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Energy Efficiency of the HVAC System of a Power Plant

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ENERGY EFFICIENCY OF THE HVAC SYSTEM OF A POWER PLANT

by

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Approved by:

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This study models the HVAC system of a power plant. It involved Computer simulations to study the energy demand by the HVAC system of the power plant as well as the energy demand of the system with modifications on the plant such as the building materials, use of energy efficient lighting, etc. Further studies on the energy demand of the system with the power plant located at different regions of the country were done to understand the effects of climate and locations. It is important to have an understanding of how a plant generating energy uses it for Heating, Ventilating and Air conditioning within the power plant building itself. This study has provided a better understanding of the energy use and how the HVAC system use in the offices and other areas located in the power plant building operates. The study included implementation of energy efficient measures in the choice of building materials for the building. The U.S. Department of Energy (DOE) EnergyPlus program was used to model the HVAC system of the power plant making use of the parameters and modified parameters of the power plant. The results of this study show that the energy demand of the HVAC system of a power plant is significantly affected by the choice of materials for the building. It was found that there is a reduction in the power demand of the HVAC system of the plant by about an average of about 21.7 % at the different the locations. It was also found that this

resulted in the amount of energy saved per year of about 87,600 kWh. This gives an average cost savings per year of about $10,512.

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CHAPTER 1

INTRODUCTION

1.1: OVERVIEW

Energy efficiency is a way or an approach utilized for achieving maximum output with minimum resources and expenses. It has become an optimum goal in use for production and consumption of goods and services and when dealing with power plants. It is essential to understand the goal of energy efficiency especially in connection with the limited amount of resources at our disposal for producing energy alongside with the environmental effects. A number of researches have been carried out to improve the efficiency of power plants and their components. This present research seeks to model the HVAC system of a power plant. Computer simulations were performed to study the energy demand by the HVAC system of the plant. Simulations were also performed to study the energy demand of the HVAC system of the power plant with certain modifications on the plant such as the building materials, use of energy efficient lighting, etc. Further study of the energy demand of the HVAC system was performed with the plant located at different regions of the country to understand the effects of climate and locations on power plants. Relevant conclusions on the energy demand of the HVAC of power plants were made based on the results of the study.

1.2: IMPORTANCE

This research project is beneficial to the power plant industry for the utilization of energy for the HVAC within the power plant building. It also creates an understanding of how a power plant generating energy uses it for Heating, Ventilating and Air conditioning within the power plant building. It is important for implementing energy efficiency measures in the building and helps towards a better understanding of the energy use and how the HVAC system of the offices and other areas located in the power plant building operate, considering the amount of thermal energy being generated, design and implementation of the energy efficient measures. It is important considering that it is of utmost importance for engineers to attain the highest reasonable technical efficiency with the lowest cost.

1.3: OBJECTIVES

The objectives of this study are:

A. To model the HVAC system of a power plant using the DOE EnergyPlus program.

B. To perform computer simulations to study the energy demand by the HVAC system of the power plant building.

C. To perform computer simulations to study the energy demand of the HVAC system of the power plant building with certain modifications such as the building materials, the used of energy efficient lights etc.

D. To study the energy demand of the HVAC system of the power plant with the plant building located at different regions of the country.

E. To make relevant conclusions based on the results of the study.

CHAPTER 2

2.1: LITERATURE REVIEW

A few numbers of researches has been performed on the energy efficiency of the power plant. These include Annunziata, et al. [1] relating the different factors such as policies that can influence the improvement of energy efficiency in public buildings at municipal level as components of energy efficiency governance. This study was done using statistical analysis of factors that influence the efficiency of public buildings. The results showed that energy efficiency can be attained if certain things can be done. These include the importance of internal competence, managing the use of internal resources, energy audit and decision making process and perils of perception (i.e. municipal adopting cheaper and less complex energy efficiency measures in their buildings) existed. Won et al. [2] carried out an investigation on the location of heating, ventilating and air conditioning (HVAC) offshore substation for a wind power plant using submarine cable cost model in order to minimize cost. The study was done by the variation in medium voltage (MV) inter-array cable and high voltage (HV) export cable lengths to analyze the effect on the total cost of the submarine cable. The study was able to prove that the total cost in relation to the variation in lengths of the MV inter-array cable and HV export cable to the location of the offshore substation for the HVAC wind Power plant can be minimized and also improve energy efficiency. Yangling et al. [3] studied the power plant efficiency at consumer side to enable the implementation of sustainable development in electric power sector. The study was done by analyzing and establishing electricity-saving potential optimization model to calculate the efficiency of power plant's electricity-saving potential in the saved electricity quantity, peak load shifting and other combined measures. The study found that the power potential optimization was solved using improved the particle swarm optimization (PSO) algorithm. Validity verification of the model to maximize electricity-saving potential was done using example analysis. Kiameh [4] discussed and concluded that the actual thermal efficiency of power plants is less than that of earlier studies. This is as a result of the different auxiliaries used in power plants as well as the irreversibility pertaining to them which were not put into account in those studies. He carried out this study by implementing reheat to improve the efficiency of the power plant using two stages for the reheat. The results showed that the gross efficiency is derived making use of the gross power (MW) of the turbine generator (i.e. power produced before distribution from internal equipment like the pump, compressor, etc. of power plants). Furthermore, the net efficiency is drawn from the net power of the plant which is simply the power input for the internal equipment of the plant subtracted from the gross power.

Lakovic et al. [5] reviewed the influence of cooling water temperature together with the flow rate on the condenser performance, on the output, heat rate and energy efficiency of the power plant. The study was performed by the avoidance of air leakage into the system and constant air removal to avert any accumulation of non-condensing gas that can lead to increased thermal resistance on the shell side and overall heat transfer coefficient of the tubes. This was done to avoid the rise in pressure which would lead to reduction in the efficiency of the plant. The results verified that the energy efficiency for the reference plant is given as a function of the change in condensing pressure. Additionally, it was concluded that when increased temperature of the cooling water temperature cannot be avoided in the summer, to maximize its use, it is essential to increase the cooling water flow rate to maintain the same heat transfer rate at higher vacuum in the condenser thereby increasing the efficiency of the plant.

Li and Cheng-wei [6], studied the relationship between the boiler thermal efficiency and coefficient of excess air. The methodology used a simplified calculation formula. Results proved that using the different methods in solving the same optimal problem will lead to obtaining optimal excess air coefficients. Also, it was found that to save time spent in calculating the coefficients of the mixed coal, it can be derived from the simplified calculation formula. Ahmed et al. [7] worked on how the efficiency of a steam power plant can be enhanced by integrating solar energy to increase the temperature of the feed water entering the boiler of the steam power plant. This research was carried out by integrating sunlight into the feed water before it enters into the boiler of the steam power plant. Furthermore, it was demonstrated that performance can be enhanced by using sun tracking mirror. The integration of sunlight into the feed water minimizes the cost as well as gas emission that is harmful to the environment. The overall fuel consumption is decreased while efficiency of the power plant is increased. Although the study indicates that the initial cost of implementing this method might be high, it indicated also that in the long run, with increased efficiency, profit is gained.

Stevanovic et al. [8], studied how addition of a high pressure economizer will increase the efficiency and power of an aged 620 MWe lignite-fired power plant.

Installation of an additional high pressure economizer in parallel connection was the first section of the originally built economizer. The results indicated an increase in gross efficiency of 0.53 percentage points and also a 9.4 MWe of electric power production. There was also an increase in the plant electric power of up to 24.5 MWe and decrease in pressure drop in the feed water line and economizers, leading to reduced energy consumption for the main feed water pump operation thereby making the plant more energy efficient.

Moyer and Mathias [9] studied how to reduce energy use and how energy efficiency can be accomplished in the plant by referencing a large tire manufacturing plant located in the Midwest of the United States operating 24 hours per day, 365 days per year and producing a total of about 32000 commercial and passenger tires per day. The study was done based on which energy-saving technology (i.e. use of cogeneration, a pressure-reduction turbine (PRT) and the use of variable-frequency drives (VFD) would be appropriate for the manufacturing plant. The use of cogeneration anticipated a significant cost saving but was a huge change that required the major infrastructural change and downtime of the facility. Wolowicz, at al [10], analyzed how the efficiency of an 800 MW class plant can be increased by lowering the temperature heat of flue gases. The 800 MW- class power units was made to operate in off-design conditions and supplied with steam from a BB-2400 boiler. Also the use of commercially available software and Stodola equation and stress corrosion cracking (SCC) method, the most appropriate position for the installation of the low temperature heat exchanger was determined. The results showed that after all the modification on the system is done, heat and electricity generation could be increased by adding low-temperature heat exchanger thereby increasing the energy efficiency of the system.

Kotowicz and Michalski [11] studied why the net efficiency of a supercritical power plant was lower than the reference efficiency by 9-10.5 percentage points and how this loss can be minimized. It was done using a hard-coal-fired supercritical power plant with four-end high-temperature membrane for air separation. The net efficiency was calculated as a function of the oxygen recovery rate. Results showed an increase in the gross electric power by up to 50.5 MW. This implies that the net efficiency of a power plant can be improved to 5.5 percentage points less than the reference efficiency. Kotowicz and Balicki [12] did another study on improving the efficiency of a lignite-fired oxyfuel power plant. It was done by using circulating fluidized bed boiler and membrane-based air separation unit. The results showed that lignite with drying intensity of 20% reduced the loss of net efficiency to 3.9 percentage points whereas with a drying intensity of 10% it gave a 3.3 percentage point reduction in energy efficiency loss for the system. Not only does the increase in drying intensity of the lignite increase the system efficiency it reduces the required membrane surface. The study also found that installation of a steam turbine can increase the efficiency by about 0.4 percentage point and increase in turbine power.

Kanoglu et al. [13] studied a number of energy and exergy based efficiencies used in power plants and discussed the implications associated with each definition. This was done by looking into the energy analysis and exergy analysis of which exergy identifies the real losses, their causes and location in the power plant. Overall the study concluded that an understanding of both energy and exergy efficiencies is essential for designing, analyzing, optimizing and improving energy system through appropriate energy policies and strategies. Mehmet and Ege [14] performed a chemical exergy analysis on Afsin-Elbistan and how it affects the exergy efficiency of a thermal power plant. This was done using the chemical exergy analysis method on designed lignite to observe the results on the exergy efficiency at various rates of power. It was shown that efficiencies between 2.08 percent and 4.29 percent from the average value of the methods used, implied the existence of an array of exergy efficiency.

This present research on the energy efficiency of the power plant involves modeling the HVAC system of the plant building using the DOE EnergyPlus program. It is a study that analyzed the energy demand by the HVAC system of the power plant at different locations and how the energy demand of the system can be minimized while increasing the energy efficiency of the plant. Additionally, in minimizing the energy demand of the system, different energy savings methodology were incorporated which include, change in the building materials, source of energy, energy saving practices etc.

CHAPTER 3

3.1: INTRODUCTION TO POWER PLANTS

A power plant can be referred to as a power generating station, power station or power house. It is an industrial location utilized for the generation and distribution of electric power usually in the order of several 1000 Watts [16]. Nevertheless there are different kinds of power plants some of which include steam power plant, coal power plant, nuclear power plant, thermal power plant, hydro power plant and so many others. They are dependent on the kind of fuel being used to generate the electricity. Additionally, offices, control room, locker rooms, toilets etc. could be located within the power plant building. The HVAC system has to be accounted for properly, considering the amount of heat being generated within the building.

There are also, other types of power plants some of which are geothermal power plant, wind power plant, solar power plant, natural gas power plant and the combination power plant. The different types of power plants work in a similar way whereby water is converted to steam to drive the turbine to generate electricity. The coal power plant as the name suggests, is a coal driven power plant. It entails the turning of water into steam by means of the coal, which in turn drives turbine generators to produce electricity [17]. It is a process whereby heat is created by the burning of coal, which is pulverized to the fineness of talcum powder before it is burned. The pulverized coal is mixed with hot air and blown into the firebox of the boiler which produces the maximum heat possible. Purified water is passed through the boiler which is then converted to steam by the heat generated by the combustion of coal and then piped to the turbine. The temperature and pressure reached at this point is about 1000 degrees Fahrenheit and 3500 pounds per square inch. With the amount of pressure possessed by the steam, enough force is exerted to turn the blades of the turbine turning the shaft. The turbine shaft is connected to the shaft of the generator**,** where magnets spin within wire coils to produce electricity. The steam turns back to water and is used again in the cycle. Figure 3.1 shows the flow of the coal power plant. In the figure coal in the form of talcum powder is burned, mixed with hot air and blown into the firebox of the boiler. This generates maximum possible heat in its most combustible state. This heat converts the purified water passed through pipes in the boiler to steam. This steam turns the turbine shaft which is connected to the generator shaft which converts the mechanical energy of the shaft to electricity.

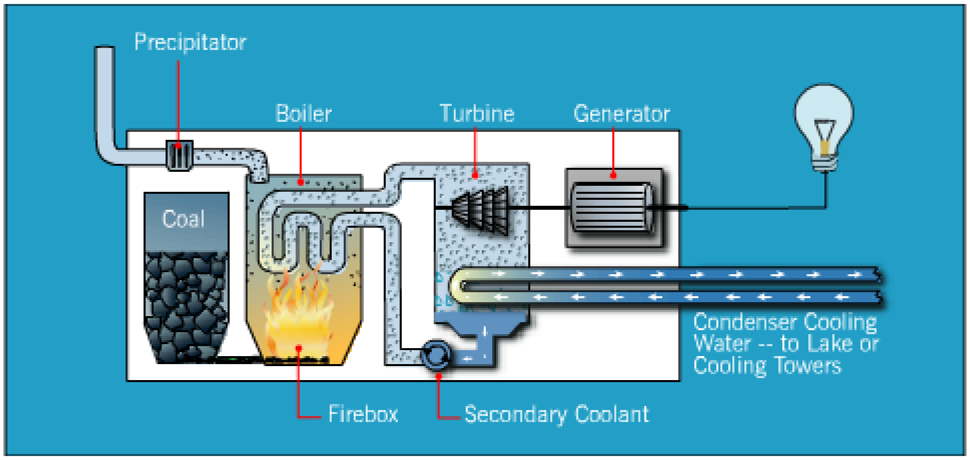

Figure 3.1: Coal power plant [17].

Nuclear power plant involves the creation of heat when uranium atoms split (also known as fission). There is no combustion involved in the process. Water is heated to steam and piped to the turbine to generate electricity. There are two types of nuclear reactors; pressurized water reactor (PWRs) and boiling water reactor (BWRs). The difference in the two is that the water in PWRs is kept under pressure to be heated to steam rather than boil whereas in BWRs the water is boiled to steam. Figure 3.2 shows a typical pressurized water reactor nuclear power plant. In Figure 3.2, pressurized water reactors (also known as PWRs) which are found in the containment structure keep water under pressure so that it heats, but does not boil. This heated water is circulated through tubes in steam generators, allowing steam to be generated. This steam turns the turbine and the generator to produce electricity. Any condensed water in the condenser is reused by the power plant and the rest is allowed to flow to a lake or other water bodies.

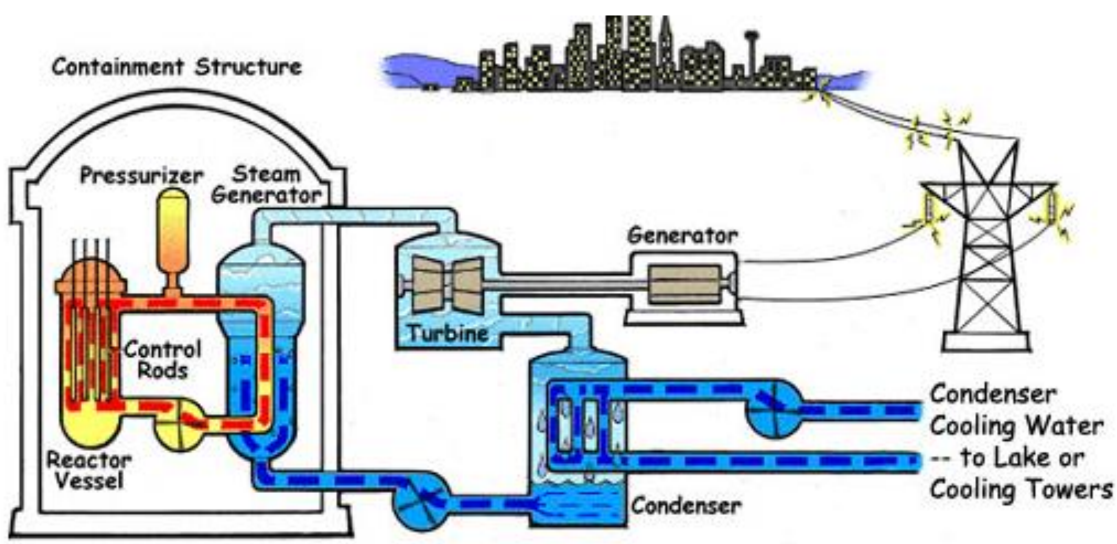

Figure 3.2: Nuclear Power Plant [18].

The solar power plant comprises of solar collectors that capture and concentrate sunlight to heat synthetic oil called therminol, which heats water to create steam. The steam is piped to an onsite turbine-generator to produce electricity [18]. Figure 3.3 shows the solar power plant. It shows a pictorial description of how the solar collector captures direct sunlight and used to heat a liquid to steam which turns the turbine and the generator to produce electricity.

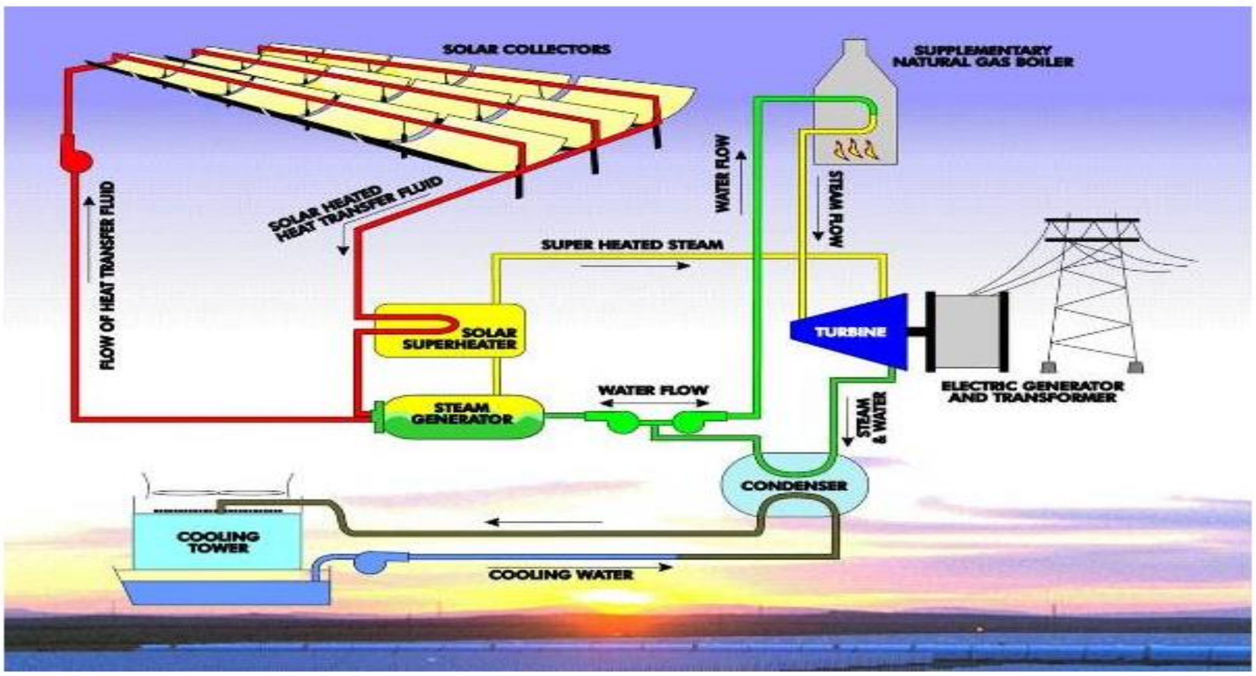

Figure 3.3: Solar Power Plant [19].

Geothermal means heat from the earth (i.e. geo meaning earth and thermal as heat). Geothermal power plant involves the heat from the earth. Energy in this situation is accessed by drilling water or steam wells in a process similar to drilling for oil [19]. Similar to other power plants, when the steam is generated, it is piped to the turbine which powers the generator to produce electricity. The difference from other power plants is that the heat used to produce steam is from the earth. Figure 3.4 is a simplified demo of the geothermal power plant. It shows a production well drilled into a geothermal reservoir. Hot geothermal fluids flow from this production well through pipes to the power plant where the turbine and generators are located to generate electricity. An injection well is equally drilled to return the geothermal fluid to the reservoir.

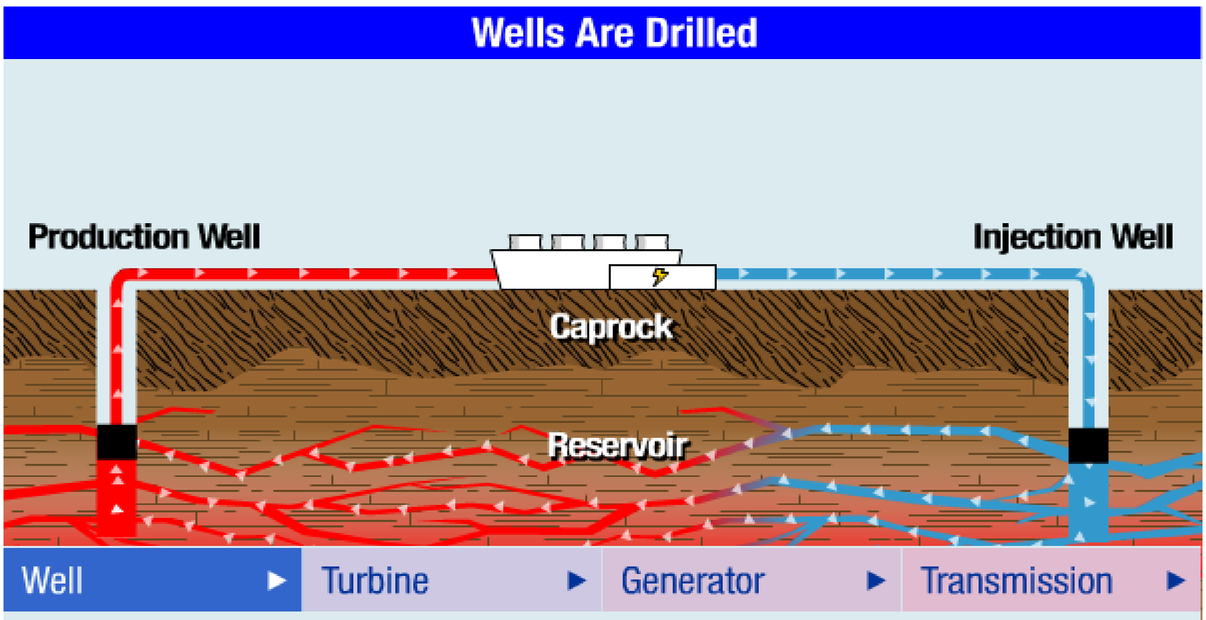

Figure 3.4: Geothermal Power Plant [20]

There are other types of power plants but the concept of power production is the same (i.e. steam is produced and used to turn the blades of the turbine and then the generator which produces electricity). The choice of power plants is dependent on the location, the available fuel for the production of energy, the cost and the overall energy efficiency of the plant.

For this research the power plant studied, is a combination of steam and coal power plant (i.e. the fuel being used is steam and coal but more of coal). The plant consumes approximately 50,000 tons of 2x0 coal and 10,000 tons of Stoker coal per year. Also, the plant produces a maximum of 3.14 megawatts of energy which is said to save the university (Southern Illinois University Carbondale), 1.4 Million dollars per year in deferred electrical cost. In the process of this research other forms of fuel such as natural gas as provided by the EnergyPlus program were used to analyze alternate energy and energy savings. This would be discussed in more details in chapter 6.

CHAPTER 4

BUILDING DESCRIPTION, WEATHER AND INTRODUCTION TO ENERGYPLUS PROGRAM

4.1: BUILDING DESCRIPTION

The sizes of power plants vary from location to location as well as how much power output that is generated. The power plant used for this research is located in Carbondale, Illinois on the campus at of Southern Illinois University (SIU). The SIU power plant was built in1995 and commissioned in the spring of 1997. The location is oriented 30 degrees from the North. It has four floors with certain parts of the building designated for the boilers, chillers, and furnace. The first floor mostly has the office, rest rooms and a control room with a total area of 22,532 square meters. These are shown on the first floor building plan shown in Figure 4.1. As shown

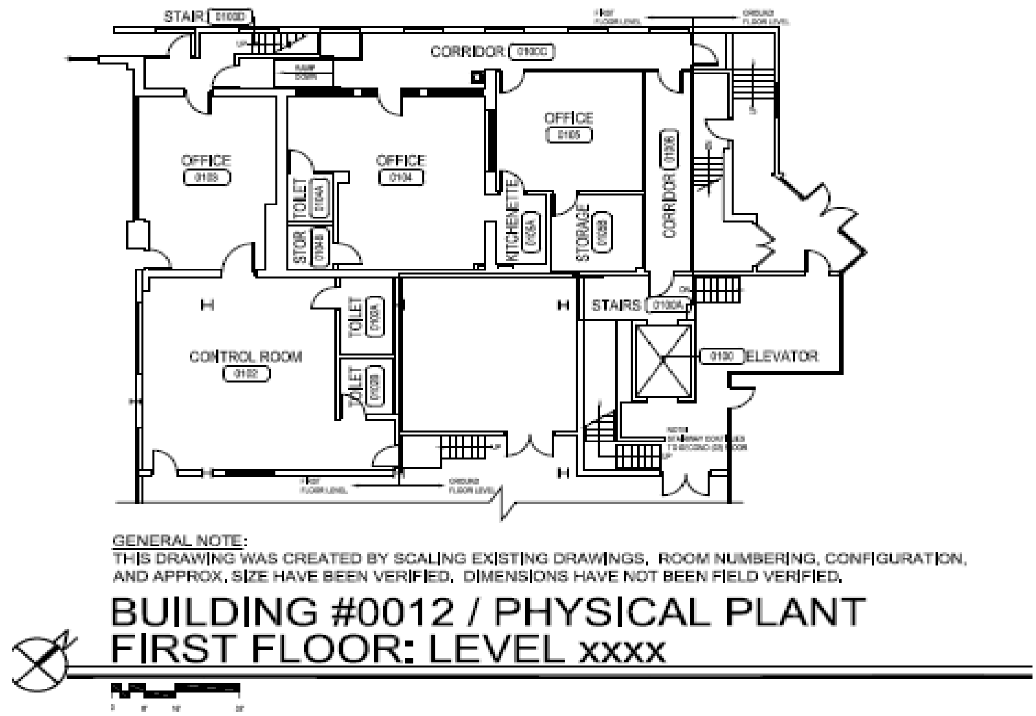

Figure 4.1: First Floor Building Plan

in the figure, there are three offices and a control room. The control room is where all the activities within the power plant are monitored.

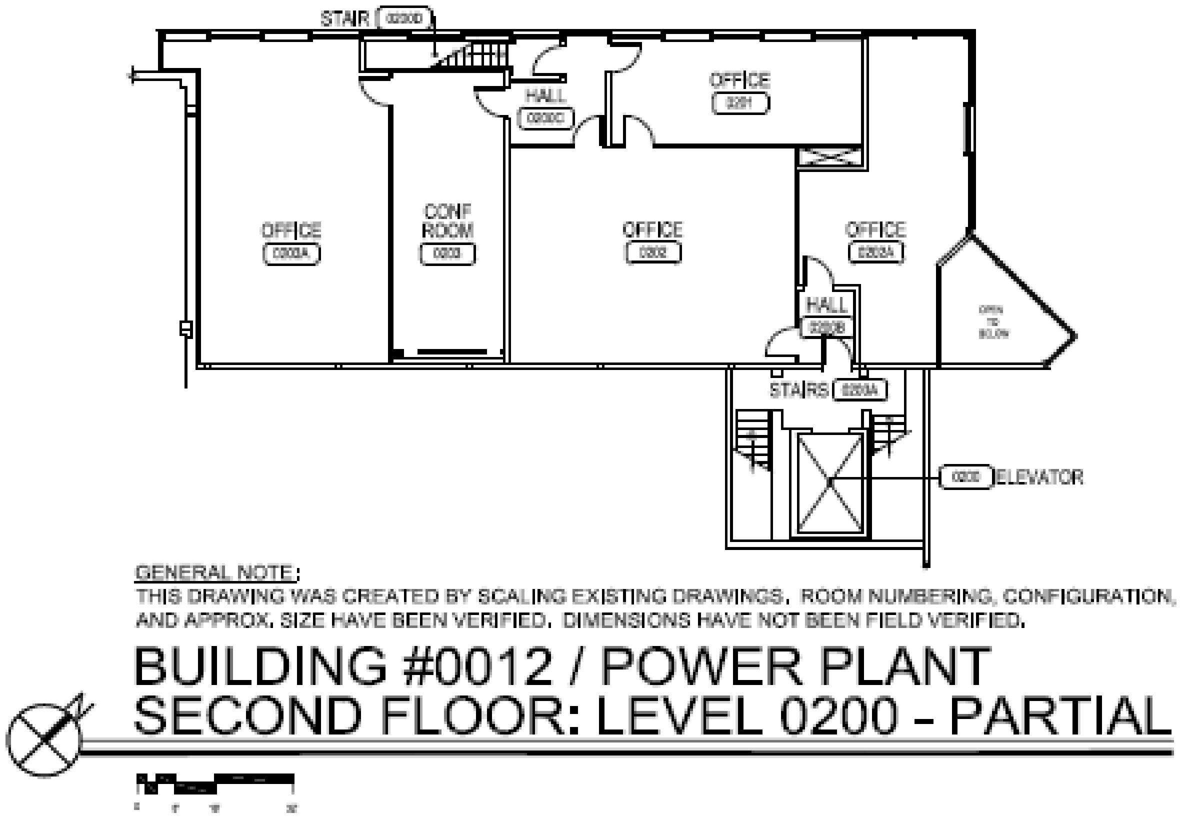

Figure 4.2: Second Floor Building Plan

The second floor is about 12,553 square meters with four offices and a conference room as shown in Figure 4.2. It has the same number of rooms those located on the first floor. The third floor which has a floor space of about 6,343 square meters comprises of the electrical room, and the men's and women's locker and a break rooms are shown in Figure 4.3.

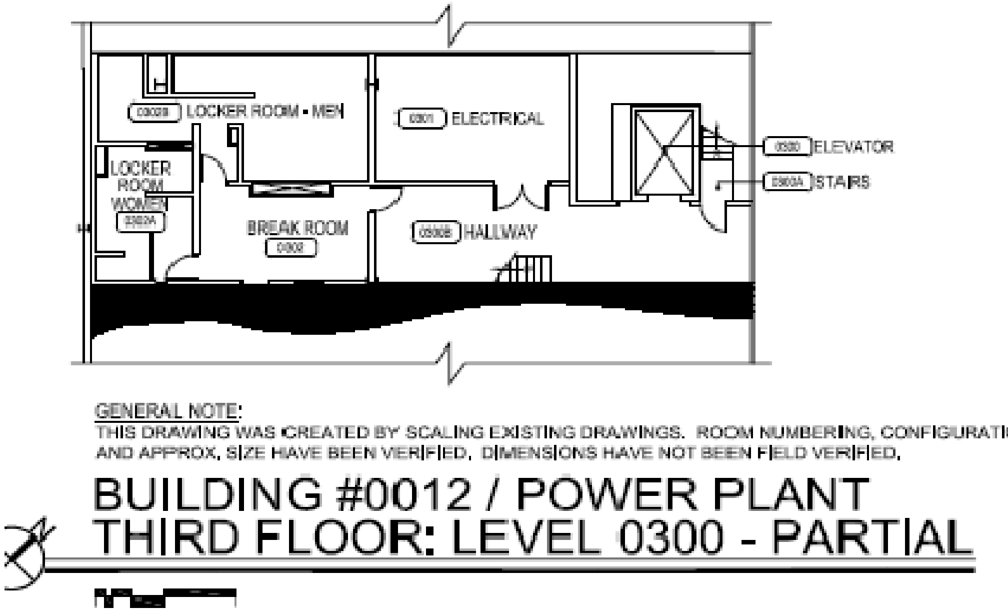

Figure 4.3: Third Floor Building Plan

The fourth floor is about the 7461 square meters in area. It basically has a conference room and a mechanical room. The floor plan is illustrated in Figure 4.4.

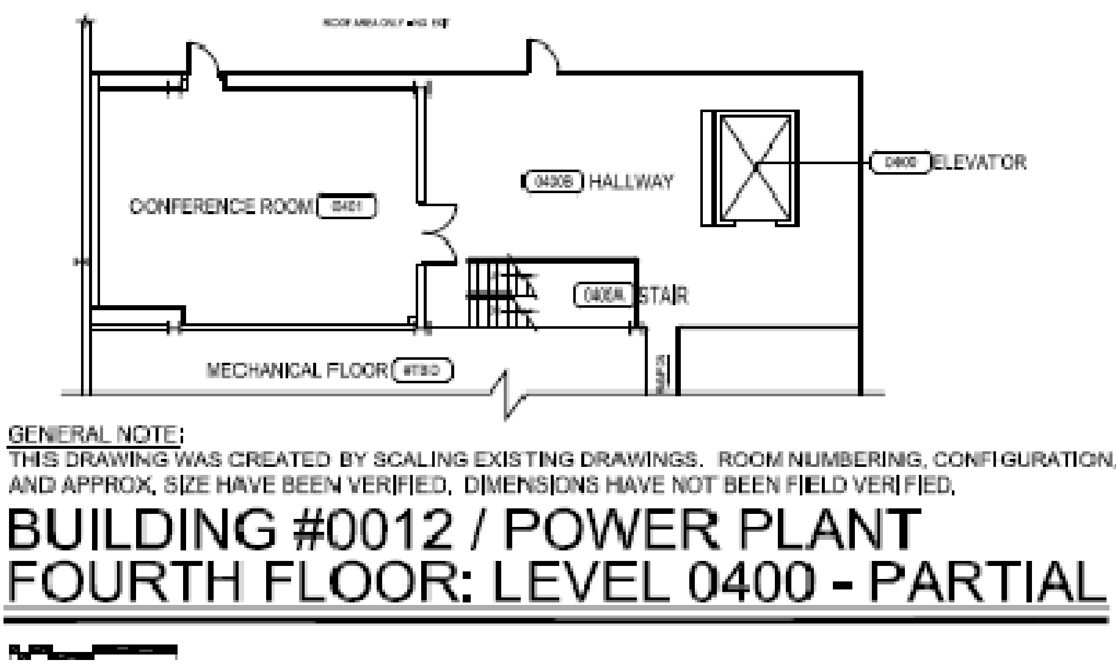

Figure 4.4: Fourth Floor Building Plan

Each floor has an access to the plant. The plant has an elevator as well as a stair way access. The windows in this building are located on the first and second floors.

This plant can produce a maximum of 3.14 megawatts for 70 buildings on campus and runs for 24 hours a day and 365 days a year. It makes use of 50,000 tons of 2x0 coal and 10,000 tons of stoker coal per year. For a typical summer day reading for the power plant, the hot water supply set point is 120 degrees Fahrenheit. The air handling unit chilled water entering temperature is approximately 49 degrees Fahrenheit. The chiller entering and leaving temperatures are 53 and 46 degrees for an outdoor air temperature of 86 degrees Fahrenheit. The occupied cool and occupied heat set points for the rooms are 72 and 69 degrees Fahrenheit respectively. As part of the energy saving measures, the plant control has sensors that meet the HVAC system of a room when it is occupied and unoccupied with relation to the outdoor weather conditions. This plant saves the university about 1.4 million dollars per year of deferred electricity.

4.2: WEATHER DESCRIPTION

Carbondale IL, the location of the plant, is a city in the Southern of Illinois area of United States of America at about {N 37° 46'} {W 89° 15'} in the central time zone. It has an elevation above sea level of 128 m and a standard pressure of 99,797 Pa. Weather files for the design Conditions were obtained from the DOE EnergyPlus program used. The weather design condition is based on a period of record, usually 30 years on a location and usually suitable for use in heating /cooling load calculations. The weather files vary, depending on the different locations that were used for the study (i.e. Miami, Seattle, New York and Los Angeles).

Miami is a city located on the Atlantic coast in Southeastern Florida in the United States of America at about {N 25° 46'} {W 80° 12'} with a time zone GMT -5.0 Hours. It has an elevation above sea level of 4 m and a standard atmospheric pressure of 101,277 Pa. Weather files for the design conditions were also obtained from the DOE EnergyPlus program used in the study. Miami was selected to represent the weather conditions in the South East region of the country while Seattle was chosen to represent the North West region. Seattle is a coastal seaport city located in Washington state of the United States of America at about {N 47° 36'} {W 122° 19'} with a time zone of GMT -8.0 Hours. It has an elevation above sea level of 20 m and a standard atmospheric pressure of 101 kPa. The city of New York is a city in the center of metropolitan area of the state of New York. It was used to represent the North east region of the country for this study. It is at about {N 40° 42'} {W 74° 00'} with a time zone GMT -5.0 Hours. It has an elevation above sea level of 5 m and a standard atmospheric pressure of 101 kPa. Los Angeles also known as LA is city located in the southern region of the state of California. For this research, LA was chosen to represent of the South west region. It has a coordinate of about {N 34° 03'} {W 118° 15'} with a time zone GMT -8.0 Hours. It has an elevation above sea level of 32 m and a standard atmospheric pressure of 100,491 Pa.

4.3: INTRODUCTION TO ENERGYPLUS PROGRAM

EnergyPlus is an energy analysis and thermal load simulation program [15], which was developed by the U.S. department of energy. It combines features and capabilities from older programs, BLAST and DOE-2 alongside with some new capabilities. It is a user friendly program in the sense that it can read inputs and write outputs in text files. Also, it can give specific errors which might have occurred during the simulation run.

EnergyPlus has a number of capabilities which includes: integrated solution in the sense that the building response, primary and secondary systems are intertwined. With EnergyPlus it is possible to get accurate results based on the time steps (i.e. monthly, weekly, hourly and so on). Additionally, it has the capability of calculating atmospheric pollution, heat and mass transfer, daylight controls and many other features to enable energy and thermal analysis.

In this research, the program was used to analyze the energy demand by the HVAC system of the power plant. Simulations were also performed to study the energy demand with various modifications on the power plant as well as with the plant located at different regions of the country.

CHAPTER 5

5.1. PROCEDURES

The very first step taken to begin this research was to gather the necessary data about the SIU power plant building which included the building plan, location details (i.e. latitude, longitude etc.), run time and so on. After this, the building floor plans were drafted using AutoCAD to enable the assignment of x, y and z coordinates of each point, wall, door, window, floor, ceiling and roof of the building. Figure 5.1shows the AutoCAD floor plans.

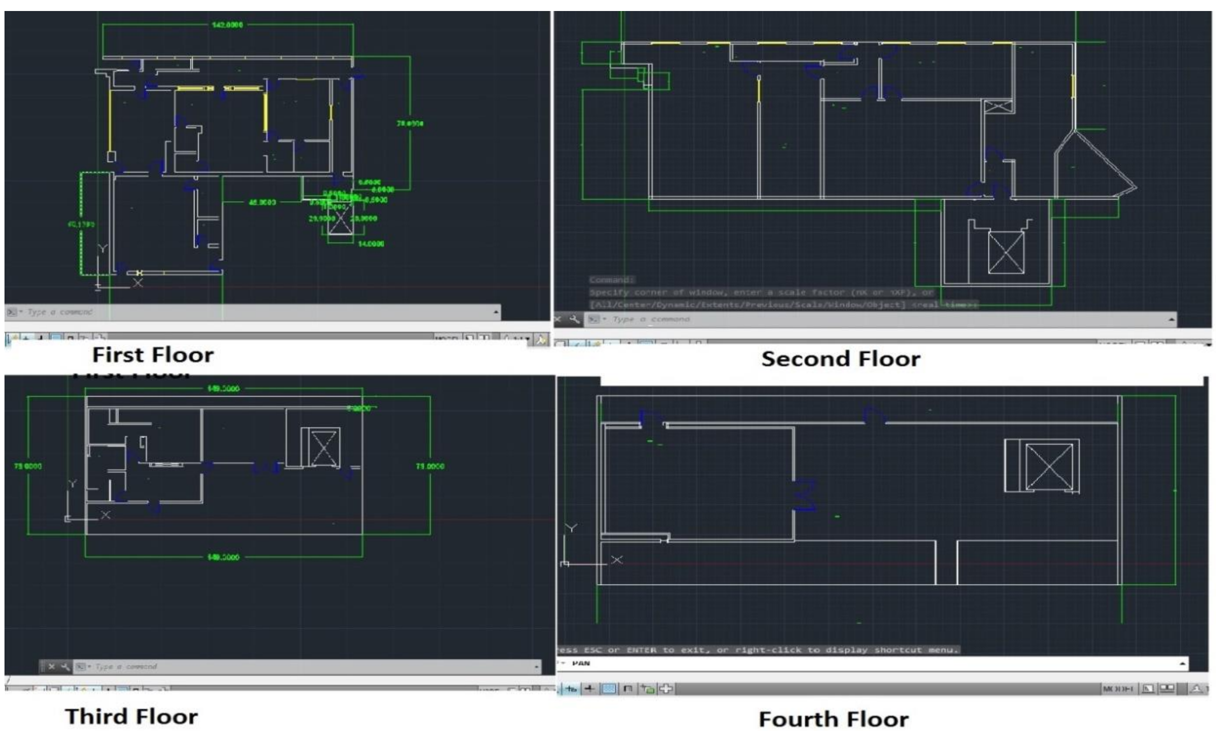

Figure 5.1: Floor Plans AutoCAD drawings

The reason behind the coordinate assignments is to be able to implement these coordinates in the EnergyPlus program. This is shown in Figure 5.2 (the EnergyPlus interpretation of the coordinates in the building plan). This figure is the EnergyPlus interpretation of the coordinates and the different colors of line represent such as walls, doors, floors, ceiling, roof and windows.

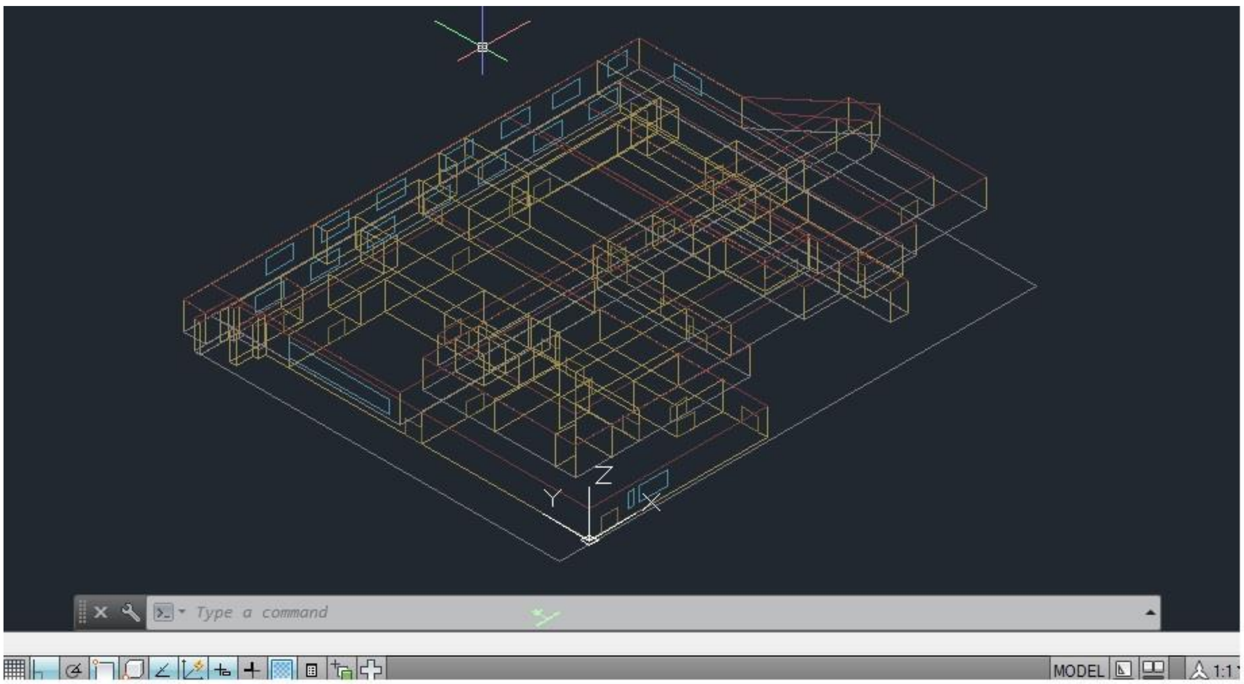

Figure 5.2: Output EnergyPlus Building Plan

Additionally, weather files for all involved location were downloaded from the department of energy website. Incorporating the building materials used which included doors, floor, walls, windows, people, light types etc. Computer simulation studies were performed for the original location (Carbondale), and similarly for the other four locations (Miami, Seattle, New York and Los Angeles). These locations were picked as a typical representation of the different regions in the United States (i.e. southeast, northwest, northeast and southwest represented by Miami, Seattle, New York and Los Angeles respectively). Miami and Los Angeles have very similar temperatures, mostly warm all year whereas Carbondale (representing the Mid-West region) and New York have colder temperature with the exception of the warm temperatures in the summer. In order to perform the computer simulation studies, the weather files, building materials, orientation and plans were converted to readable EnergyPlus program files. Hence output files which show the total energy of the building, windows and doors heat gain, outdoor wet bulb and dry bulb temperatures etc. are generated from the run. Data, such as total energy from different sources of energy, heat gain from the windows, radiative and convective heat gains were collected from the output files for use to analyze the energy demand of the power plant. Detailed discussions on the results of these simulations are given in Chapter 6. Results were documented and used to execute computer simulations. This execution entailed changes in building materials and fuel being used. At the end, the two sets of results from the computer simulations were compared and analyzed based on the energy consumption in different criteria. Thereafter, relevant conclusions were drawn based on the analysis. Also suggestions and assumptions were made based on best practiced energy efficient measures which could not be implemented using the EnergyPlus program.

5.2. TASKS

The tasks completed during this research can be summarized to include:

A. Determination of power plant building orientation, location and run time of the power plant.
B. Collection of weather condition files for Carbondale, Los Angeles, Miami, New York and Seattle.
C. Design of the power plant building from original power plant building and incorporating into the EnergyPlus Program using coordinates.
D. Windows, doors, walls, floors, ceiling and roofs specifications accounting in EnergyPlus program for adequate heat gains and losses.
E. Computer simulations on the power plant in its present location (Carbondale).
F. Further simulations on the power plant with locations at different regions of the country (i.e. Miami, Seattle, New York and Los Angeles representing South-East, North-West, North-East and South-West respectively).
G. Computer simulations on the plant in its present location.
H. Computer simulations with location in Carbondale and then modifications for improved energy consumption.
I. Computer simulations with best energy consumption situation and the location of the plant at the different parts of the country.
J. Analysis of the results and obtaining the relevant conclusions.

CHAPTER 6

RESULTS AND DISCUSSION

6.1. INTRODUCTION

The main objective of this project is to model the HVAC system of a power plant. Computer simulations were performed to study the HVAC system of the plant as located. Further simulations were performed to study the energy demand of the HVAC system of the plant but with locations at different regions of the country. Simulations were also performed to study the HVAC system of the plant but with modified building materials. The results of the studies and discussion of the results are presented in this chapter.

Some of the computer simulations carried out entailed the use of dry bulb temperature. The dry bulb temperatures for power plant locations in Carbondale, Los Angeles, Miami, New York and Seattle are shown in the table and figures following.

Table 6.1: Dry bulb Temperature for Los Angeles, Carbondale, Miami, New York and Seattle

Month	Dry bulb temperature				
	Los Angeles	Carbondale	Miami	New York	Seattle
January	13.34998	-1.94622	19.99363	1.168112	5.427386
February	13.26293	3.771187	20.64319	-0.1768	6.57327
March	14.55176	9.546993	22.53162	5.584997	9.178612
April	15.54811	12.08988	23.71111	10.94082	11.03321
May	16.99157	21.87112	25.38115	16.0496	13.33286
June	17.64661	23.44983	26.88564	21.71061	15.75424
July	19.77692	26.46418	27.17989	25.04669	19.01974
August	20.11097	25.40054	27.9376	24.7877	18.79066
September	19.94578	21.64325	27.43589	19.95554	15.98688
October	18.13864	14.8392	25.0516	14.02345	11.73594
November	15.96852	10.32828	22.89102	7.309948	8.792066
December	14.42861	1.65121	19.39466	3.331351	6.176109

Table 6.1 shows the dry bulb temperature profile for each month for Los Angeles, Carbondale, Miami, New York and Seattle. Looking at the distributions of the dry bulb

temperature for Carbondale as shown in Figure 6.1, it is seen that the temperatures over the months of May through September are over 20 degrees.

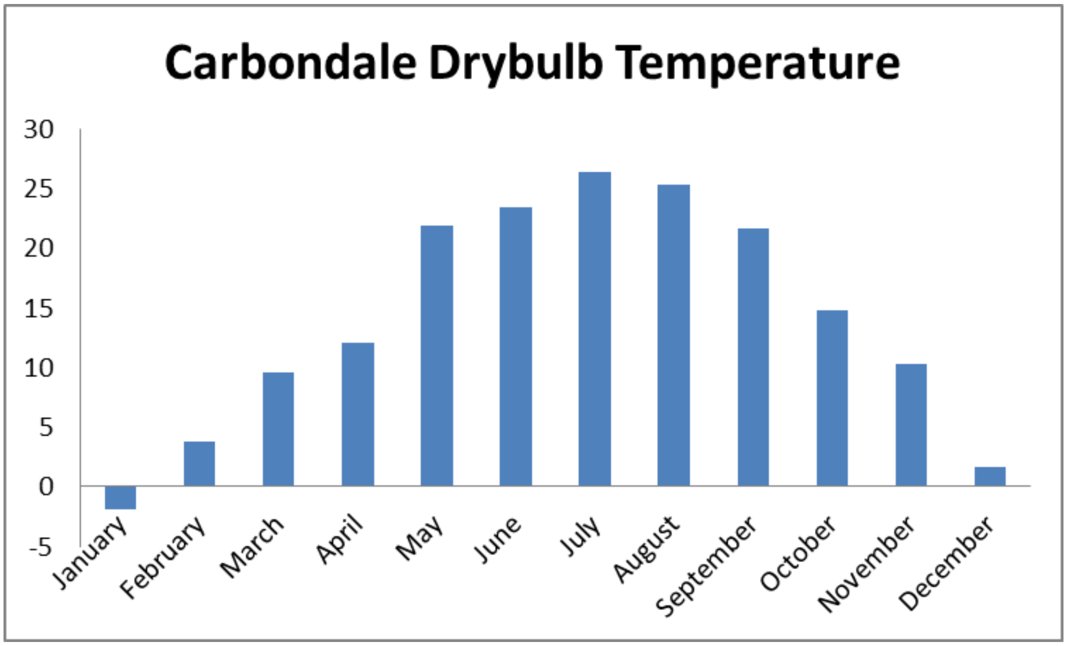

Figure 6.1: Carbondale Dry bulb Temperature

New York has a similar dry bulb profile as Carbondale with very low temperatures from December through the month of February as shown in Figure 6.2.

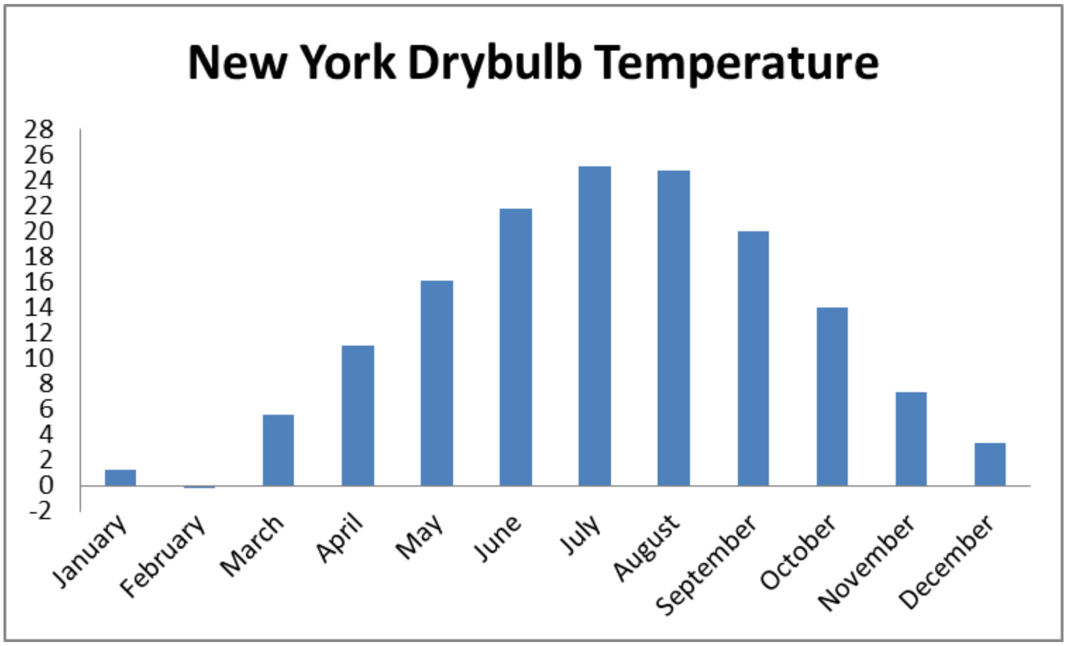

Figure 6.2: New York Dry bulb Temperature

Los Angeles has an almost stable temperature all year round as shown in Figure 6.3.

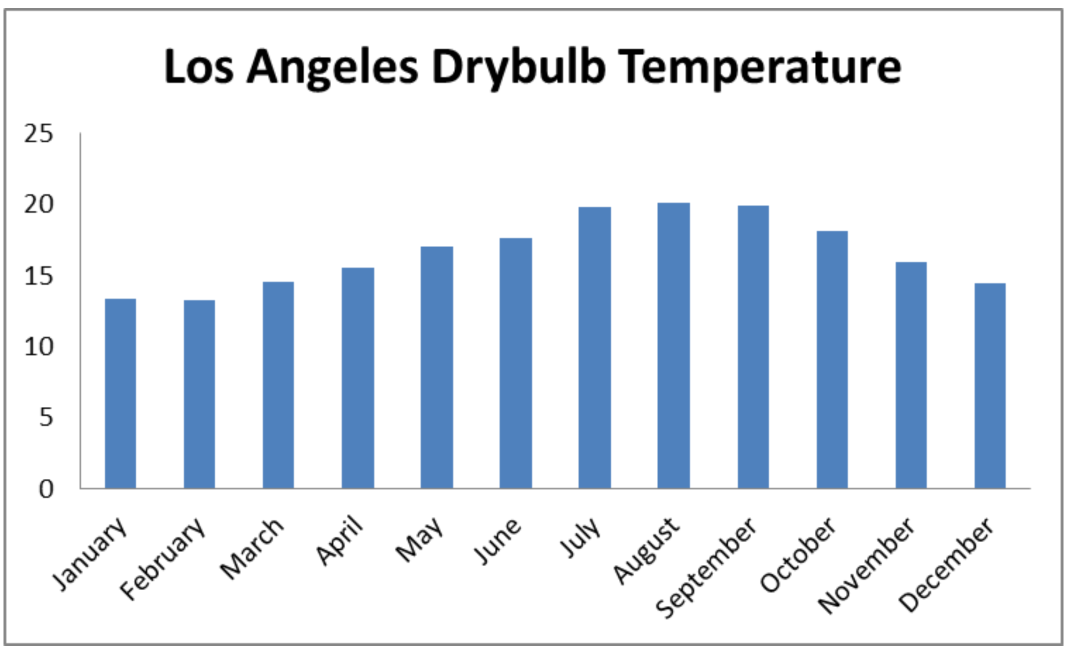

Figure 6.3: Los Angeles Dry bulb Temperature

Miami has an almost steady increase in the dry bulb temperature, until July/August when it decreases again almost steadily as shown in Figure 6.4.

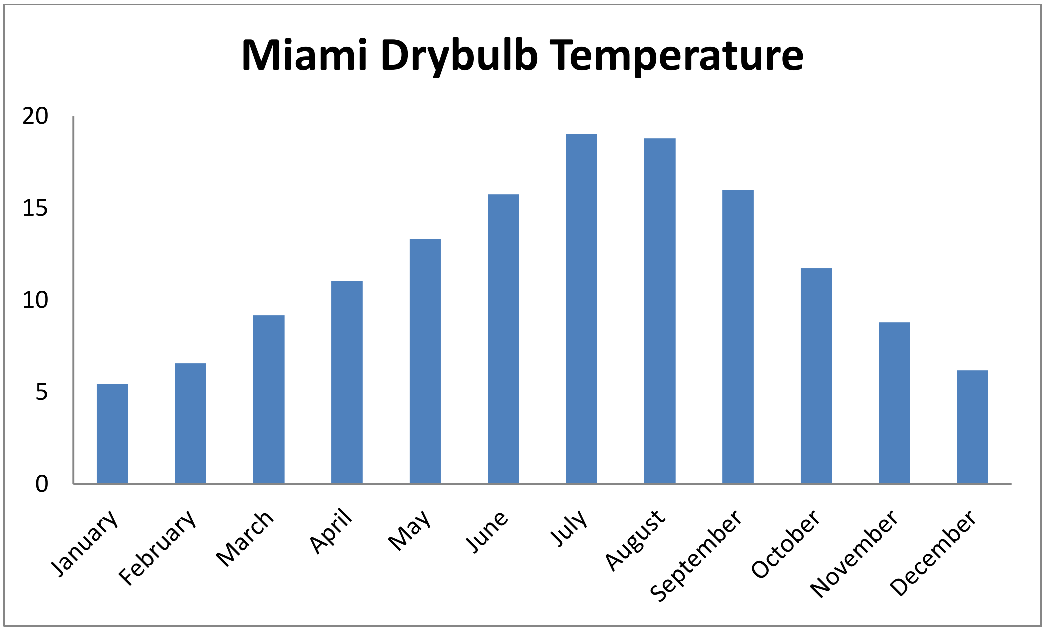

Figure 6.4: Miami Dry bulb Temperature

Figure 6.5 is a visual description of Seattle dry bulb temperature.

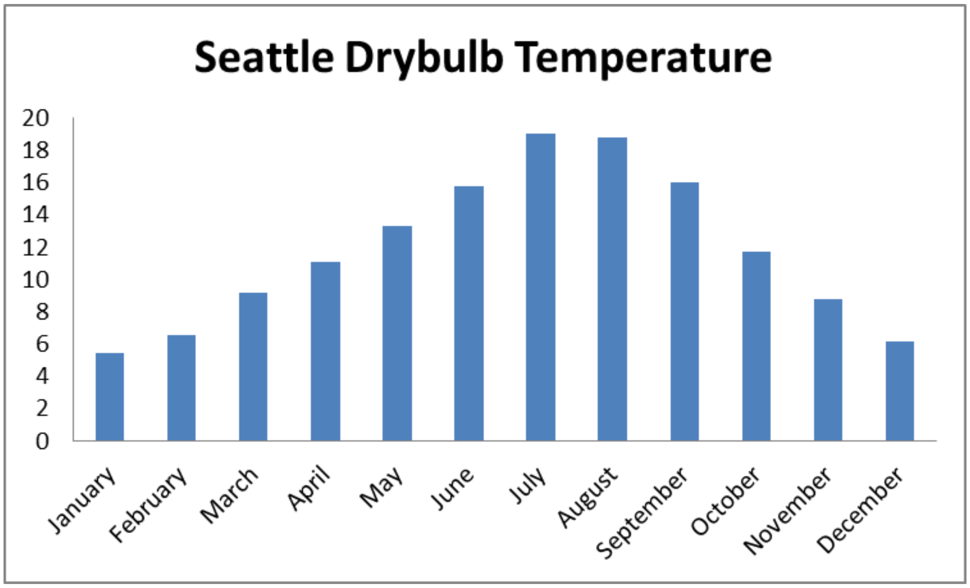

Figure 6.5: Seattle Dry bulb Temperature

6.2 RESULTS ON THE ENERGY DEMAND BY THE PLANT WITH LOCATION IN CARBONDALE

Table 6.2 shows the HVAC energy demand of the power plant throughout the year in Carbondale with the original building materials (i.e. with no modifications). The figure also shows the distribution of the energy demand from January to December.

Table 6.2: Carbondale Plant HVAC Power Demand

Month	**Carbondale**
	Power Demand [W]
January	4703.469
February	4681.423
March	4694.718
April	4475.25
May	4601.304
June	4557.364
July	4443.546
August	4624.489
September	4586.346
October	4643.994
November	4749.031
December	4647.175

As shown on Table 6.2, the highest demand for power occurs in the months of January and November. The total power demand for the year is 55408.11 W. A visual view of the data in Table 6.2 can be seen in Figure 6.6. The lowest power demand occurs in the months of April and July. This is as a result of combined heating and cooling power demand of the plant. Also the weather condition contributes to the low power demand because the immediate building weather condition was not used rather the city weather condition was implemented. I would say that the HVAC power demand profiles goes hand in hand with the weather condition profile and the cost of energy usage.

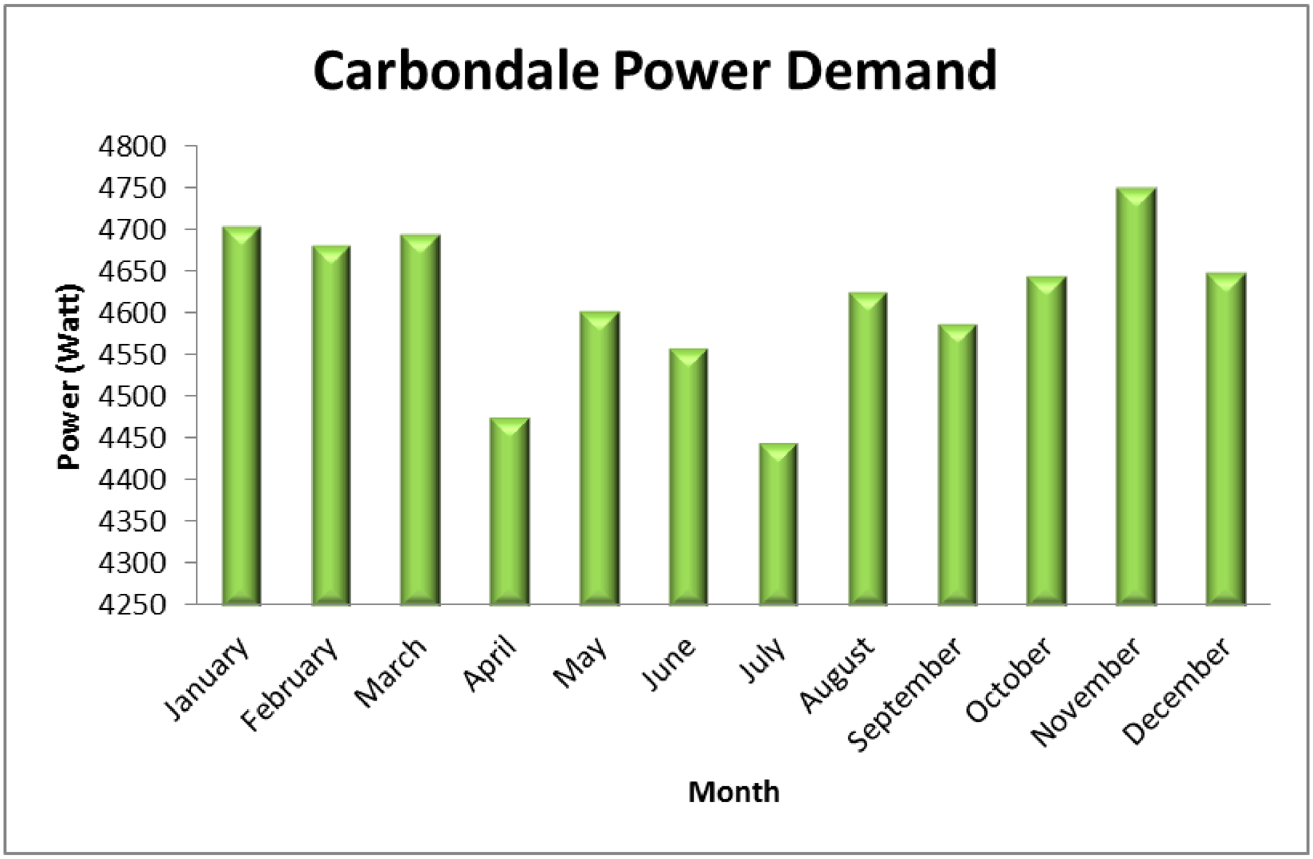

Figure 6.6: Carbondale Plant HVAC Power Demand

6.3. RESULTS ON THE ENERGY DEMAND BY THE PLANT WITH LOCATION IN LOS ANGELES

In a similar way as Carbondale, computer simulations for Los Angeles were performed. The results are shown in Table 6.3 and Figure 6.7. As shown on Table 6.3, November has the highest power demand for the HVAC system. The total power demand for the plant in Los Angeles is 55419.1 W. Similarly to Carbondale, the lowest power demand occurs in the months of April and July. This is as a result of combined heating and cooling of the power demand by the plant. Also the weather condition contributes to the low power demand because the immediate building weather condition was not used; rather the city weather condition was implemented. A visual view of the data shown on Table 6.3 can be seen in Figure 6.7.

Table 6.3: Los Angeles Plant HVAC Power Demand

Month	Los Angeles Power Demand [W]
January	4691.037
February	4674.354
March	4692.702
April	4481.5
May	4612.392
June	4577.156
July	4456.651
August	4631.882
September	4588.429
October	4638.281
November	4738.961
December	4635.75

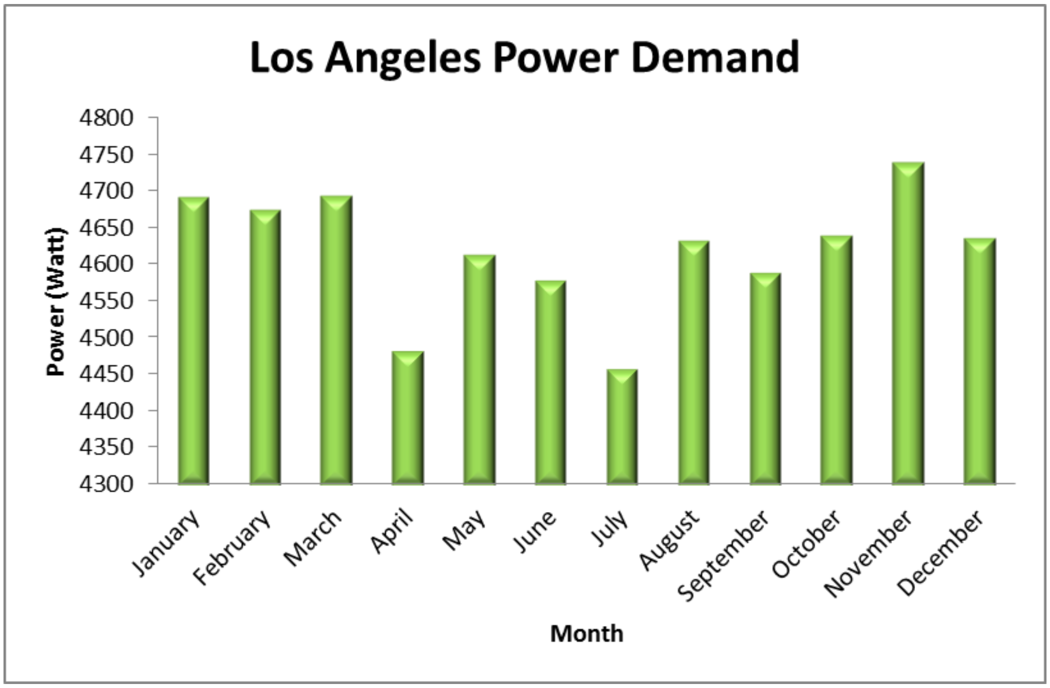

Figure 6.7: Los Angeles Plant Power Demand

6.4. RESULTS ON THE ENERGY DEMAND BY THE PLANT WITH LOCATION IN MIAMI

The results for Miami computer simulations show the HVAC power demand of the plant to be highest in the month of November with about 4718.22 watts and the total power demand for a year to be 55421.64. Table 6.4shows numeric results in Watts (W) for the months of January through December. Figure 6.8 interprets the numeric data from Table 6.4 to a bar chart. It is seen from the table and figure that the increase in demand for power by the HVAC occurs in November and next is in March. The lowest power demand occurs in April and July. This is as a result of combined heating and cooling of the power demand by the plant. The weather condition contributes to the low power demand because the immediate building weather condition was not used rather the city weather condition was implemented.

Table 6.4: Miami Plant HVAC Power Demand

Month	**Miami**
	Power Demand [W]
January	4663.147
February	4659.845
March	4691.694
April	4491.222
May	4633.562
June	4604.239
July	4482.86
August	4647.675
September	4590.165
October	4630.553
November	4718.822
December	4607.86

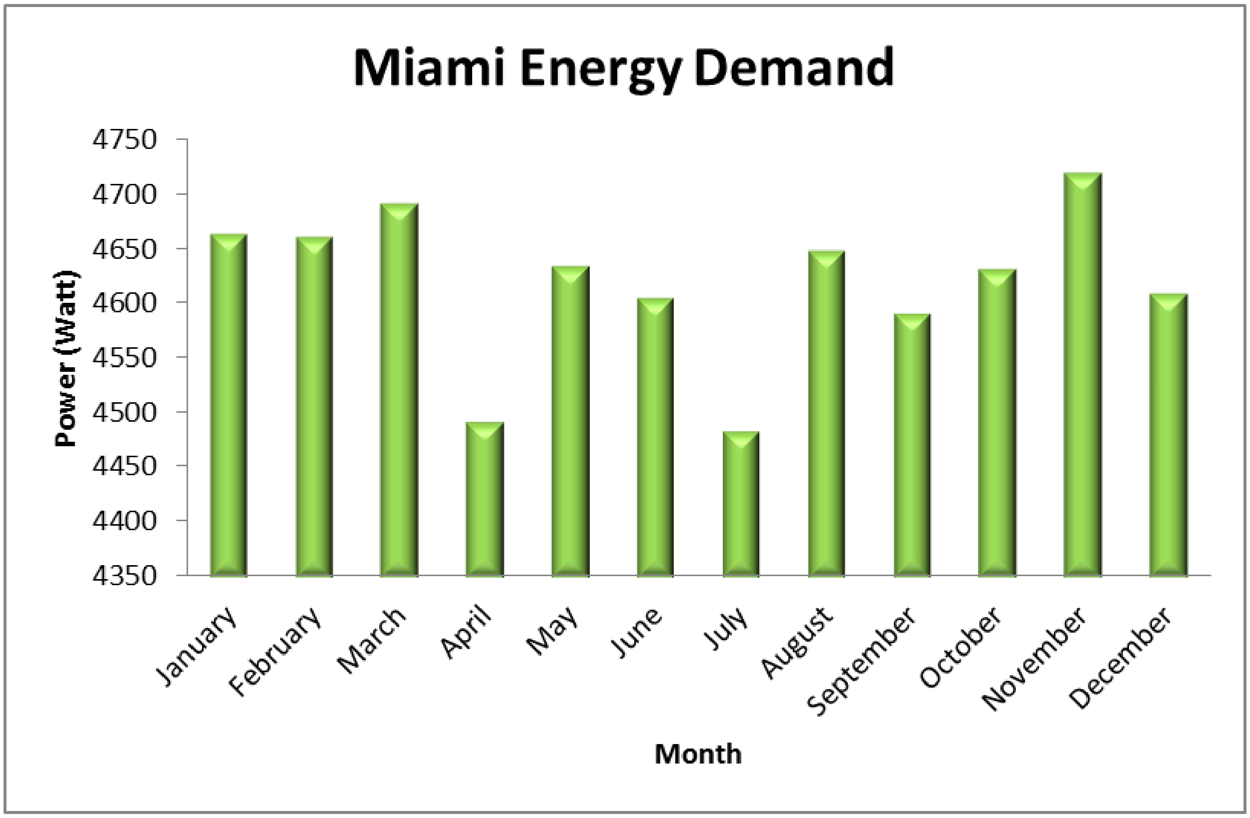

Figure 6.8: Miami Plant HVAC Power Demand

6.5. RESULTS FOR THE ENERGY DEMAND BY THE PLANT WITH LOCATION IN NEW YORK

New York power demand yields almost the same results as that of Carbondale which could be as a result of the two cities having an almost similar weather profile (i.e. at most about 12 Watt difference in energy and 6 degrees in temperature). This is shown in Table 6.5 and Figure 6.9. The highest power demand is in January and November and the lowest is in April and July. This is because the true power demand for heating and cooling is not shown separately, it is a combined power demand for the heating and cooling of the plant. The weather condition is also a contributor to the low power demand because the immediate building weather condition was not used rather the city weather condition was implemented. The total power demand for this plant for a typical year in the New York area is 55409.78 W.

Table 6.5: New York Plant HVAC Power Demand

Month	**New York**
	Power Demand [W]
January	4712.542
February	4687.375
March	4696.062
April	4471.083
May	4591.895
June	4546.253
July	4433.801
August	4618.105
September	4584.262
October	4648.026
November	4758.753
December	4661.624

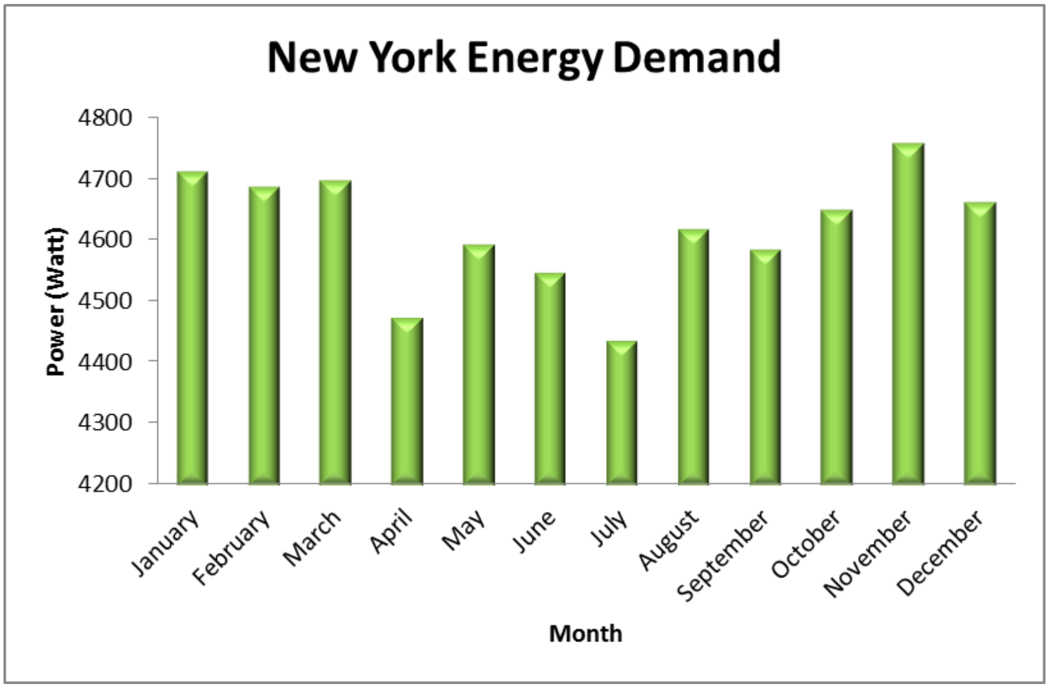

Figure 6.9: New York Plant HVAC Power Demand

6.6. RESULTS ON THE ENERGY DEMAND BY THE PLANT WITH LOCATION IN SEATTLE

The results for HVAC power demand for Seattle, shows the highest demands for the months of January, February and November. The months of April and July show the lowest power demand reason being that it is a combination of the power demand used for heating and cooling. The weather condition contribute to the low power demand because the immediate building weather condition was not used rather the city weather condition was implemented. The total power demand of this plant for a typical year in the Seattle area is 55407.45 W. These are shown in Table 6.6 and Figure 6.10.

Table 6.6: Seattle Plant HVAC Power Demand

Month	Seattle
	Power Demand [W]
January	4745.808
February	4705.604
March	4698.078
April	4458.236
May	4563.333
June	4514.308
July	4400.199
August	4597.944
September	4580.443
October	4660.459
November	4784.447
December	4698.586

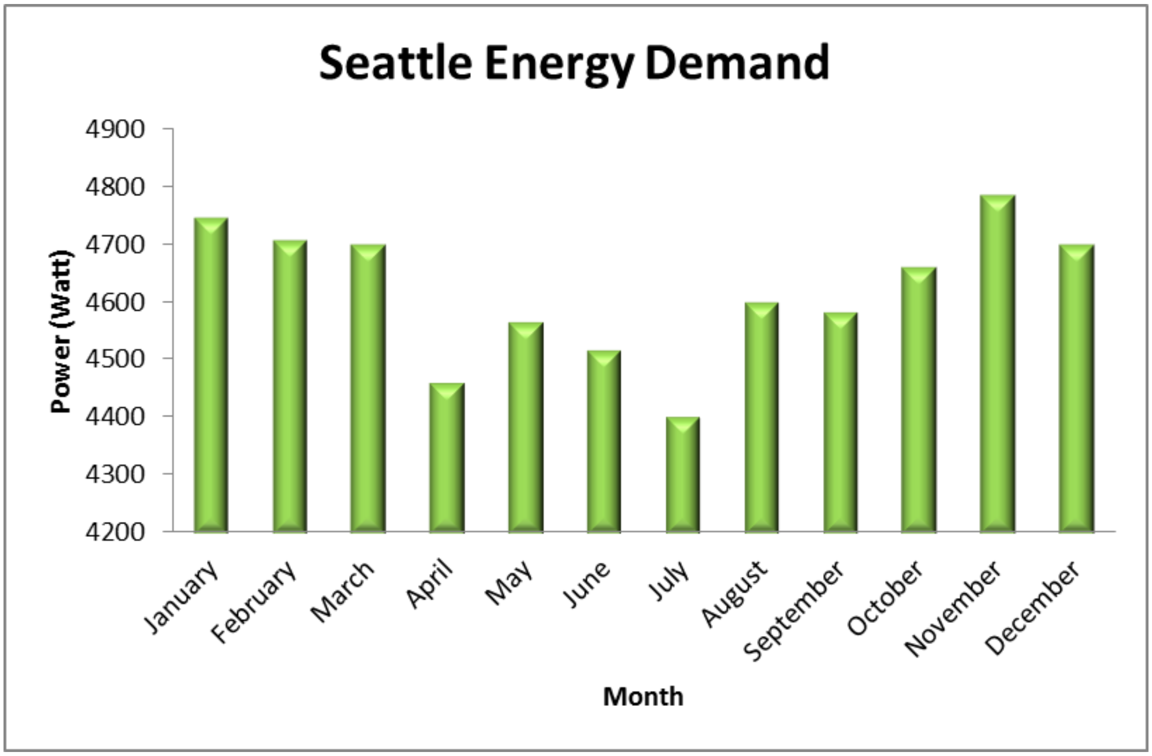

Figure 6.10: Seattle Plant HVAC Power Demand

6.7. RESULTS ON THE ENERGY DEMAND BY THE PLANT WITH LOCATION IN CARBONDALE WITH MODIFICATIONS

Table 6.7 shows a list of the building materials that were modified to analyze for improved power demand of the HVAC system of the plant. The terms, M11, M01, G01a, F16 etc. represent the material codes that were used in the EnergyPlus program. This varies based on the material properties such as the finish (smooth, rough etc.), conductivity and so on. Additionally, the sizes of the materials as well as the insulation were considered based on the logic behind heat gain and heat loss.

Table 6.7: Building Material Changes

Original Building Material	Modified Building Material
Window (clear 6 mm, airspace and clear 6 mm)	Window (Grey 6 mm, airspace and clear 6 mm)
Interior Door (Hardwood finish 19mm, Hardwood 19mm, Insulation, Hardwood 19mm)	Interior Door (Hardwood finish 19mm, Hardwood 25 mm)
Exterior Door (Hardwood finish 25 mm, Hardwood 25mm, Insulation, Hardwood 25mm)	Exterior Door (Hardwood finish 19 mm, Hardwood 25mm, Insulation, Hardwood 19mm)
Ceiling (M14a 100mm Heavy concrete, Ceiling airspace and F16 Acoustic tile)	Ceiling (M11 100mm Heavy concrete, Ceiling airspace and F16 Acoustic tile)
Exterior wall (M01 100mm brick, M15 200mm heavyweight concrete, 50mm insulation, wall airspace and G01a 19mm gypsum board)	Exterior wall (M01 100mm brick, 50mm heavyweight concrete, 50mm insulation, wall airspace and 19mm gypsum board)
Interior wall (G01a 19mm gypsum board, wall airspace and G01a 19mm gypsum board)	Interior wall (G01a 19mm gypsum board, wall airspace and G01a 19mm gypsum board)
Roof (M15 200 mm heavyweight concrete, ceiling airspace and F16 acoustic tile)	Roof (M14a 100 mm heavyweight concrete, ceiling airspace and F16 acoustic tile)
Ground floor (F16 Acoustic tile, airspace and M15 200 mm heavyweight concrete)	Ground floor (F16 Acoustic tile, airspace and M14a 100 mm heavyweight concrete)
Other floors (F16 Acoustic tile, airspace and M14a 100mm heavyweight concrete)	Other floors (F16 Acoustic tile, airspace and M11 100mm heavyweight concrete)

The expression used to obtain the percentage decrease in HVAC power demand was:

Percent decrease in power demand per year is equal to

$$\frac{Total\ power\ demand\ for\ the\ city\ per\ year - Total\ power\ demand\ (modified) for\ the\ city\ per\ year}{Total\ power\ demand\ for\ the\ city\ per\ year} \times 100$$

(Eq 6.1)

$$= \frac{55408.11 - 43407.45}{55408.11} \times 100 = 21.658\%$$

Table 6.8 and Figure 6.11 show the power demand for the power plant location in Carbondale after modifications to building materials were made. After the modification, the total power demand for the Carbondale area became 43407.45 W. It is then seen that there is about 12000.66 watt power in savings with the modifications to the building material as opposed to no modification. This is about 12 kW power in savings which is equivalent to about 21.7% reduction in energy demand by the power plant in the Carbondale area per year.

Table 6.8: Carbondale Plant HVAC Power Demand (modification)

Month	Carbondale
	Power Demand [W]
January	3745.808
February	3705.604
March	3698.078
April	3458.236
May	3563.333
June	3514.308
July	3400.199
August	3597.944
September	3580.443
October	3660.459
November	3784.447
December	3698.586

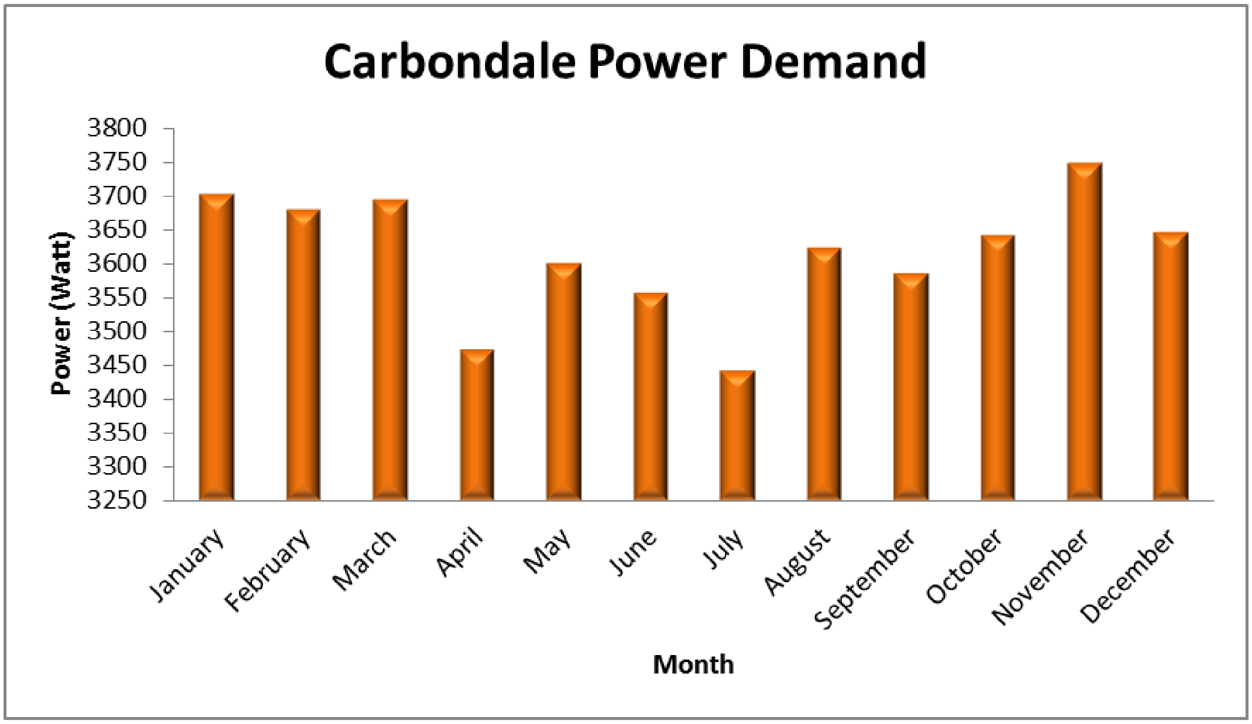

Figure 6.11: Carbondale Plant HVAC Power Demand (modification)

6.8. RESULTS ON THE ENERGY DEMAND BY THE PLANT WITH LOCATION IN LOS ANGELES WITH THE MODIFICATION

Similar to the Carbondale Plant modification, the Los Angeles Plant was modified. Results show that there was a reduction in the HVAC power demand as shown in Figure 6.12 and Table 6.9. The total power demand for the Los Angeles plant with the modifications was 43419.1 W. The results for Los Angeles show about 12000 watt power in power savings with the modifications made on the building materials. Using Equation 6.1, this also gives about 21.7% reduction in energy demand per year in the Los Angeles area.

Table 6.9: Los Angeles Plant HVAC Power Demand (modification)

Month	Los Angeles
	Power Demand [W]
January	3691.037
February	3674.354
March	3692.702
April	3481.5
May	3612.392
June	3577.156
July	3456.651
August	3631.882
September	3588.429
October	3638.281
November	3738.961
December	3635.75

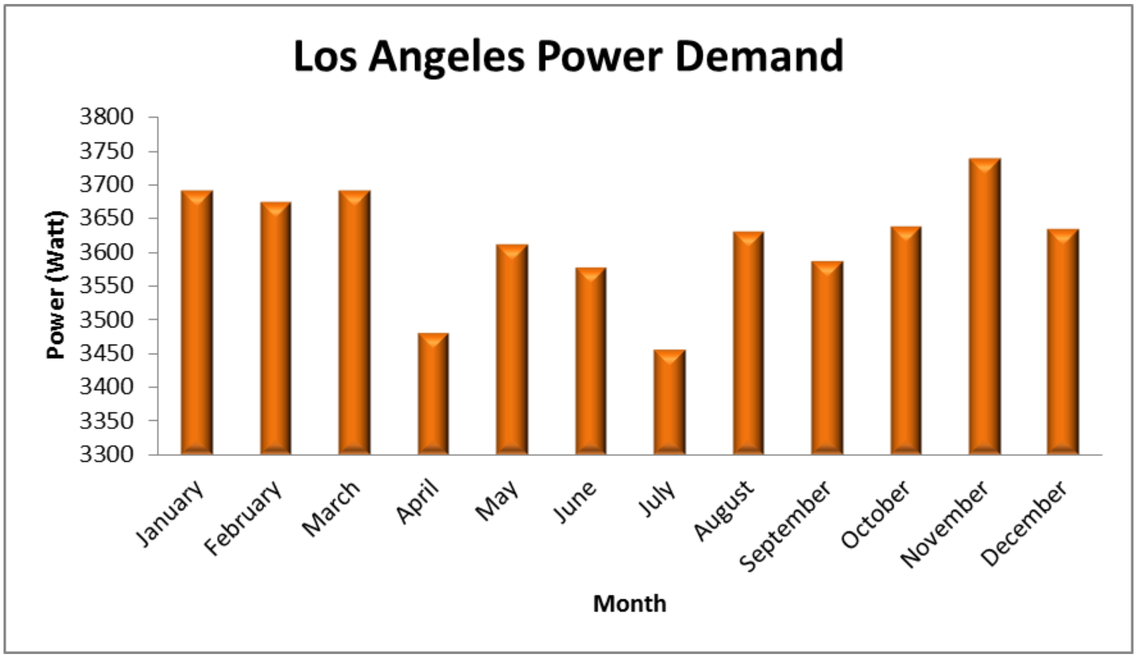

Figure 6.12: Los Angeles Plant HVAC Power Demand (modification)

6.9. RESULTS FOR THE ENERGY DEMAND BY THE PLANT WITH LOCATION IN MIAMI WITH MODIFICATION

The highest and lowest power demand months remain the same but the energy demand decreased compared to the power demand of the Miami plant without modification. This is shown in Table 6.10 and Figure 6.13. There is a total power demand of 43421.64 W yielding about 12000 Watt reduction in power demand by the plant as a result of the modification. This is about bout 21.7% reduction in energy demand per year by the plant when located in the Miami area.

Table 6.10: Miami Plant HVAC Power Demand (modification)

Month	Miami
	Power Demand [W]
January	3663.147
February	3659.845
March	3691.694
April	3491.222
May	3633.562
June	3604.239
July	3482.86
August	3647.675
September	3590.165
October	3630.553
November	3718.822
December	3607.86

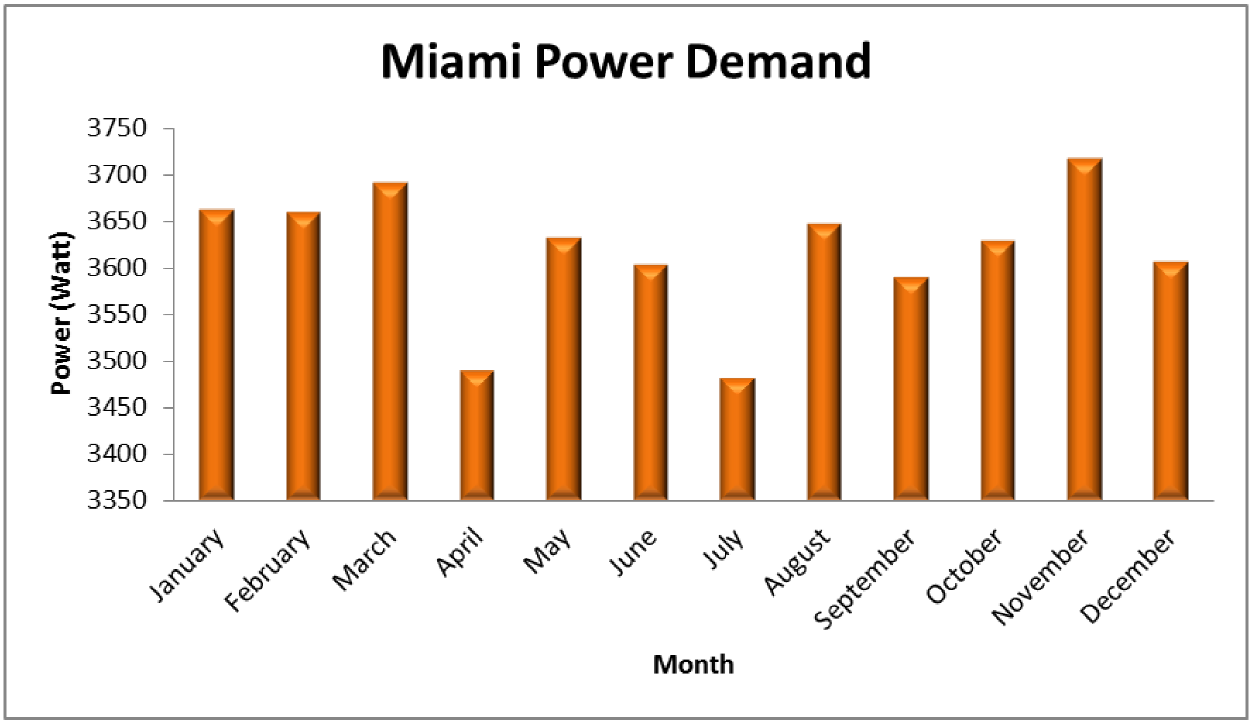

Figure 6.13: Miami Plant HVAC Power Demand (modification)

6.10. RESULTS ON THE ENERGY DEMAND BY THE PLANT WITH LOCATION IN NEW YORK WITH MODIFICATION

Similar to the Miami location of the Plant, the HVAC power demand for the New York location showed a decrease but the highest and lowest power demand months remain the same. This is expected, since the power demand per month is related to the weather condition per month in a typical year. The results are shown in Table 6.11 and Figure 6.14. It was determined that there is a total power demand for the year of 43409.78 W with the modifications. This is about 12000 Watt reduction in power demand by the plant. The total energy demand per year of the plant shows a 21.7% reduction in energy demand for the plant location in the New York area.

Table 6.11: New York Plant HVAC Power Plant (modification)

Month	New York Power Demand [W]
January	3712.542
February	3687.375
March	3696.062
April	3471.083
May	3591.895
June	3546.253
July	3433.801
August	3618.105
September	3584.262
October	3648.026
November	3758.753
December	3661.624

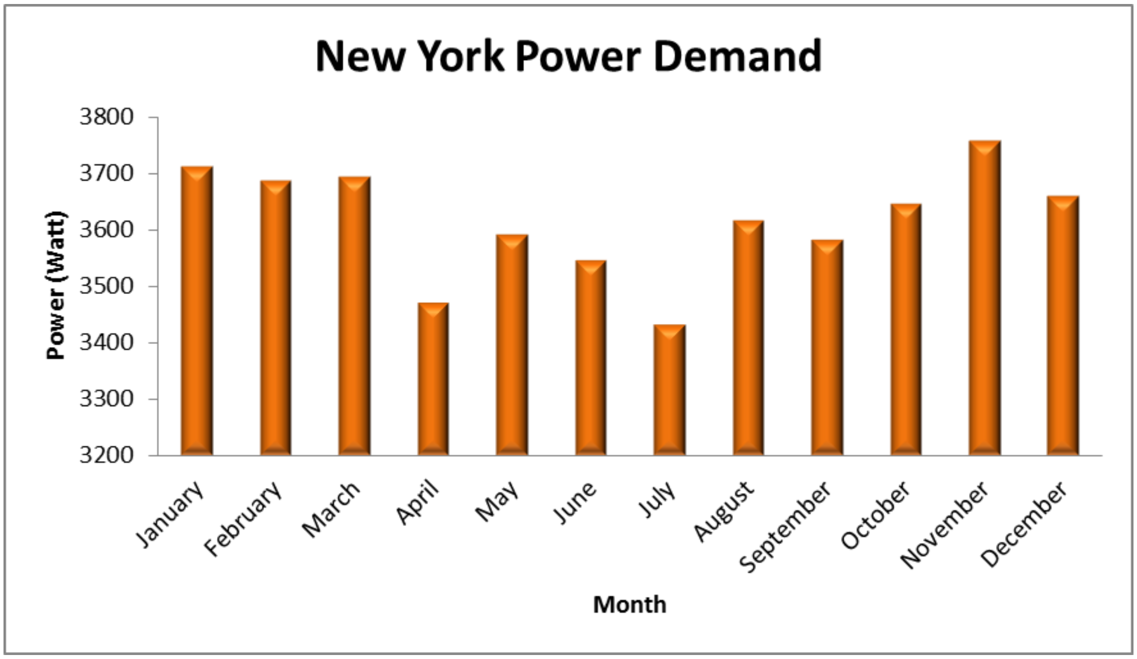

Figure 6.14: New York Plant HVAC Power Plant (modification)

6.11. RESULTS FOR THE ENERGY DEMAND BY THE PLANT WITH LOCATION IN SEATTLE WITH MODIFICATION

With the listed modifications on Table 6.7 in section 6.2 computer simulations were carried out on the modified plant with location in the Seattle area. The results show that there is also a change in the HVAC power demand. This is shown in Table 6.12 with a visual display shown in Figure 6.15 as well. The results also show that for this plant located in the Seattle area, there is a total power demand of 43407.45 W for the year. This is about 12000 Watt of reduction in power demand of the plant in this area. This reduction is about 21.7%.

Table 6.12: Seattle Plant HVAC Power Plant (modification)

Month	Seattle
	Power Demand [W]
January	3745.808
February	3705.604
March	3698.078
April	3458.236
May	3563.333
June	3514.308
July	3400.199
August	3597.944
September	3580.443
October	3660.459
November	3784.447
December	3698.586

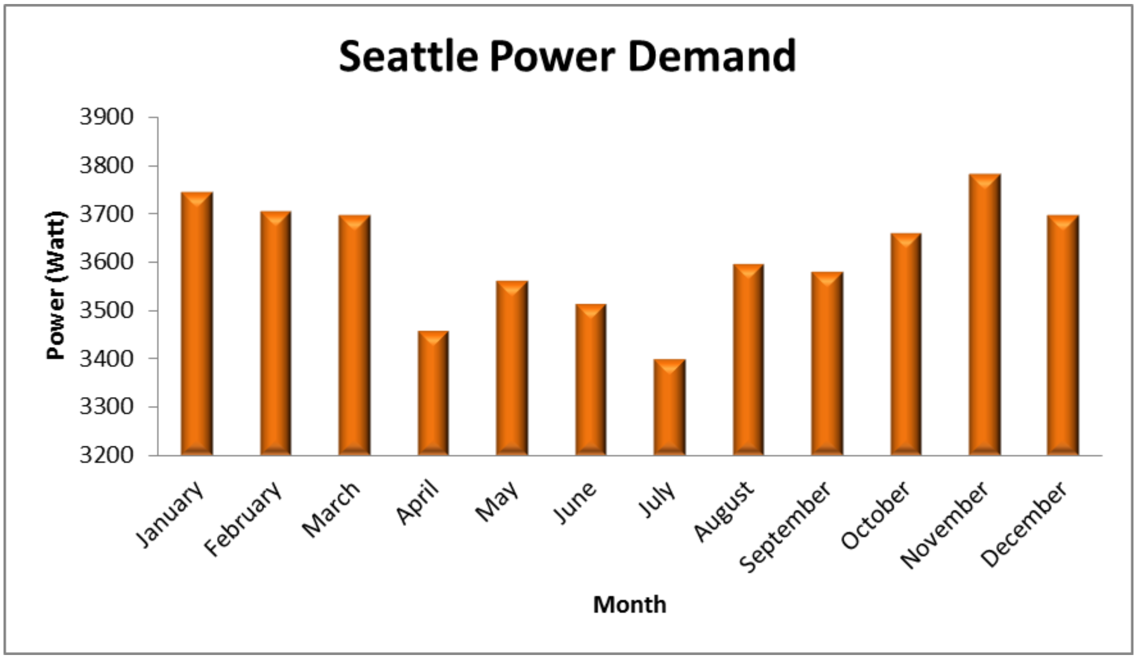

Figure 6.15: Seattle Plant HVAC Power Plant (modification)

6.12. INVESTIGATION ON THE TYPES OF ENERGY RESOURCES

Computer simulations were further used to investigate the impact of different types of energy resources on the energy demand for all the regions of the country. The energy resources investigated included natural gas, steam, electricity and coal. For each city (i.e. Los Angeles, Carbondale, Miami, New York and Seattle) steam showed the lowest energy usage per building area. Next was coal and electricity which showed the highest energy usage. Furthermore since coal was found to be the largest source of energy for all the cities, energy demand for coal by the power plant for the five cities was compared. Coal consumption by the plant at different locations seems to be most in Miami, Florida followed by Los Angeles, California, New York, Seattle and Carbondale.

This can be seen illustrated in Figure 6.16. The reason for this might be as a result of the weather condition in these locations.

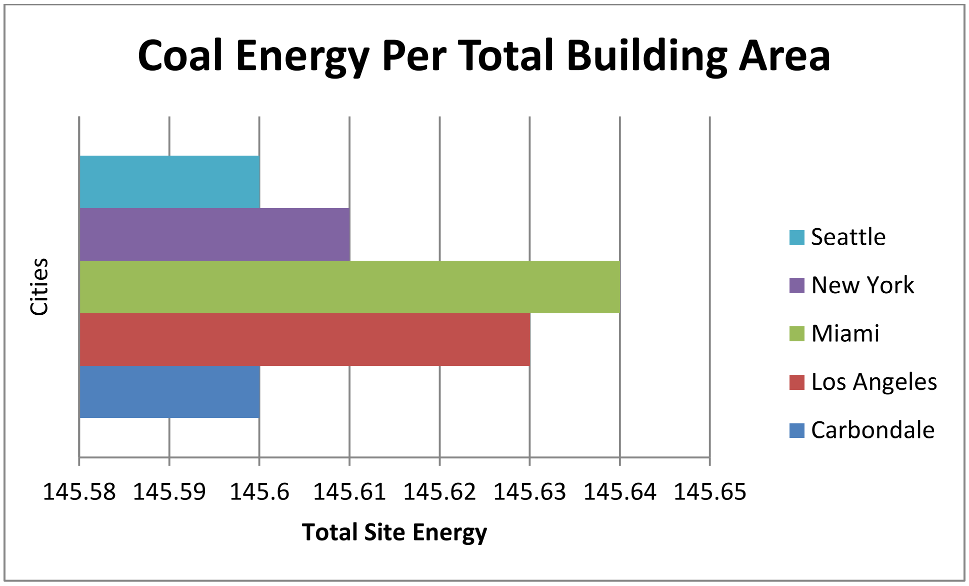

Figure 6.16: Coal Consumption for different Plant Locations

CHAPTER 7

SUMMARY, CONCLUSION AND RECOMMENDATION

7.1. SUMMARY, CONCLUSION AND RECOMMENDATION

The power demand of the HVAC system of a power plant is dependent on various factors, of which this research has covered some. As shown in the results in Chapter 6, the dry bulb temperatures are dependent on the climatic conditions of the locations of the plants. The energy demand of the HVAC system tends to increase or decrease based on the climatic conditions and time of the year. The power demand for the plants at all locations is seen to be low for the months of April and July whereas the other months are high. The power demand for April and July are abnormally low because the power demand shows a combination of both the heating and cooling. Also some of the factors that influence the results are the unavailable surrounding (immediate) power plant weather condition as opposed to the city weather condition. The power demand trends are almost the same in all conditions. This could be due to the limitation of the EnergyPlus program as well as the operational features within the power plant. Looking at the power demand for each plant after various building material were modified, it was found that there is a decrease in the power demand by the plant compared to before the modifications. The study on change in the energy resources which included natural gas, steam, electricity and coal showed that steam is the best energy source for use in the plant. Considering the limitation of availability of these energy resources, coal was chosen for further investigation. The results for the plant at different locations in the country showed that Miami has the highest coal consumption followed by Los Angeles, New York and lastly Seattle and Carbondale.

From the calculations done, it was found that there is an average of 21.7 % in power demand reduction for the plant at different the locations. There could be further reduction in the power demand of the HVAC system as the EnergyPlus program does not have a wide range of building materials, as well as the application of motion sensor lights etc.

One of the recommendations from this study is that energy saving practices such as selection of bulb/fluorescent type, electric equipment, and motion lights etc. be incorporated alongside the energy saving building materials applied in this study. In addition, if possible the use of energy should be minimized during peak hours. Also the application of passive air conditioning, solar panel applications, use of fans, improved operational features within the plant as well as the use of weather files relative to the immediate outside condition of the building should be considered for further energy saving practice. Some energy savings practices such as type of light bulb, geothermal energy source, nuclear energy source could not be implemented in the EnergyPlus program. For future research, additional means of adding energy saving methods should be considered. In conclusion, it is seen that efforts put into minimizing energy consumption goes a long way. As seen from this study, there is a reduction in the energy demand by the power plant of an average of 12,000 watts based on modification of the building materials alone. The average cost of energy per kilowatt hour is 12 cents. This power plant runs for about 20 hours a day. In a day the energy saved is 240 kWh (i.e. in a year 87,600 kWh per year). This gives an average cost savings per year of $10,512. It is therefore seen that being more energy efficient saves not only money but also, the earth and the future.

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