7	16.3	17.0	17.6	18.2	18.8
All sector	20.0	19.6	19.1	18.6	18.1	17.6	17.2	16.7	16.2	15.7	15.2	14.7	14.3	13.8	13.3	12.8	12.3	11.9
Biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Refined petroleum demand	19.4	18.9	18.5	18.0	17.5	17.0	16.5	16.1	15.6	15.1	14.6	14.1	13.6	13.2	12.7	12.2	11.7	11.2
Natural Gas	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Total Demand	28.2	28.3	28.5	28.6	28.8	28.9	29.1	29.2	29.4	29.5	29.7	29.8	30.0	30.1	30.3	30.4	30.6	30.7

Figure 5.16 Energy balance of NL island system up to year 2030 (Scenario-2)

cost. Therefore NL government is encouraged to consider introduction of electric vehicles on large scale in NL since we have excess electricity generation.

5.3.5 Scenario-3: Switch to electric heating

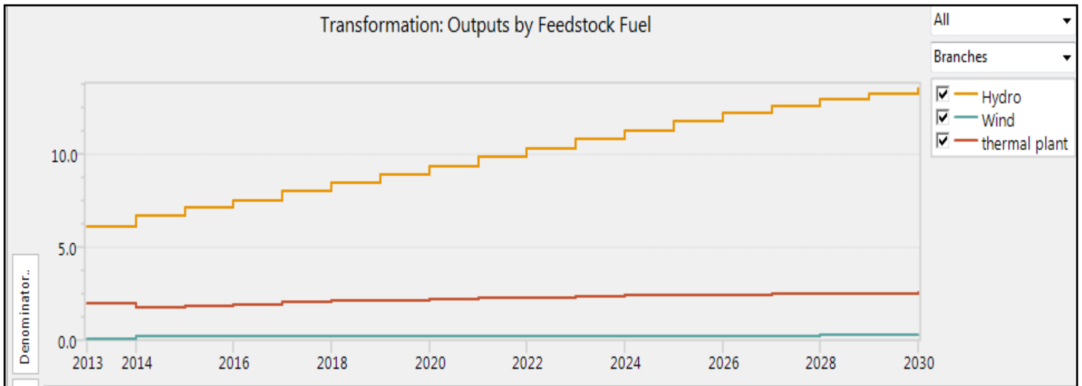
In this scenario it is assumed that all the heating oil will be replaced by electricity by year 2030. Heating oil used in the province are Light fuel oil, Stove oil & propane. From chapter-2,

Heating oil=Light fuel oil+ Stove oil+ propane

$= (199.5+301.5+30.5)* 1000\ m^3$

$=531.5*1000*10693$ kWh

$=5.65$ TWh



Branches	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	Total
Hydro	6.1	6.7	7.1	7.5	8.0	8.5	8.9	9.4	9.9	10.3	10.8	11.3	11.8	12.2	12.6	13.0	13.3	13.6	181.0
Wind	0.1	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	3.9
thermal plant	2.0	1.7	1.8	1.9	2.0	2.1	2.2	2.2	2.3	2.3	2.4	2.4	2.4	2.5	2.5	2.5	2.5	2.5	40.4
Total	8.2	8.7	9.2	9.7	10.2	10.8	11.3	11.8	12.3	12.9	13.4	13.9	14.4	14.9	15.4	15.7	16.1	16.4	225.3

Figure 5.17 Transformation output by energy sources (scenario-3)

Scenario: NL_future, Units: Terawatt-hour

	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Production	33.7	33.3	33.7	34.1	34.5	34.9	35.2	35.5	35.9	36.1	36.4	36.6	36.9	37.1	37.2	37.3	37.4	37.3
Imports	-	0.2	0.2	0.3	0.2	0.2	0.2	0.3	0.2	0.2	0.2	0.3	0.3	0.4	0.5	0.6	0.8	1.0
Exports	0.0	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Total Primary Supply	33.6	33.5	33.9	34.4	34.7	35.1	35.4	35.8	36.0	36.3	36.6	36.9	37.2	37.5	37.7	38.0	38.2	38.4
Oil refining	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Elctricity generation process	-5.4	-5.2	-5.5	-5.8	-6.0	-6.2	-6.5	-6.7	-6.8	-7.0	-7.1	-7.3	-7.4	-7.6	-7.7	-7.8	-7.9	-8.0
Total Transformation	-5.4	-5.2	-5.5	-5.8	-6.0	-6.2	-6.5	-6.7	-6.8	-7.0	-7.1	-7.3	-7.4	-7.6	-7.7	-7.8	-7.9	-8.0
Total_demand	8.1	8.7	9.2	9.7	10.2	10.8	11.3	11.8	12.3	12.9	13.4	13.9	14.4	15.0	15.5	16.0	16.5	17.0
Electricity	8.1	8.7	9.2	9.7	10.2	10.8	11.3	11.8	12.3	12.9	13.4	13.9	14.4	15.0	15.5	16.0	16.5	17.0
All sector	20.0	19.7	19.3	18.9	18.5	18.1	17.7	17.3	16.9	16.5	16.1	15.7	15.3	14.9	14.6	14.2	13.8	13.4
Biomass	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Refined petroleum demand	19.4	19.0	18.6	18.2	17.9	17.5	17.1	16.7	16.3	15.9	15.5	15.1	14.7	14.3	13.9	13.5	13.1	12.8
Natural Gas	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6	0.6
Total Demand	28.2	28.3	28.5	28.6	28.7	28.9	29.0	29.1	29.2	29.4	29.5	29.6	29.8	29.9	30.0	30.2	30.3	30.4

Figure 5.18 Energy balance of NL island system up to 2030 (Scenario-3)

So, in year 2030 with 2% growth rate and addition of heating energy, electricity demand will be 17.05 TWh. And Petroleum demand will decrease to 15.05 TWh. Figure 5.17 shows the output after transformation of the sources. The output electricity unit is shown in million MWh. Again Figure 5.18 shows energy balance where it is noticed that energy import is negligible in this case. So increasing hydro plant capacity to 1895 MW will be enough to meet the demand if all the heating oil is replaced by electricity by year 2030. Therefore NL government should consider switching to electric heating using existing electric generation.

5.4 Conclusion

In this Chapter, the energy model of Newfoundland island system is presented using EnrgyPLAN and LEAP software. Apart from some exceptions almost same data is used in both the softwares. In EnergyPLAN, with the base case model a model is designed by increasing the wind energy to 300 MW which shows a step toward the future energy model of NL. In the base model holyrood plant supplies a significant portion to the total consumption and there remains no surplus. But when wind energy is increased to 300 MW from 54.7 MW the surplus reaches to 1.12 TWh/yr. This implies that the use of thermal plant can be minimized to a significant level with the added renewable energy source. But EnergyPLAN software cannot predict future cases and due to some software output constraints LEAP is chosen for further analysis. Newfoundland island's energy demand and system is forecasted from year 2013 to year 2030 in LEAP. For each year the software shows an energy balance output. And for year 2013 the energy balance output shows all the existing system capacity fulfills the island's demand without the need of any import. And following the Nalcor proposed energy plan, the designed energy system in LEAP also fulfills the future need perfectly. Later three scenarios are designed to observe what happens to the system with the changes in demand. It is observed if the electricity demand is increased to 2% negligible amount needs to be imported in year 2030. Again with 2% growth rate, If 20% of the motor vehicle uses oil and the rest depend on electricity then to meet the increasing demand thermal plant will continue to operate. And addition of hydro energy will be from 1265 to 1595MW in 2017 and again to 1894 MW in year 2021 up to year 2030. But need of electricity import will arise by 2030 to 2.2 TWh in the island. The last case observes the scenario if all heating oil demand is fulfilled by electricity with 2% growth rate. It showed if hydro capacity is increased to 1895 MW, with thermal plant running demand can easily be fulfilled for future. In all the cases wind capacity (54.7 MW) remains the same. For the new scenarios, wind Energy could have been added to the system. But despite having great wind energy potential the future plan sanctioned by the government does not include any new wind farms to the Labrador-island interconnected system. To make a realistic analysis no new wind energy is added to the LEAP software analysis, rather mainly hydro energy and thermal plant are considered to meet the future demand.

Chapter-6

Conclusion and Future work

6.1 Conclusion

Energy consumption data of Newfoundland and Labrador from all possible sources was collected and presented in this thesis. The energy used per person in Newfoundland in a year is also calculated. It is found that energy consumption in year 2011 by the people of Newfoundland was 185.34 kWh/person/day, whereas the published data from statistics Canada indicates energy consumption was 168.93 kwh/person/day.

In this thesis work, a simple data logger design is presented. The designed data logger can measure inside & outside temperature and current consumption of a house accurately. Two LM35 temperature sensors and four Hall effect based current sensors are used for the design purpose. All the logged data can be saved in a SD card for almost 7 days and then needs to be transferred to a computer for further analysis. These types of data loggers are useful to log the hose energy consumption with a desired time interval. Generally we get monthly energy consumption bill at the end of each month. But for a better understanding of the energy consumption data with a faster sampling rate is needed. Apart from saving all the data in separate files in sd card the designed data logger can also show the logged data instantly on a 2x16 LCD. The developed data logger is small in size and can easily be installed in a house.

A detailed energy analysis is important to understand the energy consumption pattern of a house. Energy analysis results can identify ways to minimize the house energy consumption. Before any house improvement approach a thorough house energy analysis is advised. An energy consumption analysis is conducted successfully in this thesis for two houses in St John's, NL.

A data logger similar but not the same as Chapter 3 device is installed in both the houses and energy consumption data was taken for a period of one year. The measured data was analyzed and finally compared with the data provided by Newfoundland Power. The analysis result shows both the collected sets of data follows a similar pattern. It is observed for both the houses that in winter month consumption is high at night, late evening and in early morning. Again in summer time consumption is high in the afternoon hours.

A Building Energy optimization (BEopt) software is used to find the annual energy consumption of a house and it also calculates maximum energy saving case or minimum cost case according to the user's requirement. Both the houses are simulated in the software to get the output. The result showed the simulated output values matches with the measured yearly consumption value of the houses. Energy consumption of house#1 for one year came as 16849 kWh/yr, whereas the actual consumption for the house is 15747 kWh/yr which is very close. Again for house#2 the actual consumption of the house by utility is 27300 kWh/yr. But the simulation shows the total house consumption is 31029 kWh/yr which is a bit high, because of less number of occupants in the house.

Similarly actual garage consumption 1190.56 kWh/yr, almost matches with the software result which is 1090 kWh/yr.

Using EnrgyPLAN software existing energy system of Newfoundland Island is presented. Result showed electricity production meets with the demand for year 2013, and there is no Exportable Excess Electricity Production (EEEP) or Critical Excess Electricity Production (CEEP). An energy model for near future is also created with increased wind energy from 54.7 MW to 300 MW. The electricity production after addition of wind energy is noticeable; exportable excess electricity production becomes 1.12 TWh/yr. The annual CO_2 emission for the base case energy model is 13.248 Mt but for the future model with added wind energy CO_2 emission reduces to 12.392 Mt.

Finally Long range Energy Alternative Planning (LEAP) software is used to forecast the Newfoundland island's energy demand and system. A forecast is presented for NL from year 2013 to year 2030. One forecast is shown with the actual growth rates and sanctioned plan of the government. With the base forecast three new scenarios are designed to observe the future output. In the first scenario it is assumed that electricity demand will increase from 1.4% to 2% per year. The calculated output shows the existing energy source with increased hydro plant to 1595 MW and shut off of thermal plant in 2021 are enough to meet the future demand. Only negligible amount of electricity will be needed to import at the end of the forecasted years. The second scenario assumes the case when 20 % of the vehicle will run by oil and the remaining will be run by electricity. In such case thermal plant and wind farm will continue to run with their actual capacity.

But hydro capacity will be increased from 1265 to 1595MW in 2017 and again to 1894 MW in year 2021 to meet the demand. However, by the end of the forecasted year in 2030, 2.2 TWh electricity will need to be imported. The last scenario assumes all the heating oil for the NL island system will be replaced by electricity. It is analyzed that with thermal plant and wind farm running, addition of hydro plant capacity from 1265 to 1595MW in 2017 and again to 1894 MW in year 2021 will be enough to meet the requirement. Although there will be need of small amount of electricity by the end of the forecasted years. Finally the results show in 2030 that 1 TWh electricity will need to be imported.

6.1 Future work

- ✓ In the data logger design more sensors could have been added to measure humidity in the house or for measuring current drawn for a particular appliance. A micro SD card of 2 gb is used which can log data up to 7 days. But instead multiple SD cards or an SD card with more space could have been used to log data for longer duration of time. An LED could have been used to blink as an indicator when the SD card is full. An LCD is used to show the inside and outside house temperatures, but another LCD could have been used to show the measured current values.

- ✓ Two houses simulation in BEopt could have been done in parametric mode. More insulation could have been added to the houses to calculate the benefit. The impact of addition of a PV system and thermal storage could have been studied. Renewable energy system for the houses could have been designed.

- ✓ Power consumption analysis for House#1 could have been analysed for recent years. Study of human behaviour and energy usage of both the houses could have been completed.

- ✓ In EnergyPLAN software several design scenarios could have been compared to find the optimum case for NL energy system. More solar and wind energy could have been added to the system.

- ✓ In LEAP, design of a 100% renewable energy system with no thermal units could have been done. LEAP could have been used to analyze green house gas emission and to find the optimized least cost model.

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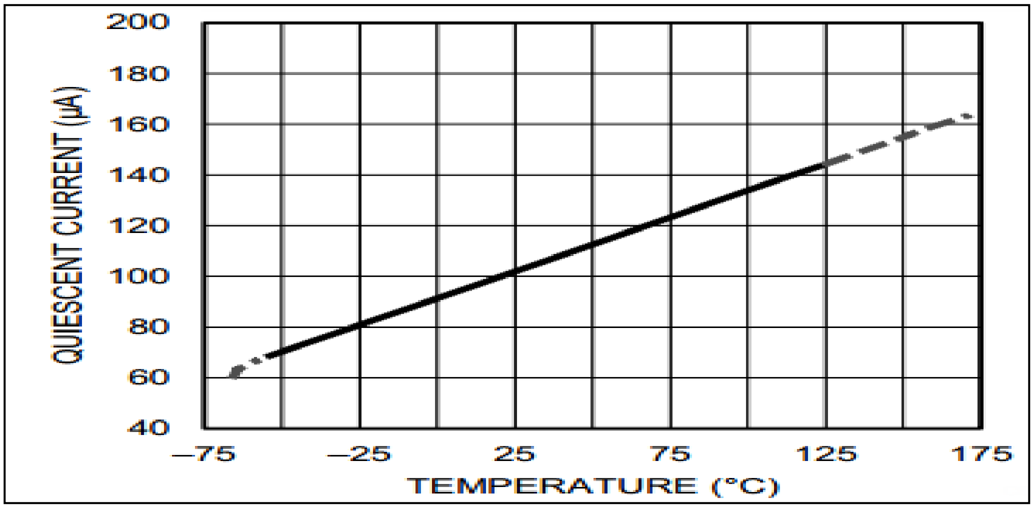
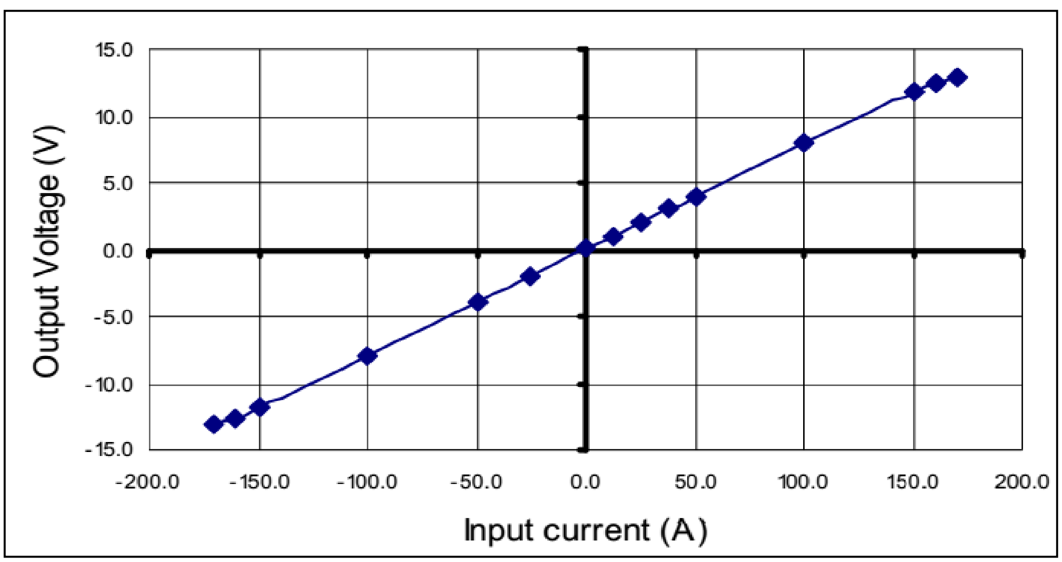
Appendix

Appendix 1 shows the Current Vs Temperature characteristic of LM35. The scaling factor of the temperature sensor is + 10-mV/°C.



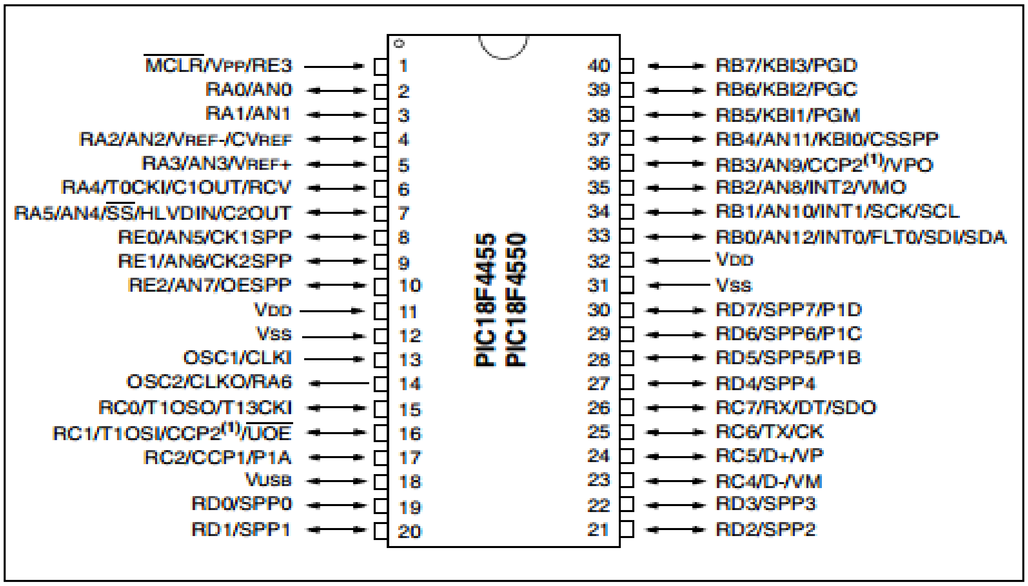
Appendix 1: Current Vs Temperature characteristic of LM35 [92]

Appendix 2 presents the saturation characteristic of current sensor L18P003D15, used for the current measurement of the house.



Appendix 2: Saturation characteristic of current sensor [93]

Appendix 3 shows the Pin configuration for PIC 18F4550, which have been used for the data logger design in this thesis.



Appendix 3: PIC18F4550 Pin configuration [94]

Appendix 4: Matlab code for calculating energy consumption per person in a year

```
Electricity=[1162168,591326000,570842000;1086754,469150000,617604000;113
3656,542145000,591511000;963552,425316000,538236000;842054,377009000,465
045000;697683,311575000,386108000;663721,323939000,339782000;700996,3834
33000,317563000;695747,409306000,286441000;817132,479284000,337848000;98
7361,535721000,451640000;1159872,640550000,519322000];


Naturalgas=[33400000;31500000;34500000;37200000;36300000;30400000;338000
00;33500000;30000000;29500000;30200000;34000000];

Refined_petroleum=[30500;800;871100;85500;301500;468200;199500;139400;12
000;10400;25600];
%cubic meter refined petroleum products of year 2011.
r1=Refined_petroleum*10693;

%data for figure 3
Propane = 10693*[30500 0]';
Aviation = 10693*[800 0]';
Motor = 10693*[871100 0]';
Turbo_Fuel = 10693*[85500 0]';
Stove_Oil = 10693*[301500 0]';
Diesel_oil = 10693*[468200 0]';
```

```
Light_Fuel = 10693*[199500 0]';
Heavy_Fuel = 10693*[139400 0]';
Asphalt = 10693*[12000 0]';
Lubre = 10693*[10400 0]';
Other_Fuel = 10693*[25600 0]';

figure(1)
x=1:12;
y=Electricity(:,1); %total available electricity to use(Mwh)
y1=Electricity(:,2); %Labrador & industrial sector consumption
y2=Electricity(:,3); %residential consumption in Newfoundland
y3=y*1000; %converting Mwh to Kwh
subplot(3,1,1), bar(x,y3,'r'),ylabel('Kwh'),title('Total available
electricity in NL'),subplot(3,1,2),
bar(x,y1),ylabel('Kwh'),title('Labrador & industrial sector
consumption'), subplot(3,1,3),bar(x,y2,'m'),xlabel('Month,
2011'),ylabel('Kwh'),title('residential consumption in
Newfoundland'),grid,pause

figure(2)
x=1:12;
z1=Naturalgas*10.365; %converting data to Kwh
bar(x,z1,'c'),xlabel('Month, 2011'),ylabel('10^6 Kwh'),title('Net
withdrawal of Natural gas'),grid,pause

figure(3)
bar([Propane Aviation Motor Turbo_Fuel Stove_Oil Diesel_oil Light_Fuel
Heavy_Fuel Asphalt Lubre Other_Fuel], 1.0);
xlabel('types of fuel');
ylabel('Kwh');
title('use of refined petroleum products');
legend('Propane', 'Aviation_Gasoline', 'Motor_Gasoline', 'Turbo_Fuel',
'Stove_Oil', 'Diesel_oil', 'Light_Fuel', 'Heavy_Fuel', 'Asphalt',
'Lubre', 'Other_Fuel');
pause;

figure(4)%wood & wood pallet consumption
a=2011;
b=14400000;
bar(a,b,'g'),xlabel('year, 2011'),ylabel('Kwh'),title('solid wood
consmption'),grid,pause

E=sum(y3);%Total electricity consumption of year 2011
N=sum(z1);%Total naturalgas consumption of year 2011
W=b;%wood use
RP=sum(r1);%Total refined petroleum products of a year;
holyrood_production=2423730070 %kWh
T=[E;N;W;RP];
figure(5)
Total=sum(T);%total energy consumption of year 2011 in NL
P=(Total-2423730070)/(525037*365);%per person per day consumption in a
year,2011,where NL population=525037
year=2011;
```

```
stem(year,P,'r*'),xlabel('year 2011'),ylabel('Kwh'),title('Total energy
consumption per person per day in year 2011 in NL'),grid
```

Appendix 5: Mikrobasic code for data logger design

```
program Final_Code
dim text,text1,textc1,textc2,textc3,textc4,emptyText as string[8]
dim J,J1,C10,C20,C30,C40 as word
dim T,value,value1,V,V0,V11,V1,C1,C2,C3,C4 as float
dim iv, mv, iout, mout, iin, min, ib, mb, iex, mex, ic, mc  as word


main:

PORTD=0
TRISD=0
PORTB=0
TRISB=0
ADCON0= 0x0B
ADCON1 = 0x09
ADCON2 = 0xAA
ADRESH = 0
ADRESL = 0
CMCON = 0x07
''LCD configuration''
LCD_Config(PORTD,3,2,1,0, PORTD,7,6,5)
Lcd_cmd(Lcd_Turn_On)

''SD card initilization''
Spi_Init_Advanced(MASTER_OSC_DIV64, DATA_SAMPLE_MIDDLE, CLK_IDLE_LOW,
LOW_2_HIGH)
if Mmc_Fat_Init(PORTC,2)=0 then
Spi_Init_Advanced(MASTER_OSC_DIV4, DATA_SAMPLE_MIDDLE, CLK_IDLE_LOW,
LOW_2_HIGH)
end if

iv = 0
iout = 0
iex = 0
iin = 0
ic = 0
ib = 0
while true

''Inside temp ''
J=ADC_Read(0)
value= J*0.0326 'convert voltage to Celsius =((J)/1023.0)*5*6.67+10;
                                                      30/4.5=6.67C/V
V=value+10                        'Adding offset
V1=V
floatToStr(V1,text1)
```

```
Lcd_Out(1,1,"IT:")
Lcd_Out(1,6,text1)
Lcd_chr(1,12,223)
Lcd_out(1,13,"C")

min = iin + 1
iin = min
Mmc_Fat_Assign("IT1TEMP.TXT", $A0)
if min >=6 then
Mmc_Fat_Append()
Mmc_Fat_Write(text1,5)
emptyText=" "
Mmc_Fat_Write(emptyText,1)
end if

''Outside temperature''
J1=ADC_Read(1)                  'Reading analog value from
AN1,A1;R2/R1=470/39
value1= J1*0.0048               'Converting to volt, 5/1023=.0048
V11=value1+1.26                 'Adding offset voltage
V0 = V11/0.062429               'Convert to Celsius range (4.37) V/70
C
Lcd_Out(2,1,"OT:")
   if J1<575 then
   T=V0-61
   Lcd_Out(2,4,"-")
   FloatToStr(T,text)
   Lcd_Out(2,6,text)
   else
   T= V0-60
   Lcd_Out(2,4,"+")
   FloatToStr(T,text)
   Lcd_Out(2,6,text)
   end if
Lcd_chr(2,12,223)
Lcd_out(2,13,"C")

mout = iout + 1
iout = mout
Mmc_Fat_Assign("OT2TEMP.TXT", $A0)
if iout >=6 then
Mmc_Fat_Append()
Mmc_Fat_Write(text,5)
emptyText=" "
Mmc_Fat_Write(emptyText,1)
end if

''Current sensor1''

C10=ADC_Read(2)                 'Reading analog value from AN2 ,A2
C1=C10*0.0054
FloatToStr(C1,textc1)
mex = iex + 1
iex = mex
```

```
Mmc_Fat_Assign("EXAMPLE.TXT", $A0)
if iex>=6 then
Mmc_Fat_Append()
Mmc_Fat_Write(textc1,5)
emptyText=" "
Mmc_Fat_Write(emptyText,1)
end if

''Current sensor2''
C20=ADC_Read(3)                    'Reading analog value from AN3 ,A3
C2=C20* 0.0054
floatToStr(C2,textc2)

mc = ic + 1
ic = mc
Mmc_Fat_Assign("CURENT1.TXT", $A0)
if ic>=6 then
Mmc_Fat_Append()
Mmc_Fat_Write(textc2,5)
emptyText=" "
Mmc_Fat_Write(emptyText,1)
end if

''Current sensor3''
C30=ADC_Read(4)                    'Reading analog value from ,AN4,A5
C3=C30* 0.0054
floatToStr(C3,textc3)

mb = ib + 1
ib = mb
Mmc_Fat_Assign("BULB60W.TXT", $A0)
if ib >= 6 then
Mmc_Fat_Append()
Mmc_Fat_Write(textc3,5)
emptyText=" "
Mmc_Fat_Write(emptyText,1)
end if

''Current sensor4''
   C40=ADC_Read(5)                 'Reading analog value from AN5,E0
   C4=C40* 0.0054
   floatToStr(C4,textc4)
mv = iv + 1
iv = mv

Mmc_Fat_Assign("VARIBL2.TXT", $A0)
if iv>=6 then
Mmc_Fat_Append()
Mmc_Fat_Write(textc4,5)
emptyText=" "
Mmc_Fat_Write(emptyText,1)
end if

delay_ms(2000)
```

```
wend
end.
```

Appendix 6: MATLAB code -Hourly consumption of each month for year 2012

```
Jan = xlsread('Jan.xlsx');
dayOfMOnth = 31;

for day=1:dayOfMOnth

    for hour=1:24,

        ha(hour,day)=mean(Jan(30*(24*(day-1)+(hour-1))+1:30*(24*(day-
1)+(hour-1))+30));

    end

end
barChart=[];
for totalHours = 1:24
avg = mean(ha(totalHours:totalHours,:));
barChart=[barChart;avg];

end
bar(barChart,'r')
xlabel('Hours of the day'),ylabel('Power consumed in kw'),title('Hourly
consumption for the month of January 2012'),grid

pause;

Feb = xlsread('Feb.xlsx');
dayOfMOnth = 29;

for day=1:dayOfMOnth

    for hour=1:24,

        ha(hour,day)=mean(Feb(30*(24*(day-1)+(hour-1))+1:30*(24*(day-
1)+(hour-1))+30));

    end

end
barChart=[];
for totalHours = 1:24
avg = mean(ha(totalHours:totalHours,:));
```

```
barChart=[barChart;avg];

end
bar(barChart,'r')
xlabel('Hours of the day'),ylabel('Power consumed in kw'),title('Hourly
consumption for the month of February 2012'),grid

pause;

Mar = xlsread('Mar.xlsx');
dayOfMOnth = 31;

for day=1:dayOfMOnth

    for hour=1:24,

        ha(hour,day)=mean(Mar(30*(24*(day-1)+(hour-1))+1:30*(24*(day-
1)+(hour-1))+30));

    end

end
barChart=[];
for totalHours = 1:24
avg = mean(ha(totalHours:totalHours,:));
barChart=[barChart;avg];

end
bar(barChart,'r')
xlabel('Hours of the day'),ylabel('Power consumed in kw'),title('Hourly
consumption for the month of March 2012'),grid

pause;

Apr = xlsread('Apr.xlsx');
dayOfMOnth = 30;

for day=1:dayOfMOnth

    for hour=1:24,

        ha(hour,day)=mean(Apr(30*(24*(day-1)+(hour-1))+1:30*(24*(day-
1)+(hour-1))+30));

    end

end
barChart=[];
for totalHours = 1:24
avg = mean(ha(totalHours:totalHours,:));
barChart=[barChart;avg];
```

```
end
bar(barChart,'r')
xlabel('Hours of the day'),ylabel('Power consumed in kw'),title('Hourly
consumption for the month of April 2012'),grid

pause;

May = xlsread('May.xlsx');
dayOfMOnth = 31;

for day=1:dayOfMOnth

    for hour=1:24,

        ha(hour,day)=mean(May(30*(24*(day-1)+(hour-1))+1:30*(24*(day-
1)+(hour-1))+30));

    end

end
barChart=[];
for totalHours = 1:24
avg = mean(ha(totalHours:totalHours,:));
barChart=[barChart;avg];

end
bar(barChart,'r')
xlabel('Hours of the day'),ylabel('Power consumed in kw'),title('Hourly
consumption for the month of May 2012'),grid

pause;

Jun = xlsread('June.xlsx');
dayOfMOnth = 30;

for day=1:dayOfMOnth

    for hour=1:24,

        ha(hour,day)=mean(Jun(30*(24*(day-1)+(hour-1))+1:30*(24*(day-
1)+(hour-1))+30));

    end

end
barChart=[];
for totalHours = 1:24
avg = mean(ha(totalHours:totalHours,:));
barChart=[barChart;avg];
```

```
end
bar(barChart,'r')
xlabel('Hours of the day'),ylabel('Power consumed in kw'),title('Hourly
consumption for the month of June 2012'),grid

pause;

Jul = xlsread('July.xlsx');
dayOfMOnth = 31;

for day=1:dayOfMOnth

    for hour=1:24,

        ha(hour,day)=mean(Jul(30*(24*(day-1)+(hour-1))+1:30*(24*(day-
1)+(hour-1))+30));

    end

end
barChart=[];
for totalHours = 1:24
avg = mean(ha(totalHours:totalHours,:));
barChart=[barChart;avg];

end
bar(barChart,'r')
xlabel('Hours of the day'),ylabel('Power consumed in kw'),title('Hourly
consumption for the month of July 2012'),grid

pause;

Aug = xlsread('Aug.xlsx');
dayOfMOnth = 31;

for day=1:dayOfMOnth

    for hour=1:24,

        ha(hour,day)=mean(Aug(30*(24*(day-1)+(hour-1))+1:30*(24*(day-
1)+(hour-1))+30));

    end

end
barChart=[];
for totalHours = 1:24
avg = mean(ha(totalHours:totalHours,:));
barChart=[barChart;avg];

end
bar(barChart,'r')
```

```
xlabel('Hours of the day'),ylabel('Power consumed in kw'),title('Hourly
consumption for the month of August 2012'),grid

pause;

Sep = xlsread('Sep.xlsx');
dayOfMOnth = 30;

for day=1:dayOfMOnth

    for hour=1:24,

        ha(hour,day)=mean(Sep(30*(24*(day-1)+(hour-1))+1:30*(24*(day-
1)+(hour-1))+30));

    end

end
barChart=[];
for totalHours = 1:24
avg = mean(ha(totalHours:totalHours,:));
barChart=[barChart;avg];

end
bar(barChart,'r')
xlabel('Hours of the day'),ylabel('Power consumed in kw'),title('Hourly
consumption for the month of September 2012'),grid

pause;

Oct = xlsread('Oct.xlsx');
dayOfMOnth = 31;

for day=1:dayOfMOnth

    for hour=1:24,

        ha(hour,day)=mean(Oct(30*(24*(day-1)+(hour-1))+1:30*(24*(day-
1)+(hour-1))+30));

    end

end
barChart=[];
for totalHours = 1:24
avg = mean(ha(totalHours:totalHours,:));
barChart=[barChart;avg];

end
bar(barChart,'r')
xlabel('Hours of the day'),ylabel('Power consumed in kw'),title('Hourly
consumption for the month of October 2012'),grid
```

```
pause;

Nov = xlsread('Nov.xlsx');
dayOfMOnth = 30;

for day=1:dayOfMOnth

    for hour=1:24,

        ha(hour,day)=mean(Nov(30*(24*(day-1)+(hour-1))+1:30*(24*(day-
1)+(hour-1))+30));

    end

end
barChart=[];
for totalHours = 1:24
avg = mean(ha(totalHours:totalHours,:));
barChart=[barChart;avg];

end
bar(barChart,'r')
xlabel('Hours of the day'),ylabel('Power consumed in kw'),title('Hourly
consumption for the month of November 2012'),grid

pause;

Dec = xlsread('Dec.xlsx');
dayOfMOnth = 31;

for day=1:dayOfMOnth

    for hour=1:24,

        ha(hour,day)=mean(Dec(30*(24*(day-1)+(hour-1))+1:30*(24*(day-
1)+(hour-1))+30));

    end

end
barChart=[];
for totalHours = 1:24
avg = mean(ha(totalHours:totalHours,:));
barChart=[barChart;avg];

end
bar(barChart,'r')
xlabel('Hours of the day'),ylabel('Power consumed in kw'),title('Hourly
consumption for the month of December 2012'),grid
pause;
```