AMERICAN UNIVERSITY OF BEIRUT

DESIGN AND FEASIBILITY OF A SMALL NEGAWATT POWER PLANT

by
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A thesis
submitted in partial fulfillment of the requirements
for the degree of Master of Engineering
to the Department of Electrical and Computer Engineering
of the Faculty of Engineering and Architecture
at the American University of Beirut

Beirut, Lebanon
December 2014

AMERICAN UNIVERSITY OF BEIRUT

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ACKNOWLEDGMENTS

I would like to address my gratitude to my advisor Professor Farid Chaaban for his support and valuable guidance and assistance throughout my thesis project. I would also like to thank my committee members Professor Chedid and Professor Jabr for their advices. I am also grateful for Professor Karaki for providing me with the data from previous audits and Mr. Jean Abdelnour for providing the data from the power plant.

AN ABSTRACT OF THE THESIS OF

Dana Fawzi Sbeity for Master of Electrical Engineering
Major: Energy and Power Systems

Title: Design and Feasibility of a Small NegaWatt Power Plant

The global energy consumption, and hence GHG emissions, have increased significantly over the past two decades due to the increase in the population size, rapid developments in many large countries, and the technological boom at global scale. Human progress was accompanied by a substantial rise in the consumption of various forms of energy resources mainly fossil fuels, an increase that might result in a risk of depletion of these resources in the near future.

Due to this increase in demand for energy, and the anticipated impacts on global economy and resources, a wide range of academic and industrial research activities are currently focused on seeking solutions targeting better energy sustainability and resources management.

One solution is via modifying the end-users trends with respect to energy usage and redirecting their choices and decisions towards cleaner and renewable resources, and in more efficient manners.

This thesis aims at studying different energy conservation options as well as their effectiveness and economic feasibility. The approach will make use of the recently established NegaWatt (NW) concept which is based on assessing the feasibility of implementing clean and more energy- efficient technologies to reduce consumption, rather than expanding the power supply capacity to meet the growing demand.

Feasibility of a small NW power plant for AUB is assessed. The most appropriate alternative technologies are selected and options are focused on the lighting fixtures, roof insulation, double glazed windows and on upgrading the HVAC and pumping systems. Feasibility study is carried out to compare the cost of clean technologies to the cost of expansion of the supplied thermal power, with and without CO_2 removal cost. The obtained results show that NW solutions are more economically feasible, they also save energy resources, and lead to substantial GHG reduction.

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ABBREVIATIONS

NW	NegaWatt
AUB	American University of Beirut
GHG	Greenhouse gases
DSM	Demand Side Management
DOE	US Department of Energy
VFD	Variable frequency drives
HVAC	Heating, Ventilating and Air conditioning
AUBMC	AUB medical center
LED	Light emitting diode
EIA	Energy Information Administration
NPV	Net present value
ECM	Energy conservation measures
RI	Roof Insulation
DGW	Double glazed windows

CHAPTER I

INTRODUCTION

The term NegaWatt, a theoretical unit, represents the amount of power or energy saved or conserved as a result of technology upgrading, structural changes, or other initiatives. The term was created by Amory Lovins; an American, environmental scientists and the chief scientist of the Rocky Mountain Institute. Lovins in 1989 claims creating the NegaWatt market as a win- win solution as it is cheaper to conserve fuel rather than burning it and as it finds solution to the environmental problems by reducing the CO_2 and other emissions. He argues that the demand side customers care about the energy services rather than the amount of KWh of electricity. Energy services can be bought cheaply by using the electricity in a more efficient manner [1].

According to Anderson and Newell in their paper entitled: “Information programs for technology adoption: the case of energy-efficiency audits” [2], the main reasons behind adopting energy efficient improvements are the environment, the instability in the energy price and the national security. The US National Energy Policy in the white house considers the improvement of the energy efficiency as a “national priority” in order to reduce the “greenhouse gas intensity”. The adopted improvements, as noted in the paper, are the one with a short payback period, low cost, that will generate high annual savings with high energy prices and consider as the best alternatives for accomplishing high percentage of energy conservation [2].

The demand side management (DSM) decreases the peak demand for electricity by reducing the load on the end user side, thus avoiding the more need for building new electrical capacities and transmission lines. DSM also helps detecting the blackouts, reduces the usage of fuel consumption, and reduces the harmful gas emissions and greenhouse gases as well as it plays an important role in increasing the system efficiency. DSM includes lighting retrofitting, power factor correction, motors, drives, double glazing, and taking advantage of daylight. DSM consists of collecting data, monitoring the purchase of energy, identify energy conservation measures followed by financial studies, implementing the projects and checking the performance of the system [3].

An energy audit was done for the Oregon State University Kerr Administration Building. The methodology consisted on two site visits to collect data followed by analysis and simulations using DOE software. A baseline was formed depending on the collected data, energy conservation measures were applied to the baseline scenario and the results were noted. A cost analysis based on simple calculations followed in order to detect the payback period. After applying the energy conservation measures 29.5% of the total consumed energy were saved and the payback period was 16.1 years. The energy conservation measures were modifying the lighting T12 to more efficient lighting (T8 in their case), modifying the HVAC system, adding ventilation control by installing CO_2 sensors, using daylight control sensors, adding heat recovery chillers [4].

Art Rosenfeld as a pioneer in then efficiency field and as being a member of the California Energy Commission assumes that Americans are capable of saving a minimum of 200 TWh of electricity per annum by applying energy efficiency standards and buying more efficient fridges over the years. The 200 TWh are a substitute for 80 power plants [5].

The US department of Energy indicated that more than 25% of the original costs paid by the universities on energy can be saved by managing the usage of electricity. In order to optimize the energy performance some control applications were identified. Zone scheduling divides the building into zones and permits the HVAC and the lighting to shut down according to a certain schedule. The occupancy sensor detects the motion and turn on and off the HVAC and lighting system. Variable frequency drives (VFD) can reduce up to 50% if the electrical consumption, resetting the system hot water temperature taking into consideration outside temperature can decrease the heat losses in the pipelines, ventilation on demand depending on the CO_2 level, chiller optimization, taking advantage of daylight and optimizing the cooling tower by decreasing the set point temperature. All these methods can help decreasing the energy consumption without affecting the comfort. [6]

In a paper entitled: “The Eco-Watt Project”: building a NegaWatt power plant in a school” [7], energy savings and conservation measures were applied at a school in Freiburgm Germany. The methodology consisted of a feasibility study followed by energy conservation measures related to refurbishment of the lighting such as replacement of the luminaires to a daylight-dependent control system of the lighting, heating systems, water savings, increasing the efficiencies of the circulation pumps and the construction of two solar plants. The project capital cost was equivalent to EUR 250,000. The total energy saved was 200 MWh at a cost of EUR 65,000 per year, i.e. with a payback period slightly less than 4 years. In addition the NegaWatt project achieved a reduction of 350 tons of CO_2 per year.

A. The AUB Power Demand

The demand for electric power in the American University of Beirut (AUB) has been increasing consistently due to the growth in programs, student numbers, and facilities. AUB is a pioneering and one of the leading universities in the Arab region. It consists of 55 buildings including a medical center (AUBMC). A good database, of total energy consumption in 2012, was established for the load distribution of the 11.6MW installed [8]. It is estimated that additional 2MW units will be needed in a short period of time. New generators thus will be needed which leads to higher costs and higher fuel consumption. Another alternative is applying energy conservation measures which, if adopted properly, may reduce the consumption and lead to increasing the system efficiency without affecting the comfort. Applying these measures will reduce the impacts on the environment, reduce fuel combustion, and thus emit less CO_2 emissions.

B. The Methodology

The NegaWatt power plant will be built over three stages and each stage will cover a number of tasks.

The first stage consists of data collection and monitoring in order to estimate the energy consumed. The collected data includes the total annual energy consumption (KWh) for the AUB buildings and the AUBMC, the power consumed, the air-conditioning system in each building, the lighting system used in the buildings; the type of luminaires used, their ratings , their power consumption, the lux level they provide as well as their usage schedule. It also includes the HVAC system; construction material used in the buildings, type of glass, as single or doubles glazing, and the area it occupies in each building, pumps, chillers and the occupancy schedule of buildings. All these data will be used as intuition and will enable us identifying the energy lost in order to increase the efficiency and decrease the energy consumed.

The second stage consists of analyzing the collected information and identifying the problems and the losses of energy in the existing systems. Energy conservation measures will be applied on the baseline building followed by testing and analysis. Depending on the obtained results the best alternative will be chosen. The measures and the alternatives mainly will consist of replacing the existing lighting in the buildings by more efficient ones, replacement of single glazed windows by double glazed, roof insulation and modifying the HVAC system. When the simulations are done, the total reduction obtained from the various sources will form the NegaWatt power plant.

The third stage consists of forming the NW power plant. At this stage all the simulations and enhancements would have been done. An economical study showing the comparison between a MW and a NW power plant will be done taking into consideration the capital cost, the fuel cost and the CO_2 emissions. The feasibility study will take into consideration the market prices of the above suggested alternatives and calculating the expected payback period. The results will be compared to the actual cost of the MW electrical power obtained from various fuel resources (Natural Gas, fuel oil, diesel…).

By the end of the third stage, the feasibility of a small NW power plant will be determined and will highlight the fact that the energy saving measures will assure a reduction in the annual consumption associated with a climate protection as well as being economically feasible.

C. The Design Procedure

1. 3D model of the Building

The main building of the faculty of Engineering was modeled in Visual DOE 4.0 software taking into consideration the collected data. The autocad architectural files of each floor of the building are transfered to dxf extensions as the architecture of the floor is transformed into polygones as shown in figure 1.1.

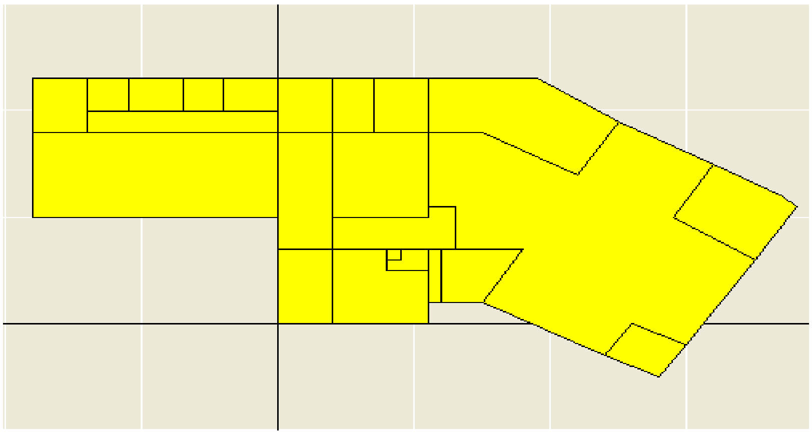

Figure 1.1 Bechtel building First Floor

Then all the polygons of all the floors were added and the 3D model of the building can now be observed in DOE software.

2. Simulating the Base Case Model of the building

The glass type, the floor, the wall, the roof, the insulation types, the lighting, the HVAC system are all selected from the DOE 2 library that corresponds to the real case scenario. For the lighting system we calculated the total lighting power density by dividing the available wattage of the lighting per zone by the total area of the zone. Using the same calculation for the equipment power density, we divide the total actual power of the equipment by the total area of the zone. The schedule of operation of the lighting, equipment and the HVAC system were fixed as well as indicating the occupancy of the rooms and then we run the modeled building. All data were inserted in zones. The zone selection varied from each floor considered as zone to each room considered as zone. The annual energy consumption of the simulate building was then compared to the actual annual consumption of the building that was provided by the power plant.

3. Applying the ECM and building the NW power plant

After building the base case model, energy conservation measures were applied to the base case model and the total reduced MWh from all the buildings constitute the NegaWatt power plant.

CHAPTER II

BECHTEL BUILDING

The Bechtel building consists of 5 levels having a total area 6,136 m^2 out of which 5,509 m^2 is a closed conditioned space mainly distributed as classrooms, offices, laboratories and library.

The building walls are of concrete block masonry construction with little or no insulation and the interior floors are mainly concrete slabs. Windows are single glazed and mounted in un-insulated aluminum or metal frames of 3 mm- thick clear glass. Windows have no sealing which allows the infiltration of outside air into the conditioned areas in large amounts. The windows total area is 873 m^2 and the conditioned area is 5,509 m^2.

The lighting system in Bechtel is mainly composed of T12 fluorescent lamps accounting for approximately 90% of the total installed luminaires where the other 10% is composed of T8, T5 fluorescents and incandescent lamps.

The HVAC system of the Bechtel building constitutes a 120 tons chiller that provides the conditioned air for the whole building. Two fixed speed 11 KW circulating pumps operate alternatively and circulate the chilled water to the fan coils. In addition, small split units are available in various rooms of the building such as the engineering lecture hall, departments and dean's office.

Various equipment are available in the building such as computers and accessories, printers, photocopiers, scanners, personal laptops, in addition to different miscellaneous equipment distributed along the building and heavy machinery in various labs (soil lab, concrete lab and soil mechanic lab) [9].

A. Building Consumption and Schedule

Table 2.1 Bechtel Monthly Energy Consumption

Month	Energy consumption (KWh)
January	42,711
February	46,161
March	49,084
April	39,577
May	58,578
June	90,737
July	90,927
August	87,599
September	87,211
October	92,995
November	67,543
December	51,515
Total	804,638

The total annual energy consumption (KWh) in 2012, and the monthly variations, for all Bechtel building is provided by the AUB Power Plant. From the data provided in table 2.1 the total annual energy consumption is 804,638 KWh.

The building energy consumption monthly variation is shown in figure 2.1.

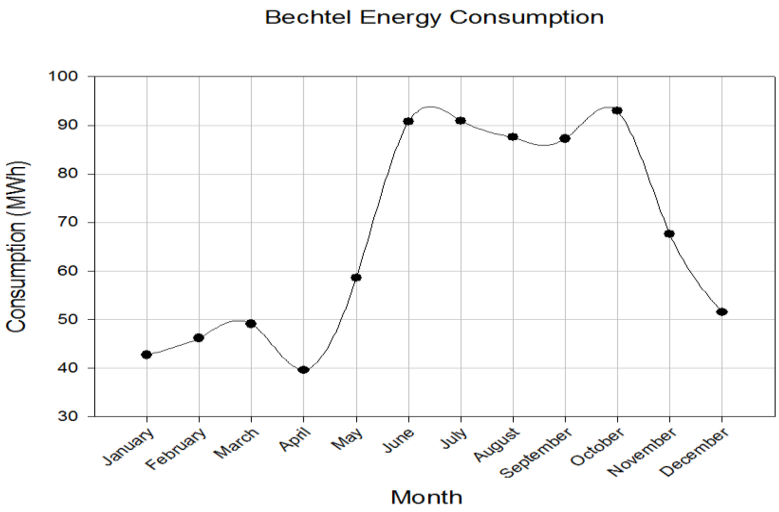

Figure 2.1 Bechtel Monthly Energy Consumption Variations

The building schedule of operation generally ranges from 7:30 am till 6:30 pm on weekdays. Make- up sessions, if any, are generally scheduled on Saturdays, and during Sundays, the building is normally closed.

The Visual DOE built base case resulted a total annual energy consumption of 773.589 MWh compared to the actual annual consumption 804.638 MWh. Hence, the base case was built with 3.86% error, which is regarded as an acceptable margin.

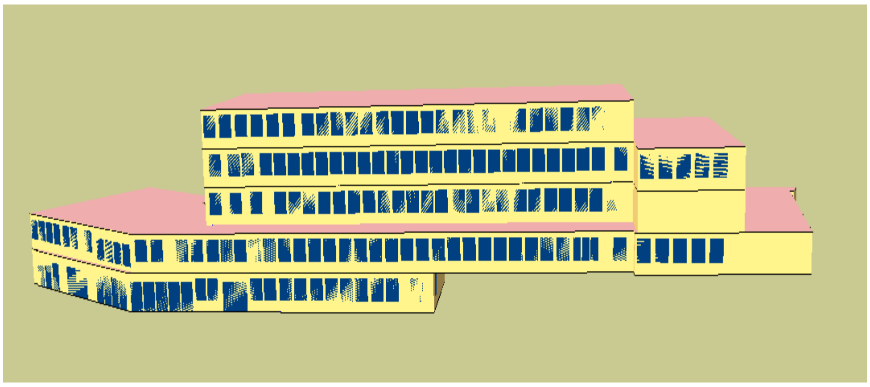

Figure 2.2 3D representation of the Bechtel Building

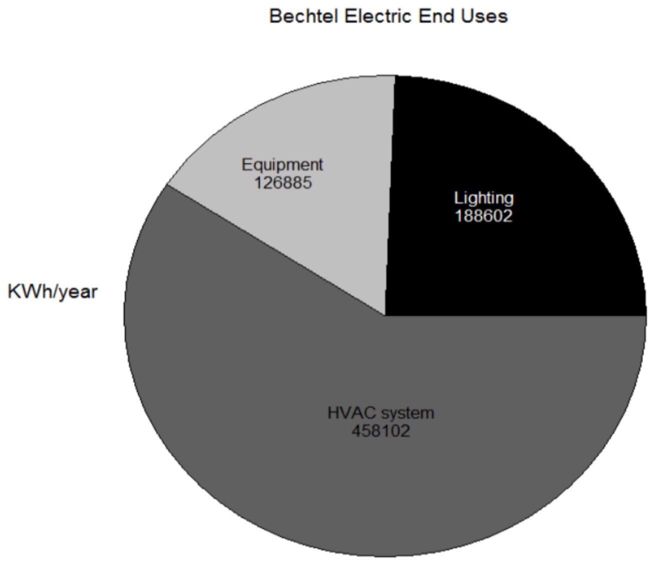

Figure 2.3 Load distribution in Bechtel building

The electric energy load in Bechtel building is distributed as shown in figure 2.3. The lighting accounts for 24.38% of the total electric consumption, various equipment accounts for 16.4% and the HVAC system accounts for 59.22% of the total electricity consumption.

B. Applying Energy Conservation Measures

1. Double Glazed windows

This measure encounters the substitution of the single glazed windows by double glazed ones. Analysis showed that the yearlong solar radiations are relatively negligible for the north facade of the Bechtel building with respect to the 3 other facades of the building (West, East and South). Therefore replacing windows on the North facade with double glazed is inefficient and unnecessary.

Replacing the windows in the un-shaded regions (South, west and East) reduces the total energy consumption by 9.583 MWh, from 773.589 MWh to 764.006 MWh which is around 1.24% of the total energy consumption.

2. *Roof insulation*

This measure involves insulating the roof of the Bechtel building. The applied measure will reduce the energy consumption of the building by 28.86 MWh, from 773.589 MWh to 744.733 MWh which accounts for 3.73% of the total energy consumption. Roof insulation was done using polystyrene thermal insulation with a thickness of 5 cm.

3. *HVAC system modification*

This measure involves the substitution of the electrical main chiller with a centrifugal water cooled chiller. In addition, it includes the substitution of the fixed speed pump that circulates the chilled water by a variable speed pump. These applied measures reduced the consumption by 36.78 MWh, from 773.589 MWh to 736.809 MWh which constitutes around 4.75% of the total energy consumption.

4. *Upgrading the lighting system*

This measure will entail the substitution of the low- efficient lighting fixtures T12 fluorescents by more efficient fixtures LED that will provide the same Lux level and the same comfort level using a lower number of lighting fixtures. In addition it will consist on replacing the incandescent fixtures by energy saving fixtures.

The lighting fixture substitution simulated in DOE will result in a consumption drop of 79.852 MWh, from 773.589 MWh to 693.737 MWh which is approximately 10.32% of the total energy consumption.

5. Overall Consumption Reduction

Combining all the previous energy conservation measures reduced the electrical consumption by a total of 151.968 MWh/year, from 773.589 MWh/year to 621.621 MWh/year which is approximately 19.64% of the total energy consumption.

$$\text{KW saved} = \frac{Total\ energy\ consumption\ (KWh)}{number\ of\ hours}$$

$$= \frac{151{,}968}{298\frac{days}{year} \times 11\frac{hours}{day}} = 46.36\ \text{KW.}$$

The load factor is based on the number of working days and working hours as the building schedule of operation ranges from 7:30 am till 6:30 pm.

C. Summary of the Results

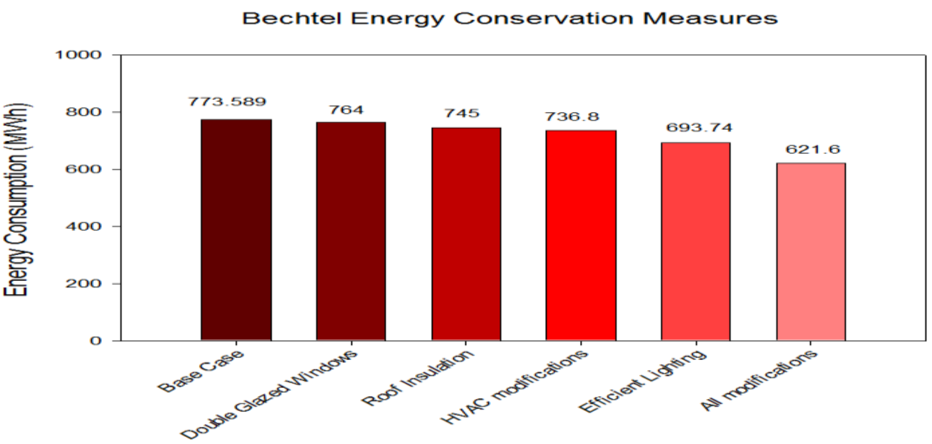

Figure 2.4 Bechtel Energy Conservation Measures

D. Savings Estimate

1. The cost of new equipment

- Cost of the double glazed windows = area of the windows (m^2) × cost of double glazing ($\$/m^2$)

  = area of the window on (east, west and south) facades × cost of DG window

  = (111+ 93+ 263) m^2 ×23 $\$/m^2$ = 10,741$

- Cost of the water cooled chiller is 100,000$
- Cost of the variable-speed drive = 75$
- The cost of the efficient lighting = Number of long LED (120 cm) × cost $ + number of energy saving lamp× cost $ + number of compact fluorescents (21 W) × cost $ + number of compact fluorescents (7 W) × cost $

  = 544 ×50$ + 15×10$ +8×20$ + $10×7 = 27,580$

- Cost of roof insulation = cost of polystyrene thermal insulation ($) × area of the roof ($m^2$)

  = 5$\$/m^2$ × 961.3 m^2 = 4,806.5$

- The total cost of the 46.36 KW = cost of double glazed windows + cost of water cooled chiller + cost of variable speed drive + cost of efficient lighting + cost of roof insulation

  = 10,741 + 100,000 + 75 + 27,580 + 4,807 = 143,203$

2. The replacement cost

- The cost of the single windows area of the windows (m^2) × cost of single glazing ($\$/m^2$)

= area of the window on (east, west and south) facades × cost of SG window

= (111+ 93+ 263) m^2 ×9 $/$m^2$ = 4,203$

- The cost of the installed lighting = cost of T12 (2×40 W) $ × number of lamps + cost of T12 (4×40 W) × number of lamps + cost of T12 (3×40 W) × number of lamps + cost of T12 (4×20 W) × number of lamps + cost of T12 (3×20 W) × number of lamps + cost of incandescent lamps × numbers of lamps + cost of T12 (1×10w) × number of lamps.

  = 114×50.27$+ 66×99$ +3×75$ +8×57.2$+ 6×43$+ 15×3$+ 8×2$+ 1×14$ = 13,280$

- The cost of the 120 tones installed air cooled chiller costs approximately 63,000$

- The replacement cost of the 46.36 KW will be:

Cost of (DGW – SGW) + (water cooled chiller-air cooled chiller) + (LED – T12 lamps) + variable speed drive + roof insulation

= (10,741-4,203)+ (100,000-63,000)+(27,580-13,280) + 75 + 4,807= 62,720 $

CHAPTER III

THE CHEMISTRY BUILDING

The Chemistry building consists of 6 levels having a total area 6,230 m^2 out of which 5,360 m^2 is a closed conditioned space mainly distributed as classrooms, offices, laboratories, lecture halls and store rooms.

The building walls are of concrete block masonry construction with little or no insulation and the interior floors are mainly concrete slabs. There exist two types of windows in the building: single glazed and mounted in un-insulated aluminum or metal frames of 3 mm- thick clear glass, and double glazed windows of 3 mm- thick clear glass mounted in un-insulated aluminum frame. Windows have no sealing which allows the infiltration of outside air into the conditioned areas in large amounts. The windows total area is 908 m^2 and the conditioned area is 5,360 m^2.

The lighting system in the chemistry building is mainly composed of low efficient T12 fluorescent lamps accounting for approximately 98.23% of the total installed luminaires where the other 1.76% is composed of T8 fluorescents.

The HVAC system constitutes a 120 KW chiller that provides the conditioned air for the whole building in addition to a 16 KW chiller serving the lecture hall in the basement.

Various equipment are available in the building such as computers and accessories, printers, photocopiers, scanners, personal laptops and lab equipment, in addition to different miscellaneous equipment distributed along the building [10].

A. Building Consumption and Schedule

Table 3.1 Chemistry Monthly Energy Consumption

Month	Energy consumption (KWh)
January	31,693
February	30,558
March	27,554
April	23,668
May	24,063
June	62,519
July	83,170
August	98,152
September	95,775
October	76,772
November	67,281
December	36,116
Total	657,321

The total annual energy consumption (KWh) in 2012, and the monthly variations, for all the chemistry building is provided by the AUB Power Plant. From the data provided in table 3.1 the total annual energy consumption is 657,321 KWh.

The building energy consumption monthly variation is shown in figure 3.1.

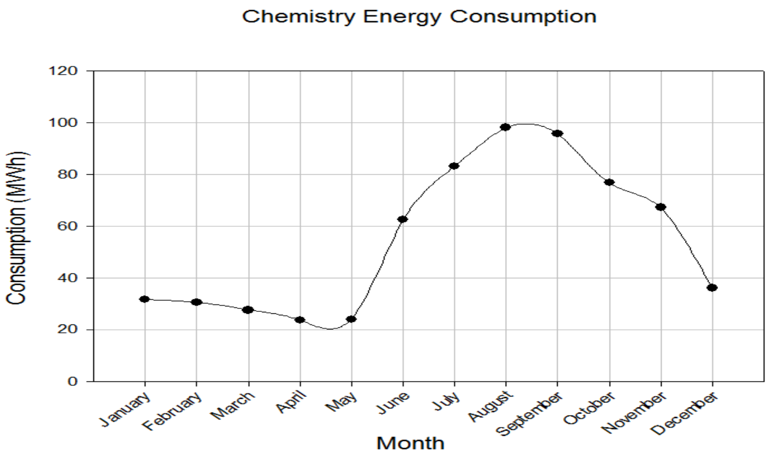

Figure 3.1Chemistry Monthly Energy Consumption

The building schedule of operation generally ranges from 8 am till 7 pm on weekdays.

The Visual DOE built base case resulted a total annual energy consumption of 657.32 MWh compared to the actual annual consumption 582.65 MWh noting that the equipment power density was doubled in each floor since the data collection was done in 2008 yet the lighting and the HVAC system was not modified but more equipment were bought. Hence the base case was built with 11.37% error, which is regarded as acceptable margin.

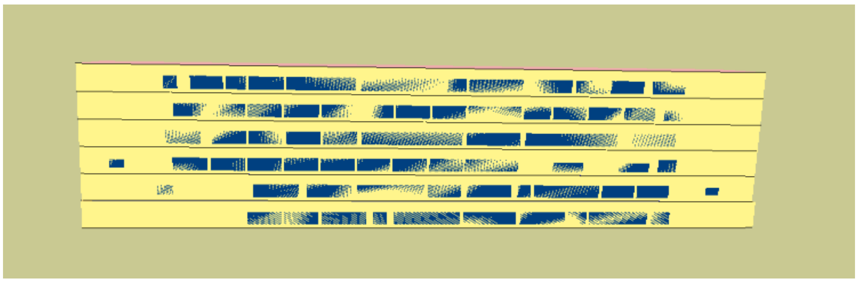

Figure 3.2 3D representation of the Chemistry Building

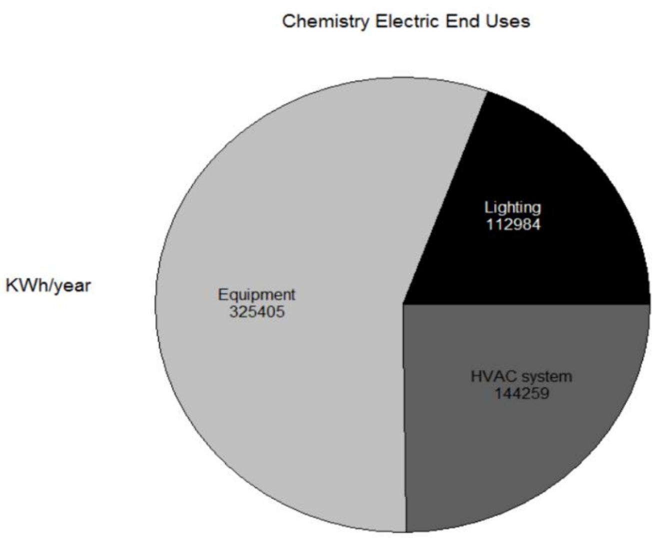

Figure 3.3 Load distribution in Chemistry building

The electric energy load in the chemistry building is distributed as shown in figure 3.3. The lighting accounts for 19.4% of the total electric consumption, various equipment accounts for 55.84% and the HVAC system accounts for 24.76% of the total electricity consumption.

B. Applying Energy Conservation Measures

1. Double Glazed windows

The windows of the chemistry building are divided into two categories single glazed windows and double glazed windows. Analyses showed that the single glazed windows are shaded facing the woods. Replacing the windows is useless and thus will not help reducing the energy consumption.

2. Roof insulation

The applied measure will reduce the energy consumption of the Chemistry building by 18.437 MWh, from 582.65 MWh to 564.213 MWh which accounts for 3.16% of the total energy consumption. Roof insulation was done using polystyrene thermal insulation with a thickness of 5 cm.

3. Upgrading the lighting system

The lighting fixture substitution simulated in DOE will result in a consumption drop of 79.06 MWh, from 582.65 MWh to 503.59 MWh which is approximately 13.57% of the total energy consumption.

4. Overall Consumption Reduction

Combining all the previous energy conservation measures and taking into consideration the reduction in the infiltration rate reduced the electrical consumption by a total of 53.6 MWh/year, from 582.65 MWh/year to 529.05 MWh/year which is approximately 9.2% of the total energy consumption.

$$\text{KW saved} = \frac{Total\ energy\ consumption\ (KWh)}{number\ of\ hours}$$

$$= \frac{53\ 600}{298\frac{days}{year} \times 11\frac{hours}{day}} = 16.35\ \text{KW}$$

The building load factor depends on the building schedule of operation that ranges from 8 till 7 pm.

C. Summary of the results

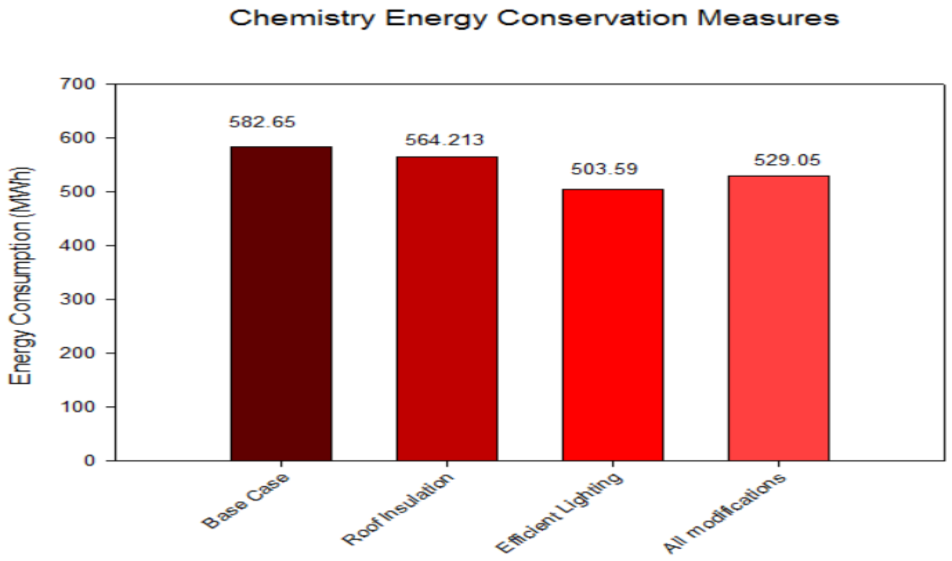

Figure 3.4 Chemistry Energy Conservation Measures

D. Savings Estimate

1. The cost of new equipment

- Cost of roof insulation = cost of polystyrene thermal insulation ($) × area of the roof ($m^2$)

$$= 5\$/m^2 \times 877.166 = 4,385.83\ \$$$

- The cost of the efficient lighting = Number of LED (120 cm) × cost ($)

$$= (659) \times 50\$ = 32,950\ \$$$

- The total cost of the 16.35 KW = cost of the insulated roof + cost of efficient lighting

$$= 4,386 + 32,950 = 37,335.83\ \$.$$

2. The replacement cost

- The cost of the installed lighting = cost of T12 (2 ×40W) × number of lamps + cost of T12 (1×40W) × number of lamps + cost of T12 (4×40W) × number of lamps + cost of T12 (2×20W) × number of lamps + cost of T12 (3×40W) × number of lamps + cost of T12 (2×34W) × number of lamps + cost of T12 (4×34W) × number of lamps + cost of T12 (3×34W) × number of lamps

  = 110× 50.27$ + 20×22$ + 99$×66 + 28.6$ × 20+11×75$+22×50.27 $+4×99$ + 7×75= 15,928$

- The replacement cost of the 16.35 KW will be:

  Cost of (LED – T12 lamps) + roof insulation

  = 4,386+ (32,950-15,928) = 21,408$

CHAPTER IV

THE VAN DYCK BUILDING

The Van Dyck building consists of 4 levels having a total area 6,154 m^2 out of which 5,378 m^2 is a closed conditioned space mainly distributed as classrooms, offices and laboratories.

The building walls are of concrete block masonry construction with little or no insulation and the interior floors are mainly concrete slabs. Windows in the building are single glazed and mounted in un-insulated aluminum of 3 mm- thick clear glass. Windows have no sealing which allows the infiltration of outside air into the conditioned areas in large amounts. The windows total area is 987 m^2 and the conditioned area is 5,360 m^2.

The lighting system in the chemistry building is mainly composed of low efficient T12 fluorescent lamps accounting for approximately 58.2% of the total installed luminaires where the other 38.3% is composed of T8 fluorescents and the remaining 3% are light bulbs.

The HVAC system constitutes a 8.64 KW chiller that provides the conditioned air for the whole building shared by many buildings in addition to various split units available in the building. Two fixed speed 11 KW circulating pumps operate alternatively and circulate the chilled water to the fan coils [11].

Various equipment are available in the building such as computers and accessories, printers, photocopiers, scanners, personal laptops, lab equipment, in addition to different miscellaneous equipment distributed along the building.

A. Building Consumption and Schedule

Table 4.1 Van Dyck Monthly Energy Consumption

Month	Energy consumption (KWh)
January	111,2480
February	125,0600
March	109,9790
April	108,0040
May	125,0220
June	148,7460
July	143,2990
August	167,2110
September	163,6390
October	144,8060
November	143,5360
December	111,3490
Total	1,601,899

From the data provided in table 4.1 the total annual energy consumption is 1,601,899 KWh.

The building energy consumption monthly variation is shown in figure 4.1.

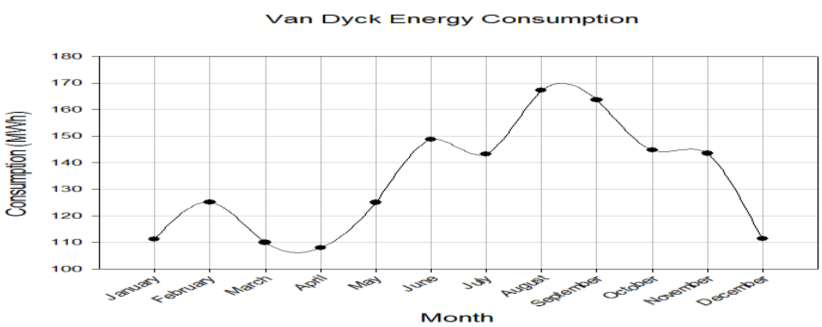

Figure 4.1Van Dyck Monthly Energy Consumption

The building schedule of operation generally ranges from 8 am till 6 pm on weekdays.

The Visual DOE built base case resulted a total annual energy consumption of 1,216.577 MWh compared to the actual annual consumption 1,601.899 MWh noting that the equipment power density was doubled in each floor since the data collection was done in 2007 yet the lighting and the HVAC system was not modified but more equipment were bought. Hence the base case was built with 24.05% error.

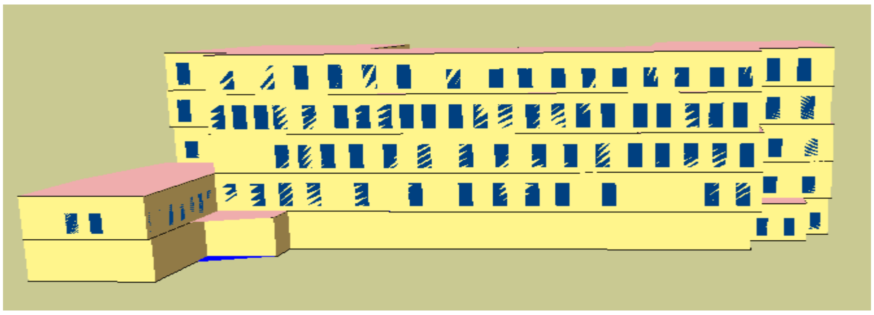

Figure 4.2 3D representation of the Van Dyck Building

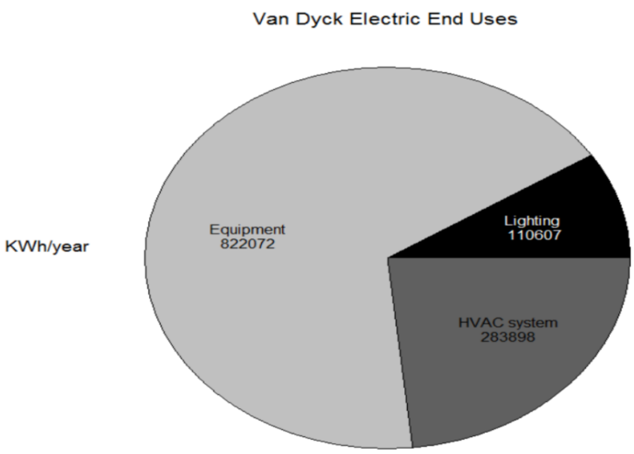

Figure 4.3 Load distribution in Van Dyck building

The electric energy load in Bechtel building is distributed as shown in figure 4.3. The lighting accounts for 10% of the total electric consumption, various equipment accounts for 67.57% and the HVAC system accounts for 22.43% of the total electricity consumption.

B. Applying Energy Conservation Measures

1. Double Glazed windows

Applying double glazed windows on the South and the West facades will reduce the energy consumption by 11.062 MWh, from 1,216.577 MWh to 1,205.515 MWh which accounts for 0.91% of the total energy consumption.

2. Roof insulation

The applied measure will reduce the energy consumption of the building by 18.437 MWh, from 1,216.577 MWh to 1,216.081 MWh which accounts for 0.04% of the total energy consumption.

3. Upgrading the lighting system

The lighting fixture substitution simulated in DOE will result in a consumption drop of 43.233 MWh, from 1,216.577 MWh to 1,173.344 MWh which constitutes 3.55% of the total energy consumption.

4. HVAC system modification

This measure involves the substitution of the electrical main chiller with a centrifugal water cooled chiller. In addition, it includes the substitution of the fixed speed pump that circulates the chilled water by a variable speed pump. These applied measures reduced the consumption by 38.58 MWh, from 1,216.577 MWh to 1,178.001 MWh which constitutes around 3.17% of the total energy consumption.

5. Overall Consumption Reduction

Combining all the previous energy conservation measures and taking into consideration the reduction in the infiltration rate reduced the electrical consumption by a total of 172.138 MWh/year, from 1,216.577 MWh/year to 1,044.439 MWh/year which is approximately 14.15% of the total energy consumption.

$$\text{KW saved} = \frac{Total\ energy\ consumption\ (KWh)}{number\ of\ hours}$$

$$= \frac{172{,}138}{298\frac{days}{year} \times 11\frac{hours}{day}} = 52.51\ \text{KW}.$$

The load factor depends on the schedule of operation of the building which ranges from 8 am till 6 pm.

C. Summary of the results

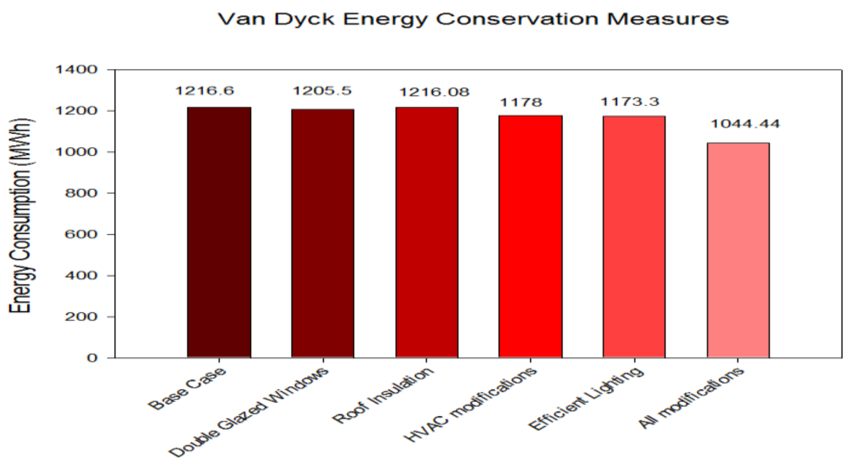

Figure 4.4 Van Dyck Energy Conservation Measures

D. Savings Estimate

1. *The cost of new equipment*

Cost of the double glazed windows = area of the windows (m^2) × cost of double glazing ($\$/m^2$)

= area of the window on (south and west) facades × cost of DG window

= (181 + 203) m^2 × 23$/ m^2 = 8,832 $

- Cost of roof insulation = cost of polystyrene thermal insulation ($) × area of the roof ($m^2$)

= 5$/ m^2 × 1280.79 m^2 = 6,403.95 $

Cost of the water cooled chiller = 2000$

Cost of the variable speed drive =75$

Cost of the efficient lighting = number of LED (120 cm) × cost ($) + number of LED (60 cm) × cost ($) + number of energy savings lamp × cost ($)

= 50$ × (590) + 40$ ×30 + 10$ × 50 = 31,200 $

- The total cost of the 52.51 KW = cost of double glazed windows + cost of roof insulation + cost of water cooled chiller + cost of variable speed drive + cost of efficient lighting

= 8,832 +6,403.95 + 2,000 + 75 + 31,200 = 48,511 $

2. The replacement cost

- The cost of the single windows area of the windows (m^2) × cost of single glazing (\$/m^2)

= area of the window on (south and west) facades × cost of SG window

= (181 + 203) m^2 × 9 \$/ m^2 = 3,456\$

- Cost of the installed lighting = number of T12 (2×40W) × cost (\$) + number of T12 (4×40W) × cost (\$) + number of T12 (4×20W) × cost (\$) + number of light bulbs × cost (\$)

= 288 ×50.27\$+4×99\$+8×57.2\$+50\$ = 15,381\$

Cost of the air cooled installed chiller around 1,313\$

The replacement cost of the 52.51 KW will be:

Cost of (DGW – SGW) + (water cooled chiller-air cooled chiller) + (LED – T12 lamps) + variable speed drive + roof insulation

(8,832-3,456)+6,403.95+ (2,075-1,313) + (31,200-15,381) = 28,361\$

CHAPTER V

BIOLOGY BUILDING

The Biology building consists of 4 levels having a total area 3,212 m^2 out of which 2,757 m^2 is a closed conditioned space mainly distributed as classrooms, offices, storerooms and laboratories.

The building walls are of concrete block masonry construction with little or no insulation and the interior floors are mainly concrete slabs. Windows in the building are of two types: single glazed windows mounted in un-insulated aluminum of 3 mm- thick clear glass located in the south and north facades of the building and double glazed windows mounted in un-insulated aluminum of 6 mm- thick clear glass located in the east façade in addition to some rooms in the south façade. Windows have no sealing which allows the infiltration of outside air into the conditioned areas in large amounts. The windows total area is 782 m^2 and the conditioned area is 2,757 m^2.

The lighting system in the Biology building is mainly composed of low efficient T12 fluorescent lamps accounting for approximately 83% of the total installed luminaires where the other 27% is composed of T8, T5 fluorescents and incandescent lamps.

The HVAC system is composed of split units available in all rooms. The pumps and the water pipes circulate the steam from the steam heating coils to provide the hot water to the 4 existing fan coils. Steam supply is controlled manually by an installed valve available in the basement.

Various equipment are available in the building such as computers and accessories, printers, photocopiers, scanners, personal laptops and lab equipment, in addition to different miscellaneous equipment distributed along the building [12].

A. Building Consumption and Schedule

Table 5.1 Biology Monthly Energy Consumption

Month	Energy consumption (KWh)
January	33,5950
February	30,5530
March	35,8500
April	41,8810
May	52,7640
June	71,9420
July	80,5950
August	75,9560
September	87,6940
October	75,7900
November	62,0930
December	44,6790
Total	693,392

From the data provided in table 4 the total annual energy consumption is 693,392 KWh.

The building energy consumption monthly variation is shown in figure 5.1.

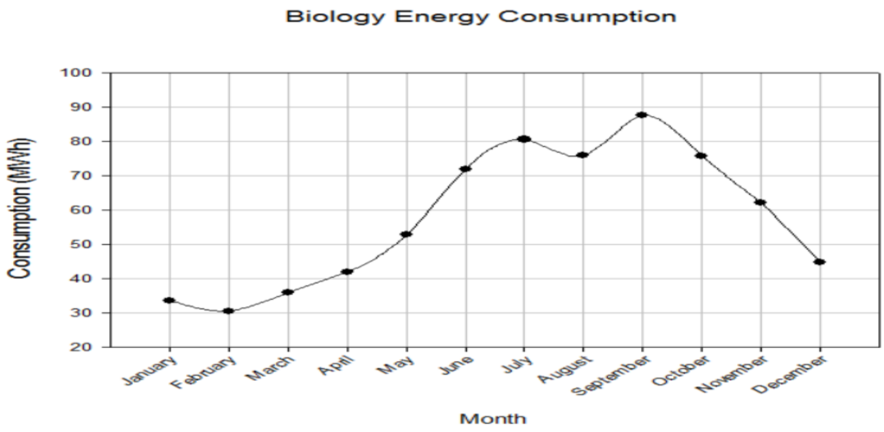

Figure 5.1Biology Monthly Energy Consumption

The building schedule of operation generally ranges from 7 am till 8 pm on weekdays.

The Visual DOE built base case resulted a total annual energy consumption of 626.571 MWh compared to the actual annual consumption 693.392 MWh noting that the equipment power density was multiplied by 1.8 in each floor since the data collection was done in 2007 yet the lighting and the HVAC system was not modified but more equipment were bought. Hence the base case was built with 10.45% error which is an acceptable margin.

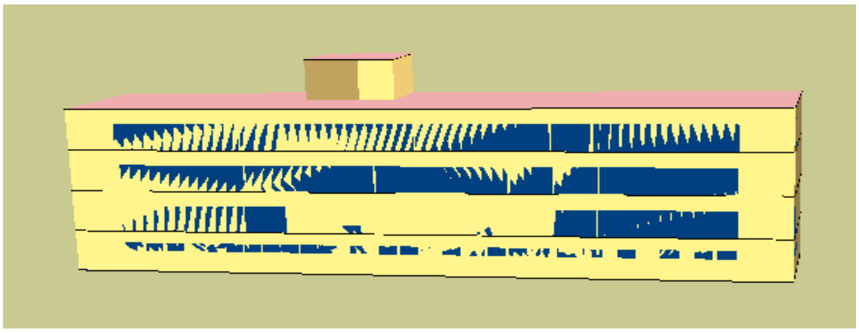

Figure 5.2 3D representation of the Biology building

The load in Biology building is distributed as follows

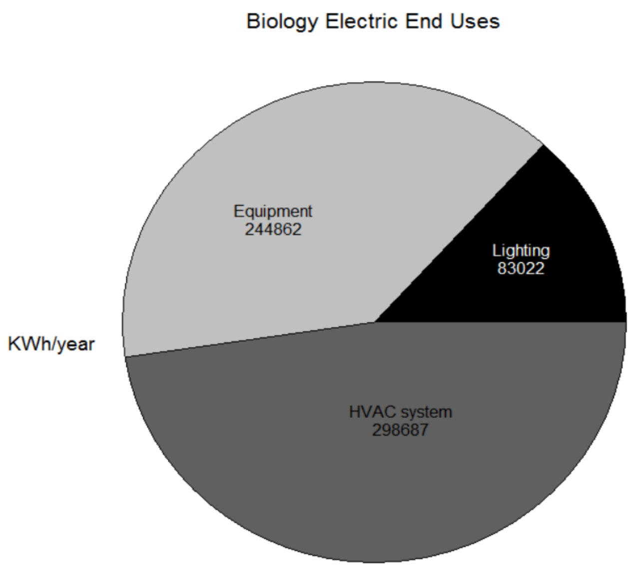

Figure 3.3 Load distribution in Biology building

The electric energy load in Bechtel building is distributed as shown in figure 5.3. The lighting accounts for 13.25% of the total electric consumption, various equipment accounts for 39.08% and the HVAC system accounts for 47.67% of the total electricity consumption.

B. Applying Energy Conservation Measures

1. Double Glazed windows

Applying double glazed windows on the South and the North facades will reduce the energy consumption by 2.355 MWh, from 626.571 MWh to 624.216 MWh which accounts for 0.38% of the total energy consumption.

2. Roof insulation

The applied measure will reduce the energy consumption of the building by 31.93 MWh, from 626.571 MWh to 594.642 MWh which accounts for 5.1% of the total energy consumption.

3. Upgrading the lighting system

The lighting fixture substitution simulated in DOE will result in a consumption drop of 48.911 MWh, from 626.571 MWh to 577.660 MWh which constitutes 7.8% of the total energy consumption.

4. Overall Consumption Reduction

Combining all the previous energy conservation measures and taking into consideration the reduction in the infiltration rate reduced the electrical consumption by a total of 101.029 MWh/year from 626.571 MWh/year to 525.542 MWh/year which is approximately 16.12% of the total energy consumption.

$$\text{KW saved} = \frac{Total\ energy\ consumption\ (KWh)}{number\ of\ hours}$$

$$= \frac{101.029}{298\frac{days}{year} \times 13\,\frac{hours}{day}} = 26.08\ \text{KW.}$$

The load factor depends on the building schedule of operation which ranges from 7 am till 8 pm.

C. Summary of the results

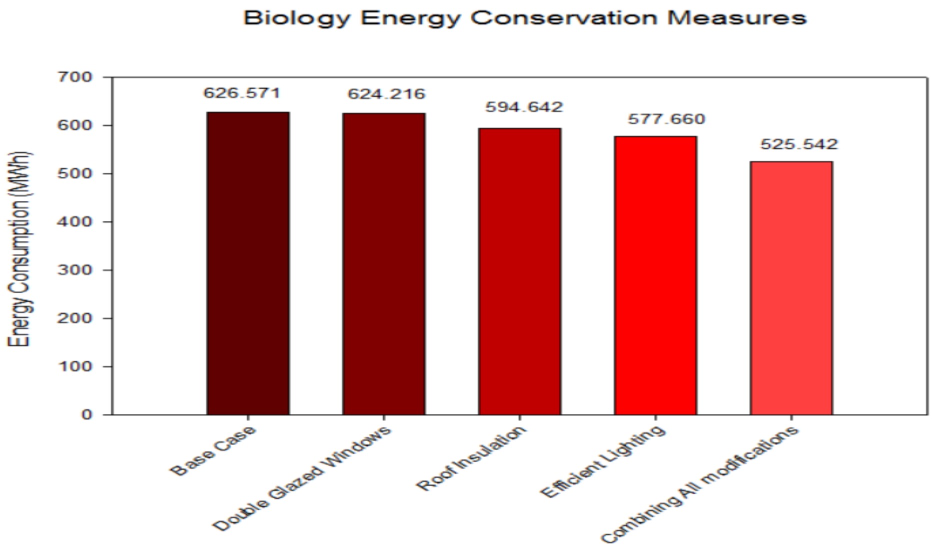

Figure 5.4 Biology Energy Conservation Measures

D. Savings Estimate

1. The cost of new equipment

- Cost of the double glazed windows = area of the windows (m^2) × cost of double glazing ($\$/m^2$)

  = area of the window on (south and north) facades × cost of DG window

  = (255 + 357) m^2 ×23 $\$/m^2$ = 14,076 $

- Cost of roof insulation = cost of polystyrene thermal insulation ($) × area of the roof ($m^2$)

  = 5$\$/m^2$ × (790.56 + 50) m^2 = 4,202.8 $

- Cost of the efficient lighting = number of LED (120 cm) × cost ($) + number of LED (60 cm) × cost ($) + number of energy savings lamp × cost ($)

= (527) × 50\$ + 28 × 40\$ + (15) × 10\$ = 27,620\$

- The total cost of the 26.08 KW = cost of double glazed windows + cost of roof insulation + cost of the efficient lighting

= 14,076 + 4,202.8 + 27,620 = 45,900 \$

2. The replacement cost

- The cost of the single windows area of the windows (m^2) × cost of single glazing (\$/m^2)

= area of the window on (south and north) facades × cost of SG window

= (255 + 357) m^2 × 9 \$/m^2 = 5,508\$

- The cost of the installed lighting = number of T12 (2×40W) × cost (\$) + number of T12 (4×34W) × cost (\$) + number of incandescent lamps × cost (\$) + number of T12 (4×20W) × cost (\$)

= 256×50.27\$+4×99\$+12\$+3\$+7×57.2\$ = 13,681\$

- The replacement cost of the 26.08 KW will be:

Cost of (DGW – SGW) + roof insulation + (LED – T12 lamps)

= (14,076-5,508) + 4,203 + (27,620-13,681) = 26,710\$

CHAPTER VI

BLISS HALL BUILDING

The Bliss Hall building consists of 3 levels having a total area 3,121 m^2 out of which 2,381 m^2 is a closed conditioned space mainly distributed as classrooms, offices and laboratories.

The building walls are of stone block masonry construction with little or no insulation and the interior floors are mainly concrete slabs. Windows in the building are single glazed and mounted in un-insulated aluminum of 6 mm- thick clear glass. Windows have no sealing which allows the infiltration of outside air into the conditioned areas in large amounts. The windows total area is 542 m^2 and the conditioned area is 2,381 m^2.

The lighting system in the Bliss Hall building is mainly composed of low efficient T12 fluorescent lamps accounting for approximately 85.3% of the total installed luminaires where the other 14.7% is composed of T8 and T5 fluorescents.

The HVAC system of the Bliss Hall building constitutes a 70 tons chiller that provides the conditioned air for the whole building. Two operated and one standby fixed speed 4 KW circulating pumps circulate the chilled water to the fan coils. In addition, small split units are available in various rooms of the building.

Various equipment are available in the building such as computers and accessories, printers, photocopiers, scanners, personal laptops and projectors distributed along the building [13].

A. Building Consumption and Schedule

Table 6.1 Bliss Hall Energy Consumption

Month	Energy consumption (KWh)
January	20,3840
February	13,9690
March	13,7920
April	16,2770
May	16,9010
June	39,5940
July	48,8160
August	67,7380
September	53,5700
October	49,8000
November	43,6720
December	15,2460
Total	399,759

From the data provided in table 6.1 the total annual energy consumption is 399,759 KWh.

The building energy consumption monthly variation is shown in figure 6.1.

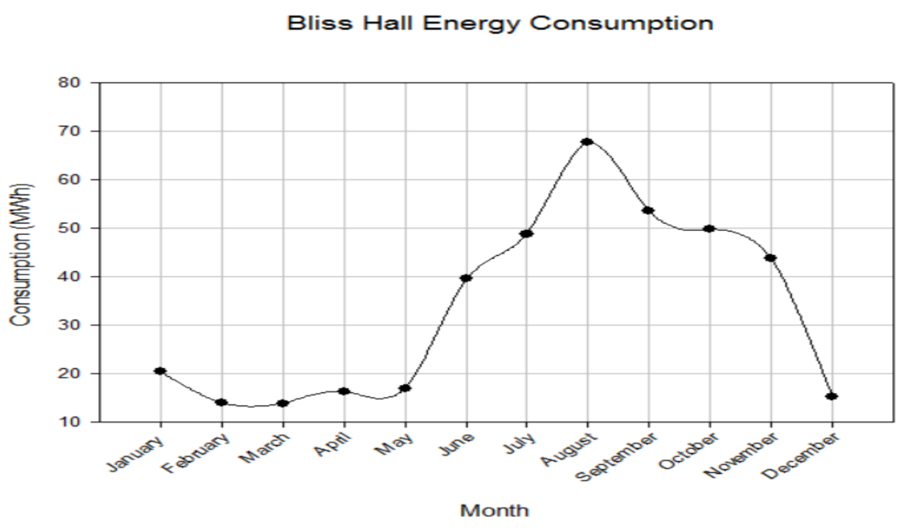

Figure 6.1Bliss Hall Energy Consumption

The building schedule of operation generally ranges from 7 am till 9 pm on weekdays.

The Visual DOE built base case resulted a total annual energy consumption of 382.033 MWh compared to the actual annual consumption 399.759 MWh. Hence the base case was built with 4.43% error, which is regarded as an acceptable margin.

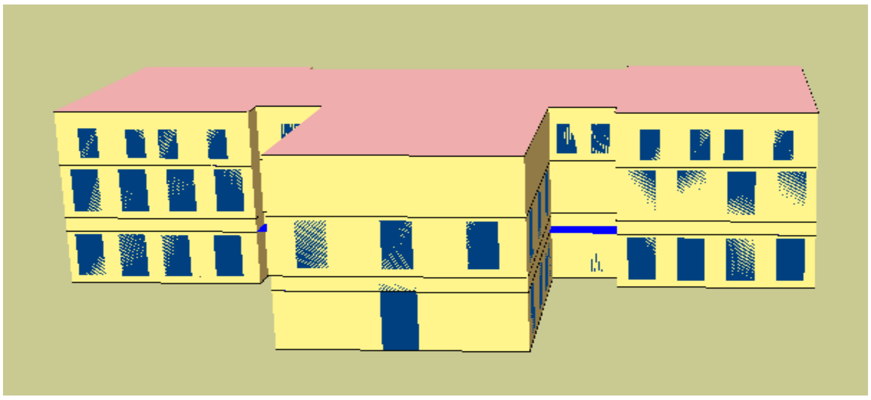

Figure 6.2 3D representation of the Bliss Hall building

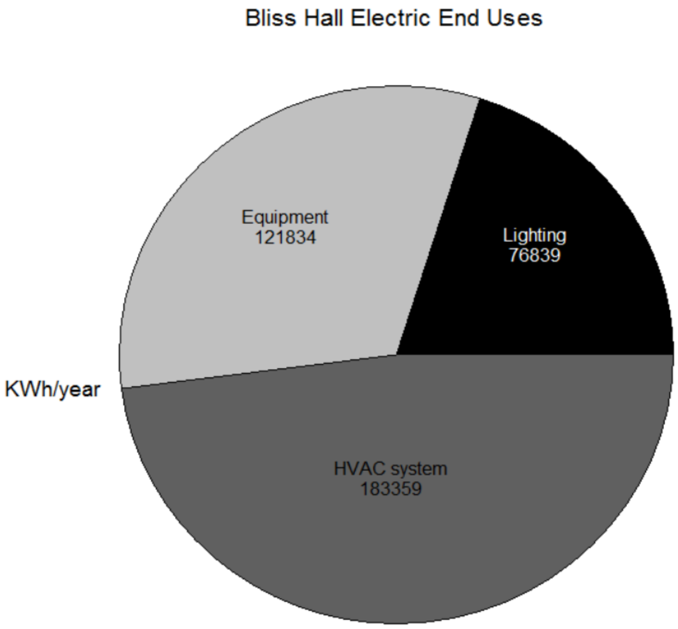

Figure 4.3 Load distribution in Bliss Hall building

The electric energy load in Bechtel building is distributed as shown in figure 6.3. The lighting accounts for 20.11% of the total electric consumption, various equipment accounts for 31.89% and the HVAC system accounts for 48% of the total electricity consumption.

B. Applying Energy Conservation Measures

1. Double Glazed windows

Applying double glazed windows on the East and the West facades will reduce the energy consumption by 24.008 MWh, from 382.033 MWh to 358.025 MWh which accounts for 6.28% of the total energy consumption.

2. Upgrading the lighting system

The lighting fixture substitution simulated in DOE will result in a consumption drop of 40.468 MWh, from 382.033 MWh to 341.565 MWh which is approximately 10.6% of the total energy consumption.

3. Modifying the HVAC system

By adding a variable speed drive to the fixed speed pumps will result in a decrease of 0.661 MWh, from 382.033 MWh to 341.372 MWh which is approximately 0.173% of the total energy consumption.

4. Overall Consumption Reduction

Combining all the previous energy conservation measures and taking into consideration the reduction in the infiltration rate reduced the electrical consumption by a total of 53.81 MWh/year, from 382.033 MWh/year to 328.223 MWh/year which is approximately 14.08% of the total energy consumption.

$$\text{KW saved} = \frac{Total\ energy\ consumption\ (KWh)}{number\ of\ hours}$$

$$= \frac{53.81}{298\frac{days}{year} \times 14\,\frac{hours}{day}} = 12.9\text{ KW.}$$

The load factor depends on the schedule of operation of the building which ranges from 7 am till 9 pm.

C. Summary of the results

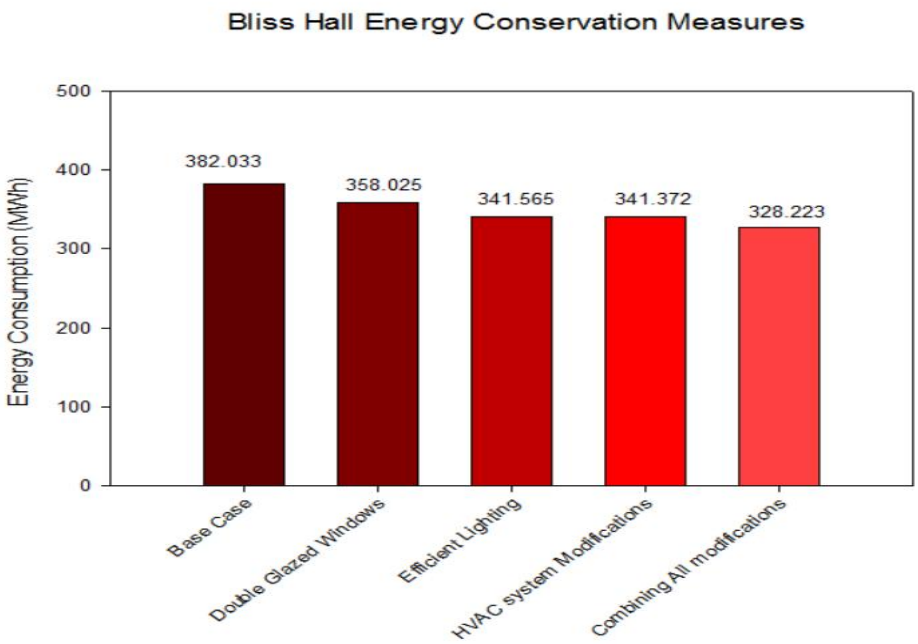

Figure 6.4 Bliss Hall Energy Conservation Measures

D. Savings Estimate

1. The cost of new equipment

- Cost of the double glazed windows = area of the windows (m^2) × cost of double glazing ($\$/m^2$)

  = area of the window on (East and west) facades × cost of DG window

  = 23 $\$/m^2 \times (111 + 111)\ m^2$ = 5,106 $

- Cost of the efficient lighting = number of LED (120 cm) × cost ($)

  = 50$ × (244 + 51) = 14,750 $

- The cost of variable speed drive = 75$
- The total cost of the 12.9 KW = cost of double glazed windows + cost of efficient lighting + cost of variable speed drive

  = 5,106+ 14,750 + 75 = 19,931$

2. The replacement cost

- The cost of the single windows area of the windows (m^2) × cost of single glazing ($\$/m^2$)

  = area of the window on (east and west) facades × cost of SG window

  = 9 $\$/m^2 \times (111 + 111)\ m^2$ = 1,998 $

- Cost of the installed lamps = number of T12 (2× 40W) × cost ($) + number of T12 (4×40W) × cost ($)

  = 122×50.27$+40×99$=10,093$

- The replacement cost of the 12.9 KW will be:

Cost of (DGW – SGW) + (LED – T12 lamps) + variable speed drive

= (5,106-1,998) + (14,750-10,093) + 75 = 7,840$

CHAPTER VII

THE PHYSICS BUILDING

The Physics building consists of 4 levels having a total area 4,908 m^2 out of which 2,972 m^2 is a closed conditioned space mainly distributed as classrooms, offices and laboratories.

The building walls are of concrete block masonry construction with little or no insulation and the interior floors are mainly concrete slabs. There exist two types of windows in the building: single glazed windows located on the south and west facades mounted in un-insulated aluminum or metal frames of 3 mm- thick clear glass, and double glazed windows of 6 mm- thick clear glass mounted in un-insulated aluminum frame located on the east and north facades. Windows have no sealing which allows the infiltration of outside air into the conditioned areas in large amounts. The windows total area is 401 m^2 and the conditioned area is 2,972 m^2.

The lighting system in the Physics building is mainly composed of low efficient T12 fluorescent lamps accounting for approximately 81.25% of the total installed luminaires where the other 18.75% is composed of T8 fluorescents.

The HVAC system is composed of split units available in all rooms. The pumps and the water pipes circulate the steam from the steam heating coils to provide the hot water to the 4 existing fan coils. Steam supply is controlled manually by an installed valve available in the basement. Two rooftop chillers provide the conditioned air for the whole building alternatively at a constant flow rate without taking into consideration the load on the cooling system.

Various equipment are available in the building such as computers and accessories, printers, photocopiers, scanners, personal laptops, projectors and lab equipment distributed along the building [14].

A. Building Consumption and Schedule

Table 7.1 Physics Monthly Energy Consumption

Month	Energy consumption (KWh)
January	34,3690
February	38,4780
March	35,0260
April	40,3610
May	39,1650
June	36,2330
July	49,0110
August	49,2130
September	45,3840
October	35,4060
November	10,3190
December	24,8840
Total	437,849

From the data provided in table 7.1 the total annual energy consumption is 437,849 KWh.

The building energy consumption monthly variation is shown in figure 7.1.

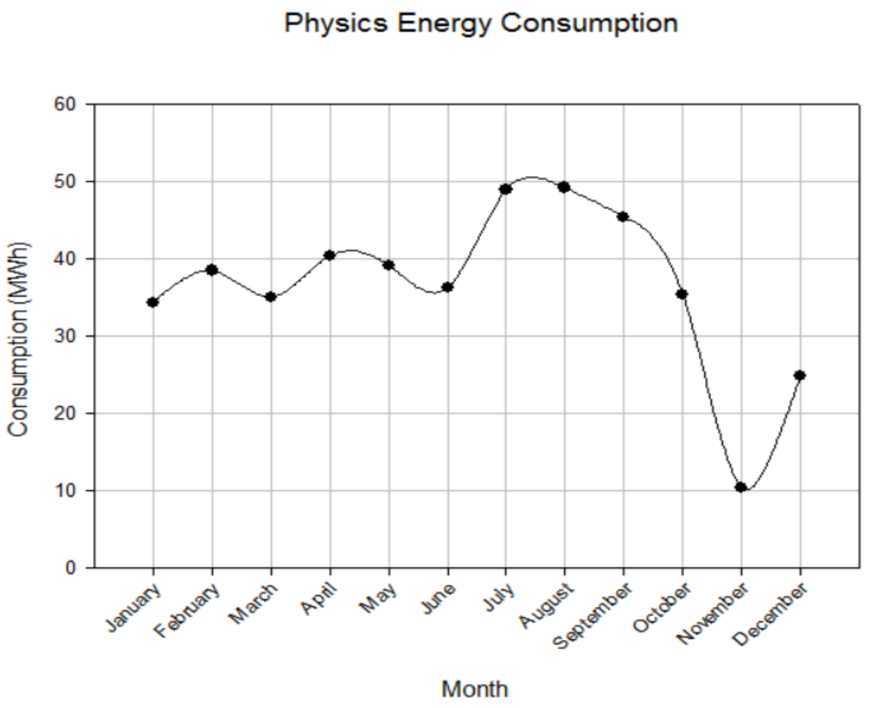

Figure 7.1 Physics Monthly Energy Consumption

The building schedule of operation generally ranges from 8 am till 8 pm on weekdays.

The Visual DOE built base case resulted a total annual energy consumption of 403.295 MWh compared to the actual annual consumption 437.849 MWh. Hence the base case was built with 7.89% error, which is regarded as an acceptable margin.

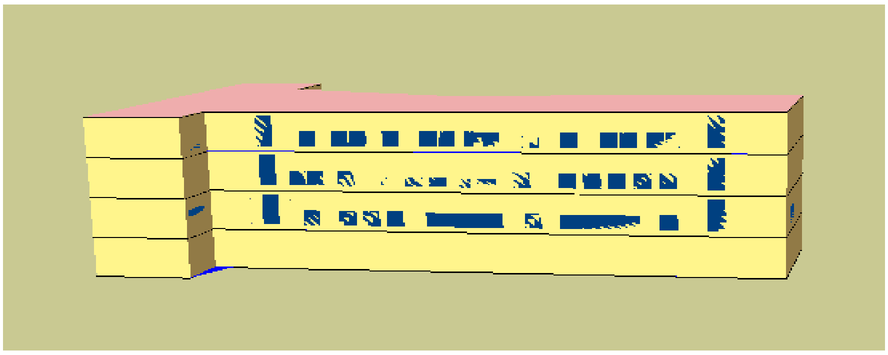

Figure 7.2 3D representation of the Physics building

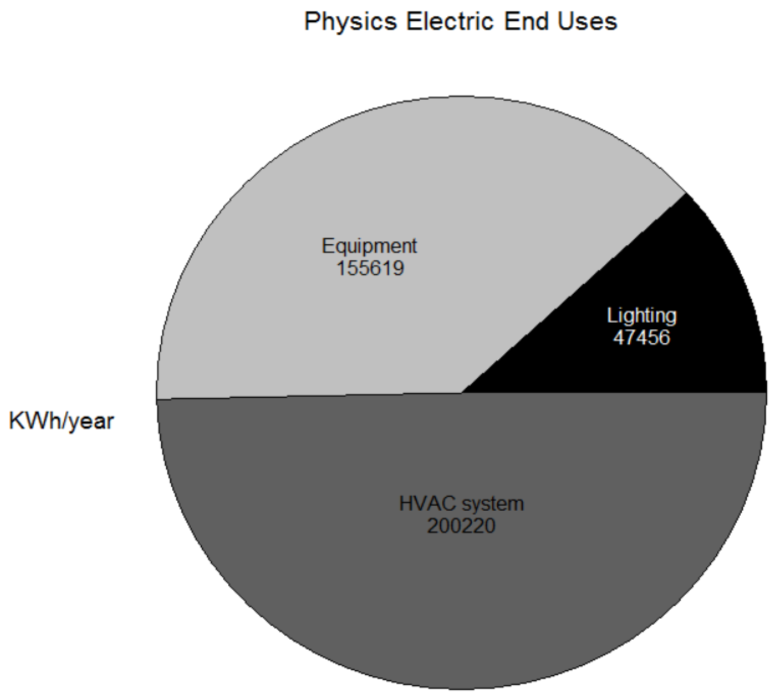

Figure 7.3 Load distribution in Physics building

The electric energy load in Bechtel building is distributed as shown in figure 7.3. The lighting accounts for 11.77% of the total electric consumption, equipment accounts for 38.59% and the HVAC system accounts for 49.65% of the total electricity consumption.

B. Applying Energy Conservation Measures

1. Double Glazed windows

Applying double glazed windows on the South and the West facades will reduce the energy consumption by 9.378 MWh, from 403.295 MWh to 393.917 MWh which accounts for 2.33% of the total energy consumption.

2. Upgrading the lighting system

The lighting fixture substitution simulated in DOE will result in a consumption drop of 23.044 MWh, from 403.295 MWh to 380.251 MWh which is approximately 5.71% of the total energy consumption.

3. Roof Insulation

The applied measure will reduce the energy consumption of the building by 42.415 MWh, from 403.295 MWh to 360.880 MWh which accounts for 10.52% of the total energy consumption.

4. Modifying the HVAC system

It consists of substituting the old chiller by a centrifugal water cooled chiller and replacing the fixed speed circulating pump by a variable speed pump. This alternative will reduce the energy consumption by 34.226 MWh, from 403.295 MWh to 369.069 MWh which constitutes 8.5% of the total energy consumption.

5. Overall Consumption Reduction

Combining all the previous energy conservation measures and taking into consideration the reduction in the infiltration rate reduced the electrical consumption by a total of 126.038 MWh/year, from 403.295 MWh/year to 277.257 MWh/year which is approximately 31.25% of the total energy consumption.

$$\text{KW saved} = \frac{Total\ energy\ consumption\ (KWh)}{number\ of\ hours}$$

$$= \frac{126.038}{298\frac{days}{year} \times 12\frac{hours}{day}} = 35.25\ \text{KW}.$$

The load factor depends on the schedule of operation which ranges from 8 am till 8 pm.

C. Summary of the results

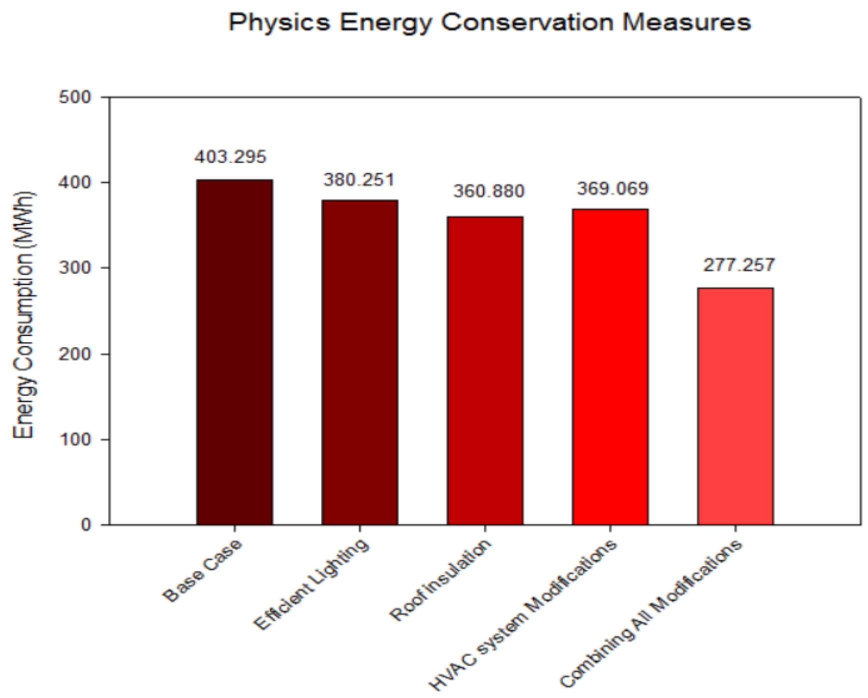

Figure 7.4 Physics Energy Conservation Measures

D. Savings Estimate

1. The cost of new equipment

- Cost of the double glazed windows = area of the windows (m^2) × cost of double glazing ($\$/m^2$)

= area of the window on (south and west) facades × cost of DG window

= (16+96) m^2 × 23 $\$/m^2$ = 2,576 $

- Cost of the water cooled chiller = 2,000$
- Cost of the variable speed drive = 75$
- Cost of roof insulation = cost of polystyrene thermal insulation ($) × area of the roof ($m^2$)

$$= 5\$/\ m^2 \times 981.6152\ m^2 = 4{,}908\ \$$$

- Cost of the efficient lighting = number of LED (120 cm) × cost ($)

  = 50$ × (302) = 15,100 $

- Cost of the 35.25 KW saved = cost of double glazed windows + cost of water cooled chiller + cost of variable speed drive + cost of roof insulation + cost of efficient lighting

  = 2576 + 2,000 + 75 + 4,908 + 15,100 = 24,659 $

2. ***The replacement cost***

- The cost of the single windows area of the windows (m^2) × cost of single glazing ($\$/m^2$)

  = area of the window on (south and west) facades × cost of SG window

$$= (16+96)\ m^2 \times 9\ \$/\ m^2 = 1{,}008\ \$$$

- Cost of the installed lamps = number of T12 (4×40W) × cost ($) + number of T12 (2×40W) × cost ($) + number of T12 (1×34W) × cost ($) + number of T12 (3×40W) × cost ($)

= 32 × 99$ + 36 × 50.27$ + 26 × 20$ + 26 × 75$ = 7,448$

- Cost of the air cooled chiller: 1312.5$
- The replacement cost of the 35.25KW will be:

Cost of (DGW – SGW) + (water cooled chiller – air cooled chiller) + (LED – T12 lamps) + variable speed drive + roof insulation

(2,576-1,008) + (2,000 -1,312.5) + (15,100-7,448) + 75 + 4,908 = 14,890.5$

CHAPTER VIII

THE AUB MEDICAL CENTER

The AUB Medical Center consists of 2 phases composed of 8 levels having a total area 66,134 m^2 mainly distributed as offices, stores, various rooms, clinics and laboratories.

The building walls are of concrete block masonry construction with little or no insulation and the interior floors are mainly concrete slabs. The windows in the building are single glazed windows mounted in un-insulated aluminum or metal frames of 6 mm- thick clear glass. Windows have no sealing which allows the infiltration of outside air into the conditioned areas in large amounts.

The lighting system in the Medical center is mainly composed of low efficient T12, T8 fluorescent and few incandescent lamps.

The HVAC system is composed of three 680 tons chillers and one 750 tone air-cooled chiller in addition to split units available in many rooms. The pumps and the water pipes circulate the steam from the steam heating coils to provide the hot water to the existing fan coils.

Various equipment are available in the building such as computers and accessories, printers, photocopiers, scanners, personal laptops, projectors, lab equipment and medical equipment distributed along the building.

A. Building Consumption and Schedule

Table 8.1 AUBMC Monthly Energy Consumption

Month	Energy consumption (KWh)
January	1,140,163.5
February	1,199,055.9
March	1,185,385.6
April	1,413,811.9
May	1,473,692
June	2,062,401.9
July	2,605,345.1
August	2,830,466
September	2,358,902.9
October	2,197,969
November	1,857,494
December	1,210,177.5
Total	21,534,865

From the data provided in table 4 the total annual energy consumption is 21,534,865 KWh.

The building energy consumption monthly variation is shown in figure 8.1.

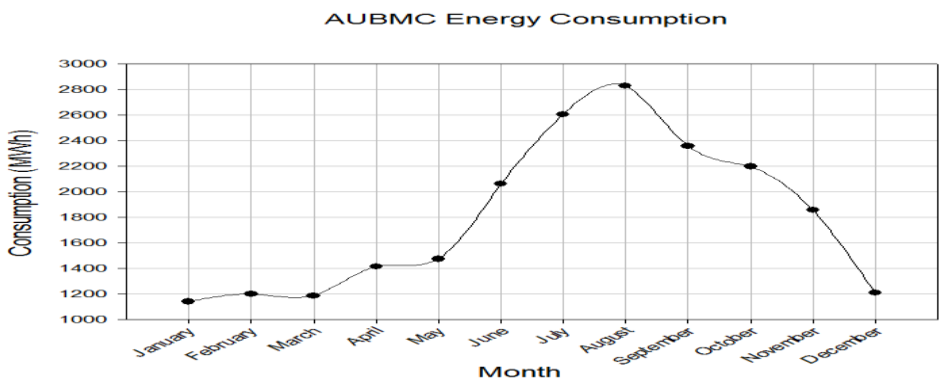

Figure 8.1AUB Medical Center Monthly Energy Consumption

The building schedule of operation is generally 24 hours a day.

The Visual DOE built base case resulted in a total annual energy consumption of 17,326.885 MWh compared to the actual annual consumption 21,534.865 MWh. Hence the base case was built with 19.5% error.

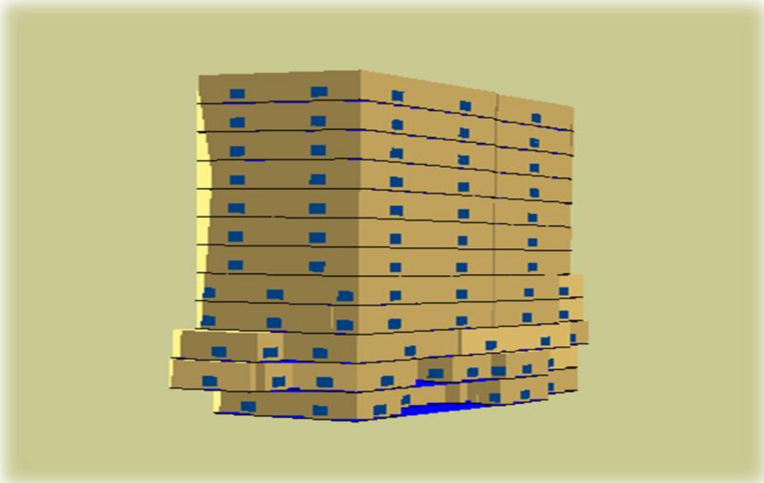

Figure 8.2 3D representation of the AUB Medical Center

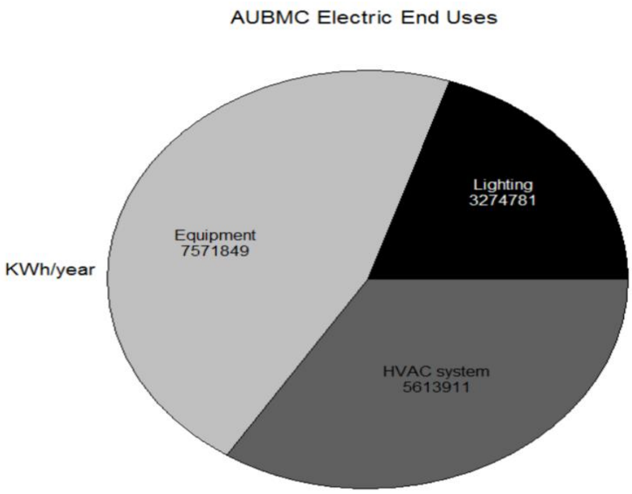

Figure 8.3 Load distribution in the AUBMC

The electric energy load in Bechtel building is distributed as shown in figure 8.3. The lighting accounts for 18.9% of the total electric consumption, various equipment accounts for 43.7% and the HVAC system accounts for 37.4% of the total electricity consumption.

B. Applying Energy Conservation Measures

1. Upgrading the lighting system

The lighting fixture substitution simulated in DOE will result in a consumption drop of 745 MWh, from 17,327 MWh to 16,582 MWh which is approximately 4.3% of the total energy consumption.

2. Modifying the HVAC system

a. Increasing the set point temperature

This strategy has been implemented many years ago in different places in the world and especially in Europe in 1970s. By lowering the thermostat by one degree one can save around 3% of the electricity cost [15].

A 5^{o}F decrease in the set-point temperature reduces the energy by 8.7%. This alternative will reduce the energy consumption by 1507.4 MWh, from 17,326.885 MWh to 15,819.446 MWh.

We have to note that we cannot increase the set-point temperature for all the rooms of the hospital, especially for certain labs and operating rooms where the set-point temperature should very low between 16-21 degrees Celsius as a biomedical standard.

b. Replacing the Air-cooled chiller by water-cooled chiller

It consists of substituting the old chiller by a centrifugal water cooled chiller. This alternative will reduce the energy consumption by 611.639 MWh, from 17,326.885 MWh to 16,715.25 MWh which constitutes 3.53% of the total energy consumption.

3. Overall Consumption Reduction

Combining all the previous energy conservation measures and taking into consideration the reduction in the infiltration rate reduced the electrical consumption by a total of 2,139.3 MWh/year from 17,326.885 MWh/year to 15,187,6 MWh/year which is approximately 12.35% of the total energy consumption.

$$\text{KW saved} = \frac{Total\ energy\ consumption\ (KWh)}{Load\ Factor \times number\ of\ hours}$$

$$= \frac{2{,}139.3}{365\frac{days}{year} \times 24\frac{hours}{day}} = 244.212\ \text{KW}.$$

The load factor depends on the schedule of operation of the building which is 24 hours a day.

C. Summary of the results

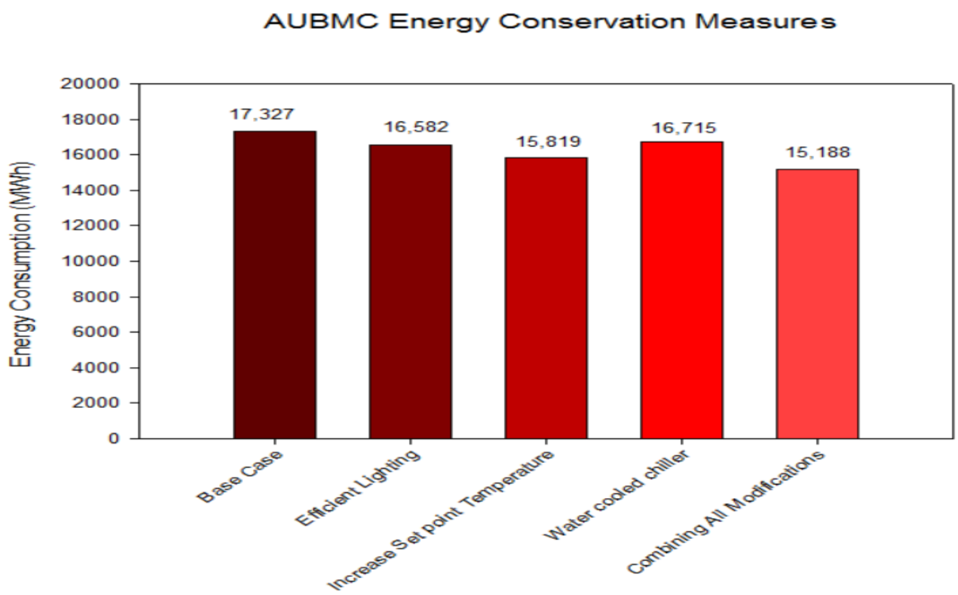

Figure 8.4 AUBMC Energy Conservation Measures

D. Savings Estimate

1. The cost of new equipment

- Cost of the efficient lighting = number of LED (120 cm) × cost ($)

  = 2,444 × 50$ = 122,200$

- The cost of the programmable rheostat = 20 $
- The total cost of installing the water cooled chiller = 400,000$
- The total cost of the 244.212 KW = cost of efficient lighting + HVAC system modifications = 122,200$ + (20 + 400,000) = 522,220$

2. The replacement cost

- Cost of the installed lighting = number of T12 lamps (4×40W) × cost ($)

  = 611× 99 = 60,489$

- Cost of air cooled chiller = 350 × 750 × 1.5 = 393,750$
- The replacement cost of the 244.212 KW will be:

  Cost of (LED – T12 lamps) + (water cooled chiller – air cooled chiller) + programmable rheostat

  = (400,000-393,750) + (122,200-60,489) + 20$= 67,981$

CHAPTER IX

AGRICULTURE BUILDING

The Agriculture building consists of 2 buildings wing A and B. Wing A consists of 3 levels and the wing B consists of 2 levels having a total area 5,080 m^2 out of which 3,566 m^2 is a closed conditioned space mainly distributed as classrooms, offices, stores, various rooms and laboratories.

The building walls are of concrete block masonry construction with little or no insulation and the interior floors are mainly concrete slabs. There exist two types of windows in the building: single glazed windows mounted in un-insulated aluminum or metal frames of 3 mm- thick clear glass, and double glazed windows of 6 mm- thick clear glass mounted in un-insulated aluminum frame located on the east side of wing A. Windows have no sealing which allows the infiltration of outside air into the conditioned areas in large amounts. The windows total area is 671 m^2 and the conditioned area is 3,566 m^2.

The lighting system in the Agriculture building is mainly composed of low efficient T12 fluorescent lamps accounting for approximately 63% of the total installed luminaires where the other 37% is composed of T8, T5 fluorescents in addition to a small percentage of incandescent lamps.

The HVAC system is composed of split units available in all rooms. The pumps and the water pipes circulate the steam from the steam heating coils to provide the hot water to the existing fan coils. Steam supply is controlled manually by an installed valve available in the basement.

Various equipment are available in the building such as computers and accessories, printers, photocopiers, scanners, personal laptops, projectors and lab equipment distributed along the building [16].

A. Building Consumption and Schedule

Table 9.1 Agriculture Monthly Energy Consumption

Month	Energy consumption (KWh)
January	45,2290
February	49,3370
March	55,2470
April	98,6370
May	107,3160
June	102,7530
July	117,1220
August	114,7080
September	118,3320
October	98,4410
November	87,9060
December	71,2630
Total	1,066,291

From the data provided in table 9.1 the total annual energy consumption is 1,066,291 KWh.

The building energy consumption monthly variation is shown in figure 9.1.

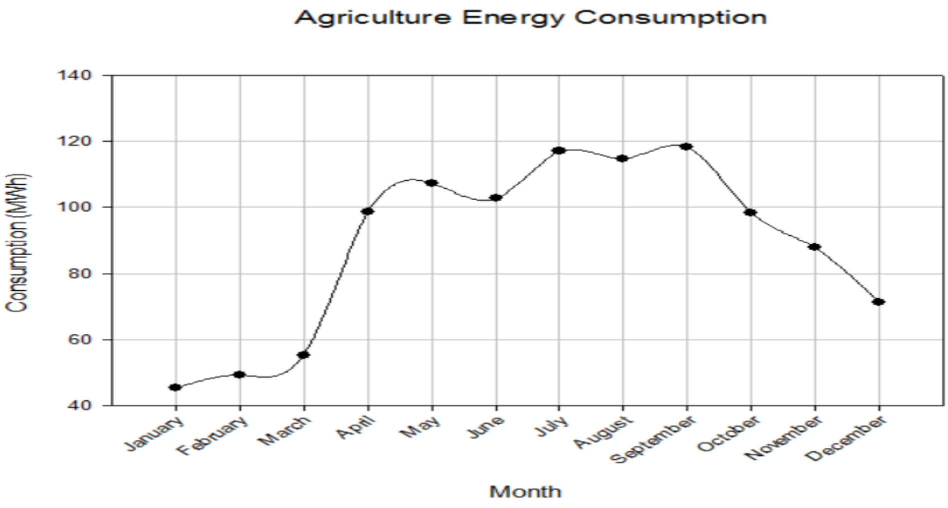

Figure 9.1 Agriculture Monthly Energy Consumption variation

The building schedule of operation generally ranges from 8 am till 7 pm on weekdays. The Visual DOE built case resulted in a total annual energy consumption of 936.401 MWh compared to the actual annual consumption of 1,066.291 MWh. Hence the base case was built with 12% error, which is regarded as an acceptable margin.

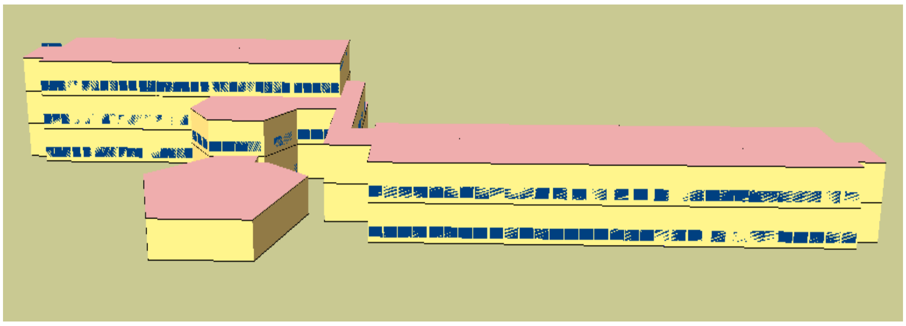

Figure 9.2 3D representation of the Agriculture building

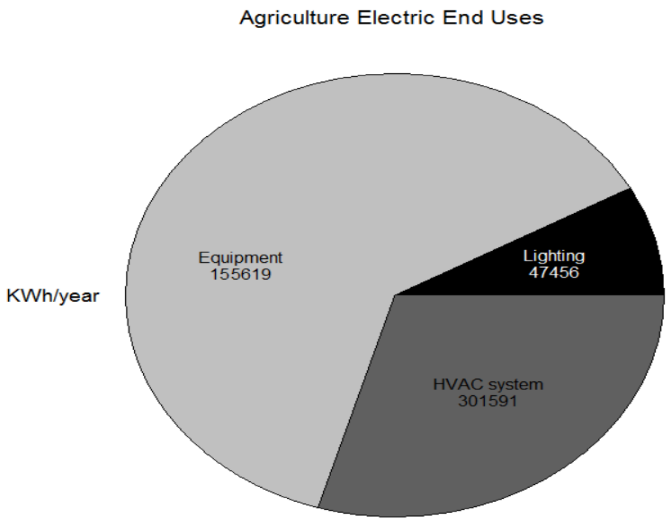

Figure 9.3 Load distribution in the Agriculture building

The electric energy load in Bechtel building is distributed as shown in figure 9.3 the lighting accounts for 8.77% of the total electric consumption, various equipment accounts for 67.8% and the HVAC system accounts for 23.43% of the total electricity consumption.

B. Applying Energy Conservation Measures

1. Double Glazed windows

Applying double glazed windows on the East and the West facades will reduce the energy consumption by 2.734 MWh, from 936.401 MWh to 933.667 MWh which accounts for 0.3% of the total energy consumption.

2. Upgrading the lighting system

The lighting fixture substitution simulated in DOE will result in a consumption drop of 39.28 MWh, from 936.401 MWh to 897.121 MWh which is approximately 4.19% of the total energy consumption.

3. Roof Insulation

The applied measure will reduce the energy consumption of the building by 6.211 MWh, from 936.401 MWh to 930.190 MWh which is approximately 0.66% of the total energy consumption.

4. Overall Consumption Reduction

Combining all the previous energy conservation measures and taking into consideration the reduction in the infiltration rate reduced the electrical consumption by a total of 72.75 MWh/year, from 936.401 MWh/year to 863.654 MWh/year which is approximately 7.77 % of the total energy consumption.

$$\text{KW saved} = \frac{Total\ energy\ consumption\ (KWh)}{number\ of\ hours}$$

$$= \frac{72.75}{298\frac{days}{year} \times 12\ \frac{hours}{day}} = 20.34\ \text{KW.}$$

The load factor depends on the schedule of operation of the building which ranges from 8 am till 7 pm.

C. Summary of the results

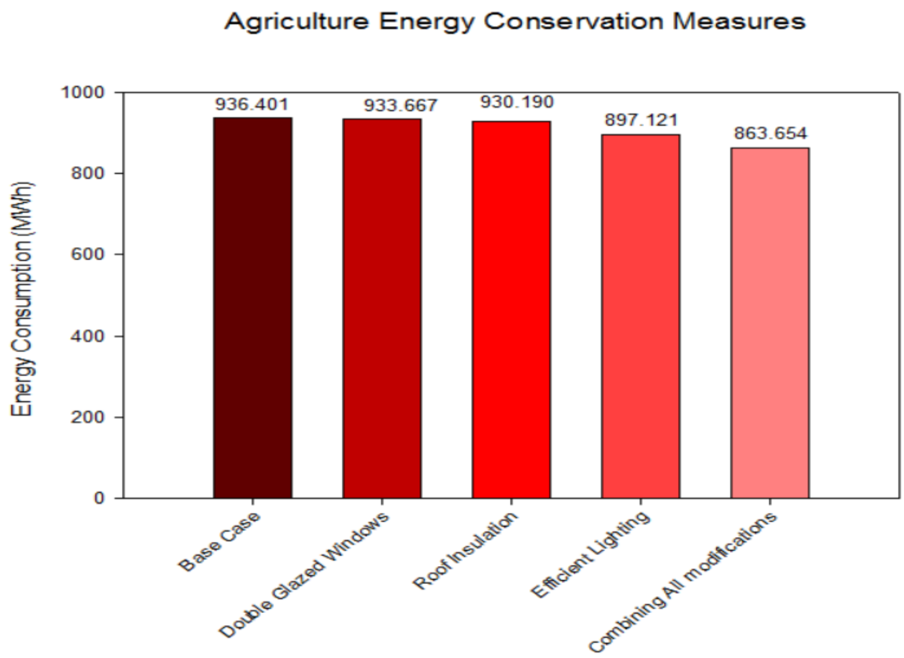

Figure 9.4 Agriculture Energy Conservation Measures

D. Savings Estimate

1. The cost of new equipment

- Cost of the double glazed windows = area of the windows (m^2) × cost of double glazing ($\$/m^2$)

  = area of the window on (east and west) facades × cost of DG window

  $= 23\ \$/m^2 \times (200 + 223)\ m^2 = 9{,}729\ \$$

- Cost of roof insulation = cost of polystyrene thermal insulation ($) × area of the roof ($m^2$)

  $= 5\$/m^2 \times (1988.6 + 727.6) = 13{,}581\ \$$

- Cost of the efficient lighting = number of LED (120 cm) × cost ($) + number of LED (60 cm) × cost ($) + number of efficient lighting × cost ($)

  = (349) × 50$ + 60×40$ + 3× 10$ = 19,880$

- The total cost of the 20.34 KW = cost of double glazed windows + cost of roof insulation + cost of efficient lighting

  = 9,729 + 13,581 + 19,880 = 43,190 $

2. The replacement cost

- The cost of the single windows area of the windows (m^2) × cost of single glazing ($\$/m^2$)

  = area of the window on (east and west) facades × cost of SG window

  = 9 $\$/m^2$ × (200 + 223) m^2 = 3,807 $

- Cost of the installed T12 lamps = number of T12 (4×40W) × cost ($) + number of T12 (2×40W) × cost ($) + number of T12 (4×17W) × cost ($) + number of incandescent × cost ($) + number of T12 (4×20W) × cost ($)

  = 52×99$+33×50.27$+20$+2×28.6$+16×57.2$ = 7,799$

- The replacement cost of the 27.74 KW will be:

  Cost of (DGW – SGW) + (LED – T12 lamps) + roof insulation

  = (9,729-3,807) + (19,880-7,799) + 13,581 = 31,584$

CHAPTER X

FINAL RESULTS

According to the Energy Information Administration (EIA), the CO_2 emission coefficients for various types of fossil fuels are as follows: [17]

The CO_2 emission coefficient from diesel is 73.15 Kg CO_2/Million Btu. Since 1kWh = 3412.969 Btu, then converting to kWh gives:

$$= \frac{73.2\ Kg\ CO_2}{10^6 \times 0.000293\ KWh} = 0.25 \text{ Kg } CO_2/\text{KWh}$$

The CO_2 emission coefficient from fuel oil is 74.54 Kg CO_2/Million Btu [18]

$$= \frac{73.15\ Kg\ CO_2}{10^6 \times 0.000293\ KWh} = 0.254 \text{ Kg } CO_2/\text{KWh}$$

The CO_2 emission coefficient from natural gas is 53.1 Kg CO_2/Million Btu

$$= \frac{53.1\ Kg\ CO_2}{10^6 \times 0.000293\ KWh} = 0.181 \text{ Kg } CO_2/\text{KWh}$$

The CO_2 emission coefficient from heavy fuel is 78.8 Kg CO_2/Million Btu

$$= \frac{78.8\ Kg\ CO_2}{10^6 \times 0.000293\ KWh} = 0.27 \text{ Kg } CO_2/\text{KWh}$$

Table 10.1 summarizes the results.

Table 10.1 CO_2 emissions coefficient for different fuels.

Type of fuel	CO_2 emission coefficient (Kg/MBtu)	CO_2 emission coefficient (Kg/KWh)
Diesel	73.2	0.25
Fuel oil	74.54	0.254
Natural gas	53.1	0.181
Heavy fuel	78.8	0.27

A. **Environmental Cost**

Global warming and hence greenhouse gas emissions, acid rain, the ozone layer depletion as well as the climate change are the main reasons behind imposing the carbon tax rate in many countries. The main purpose of the carbon tax is to mitigate these problems facing our societies nowadays by increasing the expenses on the fossil fuels and thus motivating the utility, corporates and even individuals to reduce their actual consumption and switching to cleaner and less emitting technologies such as renewable energy or simply increasing the efficiency. [20]

Carbon tax is considered as a pollution tax imposed on the industries that burn various types of fuels in their production operations. The tax is based mainly on the carbon content of each fuel type. Different governments such as in the USA, EU, UK and others have set a price of carbon per ton of fuel burnt.

Countries of the European Union have imposed carbon taxes in the range of 4-30 €/tons CO_2 where 17€/tons CO_2 which is equal to 21.5 $ being the average tax proposal [21]. This is almost the same like the US carbon taxes of 20$/tons CO_2. [22]

The Environmental cost for all 4 types of fuels is estimated such that:

Avoided Tons of CO_2 = CO_2 emission coefficient (tons/ KWh) × reduced consumption (kWh)

And: Environmental cost = Tons of CO_2 avoided × carbon tax ($)

Four scenarios are considered for all different types of fuels. The measures adopted include lighting, roof insulation, double glazing and HVAC systems modifications. Tables 10.1-10.5 present the outcomes in terms of consumption reduction, avoided CO_2

emissions, and the corresponding environmental costs reflected in carbon tax reductions.

Diesel:

Table 1.2 Diesel Fuel Environmental cost

Building	Reduced consumption (MWh)	Tons of CO_2 avoided	Environmental cost reduction EU ($)	Environmental cost reduction US ($)
Bechtel	151.968	38	817	760
Chemistry	53.6	13.4	288	268
Van Dyck	172.138	43.03	925	860
Biology	101.029	25.26	543	505
Bliss Hall	53.81	13.45	289	269
Physics	126.038	31.5	677	630
Agriculture	72.75	18.19	391	364
AUBMC	2,139.3	534.82	11,499	10,696

Fuel Oil:

Table 2.3 Fuel Oil Environmental cost

Building	Reduced consumption (MWh)	Tons of CO_2 avoided	Environmental cost reduction EU ($)	Environmental cost reduction US ($)
Bechtel	151.968	38.6	830	772
Chemistry	53.6	13.61	293	272
Van Dyck	172.138	43.72	940	874
Biology	101.029	25.66	552	513
Bliss Hall	53.81	13.67	294	273
Physics	126.038	32	688	640
Agriculture	72.75	18.48	397	370
AUBMC	2,139.3	543.38	11,683	10,868

Natural Gas:

Table 3.4 Natural Gas Environmental cost

Building	Reduced consumption (MWh)	Tons of CO_2 avoided	Environmental cost reduction EU ($)	Environmental cost reduction US ($)
Bechtel	151.968	27.51	591	550
Chemistry	53.6	9.7	209	194
Van Dyck	172.138	31.16	670	623
Biology	101.029	18.29	393	366
Bliss Hall	53.81	9.74	209	195
Physics	126.038	22.81	490	456
Agriculture	72.75	13.17	283	263
AUBMC	2,139.3	387.21	8,325	7,744

Heavy Fuel:

Table 4.5 Heavy Fuel Environmental cost

Building	Reduced consumption (MWh)	Tons of CO_2 avoided	Environmental cost reduction EU ($)	Environmental cost reduction US ($)
Bechtel	151.968	41.03	882	821
Chemistry	53.6	14.47	311	289
Van Dyck	172.138	46.48	999	930
Biology	101.029	27.28	587	546
Bliss Hall	53.81	14.53	312	291
Physics	126.038	34.03	732	681
Agriculture	72.75	19.64	422	393
AUBMC	2,139.3	577.61	12,419	11,552

A. Calculating the cost of a NegaWatt

1. Without the environmental cost

Table 5.6 Cost calculation without Environmental cost

Building	Reduction (KW)	New equipment cost ($)	Replacement cost ($)
Bechtel	46.36	138,396	62,720
Chemistry	16.35	37,336	21,408
Van Dyck	52.51	48,511	28,361

Biology	26.08	45,900	26,710
Bliss Hall	12.9	19,931	7,840
Physics	35.25	24,659	14,891
Agriculture	20.34	43,190	31,584
AUBMC	244.212	522,295	67,981
TOTAL	454.002	880,218	261,495

Cost of KW = $\frac{Replacement\ cost}{Reduction}$

= $\frac{261{,}495}{454}$ = 576$

Hence cost of 1NW = 0.576 million $

2. *With environmental cost*

Diesel:

Table 10.7 Cost calculation for Diesel Fuel

Building	Reduction (KW)	New equipment cost ($)	Replacement cost ($)	Replacement cost – Environmental cost (EU)	Replacement cost – Environmental cost (US)
Bechtel	46.36	138,396	62,720	61,903	61,960
Chemistry	16.35	37,335.83	21,408	21,120	21,140
Van Dyck	52.51	48,511	28,361	27,436	27,500
Biology	26.08	45,900	26,710	26,167	26,205
Bliss Hall	12.9	19,931	7,840	7,551	7,571
Physics	35.25	24,659	14,891	14,214	14,261
Agriculture	20.34	43,190	31,584	31,193	31,220
AUBMC	244.212	522,295	67,981	56,482	57,285
TOTAL	454.002	880,217.8	261,495	246,066	247,142

Cost of KW = $\frac{Replacement\ cost - Environmental\ cost\ (\$)}{Reduction\ (KW)}$

Cost of KW (EU) = $\frac{246{,}066}{454}$ = 542$

Hence cost of 1NW = 0.542 million $

Cost of KW (US) = $\frac{247{,}142}{454}$ = 544.37$

Hence cost of 1NW = 0.544 million $

Fuel Oil:

Table 10.8 Cost calculation for Fuel oil

Building	Reduction (KW)	New equipment cost ($)	Replacement cost ($)	Replacement cost – Environmental cost (EU)	Replacement cost – Environmental cost (US)
Bechtel	46.36	138,396	62,720	61,890	61,948
Chemistry	16.35	37,335.83	21,408	21,115	21,136
Van Dyck	52.51	48,511	28,361	27,421	27,487
Biology	26.08	45,900	26,710	26,158	26,197
Bliss Hall	12.9	19,931	7,840	7,546	7,567
Physics	35.25	24,659	14,890.5	14,203	14,251
Agriculture	20.34	43,190	31,584	31,187	31,214
AUBMC	244.212	522,295	67,981	56,298	57,113
TOTAL	454.002	880,217.8	261,495	245,818	246,913

Cost of KW (EU) = $\frac{245,818}{454}$ = 541.45 $

Hence cost of 1NW = 0.541$

Cost of KW (US) = $\frac{246,913}{454}$ = 543.86 $

Hence cost of 1NW = 0.544 million $

Natural Gas:

Table 10.9 Cost calculation for Natural Gas

Building	Reduction (KW)	Replacement cost ($)	Incremental cost ($)	Replacement cost – Environmental cost (EU)	Replacement cost – Environmental cost (US)
Bechtel	46.36	138,396	62,720	62,129	62,170
Chemistry	16.35	37,335.83	21,408	21,199	21,214
Van Dyck	52.51	48,511	28,361	27,691	27,738
Biology	26.08	45,900	26,710	26,317	26,344
Bliss Hall	12.9	19,931	7,840	7,631	7,645
Physics	35.25	24,659	14,890.5	14,401	14,435
Agriculture	20.34	43,190	31,584	31,301	31,321
AUBMC	244.212	522,295	67,981	59,656	60,237
TOTAL	454.002	880,217.8	261,495	250,325	251,104

Cost of KW (EU) = $\frac{250,325}{454}$ = 551.38$

Hence cost of 1NW = 0.551 million $

Cost of KW (US) = $\frac{251,104}{454}$ = 553.1$

Hence cost of 1NW = 0.553 million $

Heavy Fuel:

Table 10.10 Cost calculation for Heavy Fuel

Building	Reduction (KW)	Replacement cost ($)	Incremental cost ($)	Replacement cost – Environmental cost (EU)	Replacement cost – Environmental cost (US)
Bechtel	46.36	138,396	62,720	61,838	61,899
Chemistry	16.35	37,335.83	21,408	21,097	21,119
Van Dyck	52.51	48,511	28,361	27,362	27,431
Biology	26.08	45,900	26,710	26,123	26,164
Bliss Hall	12.9	19,931	7,840	7,528	7,549
Physics	35.25	24,659	14,890.5	14,159	14,210
Agriculture	20.34	43,190	31,584	31,162	31,191
AUBMC	244.212	522,295	67,981	55,562	56,429
TOTAL	454.002	880,217.8	261,495	244,831	245,992

Cost of KW (EU) = $\frac{244,831}{454}$ = 539.28$

Hence cost of 1NW = 0.539 million $

Cost of KW (US) = $\frac{245,992}{454}$ = 541.83$

Hence cost of 1NW = 0.542 million $

B. **Calculating the payback period**

The payback period of the NegaWatt power plant is calculated taking into consideration the replacement cost of the applied measures as the investment cost and the annual saved cost is equal to the amount of KW saved multiplied by the cost of KW with and without environmental cost [27].

1. ***Without environmental cost***

The total replacement cost is equal to 880,218$

The total reduction is equal to 454 KW

The cost of KW is equal to 576$

The annual saved cost = 454 KW × 576$/KW = 261,504$

The payback period of the investment is equal to 3.37 years.

2. ***With environmental cost***

Diesel

The total replacement cost is equal to 880,218$

The total reduction is equal to 454 KW

The cost of KW is equal on average between Europe and US 543.2$

The annual saved cost = 454 KW × 543.2$/KW = 246,613$

The payback period of the investment is equal to 3.57 years.

Fuel oil

The total replacement cost is equal to 880,218$

The total reduction is equal to 454 KW

The cost of KW is equal on average between Europe and US to 542.5$

The annual saved cost = 454 KW × 541.5$/KW = 246,295$

The payback period of the investment is equal to 3.57 years.

Natural Gas

The total replacement cost is equal to 880,218$

The total reduction is equal to 454 KW

The cost of KW on average between Europe and US is equal to 552$

The annual saved cost = 454 KW × 552$/KW = 250,608$

The payback period of the investment is equal to 3.51 years.

Heavy fuel

The total replacement cost is equal to 880,218$

The total reduction is equal to 454 KW

The cost of KW on average between Europe and US is equal to 541$

The annual saved cost = 454 KW × 541$/KW = 245,614$

The payback period of the investment is equal to 3.58 years.

The results are summarized in Table 10.11.

Table 10.11 Payback periods for different fuels

	Replacement cost ($)	Total reduction (KW)	Cost of KW	Annual saved cost ($)	Payback period (years)
Without Env. Cost	880,281	454	576	261,504	3.37
With Env. Cost					
Diesel	880,281	454	543.2	246,613	3.57
Fuel oil	880,281	454	541	245,614	3.58
Natural gas	880,281	454	552	250,608	3.51
Heavy fuel	880,281	454	541.5	246,295	3.57

C. Comparing the NegaWatt to the actual Megawatt

According to the ministry of Energy and Water:

The levelized cost of production for combined cycle gas turbine for the available liquid fuels is as follows:

1. Diesel oil equal to 21.7 ₵/KWh,
2. For heavy fuel oil equal to 16.35₵/KWh

3. For natural gas equal to 9.1 ₵/KWh.

Based on 60% load factor the electricity cost is calculated.

1. Diesel oil → $\frac{\frac{\frac{21.7 \times 1000}{100}}{MW}}{8760 \times 0.6}$ = 1.14 Million $

2. Heavy fuel oil → $\frac{\frac{\frac{16.35 \times 1000}{100}}{MW}}{8760 \times 0.6}$ = 0.86 Million $

3. Natural Gas → $\frac{\frac{\frac{9.1 \times 1000}{100}}{MW}}{8760 \times 0.6}$ = 0.48 Million $

Table 10.12 shows the comparison between the cost of megawatt for different types of fossil fuels to the cost of NegaWatt with and without environmental cost.

Table 10.12 Comparison between Megawatt and NegaWatt costs.

Type of fuel	Megawatt cost (Million $)	NegaWatt without environmental cost (Million $)	NegaWatt with environmental cost (EU) (Million $)	NegaWatt with environmental cost (US) (Million $)
Diesel	1.14	0.576	0.542	0.544
Fuel oil	1	0.576	0.541	0.544
Natural gas	0.48	0.576	0.551	0.553
Heavy Fuel	0.86	0.576	0.539	0.542

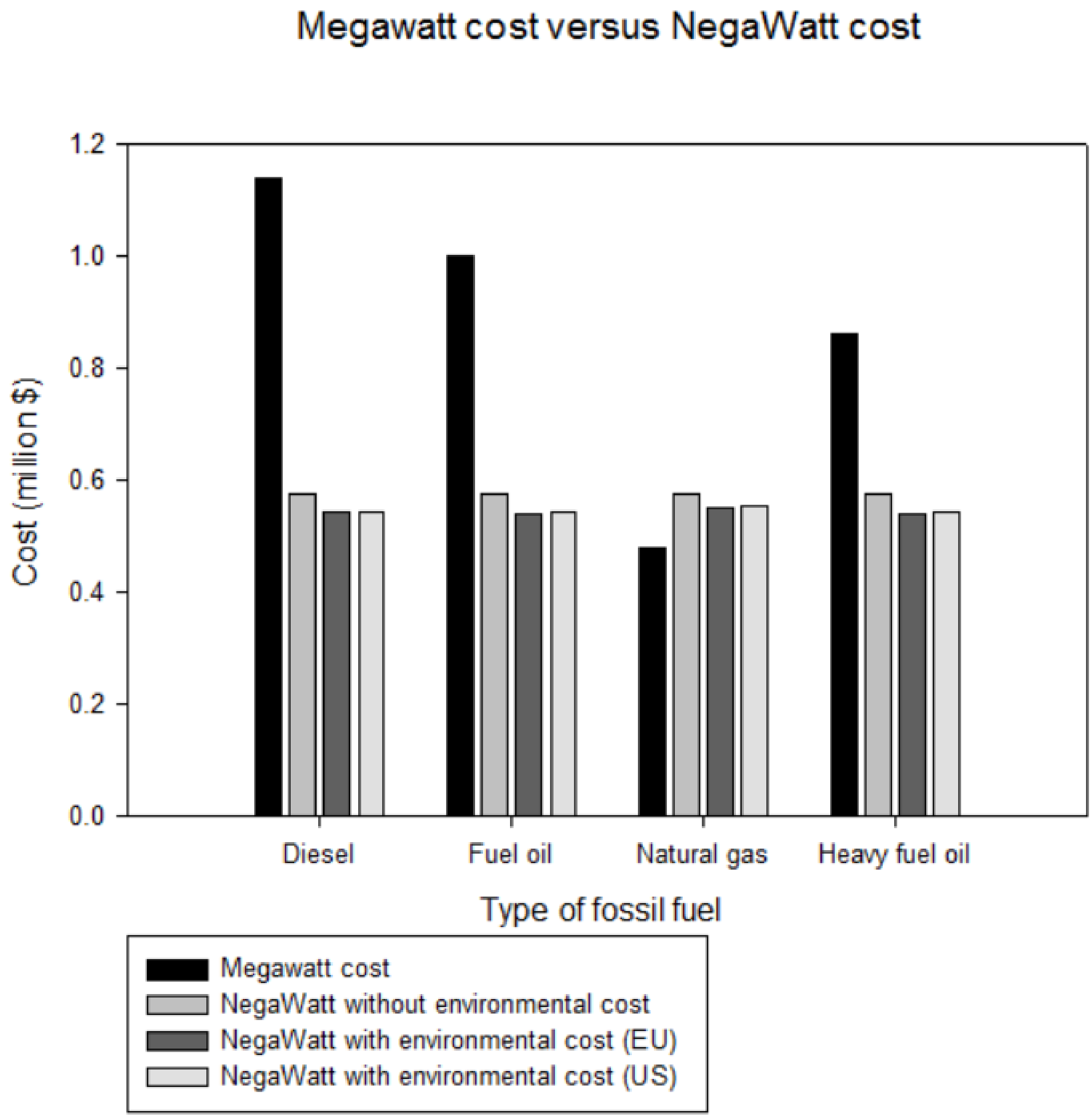

Figure 10.1 Megawatt versus NegaWatt cost

As shown in table 10.12 and figure 10.1, the price of a NegaWatt as estimated based on Lebanese energy market is half of the price of a megawatt of diesel fuel oil without taking into consideration the environmental cost and is even lower when substituting the environmental cost from the replacement cost which allows a major reduction of around 5.7% in the price of the NegaWatt.

In the case of the fuel oil, the price of a NegaWatt is 42% lower than the actual cost of a megawatt without considering the environmental cost which allows a higher reduction of around 5.8% in the price of the NegaWatt.

In the case of the heavy fuel oil, the price of the installed NegaWatt is 33% lower than the actual cost of a megawatt power plant. The environmental cost allows an additional reduction of around 6.16% in the price of the NegaWatt.

However in the case of a natural gas the NegaWatt price was higher than the price of a megawatt and taking into consideration the environmental cost won't add an important reduction cost wise due to the lower carbon content of the natural gas.

Table 10.13 Original Power consumption versus reduced power consumption

Building	Original Power consumption (KW)	Reduced Power consumption (KW)
Bechtel	235.99	189.63
chemistry	177.75	161.4
Van Dyck	371.13	318.62
Biology	161.74	135.66
Bliss Hall	91.57	78.67
Physics	112.78	77.53
AUBMC	1978	1733.788
Agriculture	261.86	241.52
Total	3391	2937

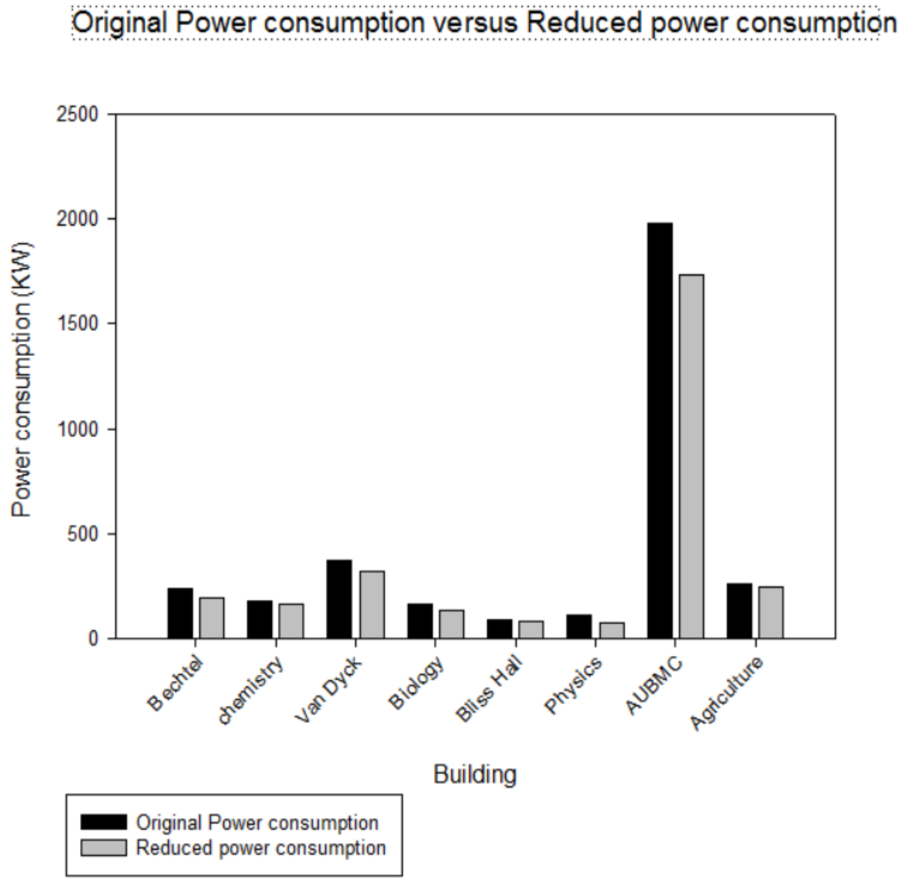

Figure 10.2 Original power consumption versus reduced consumption

As shown in table 10.13 and Figure 10.2, the applied conservation measures proposed in the previous chapters have shown a valuable reduction of 13.4% in the total power consumption where the electricity consumption of the eight buildings dropped by 454 KW from 3.391 MW to 2.937 MW. The considered buildings account for 53% of the total AUB buildings consumption (27,241 MWh out of 51,380 MWh for the year 2012). If we generalize the results for all the buildings assuming that they operate in a uniform level the total NegaWatt capacity will be equal to 0.86 MW.

The annual fuel consumption for all AUB buildings and AUBMC is 5,643,655 Liters of diesel fuel at an annual cost of 4,690,000$. The total energy consumption for all the buildings is equal to 51,380,179 MWh. The total power consumption is around 10.141 MW so the cost of a MW of fuel is equal to $\frac{4,690,000}{10.141}$ = 462,479$.

For the 0.86 saved MW the total cost of the fuel saved will be equal to 397,732$. We note that in the case of a NegaWatt power plant less fuel are being burnt to supply the same load demand. Reducing the fuel cost from the previously calculated costs for the diesel fuel will result in a higher reduction in the price of the NegaWatt and the results are shown in table 10.14.

Table 10.14 NegaWatt price for diesel fuel

Type of fuel	Megawatt cost (Million $)	NegaWatt without environmental cost (Million $)	NegaWatt with environmental cost (EU) (Million $)	NegaWatt with environmental cost (US) (Million $)
Diesel	1.14	0.114	0.08	0.082

The results have shown that the NegaWatt solutions save energy resources and can be economically feasible.

CHAPTER XI

CONCLUSION

The goal of the NegaWatt project is to utilize recent developments in clean and more efficient technologies to provide a solution for the power deficiency problem at AUB by modifying the usage of electricity at the end user side with low or without additional costs and without affecting the comfort of the community in general. This thesis showed that building a NegaWatt (NW) power plant is more cost- effective than building a new thermal power plant or installing standby units in order to cover the shortage of electricity in the AUB buildings. In addition, the NW power plant is a green technology that will assure reduction of overall greenhouse gas emissions and specially CO_2 gas, since less fuel are being used to supply the load demand of electricity.

In this thesis an energy audit was conducted for various AUB buildings in order to carry out some feasibility of upgrading some of the electrical appliances to reduce the energy consumption. The buildings were modeled and simulated using visual DOE 4.0 software taking into consideration all the collected data. Data were also obtained from previous audit that was conducted in 2005. Energy conservation measures were applied to the modeled buildings and the best alternatives were chosen such as roof insulation, HVAC system modifications, efficient lighting and double glazed windows. The simulations showed a reduction of around 13.4% can be achieved in the total power consumption of the buildings where the electricity consumption of the 8 selected buildings dropped by 454 KW, from 3.391 MW TO 2.937 MW.

In the second part of the thesis the cost of the NegaWatt was calculated taking into consideration the cost of the upgraded appliances, their replacement cost in addition to the environmental cost. Four scenarios were considered for different types of fuels. The amount of avoided CO_2 emissions was calculated as well as the corresponding environmental costs reflected in carbon tax reductions. The environmental cost has achieved a valuable reduction in the price of a NW, and considering the diesel fuel reduction cost in the calculations achieved a higher reduction in the price of a NW. In addition the payback period of the built NegaWatt plant has been estimated taking into consideration the cost of the new appliances as investment cost and the reduced energy cost as annual savings.

The calculations have proved that the price of a NegaWatt is much lower than the actual price of a conventional thermal megawatt for different types of classical power plants (diesel, fuel oil and heavy fuel) however it is higher than the price of a megawatt associated with natural gas.

The results have also shown that the idea of NegaWatt is considered as an important and economically- feasible option that leads to efficiency improvements and deployment of clean technology.

Further work could include generalizing the concept of NegaWatt on the Lebanese electric power system. This thesis was done on a commercial case and specifically for academic institutions. Applying the measures on the industrial, residential and other commercial buildings can be considered as the best economical and feasible solution for the shortage of electricity in the Lebanese regions, since no additional configurations in the originally built power plant will be needed; neither transmission lines nor additional distribution networks will be built. It will also lead to substantial savings in the country's energy bill. Further work could also take the NPV and other economic indices while estimating the payback period.

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