Energy Performance Analysis of USPCASE, NUST Islamabad Building using eQUEST

By

Dilshad Ahmed Khan

Reg.# 00000171200

Session 2016-18

Supervised by

Dr. Muhammad Bilal Sajid

A Thesis Submitted to the US-Pakistan Center for Advanced Studies in Energy in partial fulfillment of the requirements for the degree of

MASTERS of SCIENCE in

(Thermal Energy Engineering)

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National University of Sciences and Technology (NUST)

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THESIS ACCEPTANCE CERTIFICATE

Certified that final copy of MS/MPhil thesis written by Mr. **Dilshad Ahmed Khan** (Registration No. 00000171200), of **US-Pakistan Center for Advanced Studies in Energy, NUST** has been vetted by undersigned, found complete in all respects as per NUST Statues/Regulations, is within the similarity indices limit and is accepted as partial fulfillment for the award of MS/MPhil degree. It is further certified that necessary amendments as pointed out by GEC members of the scholar have also been incorporated in the said thesis.

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Certificate

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Dedication

I take this opportunity to dedicate this thesis to Dr. Muhammad Bilal Sajid, who has always been very cooperative towards me and who has instilled in me all the skills required to complete this study. Moreover, this thesis is dedicated to all my family members who, despite having tough time schedule of my job, have always encouraged me to complete this study. Furthermore, I must thank my GEC members who have always been very supportive throughout this study. In addition to that, I hereby acknowledge all the facilities provided by USPCASE, NUST to perform this study. And last but not the least, I would like to express my gratitude to USAID-Pakistan for all the support offered throughout this graduation.

Abstract

Building sector consumes approximately 32 % of the final energy consumption globally. If energy efficiency measures are taken, building sector can save a significant portion of final energy consumption. To find the energy saving potential of any building, it is always worthwhile to analyze its energy consumption pattern. In this study, energy consumption of USPCASE, NUST, Islamabad building was modeled in eQUEST. Results obtained from eQUEST were validated by comparing it with actual energy consumption of the building. Afterwards, some energy efficiency measures were proposed, and their impact on final energy consumption of the building were investigated in eQUEST. Final annual energy consumption of the building was found to be 219.22 x 10^3 kWh. And if energy efficiency measures are taken, the final annual energy consumption can be reduced to 170.71 x 10^3 kWh.

Keywords

Energy Consumption, Energy Saving Potential, Energy Efficiency Measures, Energy Modeling, eQUEST

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1. "Energy Performance Analysis of a Commercial Building using eQUEST." Dilshad Ahmed Khan et al. *First International Conference on High Performance Energy Efficient Buildings and Homes HPEEBH 2018, UET Lahore.*

List of Abbreviations

BDL	Building Description Language
CFL	Compact Fluorescent Lamps
CFM	Cubic Feet per Minute
DCV	Demand Control Ventilation
DOE	Department of Energy
DSF	Double Skin Façade
EEM	Energy Efficiency Measure
eQUEST	Quick Energy Simulation Tool
FPFA	Fan Coil plus Fresh Air
HVAC	Heating Ventilation and Air Conditioning
kWh	Kilo-Watt Hours
LBNL	Lawrence Berkley National Laboratory
LED	Light Emitting Diode
LPD	Lighting Power Density
NEECA	National Energy Efficiency and Conservation Authority
Ra	Rayleigh Number
VAV	Variable Air Volume
VRF	Variable Refrigerant Flow

Chapter 01

1. Introduction

The concept of energy efficient buildings was introduced in 1980s when many developed countries were facing energy shortage and the prices of fossil fuels, the main source of energy generation, was on a rise [1]. An innovative approach of energy efficient buildings was then used to reduce the demand and supply gap in energy sector. The attempts for energy efficient buildings have led the researchers to the concept of net zero energy buildings.

As of now, building sector, others being industrial and transport sector, consumes about 32 % of the final energy consumption of the world [2]. Moreover, due to rapid urbanization combined with growth of economy, energy demand in building sector is rising with higher rates than any other sector. And, if energy efficiency measures are taken, building sector has a potential of annual energy savings up to 14.72×10^{12} kWh by 2050 [3]. Similarly in Pakistan, building sector consumes large proportion of total energy consumption. National Energy Efficiency and Conservation Authority (NEECA), through its pilot project, has found a potential of 30% energy savings in buildings [4].

Energy consumption in building sector is mainly utilized for space cooling, heating and lighting purposes. The amount of energy consumed within a building largely depends upon the design and material of the building. So, energy efficient buildings are designed in a way that they consume less energy for space cooling, heating and lighting. These buildings are designed in a way that exploits the effective use of sunlight to reduce the lighting load and the materials for these buildings are selected in a way to reduce the cooling and heating loads. In addition to energy savings, energy efficient buildings do reduce the operational cost of the buildings.

To find the energy saving potential of a building, it is always significant to analyze its energy consumption. Energy simulations have been in use since 50 years to predict the energy consumption of any building [5]. It can also predict the energy saving potential of any retrofit measure before it has been enacted. So it has been an effective tool in design and decision making in building sector.

1.1. Objectives of the Study:

This study was conducted to find out the energy consumption pattern of a commercial building. The building of USPCASE, NUST, Islamabad was selected as a showcase in this study. Following questions were to be answered:

i. What is the energy consumption pattern of the building?
ii. What is the energy saving potential of the building? How much energy can be saved by adopting different proposed energy efficiency measures?

Since the energy consumption for any operations other than space cooling, heating and lighting is not affected by the building design and material efficiency so this study is limited only to the energy required for heating, cooling, and lighting. Moreover, the economic analysis for some energy conservative measures is out of scope of this study.

1.2. Methodology:

All the data required for energy modeling was collected from the administration unit. By using this data, a computer based energy model of the building was developed in eQUEST. Results from eQUEST were validated by comparing it with actual billing data of the building. After analyzing the results from the energy model, some energy efficiency measures were proposed, and these energy efficiency measures were modeled against the original data to find the energy saving potential of each EEM.

1.3. Overview of eQUEST:

eQUEST (acronym for **Qu**ick **E**nergy **S**imulation **T**ool) is a tool based on DOE-2 used for energy simulation of buildings. It can perform the hourly analysis of energy consumption of a building for one complete year. It uses the detailed data of a building as inputs, and then calculates the energy consumption by using a weather file for specific location. Input to eQUEST may include footprints, HVAC system types, schedules and lighting load etc.

eQUEST contains following tools to model a building:

- Schematic Design (SD) Wizard
- Design Development (DD) Wizard
- Energy Efficiency Measures (EEM) Wizard
- Detailed Interface

Schematic Design Wizard and Design Development Wizard tools are collectively known as building creation wizard because these wizards are used to define specific properties of a building. Selection of which building creation wizard to use depends upon the availability of data for a building.

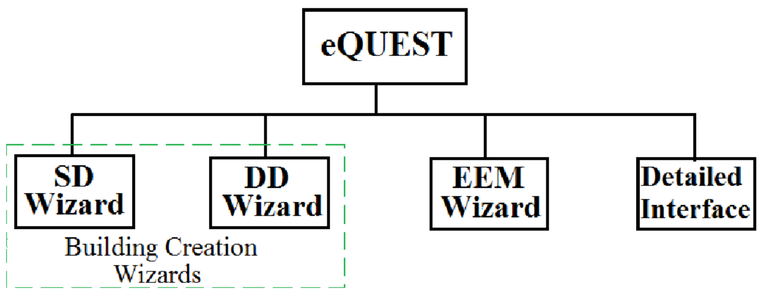

Figure 1.1: Different tools of eQUEST

1.3.1. Schematic Design Wizard

Schematic Design Wizard is used for smaller and simpler buildings i.e. having same floor layouts throughout the shell. It is used when data collected for energy modeling is very limited. Input data to Schematic Design Wizard may include,

- Weather File and Basic Properties of Building
- Floor Pattern (may be imported as ".dwg" file)
- Thermal Zones
- Wall and Roof structure
- Windows orientation
- HVAC System
- Internal Loads and Schedules

SD Wizard contains 60+ HVAC System types but only two types of HVAC systems can be assigned to a single project.

1.3.2. Design Development Wizard

Design Development Wizard can be used for complex buildings with different floor patterns for each floor. It can also model the buildings with more than one shell. It is used when more detailed information about a building is available. The same HVAC System types, as in SD Wizard, are available in DD Wizard, but there is no limit on the number of system types for a single project. Once a project is converted from Schematic Design Wizard to Design Development Wizard, it cannot be converted again to Schematic Design Wizard.

1.3.3. Energy Efficiency Measure Wizard

The Energy Efficiency Measures (EEM) Wizard is used to explore the energy performance of a preferred design-alternative for a building. So, this wizard helps in decision making. Following are the possible parametric runs for EEMs,

- Roof insulation
- Wall insulation
- Vertical or horizontal fenestrations
- Highly efficient glazing
- Energy efficient HVAC system type
- Energy efficient water cooled chillers

Up to 9 design alternatives can be modeled for a base building in EEM Wizard. Then any or all of these design alternatives can be simulated simultaneously to analyze the results as either on individual or on comparative graphs.

1.3.4. Detailed Interface

Detailed Interface shows the visual image (2-D and 3-D) of the modeled building. It enlists all the properties of a building in a component tree. Separate component trees are displayed for Building Shell, Internal Loads, Water-Side HVAC, Air-Side HVAC and Utility & Economics. In case of Building Shell, component tree is divided into floors and floors are then further divided into subsequent zones.

Summary

The building sector, consuming 32 % of final energy consumption globally, has an enormous potential of energy saving. Energy saving potential of a building can be calculated by using energy model of that building. This study is performed to develop the energy model of USPCASE, NUST building by using eQUEST. By using eQUEST, the annual energy consumption of the building and the effects of some proposed energy efficiency measures were studied.

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Chapter 02

2. Background/ Literature Review

Literature review was conducted in two stages. In the first stage, all the literature about energy modeling in general and eQUEST in specific was reviewed. And in next phase, some major energy efficient measures and its impact on building were reviewed.

2.1. Energy Modeling of Buildings:

Energy modeling of buildings has been a significant tool for designers since the last 50 years to evaluate the different options for buildings during the design stage. Initially, it was used to convince the designers to choose between gaseous or electrical systems [1]. But now, with the advanced simulation engines, energy simulation programs can be utilized to calculate the impact of different components on energy usage of the buildings. Modern simulation programs are capable enough to perform detailed hourly analysis of a complete building for a single whole year.

Currently, numerous software applications are available in market to develop energy model of any building. On the basis of their working principles, energy modeling programs are divided into three categories: physics based energy modeling, data based, and hybrid energy modeling [2]. Physics based, also known as white box, modeling programs are the most advanced and complicated energy modeling programs. These programs use scientifically derived mathematical equations to assess the behavior of the different components of buildings. While data based, also known as black box, modeling programs use historically derived statistical data to evaluate the energy performance of any building. Hybrid, or grey box, energy modeling programs use both techniques simultaneously to develop energy model of a building [3]. Mathematical equations used for hybrid energy modeling programs are less complicated and do not account for the detailed behavior of the components which consequently jeopardize the accuracy of their models. Energy model of a building developed through black or grey box methods are calibrated until it matches with real results.

Depending upon the functional performance, physics based energy modeling programs are further classified into three main groups [4]. Lighting and daylighting simulation programs are used to size and design the lighting system of a building. They can also evaluate the effect of daylighting controls on lighting load. Adeline and Radiance are the examples of this type of programs. Component based simulation programs are used to model any specific component of a building. Each component based program can model a single main system or subsystem using its distinct mathematical model. For example, CONTAM is used to predict the indoor air quality and infiltration rate for a multizone space. Similarly, HOMER Energy is a simulation program which is used to design the different energy sources for a building or site. And, whole building energy simulation programs are those which can simulate each component of a building simultaneously through an integrated engine. These types of programs utilize an advanced simulation engine capable enough to model whole building while considering the interrelation of each sub component with others. CarrierHAP, EnergyPlus, and EnergyBase are the examples of whole building simulation programs.

eQUEST is a physics based whole building energy simulation program with an advanced and user friendly graphical user interface [4]. It is capable to perform energy analysis of complex buildings with advanced HVAC systems for 8760 hours each in a year. It utilizes DOE-2.2 based simulation engine to predict the energy consumption of buildings [5]. Moreover, eQUEST recommends default values to its user according to the user selected energy standards. This property makes eQUEST an easy-to-use tool for benchmarking purposes.

As eQUEST uses DOE-2 based simulation engine, it is worthwhile to do some literature review on DOE-2. DOE-2 is a command based simulation program developed by Lawrence Berkley National Laboratory (LBNL) in collaboration with James J. Hirsch and Associates. Its development was financially supported by United States Department of Energy (USDOE) and some utility companies of USA. DOE-2 utilizes a detailed hourly weather file and building's information to predict its energy consumption. With the passage of time, different versions of DOE-2 have been introduced. The latest version of DOE-2 is DOE-2.3 which is able to model any complex buildings with latest HVAC systems.

Structure of simulation engine for DOE-2 is such that it includes four subprograms: BDL Processor, LOADS, HVAC, and ECONOMICS [6]. These sub programs run in a sequence with BDL Processor at first stage followed by LOADS then HVAC and ECON in final stage. Figure 2.1 summarizes the simulation engine structure of DOE-2.2.

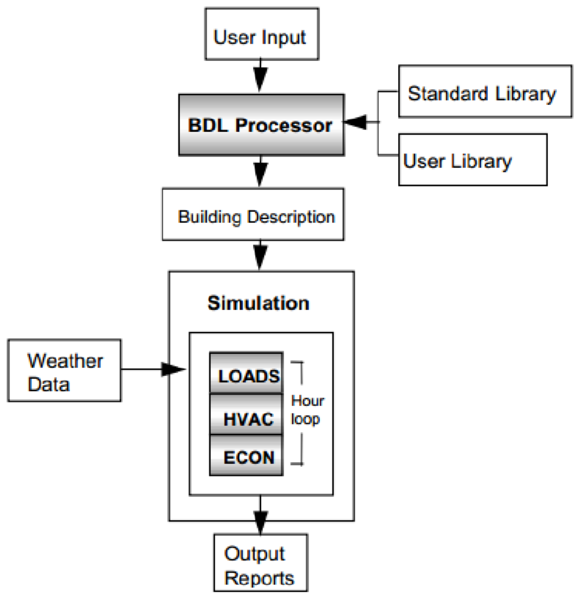

Figure 2.1: Simulation Engine Structure of DOE-2. (Source: DOE-2.2 Volume-I Basics)

BDL (Building Description Language) Processor is used to convert the building's input data into a computer readable format. BDL Processor utilizes a standard library containing different common-to-use wall materials, windows, and performance curves for HVAC components etc. to calculate the response factor. LOADS calculates the cooling and heating loads of the building using the data decoded in BDL Processor and weather file. In the next stage, HVAC program simulates the performance of air conditioning systems. It is further divided into two categories: a secondary system, known as SYSTEMS, and a primary system, known as PLANT. SYSTEMS is used to simulate the performance of different air-side components while PLANT is used to simulate the performance of water-side components. And then in the last stage, ECON simulates the model for economic analysis using utility rates file.

Different studies have been performed to analyze the building energy consumption. Most of the studies then investigated the impact of any single or multiple energy efficiency measure on final energy consumption of the building. Jiafang Song et al performed analysis of energy consumption of a university library using eQUEST [7]. They studied the effect of different variables like lighting power density, indoor personal density, and supply air temperature on the energy consumption of Tianjin Polytechnic University's library. It was found that lighting energy accounted for larger proportion of annual building energy consumption, and likewise, lighting power density has direct relation with energy consumption. They maintained that energy consumption varies inversely as indoor personal density and supply air temperature increases or decreases.

Hongting Ma et al analyzed the energy consumption pattern of 119 public buildings in North China [8]. A survey was conducted to collect the data of offices, hospitals and school buildings in Tianjin, Beijing and other parts of North China. Of 119 buildings, there were 99 office buildings, 11 office buildings, and 9 school buildings. They found that hospital buildings consume more energy than other buildings. Energy model of two buildings, from 119 surveyed buildings, were developed in eQUEST to find out the main factors affecting the annual energy consumption. It was found that air conditioning systems, building envelope, and lighting power density has significant impact on final energy consumption of a building. Carbon emission index and energy consumption variants were determined based on the average, mean, lower quartile and upper quartile values of energy consumption of 119 buildings.

Mohammad Fahmy et al performed energy efficiency and sustainability assessment of Wekalat El-Ghouri, a passively designed heritage building in Egypt [9]. Energy efficiency assessment was performed using eQUEST, while sustainability assessment was performed using a developed energy efficiency criterion. For energy efficiency assessment, the building was simulated one-by-one for six types of wall materials (i.e. 40 and 60 cm of limestone masonry blocks, 12 and 25 cm of concrete masonry blocks, and concrete masonry blocks of these sizes with 2.5 cm polyethylene insulation). Sustainability index was then measured for each case using energy simulation results. It was found that limestone blocks are more energy efficient than concrete masonry units with no insulation. While concrete masonry block of 25 cm thickness with 2.5 cm layer of polyethylene insulation is more energy efficient than limestone blocks. Likewise, sustainability index score of 25 cm concrete masonry block with 2.5 cm polyethylene insulation is highest among all others.

2.2. Energy Efficient Strategies: Envelope

Many researchers have performed research about how to minimize the heat loss through envelope. Their research was not limited to computer programs, many of them utilized mathematical equations to find out the best possible energy efficient envelope. Energy efficient envelope should have low thermal conductance and an optimized level of fenestration.

Hikmat Ali et al. performed a study to investigate the energy saving potential and economic impact of different energy efficient strategies for envelope of a school building in Jordan [10]. Energy efficient strategies included addition of insulation to exterior walls and roof, improvement of window's glass and frames, and installation of shades to control solar heat gains. DesignBuilder was used to perform the energy saving analysis, while corresponding economic analysis was performed using simple payback period analysis. It was found that, by applying the proposed energy efficient envelope, building can save upto 54% energy annually. And payback period for these measures was calculated to be 5.5 years.

Tanya Saroglou et al. investigated the effect of naturally ventilated double skin envelope over single skin envelope for hot climate regions by using EnergyPlus [11]. In first phase, they compared the use of double skin façade (DSF) of single glazing outer and low-E double glazing inner layer with single skin facades of different compositions. It was found that the single skin envelope of double glazed low-E glass with external shading outperforms the double skin facade of single clear outer and double glazed low-E inner layer in order to reduce the cooling loads. In the next stage, they investigated different types of DSFs with different inner and outer layers. It was concluded that DSFs of double glazed low-E outer and single glazed inner layer is the most energy efficient design. And in the final stage, the most energy efficient design from previous phase was simulated for different heights and was compared with most energy efficient façade of first phase. It was concluded that DSF of double glazed low-E outer and single glazed inner layer is more energy efficient design as compared to double glazed low-E glass with external shading. Energy efficiency is increased as altitude level is increased.

Tiantian Zhang et al. numerically analyzed the behavior of air layer as insulation between two walls under different boundary conditions [12]. They employed dimensionless heat transfer model and finite volume method in Fluent6.3 to find the flow and heat transfer behavior of air layer of thickness from 20 mm to 100 mm and height 1 m. It was observed that for $Ra<10^3$, the heat transfer is mainly through conduction and for $Ra>10^4$, convection mode of heat transfer starts to dominate. Moreover, for $10^4<Ra<10^5$ heat transfer through convection is in laminar region and for $Ra>10^5$ heat transfer occurs through turbulent convection. Furthermore, the critical thickness of air layer was determined to be in range of 20 mm to 30 mm depending upon the temperature difference. To verify these results, a simple office building with air layer as an insulation in exterior envelope was modeled in EnergyPlus for different locations in China. The results were compared with the simulation results of the same building with no air layer insulation. It was found that, depending upon the location, air layer can reduce the heat transfer by 10.54-39.23%.

Sye-Jye Gou and Taibing Wei performed a study to analyze the energy consumption of an academic block in National Taiwan University in eQUEST [13]. Energy model of the building was developed in eQUEST and the results were compared with three years average energy consumption. In this way energy model of the building was optimized to match with actual energy consumption. In addition to that, the building was modeled in Vasari, a computer based program to design buildings, to perform solar radiation analysis. It was found that roof, walls, and sunshades receive substantial amount of sunlight radiation. Thus, all the energy efficient proposals were centered on these components. Five different levels of energy efficient strategies for each component were devised and multiple simulations were performed by using orthogonal tests to find the energy saving potential of the building. At the end, cost analysis for each test was performed by using net present value (NPV) and sensitivity analysis. It was found that the combination of aluminum wall, steel plate roof and 1m grid sunshade was most energy efficient but economically least effective envelope. The most acceptable/ optimal envelope was of brick wall, steel plate roof, and 0.7 m grid sunshade.

Elisa Moretti et al. experimentally studied the behavior of polycarbonate panels as the fenestration component of envelope in the building [14]. Optical behavior of the panels was studied by using a large diameter integrating sphere facility containing a Xenon lamp and other suitable components, while thermal characteristics were analyzed by using hot box apparatus. Moreover, market potential of polycarbonate panels was assessed by comparing its optical and thermal values with commonly available double glazed glass units. It was found that reflectance and transmittance of the panels were approximately 0.72 and 0.25 respectively for 450-1100 nm wavelength of light. And heat transfer coefficient of polycarbonate panels was found to be in range of 1.2-1.9 W/m^2K. It was concluded that polycarbonate panels can be a good alternate of traditional glass units because these are cheap and fully compliant with local regulations of energy efficiency. In another study, Elisa Moretti et al. investigated, experimentally as well as numerically, the behavior of aerogel filled polycarbonate panels [15]. The experimental results from aerogel filled panels were compared against air filled panels. Furthermore, the effect of using aerogel filled and air filled panels on energy consumption of a building was analyzed against traditional glazing units by simulating an office building in EnergyPlus for different climatic conditions. It was found that aerogel filled panels show 44-73 % reduction in heat transfer coefficient against air filled panels. Moreover, aerogel filled panels have less transmittance and enhanced spectral response shape against air filled panels. In addition to this, simulation results show that aerogel filled panels can reduce the energy consumption by 7 to 12 %.

Arindam Dutta et al. evaluated the impact of five different types of window glazing for tropical climatic location in India by using eQUEST and TRNSYS simultaneously [16]. Base case building was modeled in eQUEST and eQUEST and results from both simulations were validated against actual energy consumption. Relative error and root mean square error (RMSE) of each model was compared with one-an-other. It was found that both tools have acceptable values for relative error and RMSE, while eQUEST was found to be less accurate than TRNSYS. After that, Optics5 and WINDOW7, window tools, were used to model five different types of single and double glazed windows for the thermal and optical properties. These models were validated experimentally by using Spectrophotometer and Integrating Sphere. After the validation, windows' models were imported to eQUEST and TRNSYS for the same building as previously. Results show that heat transfer gain of the building was reduced as compared against the base case, thus reducing the cooling load. Moreover it was found that, solar heat gain coefficient (SHGC) should be a more important factor in decision making than thermal conductance of window. Furthermore, most reduction in electrical energy consumption, 6.39 % in TRNSYS and 5.12 % in eQUEST, was observed by using Nano type double glazed glass units.

2.3. Energy Efficient Strategies: HVAC Systems

Out of the total energy usage in a building, HVAC systems, including all associated equipments, consume largest portion of energy [17]. Moreover, with advancement in the aesthetic level, the human thermal comfort conditions have been improved which demands higher energy consumption to maintain. Furthermore, the growing climate change concerns and increase in ozone layer depletion has forcefully raised the demand of using energy efficient and environmental friendly HVAC systems in buildings. So, it has always been a focusing point for researchers to design and implement modern control strategies to reduce energy consumption, and new environment-friendly refrigerants to reduce the environmental concerns of HVAC systems.

Ashfaque Ahmad Chowdry et al. experimentally performed the energy performance assessment of an institutional building in Australia [18]. Energy billing data of three consecutive years was collected and analyzed against the weather conditions of respective month. In this way, a correlation between energy consumption and weather condition was also established. Energy meters and data loggers were installed in the building to record the energy consumption data. Monthly base load of the building was induced to be 53,000 kWh, and annual energy consumption was found to grow by 2% each year. Monthly energy consumption of the building increased with increase in temperature except for March and December. In the month of March, due to the start of new academic sessions the monthly energy consumption increased despite of decreasing temperature. While for December, the monthly energy consumption decreased with increase in temperature due to vacation. It was concluded that total annual energy consumption of the building was 1,174,858 kWh per annum with HVAC systems as most energy consuming systems.

M. Santamouris et al. investigated the effects of using night ventilation on cooling load of the residential buildings in Greece [19]. The energy consumption data of 214 buildings using night ventilation was analyzed. In the initial stage, all the necessary information from 214 buildings was collected experimentally. At the same time, the information related to three years energy consumption and night ventilation of ten specific buildings were analyzed in detail. In the next stage, these ten specific buildings were modeled in TRNSYS to check the validity of simulation tool. After the validation, all 214 buildings were simulated initially for minimum night ventilation and then for specified air flow rates. The effects of night ventilation were calculated by comparing the two results of each building. Moreover, cooling load demand was also analyzed against air flow rates. It was found that night ventilation can reduce the cooling load of a residential building by 40 $kWh/m^2/y$. Moreover, the average contribution of night ventilation to cooling load was found to be 12 $kWh/m^2/y$. Furthermore, a linear correlation was observed between contributions of night ventilation to cooling load of a residential building. The contribution of night ventilation to cooling load of a building increases with increase in cooling load.

Stefano Schiavon et al. conducted a study to investigate the effect of raised floors on cooling load of a building in San Francisco by using EnergyPlus [20]. In addition to that, the effects of structure type, window-to-wall ratio, and carpets on the cooling load of the building with raised floors were analyzed. It was induced that the installation of raised floors can reduce the cooling load of a building upto 40%. Moreover, zone orientation and floor carpeting has significant effect on the energy saving of a building with raised floors. Carpeting can additionally decrease the cooling load upto 5%, depending upon the zone location. The reduction in cooling load of any zone is greatly affected by its orientation.

Y.P. Zhon et al. developed a model of variable refrigerant flow (VRF) in EnergyPlus and studied its energy efficiency potential [21]. The results of VRF model were compared with existing data available in literature to verify the model. After that, a comparative study, by using simulations, of a general building with VRF, variable air volume (VAV), and fan-coil plus fresh air (FPFA) was performed to evaluate the energy efficiency potential of VRF. It was found that VRF systems can save the energy upto 22.2% as compared to VAV, and 11.7% as compared to FPFA.

Ye Yao et al. developed a mathematical model to predict the annual energy performance of air-side economizers for variable air volume systems [22]. This model was then used to compare the energy savings brought by two different types of economizers, temperature based and enthalpy based economizer cycle, for six different climatic locations in China. It was found that climatic conditions significantly affect the energy performance of air economizers. Energy-savings-ratio for climatic condition of hot humid summer and cold winter ranges from 10% to 22%, and for cool dry summer and cold winter, it ranges from 5% to 10%. Moreover, it was concluded that the energy saving potential of enthalpy based economizer cycle is higher in hot humid location as compared to other locations, and temperature based economizer cycles are more energy efficient in dry regions.

2.4. Energy Efficient Strategies: Lighting Load

Lighting systems have a significant impact on final energy consumption of a building. Inefficient lighting systems not only increase the lighting load but also lead to increase the cooling load of a building. Moreover, any undeliberated attempt to decrease the lighting load of a building by using daylight or skylight, through energy intensive windows, may also increase the cooling load of the building. Hence, it requires a comprehensive approach to efficiently decrease the lighting load of any building.

Ming-Tsun Ke et al. conducted a study to analyze the effect of different energy consumption parameters on the final energy consumption of an office building in Taiwan by using eQUEST [23]. Initially, the developed energy model of the building was calibrated to match the results with experimentally collected data. In the next stage, the calibrated model was used to evaluate the impact of construction material, occupancy, lighting power density, HVAC systems and window glass material on the final energy consumption of the building. It was found that lighting power density has largest impact on the final energy consumption. With a decrease of 50% in LPD, the final energy consumption decreases by 30.78% and when LPD is increased by 50%, the final energy consumption increases by 31.19%.

N. Khan et al. performed techno-economic analysis of compact fluorescent lamps (CFL) as compared against other types of lighting systems used in Pakistan [24]. Energy consumption, luminous intensity, environmental effects, and operational cost of each type of the light was studied and compared with each other. It was found that a 15W LED lamp has least value of electric consumption per lumen and has least operational cost. Moreover, it was induced that, due to poor form of power factor and harmonic distortion in current, many lamps lose their power ratings with the passage of time. Fluorescent lights were found to emit ultra-violet rays and when disposed in atmosphere, may cause to emit phosphorous and mercury. LED lamps were found to be most efficient in terms of energy consumption and environmental effect. While electrode less fluorescent lamp and CFL were found to have good power rating quality.

Byung-Lip Ahan et al. devised a control mechanism to utilize the heat generated by LED lights in a building [25]. To control the heat generated by LED lights, two heat sinks were attached to the heat sink of recessed LED light. One of them was installed below the false ceiling to conduct the heat indoor in heating period, and other was attached to LED in plenum zone which was used to conduct the heat outdoor to reduce the heat gains in cooling period. In the next stage, the effects of this control mechanism were studied for a building in EnergyPlus. Four different energy models of Green Building in Korea was developed, each with fluorescent lighting, recessed LED fixtures, recessed LED fixtures with heat removed throughout the year, and recessed LED fixtures with a control strategy of heat conduction. Since the lighting load of the Green Building was very less as compared to a typical office building, a visual building based on Commercial Reference Building Model of US DOE was also simulated for the same four cases as previously to evaluate the impact of subject control strategy on other buildings as well. It was found that, for the Green Building, LED lights reduce annual energy consumption by 0.86% as compared to fluorescent lights. And if all the heat generated by LED lights is emitted to outdoor for whole year, the annual energy consumption is reduced by 1.67% with 11.57% decrease in cooling load and 2.73% increase in heating load. And with a controlled mechanism, final annual energy consumption for Green Building was reduced by 3.01%. While for the visual building, LED lights reduced the annual energy consumption by 4.77% as compared to fluorescent lights. And, reduction in energy consumption was observed to be reduced by 2.19% in case when heat generated in LEDs is emitted to outdoor. Finally, with controlled strategy, virtual building showed 9.27% decrease in annual final energy consumption.

Prashant Anand et al. numerically analyze the relations between occupancy and plug and lighting load of an institutional building in Singapore [26]. Two mathematical models comprising of energy consumption, occupancy and energy consumption per person was developed by using algorithms based on multi non-linear regression (MNLR) and deep neural network (DNN) alternately. Results from each model were compared against each other for mean absolute percentage (MAPE) values by using experimentally collected data. In the next stage, the more accurate mathematical model was used to predict the energy saved after applying some rules relating to occupant behavior in different zones. It was found that DNN based model showed more accurate results than MNLR based model. And with controlled occupant behavior, the building showed reduction of 8.9%, 3.1%, and 1,3% in plug load for classroom, open office, and computer room respectively. Similarly, lighting load was observed to reduce by 65.1%, 43.6% and 38.4% for each respective zone.

E.J Gago et al. studied different natural-light harvesting technologies by reviewing the latest research papers related to different control and guiding technologies for natural-lighting in a building [27]. Main focus of the study was to evaluate the performance of each control strategy in terms of reduction in cooling and lighting energy consumption. Controlled strategies which were studied for this paper mainly included light shelves, prismatic glazing, louver and blinds, skylight, light pipe, and some others. After reviewing the literature of each methodology, it was concluded that although each methodology tends to reduce the lighting load, there are some restrictions to the use of each strategy as well. Skylights were found to be efficient in tropical region if and only if these are used along with shading and other reflection devices. Light shelves were found to be dependent on the architectural design of building. The efficiency of louvers and blinds largely depend upon the occupant behavior. To reduce the heat gained through natural day-lighting, users tend to over close the blinds and hence resulting to increase the lighting load. It was suggested to use automated blinds to overcome this problem.

Meng Zhan et al. studied the significance of natural lighting factor against latitude, time of year, windows orientation, aspect ratio, and window-to-wall ratio for a residential building in Xi'an by using DIALux software [28]. Lighting model of the building was developed in DIALux and simulated for the worst condition of natural lighting (i.e. cloudy day). Results of the simulation were validated against the experimentally collected values. Simulation results show an average illumination value of 373 lx while experimentally collected data show illumination value to be 344 lx. In the next stage, the building was modeled for five different scenarios each with different value of aspect ratio, building height, latitude and glass transmittance value. Regression analysis was performed to develop a mathematical relation between window area and above mentioned factors. It was found that the window area and natural lighting have direct relation with building latitude and glass transmittance value. Based on the above results, a smart-phone application was developed to intelligently control the opening of curtain in the residential buildings.

Summary

Literature review for this study was performed in two phases. In the initial phase, all the literature about energy modeling techniques, especially eQUEST and DOE2, was reviewed. Afterwards, different energy efficient strategies in the building sector available in the literature were reviewed. Literature review for energy efficient strategies was divided into three categories: building envelope, HVAC, and building lighting load. The effects of these strategies for building at different locations were reviewed.

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Chapter 03

3. Energy Modeling of the Building

As discussed in Chapter 1, the building of USPCASE, NUST was selected as a showcase for this study. The subject building is situated in 33^o of North latitude and 72^o of East latitude in Islamabad. The number of floors above the grade is four with total height of approximately 52 ft from the ground level. Floor-to-floor and floor-to-ceiling height of each floor is 12.8 ft and 9.9 ft respectively. The building opens at 9 am and closes at 3:00 pm. It operates throughout the year with reduced use in summer season. The building was modeled for year 2019. Spring semester of 2019 starts from 21^{st} January and ends at 24^{th} May. Fall semester starts on 3^{rd} September and ends on 4^{th} January. Summer session starts from 10^{th} June and ends at 9^{th} August. Weather file for Islamabad was acquired from IWEC in ".epw" format. eQUEST uses weather file in ".bin" format, so weather file was converted to ".bin" format using "eQ_Wth_Proc". Since the floor plans for each floor, as discussed in next section, is different and more detailed data is collected, so DD Wizard was used to model the building.

3.1. Floor Plans

Floor plans for each floor were developed in AutoCAD and then were imported to eQUEST. Since the floor plan for each floor is different so eQUEST modeled each floor as a separate shell and placed them immediately above each other. eQUEST divides each building/shell area into different activity area types. Each activity area type corresponds to specific percentage of the building/shell and has similar occupant density and design ventilation rates. Up to 8 activity areas types can be allocated to a single building/shell. Table 3.1 shows the activity areas allocation of different spaces in the building.

eQUEST combines one or more spaces to form a single thermal zone. Different zones are then grouped together to form a zone group. Each zone group consists of different activity area types and is served by same HVAC system type. For example,
different activity area types and is served by same HVAC system type. For example,

three class rooms at 1st floor are grouped together to form a zone group which contains 100% Class Rooms activity area types.

Table 3.1: Activity Area Allocation of different spaces

Space Name	**Activity Areas Allocation**
Adm. Offices/ Teacher's Offices	Office (Open Plan)
Conference Room	Conference Room
Auditorium	Auditorium
Class Rooms/ Exam Hall	Class Room/ Lecture
Laboratories	Comm/ Ind Work (High Tech, Bio Tech, Lab)
Library	Library (Reading Areas)
Staff Room/ Common Room/ Faculty Lounge	Comm/ Ind Work (Low Bay)
Central Court	Comm/ Ind Work (High Bay)
Corridor	Corridor
Stairs/ HVAC Rooms/Toilets	Any Other

Ground floor of the building mainly includes offices, seminar hall, conference room and an academic lab. Total floor area for ground floor is 15,428 ft^2. Table 3.2 summarizes the ground floor with percentage of each activity area types. Detailed layout plan for ground floor is given in Appendix A1.

Area for first floor is 16,797 ft^2 which contains mainly class rooms and academic labs. Table 3.3 summarizes the floor plan of first floor with percentage of each activity area type. Layout plan for first floor is given in Appendix A2. Note that, although the seminar hall and central court are open to below at first floor but still their areas are included in total area calculation. It is due to the reason that eQUEST calculates the total floor area as the area within the walls of building envelope. Occupant density for these types of activity areas is entered to be zero.

Table 3.2: Floor plan for Ground Floor

Space Name	Activity Area Type	Area Percentage %	Occupant Density (ft^2/person)	Outdoor Air (CFM/person)	Zone Group	Type
PMT Office Director Office Dy. Director Office Principal Office Lobby & PA's Work Stations	Office (Open Plan)	10.03	221	54.48	Offices 00	Conditioned
Conference Room	Conference Room	5.28	54	-	Conf. Room 00	Conditioned
Seminar Hall	Auditorium	15.4	60	47.78	Seminar Hall 00	Conditioned
Combined Lab	Comm/ Ind Work (Lab)	12.9	400	-	Combined Lab	Conditioned
Central Court	Comm/ Ind Work (High Bay)	12.2	377	-	Court 00	Unconditioned
Corridor Lobby Ent. Lobby	Corridor	27.9	431	-	Corridor 00	Unconditioned
Stairs HVAC Rooms Gents/ Ladies Toilet	All Other	16.29	500	-	All Other 00	Unconditioned

Table 3.3: Floor plan for First Floor

Space Name	Activity Area Type	Area Percentage %	Occupant Density (ft^2/person)	Outdoor Air (CFM/person)	Zone Group	Type
Class 2 Class 3 Class 4	Classroom/Lecture	13.7	38	17	Classrooms 01	Conditioned
Conf. Room	Conference Room	4.85	82	34	Conf. Room 01	Conditioned
Solar Lab Enrgy Storage Lab	Comm/ Ind Work (Lab)	17.9	30	-	Labs 01	Conditioned
Corridor	Corridor	25.8	433	-	Corridor 01	Unconditioned
Seminar Hall	Auditorium	14.16	0	-	Seminar Hall 01	Unconditioned
Central Court	Comm/ Ind Work (High Bay)	11.23	0	-	Court 01	Unconditioned
Stairs HVAC Rooms Ladies/Gents Toilet	All Other	12.36	415	-	All Other 01	Unconditioned

Similarly the area for second floor is 17,169 ft^2. It mainly includes academic labs, common rooms and admin offices. Layout plan for second floor is given in Appendix A3. Floor plan of second floor is described in tabular form in Table 3.5.

Similarly, the floor plan of third floor is described in below Table 3.6. Total floor area for third floor is 17,537 ft^2. Layout plan for third floor is given in Appendix A4.

3.2. Building Envelope

Envelope of a building is made up of exterior walls, roofs and fenestrations. Poor selection of materials for building envelope may result in an increase in energy consumption. Selection of materials for fenestration is done in such a manner that it should reduce the lighting load and does not cause an increase in cooling load. Exterior walls of USPCASE building is made up of 8 in. CMU with stuccoed finish. Roof surfaces are made up of 6 in. concrete with "roof build up" finish. Vertical fenestrations i.e. windows are made up of double glazed clear glass with aluminum frame. Horizontal fenestrations i.e. skylights are made up of double acrylic sheets with iron frame.

Moreover, there are two types of exterior doors installed at the building: glass type doors and opaque doors. Glass type doors are made up of double glazed clear glass with aluminum frame. Opaque doors are made up of steel with hollow core. Table 3.4 shows the number of doors at different orientations.

Table 3.4: Number of doors for different orientation

	South	**North**	**East**	**West**
Glass Type	2	2	0	0
Opaque	1	1	1	1

Table 3.5: Floor Plan for Second Floor

Space Name	Activity Area Type	Area Percentage %	Occupant Density (ft^2/person)	Outdoor Air (CFM/person)	Zone Group	Type
Lecture Hall Synthesis Lab	Classroom/Lecture	8.67	75	57.80	Classroom 02	Conditioned
NG Staff Room Ladies Common Room Faculty Lounge	Comm/Ind Work (Low Bay)	7.46	183	43.23	Common Room 02	Conditioned
Fossil Fuel Lab Bio Fuel Lab Thermal Engineering Lab	Comm/Ind Work (Lab)	18.46	200	-	Labs 02	Conditioned
Adv. Energy Mat. Lab	Comm/ Ind Work (Lab)	5.8	200	-	Adv. Energy Lab	Conditioned
CES Admin	Offices	5.64	194	56.34	CES Adm 02	Conditioned
Corridor	Corridor	21.96	380	-	Corridor 02	Unconditioned
Central Court	Comm/Ind Work (High Bay)	14.52	0	-	Court 02	Unconditioned
Stairs HVAC Rooms Ladies/Gents Toilet	All Other	17.49	600	-	All Other 02	Unconditioned

Table 3.6: Floor Plan for Third Floor

Space Name	Activity Area Type	Percentage %	Occupant Density (ft^2/person)	Outdoor Air (CFM/person)	Zone Group	Type
Research Asso. Office Assistant Prof. Office Assosiate Prof. Office Professor Offices HOD Office Administration Office	Office (Open Plan)	28.66	335	72.87	Offices 03	Conditioned
Computer Lab	Computer Room (PC Lab)	9.1	100	29.52	Comp Lab 03	Conditioned
Exam Cell	Office (Open Plan)	2.75	121	-	Exam Cell 03	Conditioned
Library	Library (Reading Areas)	10.87	191	35	Library	Conditioned
Central Court	Comm/Ind Work (High Bay)	14.22	0	-	Court 03	Unconditioned
Corridor	Corridor	17.7	31	-	Corridor 03	Unconditioned
Stairs HVAC Rooms Ladies/Gents Toilet	All Others	16.7	580	-	All Other 03	Unconditioned

3.3. HVAC Systems

Two types of HVAC systems, Water Cooled Packaged Systems and Variable Refrigerant Flow Systems, are installed in the building. A cooling tower containing single condenser-water-loop for cooling the condensers is attached to each water cooled unit.

Six units of Variable Refrigerant Flow (VRF) system type are installed in the building. Each VRF system serves single or multiple zones and each system has an outdoor unit (condensing unit) placed at top floor of the building, and multiple indoor units which are installed at different zones. Cooling and heating source for these types of systems are direct expansion coils in which refrigerant flows. In cooling mode, the coil of indoor unit acts as an evaporator while in heating mode it acts as a condenser. A supply fan within indoor unit forces air to flow over the coils containing refrigerant. Details of each VRF are shown in Table 3.7 as below.

There are total six different water cooled packaged air conditioning units which serves different zones at different floors. Refrigerant used in these systems is R 407C. Cooling and heating source for these systems are direct expansion coil and electric resistance heating respectively. These types of systems contain a packaged unit which consists of a compressor, evaporator, supply fan and a water cooled condenser. In cooling mode, air is forced through a supply fan to flow over an evaporator which drops the temperature of air. Cooled air is then supplied to different zones through supply air ducts. While in heating mode, air is forced to flow over an electrically heated coil which increases its temperature and then supplied to different zones through ducts. Cooling and heating set points are set to be 24 ^{o}C and 22 ^{o}C respectively. Table 3.8 summarizes each water cooled packaged unit;

Table 3.7: Details of each VRF system

System Name	Indoor Capacity		Indoor Units	Max. Cap/ Unit	Outdoor Capacity		Outdoor Units	Zone Groups Served
	Cooling	Heating			Cooling	Heating		
	(kW)	(kW)	Qty.		(kW)	(kW)	Qty.	
VRF-1	47.25	54.8	5	10.9	50.4	56	1	Combined Lab
VRF-2	21	25.2	4	6.3	22.4	25	1	Conf. Room 00
VRF-3	80.5	90.1	11	8	85	95	2	Labs 01
VRF-4	95.97	100.8	11	9	96	108	3	Labs 02
VRF-5	33.49	39.5	3	13	33.5	37.5	1	Adv. Energy Lab
VRF-6	22.4	25	2	12.5	22.4	25	1	Exam Cell 03

Table 3.8: Details of each Water Cooled Packaged Unit

System Name	Cooling Capacity (Tons of Refrig.)	Heating Capacity (kW)	EER	Supply Air Flow Rate (CFM)	Served Zone Groups
WCP-1	10.5	18	11.2	4240	Offices 00
WCP-3	27.9	33	11	7162	Class Room 01
					Conf. Room 01
WCP-4	24.5	25	11.2	7195	Seminar Hall 00
WCP-7	30.3	39	11.8	10680	Classroom 02
					Common Room 02
					CES Admin 02
WCP-9	30.5	39	11.2	12385	Offices 03
WCP-10	20.6	25	11.8	7986	Library
					Comp Lab03

A cooling tower of induced draft, vertical discharge, cross flow type containing two cells is installed in the building to cool the condensers of each water cooled packaged unit. Each condenser is connected to the cooling tower through a condenser-water loop. Flow in the loop is pumped through two centrifugal pumps of capacity 466 gallons per minute each. Water entering to the cooling tower has a design temperature of 37.7 ^{o}C while it has temperature of 32 ^{o}C when leaving the cooling tower. Each condenser is connected to the loop through an isolation valve. Schematic diagram of the condenser-water loop and cooling tower is shown in Appendix B.

3.4. Lighting

Lighting system of the building consists of LEDs and fluorescent light. Different types of surface mounted LEDs, with different power ratings, are used in the building. Area lighting method was used to calculate the lighting load in which the lighting load of each area is calculated. Since eQUEST takes input for lighting loads against each activity area type so lighting load of each activity area type was calculated. Table 3.9 shows the lighting load of each activity area types.

Table 3.9: Lighting load of the building

Floor	Activity Area Type	Lighting Load (W/ft^2)
Ground Floor	Office (Open Plan)	0.58
	Conference Room	0.51
	Auditorium	0.65
	Comm/ Ind Work (Lab)	0.44
	Comm/ Ind Work (High Bay)	0.04
	Corridor	0.20
	All Other	0.37
First Floor	Classroom/Lecture	0.59
	Conference Room	0.59
	Comm/ Ind Work (Lab)	0.37
	Corridor	0.17
	Auditorium	0.00
	Comm/ Ind Work (High Bay)	0.00
	All Other	0.43
Second Floor	Classroom/Lecture	0.59
	Comm/ Ind Work (Low Bay)	0.33
	Comm/ Ind Work (Lab)	0.35
	Comm/ Ind Work (Lab)	0.60
	Offices	0.45
	Corridor	0.30
	Comm/Ind Work (High Bay)	0.00
	All Other	0.26
Third Floor	Office (Open Plan)	0.39
	Computer Room (PC Lab)	0.50
	Office (Open Plan)	0.49
	Library (Reading Areas)	0.53
	Comm/Ind Work (High Bay)	0.00
	Corridor	0.23
	All Other	0.26

3.5. Energy Model

Energy model of the building in eQUEST was developed using the data presented in previous sections. Figure 3.1 shows the energy model of the building in eQUEST interface.

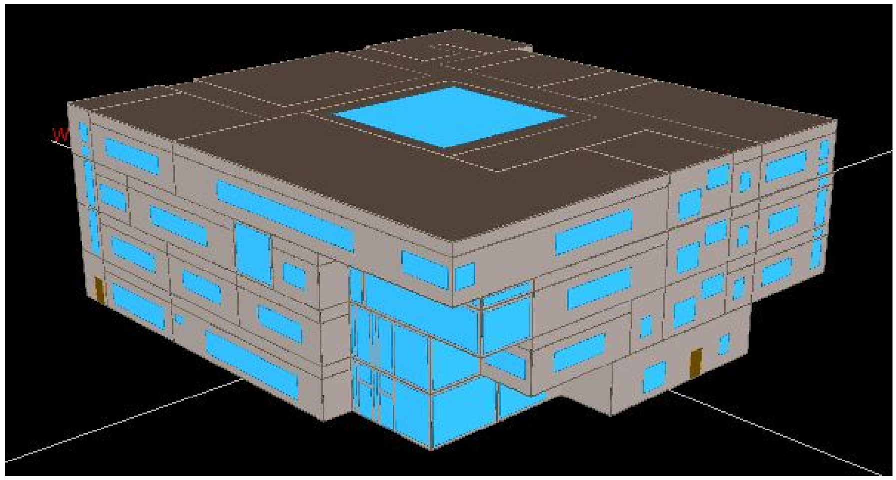

Figure 3.1: Energy Model of the building

It is worthwhile to mention here that the visual image of energy model of a building does not necessarily need to be like the architectural model of the building.

Summary

The subject building selected for this study has four above grade floor each with floor-to-floor and floor-to-ceiling height of 12.8 ft and 9.9 ft respectively. Each floor has different floor patterns and floor areas: ground floor has 15,428 ft^2 area, first floor has an area of 16,797 ft^2, second floor has an area of 17,169 ft^2, and third floor has an area of 17,537 ft^2. Two types of HVAC systems, variable refrigerant flow and water cooled packaged systems, of different capacities are serving different zones of the building. A cooling tower serving the water cooled packaged systems is installed at the top floor of the building. Lighting load of the building mainly comprises of LEDs technology. By using the above discussed data, an energy model of the building was developed in eQUEST.

Chapter 04

4. Results and Discussions

4.1. Simulation Results

Results obtained from the energy model of the building show that the building consumes approximately 219.22 x 10^3 kWh annually. Figure 4.1 shows the monthly energy consumption pattern of the building for a year. It is evident from the figure that maximum energy is consumed for space cooling followed by lighting load and then ventilation fans. The building consumes least energy in the month of February followed by the month of January. Least energy consumption for the months of January and February can be attributed to lower energy consumption required for space cooling in winter season.

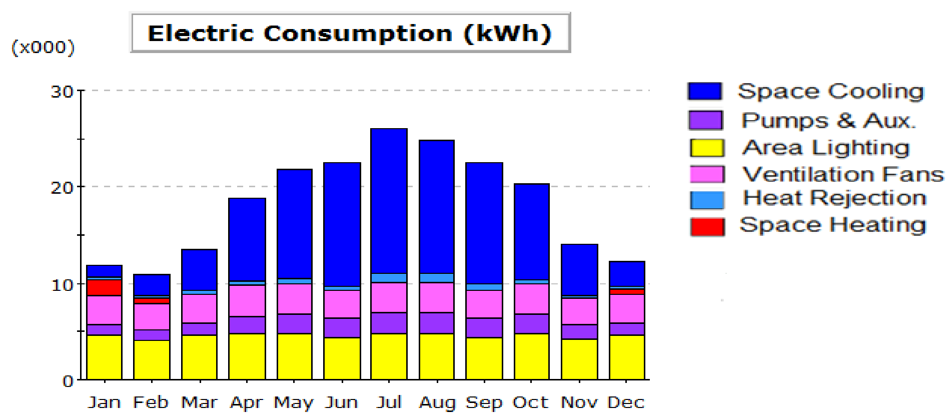

Figure 4.1: Monthly Energy Consumption of the Building

Detailed energy consumption of the building for each month is given in Table 4.1. It is worthwhile to mention that the space cooling load for the months of Jan-March, November and December is due to internal heat gains produced by occupants.

Table 4.1: Detailed Electric Consumption in $\mathbf{10^3}$ **x kWh**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	1.26	2.16	4.27	8.61	11.35	12.75	15.01	13.85	12.53	9.94	5.31	2.57	**99.60**
Heat Reject.	0.22	0.23	0.31	0.41	0.48	0.50	0.95	0.89	0.69	0.42	0.28	0.26	**5.64**
Space Heat	1.63	0.50	0.03	0	0	0	0	0	0	0	0.00	0.54	**2.70**
Vent. Fans	3.02	2.73	3.02	3.17	3.17	2.88	3.17	3.17	2.88	3.17	2.73	3.02	**36.12**
Pumps & Aux.	1.11	1.07	1.27	1.86	2.05	1.96	2.19	2.15	1.97	2.02	1.49	1.24	**20.39**
Area Lights	4.59	4.16	4.59	4.75	4.78	4.39	4.78	4.78	4.39	4.78	4.21	4.59	**54.78**
Total	11.83	10.84	13.50	18.80	21.82	22.48	26.09	24.83	22.46	20.31	14.02	12.23	**219.22**

4.2. Validation of Results:

For the purpose of validation, the simulation results are compared with actual energy consumption of the building. Actual billing data of the building shows annual energy consumption of the building to be 206.36 x 10^3 kWh. Table 4.2 shows actual energy consumption of the building for each month of year 2019.

Table 4.2: Actual Energy Consumption of Building in **10^3 x kWh**

	Actual Energy Consumption
January	15
February	10
March	10.89
April	11.77
May	17.27
June	22.77
July	29.01
August	29.43
September	20.84
October	16.87
November	11.38
December	11.13
Total	**206.36**

It is worthwhile to mention that energy consumption data for months of March and April were not available and the same were interpolated against succeeding months. Figure 4.2 shows comparison of actual energy consumption and simulation results of the building.

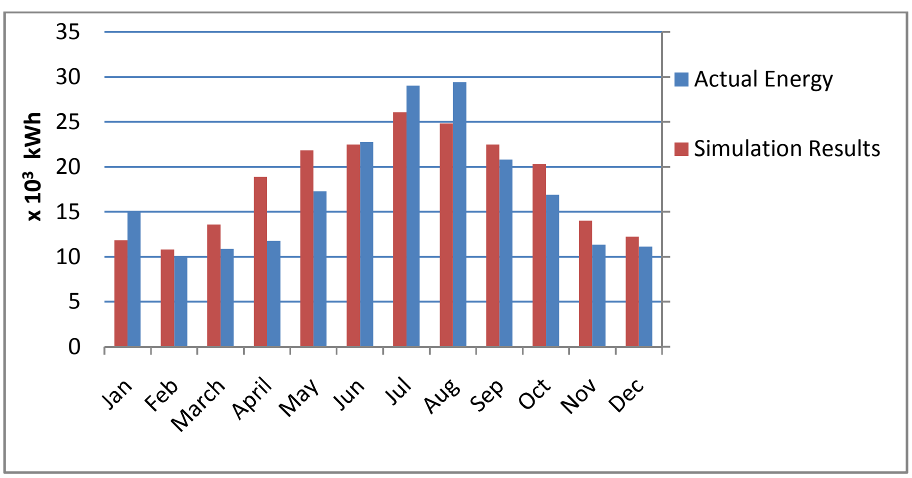

Figure 4.2: Comparison of Actual Energy Consumption and Simulation Results

Percent error for simulation results can be calculated by dividing the difference between actual measured data and simulation results with simulation results and multiplying the same with percent. Percent error turns out to be 5.87 %, and this minute value of error can be attributed to the fact that eQUEST does not incorporate human behavior while calculating the simulation results. In addition to that, an accurate and fully compliant occupancy schedule of the building for eQUEST input can't be obtained.

Detailed analysis of the simulation results (LS-F) show that heat gain in the building is largely by conduction through walls and windows, and window solar heat gain. Moreover, it was found that (SS-A) energy consumption of the water cooled HVAC units was very much greater than the VRF systems. So, the energy efficiency measures proposed for the building mainly revolves around these components. Discussed below are some energy efficiency measures proposed for the building.

4.3. EEM1: Demand Control Ventilation

Demand Control Ventilation (DCV) technology uses an intelligent control technology to modulate the outdoor air flow into the conditioned zones. It helps to reduce the energy consumption required for space cooling and heating. Moreover, for variable air volume systems, it helps to significantly reduce the energy consumed by ventilation fans. Results show that if all of the water cooled packaged systems in the building are embedded with DCV technology, the total annual energy consumption of the building can be reduced to 214.58 x 10^3 kWh. This reduction is mainly due to the reduction in energy consumption required for space cooling and heating, and subsequent reduction in heat rejection. It should be noted that since the ventilation fans in these systems are constant volume type so DCV technology does not affect the energy consumed by the ventilation fans.

4.4. EEM2: Variable Speed Drives for Cooling Tower

Variable speed drives are energy efficient motors that are responsive to demand. It is capable of changing its speed by changing its frequency. In low demand operation, it adjusts its speed so as to match the required speed. Hence, it can reduce its energy consumption by varying its speed. Simulation results show that if the single-speed fan and pump in cooling tower are replaced with variable speed fan and pump respectively, it can reduce the annual energy consumption of the building to 204.55 x 10^3 kWh. This reduction is mainly due to decreased load of pumps and auxiliary equipment in cooling tower.

4.5. EEM3: Argon Filled Low-E Glass Windows

As discussed earlier, heat gain through windows by thermal conduction and solar irradiation has a significant impact on final energy consumption. Argon filled low-E glass window tend to reduce its thermal conductance and solar heat gain coefficient by using an argon filled layer between two glass layers of low emissivity. Results show that the replacement of air filled double glazed simple glass window with double glazed argon filled low-E glass window can reduce the annual energy consumption to 206.74 x 10^3 kWh. This whole reduction is due to the reduction in energy required for space cooling in the building.

4.6. EEM4: Outdoor Air Economizer for Water Cooled Packaged Systems

Outdoor air economizers for HVAC systems efficiently utilize the outdoor air temperature to reduce the energy consumption required for space cooling. It does so by introducing ambient outdoor air when its temperature is less than the returning air temperature. Moreover, it locks out the compressor of air conditioning system when outdoor air temperature falls below a specific limit. Simulation results show that outdoor air economizer for packaged systems can reduce the final energy consumption of the building to 209.56 x 10^3 kWh annually.

Table 4.3: Percentage Energy Reduction of each Energy Efficiency Measure

Sr. No.	Description	Energy Reduction
EEM1	Demand Control Ventilation	2.12 %
EEM2	VSDs for Cooling Tower	6.7 %
EEM3	Argon filled Low-E Glass Windows	5.7 %
EEM4	Outdoor Air Economizer	4.4 %
EEM5	Daylight Controls	8.51 %

4.7. EEM5: Daylighting Controls in Offices, Classrooms and Library

Simulation results find that the installation of daylight control sensors in offices, classrooms and library of the building can reduce the annual energy consumption to 200.55 x 10^3 kWh. Daylight control sensors intelligently control the brightness level of the indoor lights by using the outdoor light level. The use of daylight control sensors not only reduce the lighting load but also reduce the space cooling load by decreasing the heat gain through lights in the building. Table 4.2 shows percentage reduction in energy consumption against all the energy efficiency measures discussed previously.

4.8. EEM6: All EEMs Combined

Simulation results show that if all of the previously discussed energy efficiency measures are applied to the building, they can reduce the annual energy consumption of the building to 170.71 x 10^3 kWh. Total percentage energy reduction through combined energy efficiency measures is calculated to be 22.12 %. Figure 4.2 shows the monthly energy consumption pattern of the building having all the energy efficiency measures for one whole year.

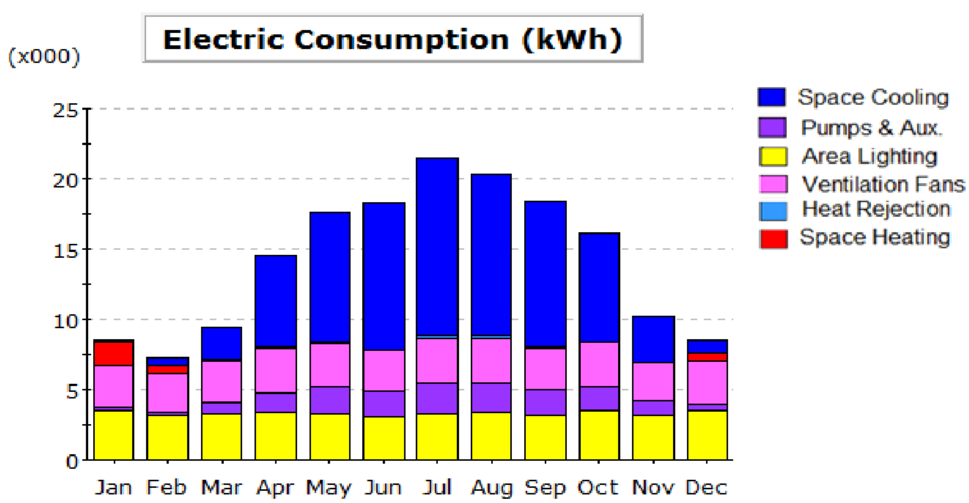

Figure 4.3: Monthly Energy Consumption of the Building with all EEMs

It should be noted that percentage energy reduction in case when all EEMs are applied is less than the sum of all the percentage energy reduction of each EEMs when applied individually. It is due to the fact that any two or more EEMs have some

Table 4.4: Detailed Electric Consumption of the Building with all EEMs in $\mathbf{10^3}$ **x kWh**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Space Cool	0.09	0.58	2.32	6.48	9.17	10.45	12.59	11.52	10.28	7.67	3.32	0.89	75.38
Heat Reject.	0.00	0.01	0.02	0.06	0.08	0.09	0.31	0.26	0.17	0.06	0.03	0.01	1.10
Space Heat	1.63	0.47	0.03	0	0	0	0	0	0	0	0.00	0.55	2.68
Vent. Fans	3.01	2.72	3.01	3.15	3.15	2.87	3.15	3.15	2.87	3.15	2.72	3.01	35.99
Pumps & Aux.	0.21	0.32	0.71	1.45	1.84	1.90	2.12	2.08	1.90	1.70	0.95	0.46	15.65
Area Lights	3.54	3.13	3.35	3.38	3.35	3.04	3.32	3.36	3.15	3.52	3.22	3.54	39.91
Total	8.48	7.24	9.45	14.52	17.59	18.35	21.50	20.38	18.37	16.11	10.24	8.48	**170.71**

overlapping effect on the final energy consumption of the building. Table 4.3 shows in detail the annual energy consumption pattern of the building when all EEMs are applied.

Summary

After performing the simulations, it was found that the annual energy consumption of the building is 219.22 x 10^3 kWh. Maximum energy is consumed for space cooling followed by lighting load and then pumps and auxiliary equipments for cooling tower. Some energy efficiency measures including demand control ventilation, variable speed drives for cooling tower, argon filled low-E glass windows, outdoor air economizer for water cooled packaged systems and daylighting controls for offices class rooms, and library were proposed for the building. Simulation results show that each energy efficiency measure has an energy reduction potential of 2.12 %, 6.7 %, 5.7 %, 4.4 %, and 8.51 % respectively. Energy consumption for the building with all energy efficiency measures combined is found to be 170.71 x 10^3 kWh annually. Due to the overlapping effects of each energy efficiency measure, the total effect of combined energy efficiency measures is less than the sum of each individual energy efficiency measure.

Chapter 05

Conclusions and Recommendations:

This study was conducted to find the final annual energy consumption of USPCASE, NUST building by using eQUEST. After performing validation of simulation model, some energy efficiency measures were proposed for the building and their impact on annual energy consumption was evaluated. Final energy consumption of the building was found to be 219.22 x 10^3 kWh. Actual energy consumption of the building for year 2019 was 206.35 x 10^3 kWh; hence percent error for simulation result is 5.87 %. Of all the proposed energy efficiency measures, daylight control has highest potential of energy saving followed by variable speed drives. Daylight control reduces energy consumption by 8.51 % and variable speed drives by 6.7 %. Demand control ventilation has least energy saving potential of 2.12 %. It was found that if all of the proposed EEMs are applied to the building, the final annual energy consumption can be reduced to approximately 170.71 x 10^3 kWh. Moreover, due to the overlapping effects of each EEM, the combined effect of all the EEMs was less as compared to the individual effect of each EEM.

It is recommended that low cost energy efficiency measures should be adopted to reduce the energy demand of the building. Moreover, awareness campaigns should e arranged to highlight the importance of energy efficiency among users of the building. Apart from that, a properly approved maintenance schedule for HVAC and other systems should be prepared to ensure the high efficiency of equipments.

Future Work:

As discussed in Chapter 01, the economic analysis of the proposed energy efficiency measures is not the scope of this study, so this study can be further extended to perform the economic analysis of all the proposed energy efficiency measures. In addition to that, a similar study can also be conducted for other conventional buildings to compare the energy saving potential of USPCASE with these buildings. Moreover, this study can be extended to other cities of Pakistan to assess the impact of location on energy saving potential of the proposed energy efficiency measures.

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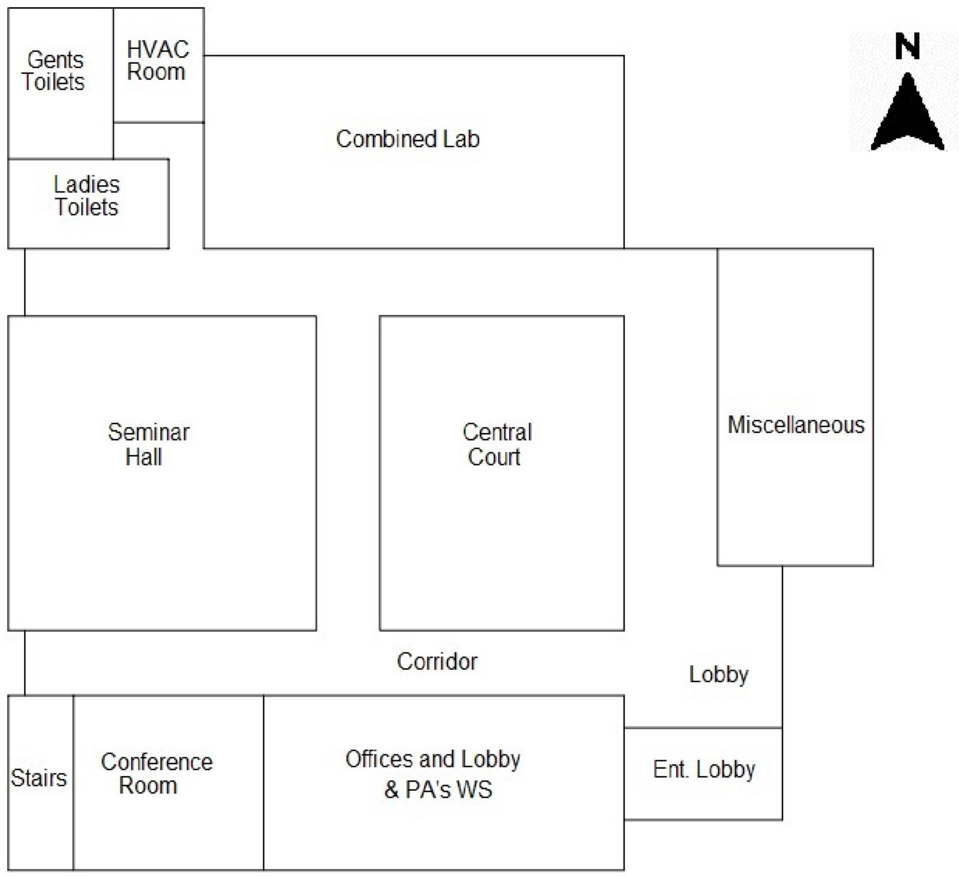
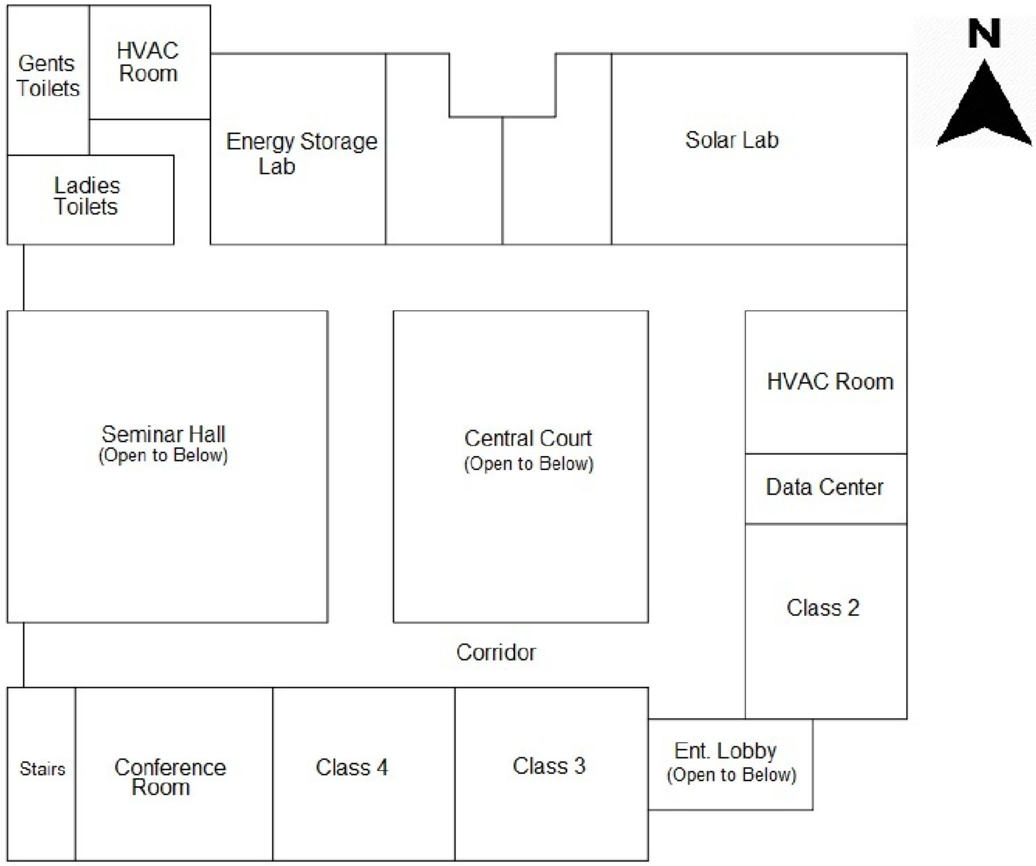
Appendices

Appendix A1:



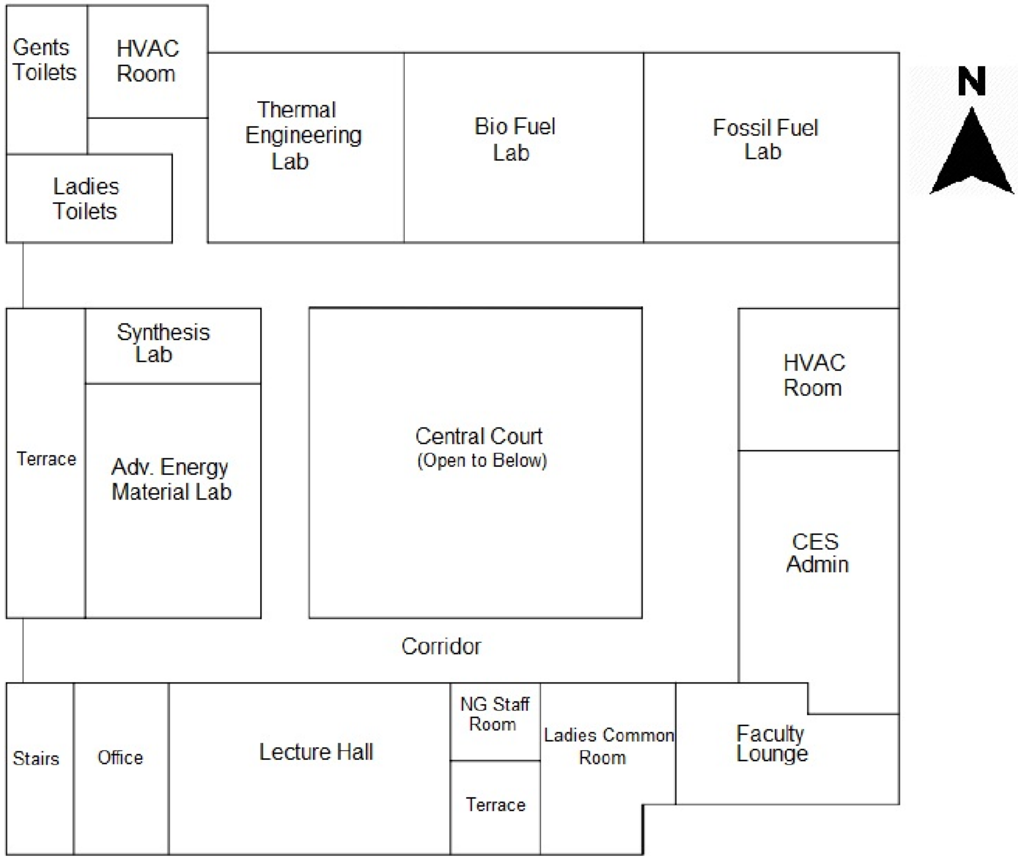
Layout Plan of Ground Floor

Appendix A2:



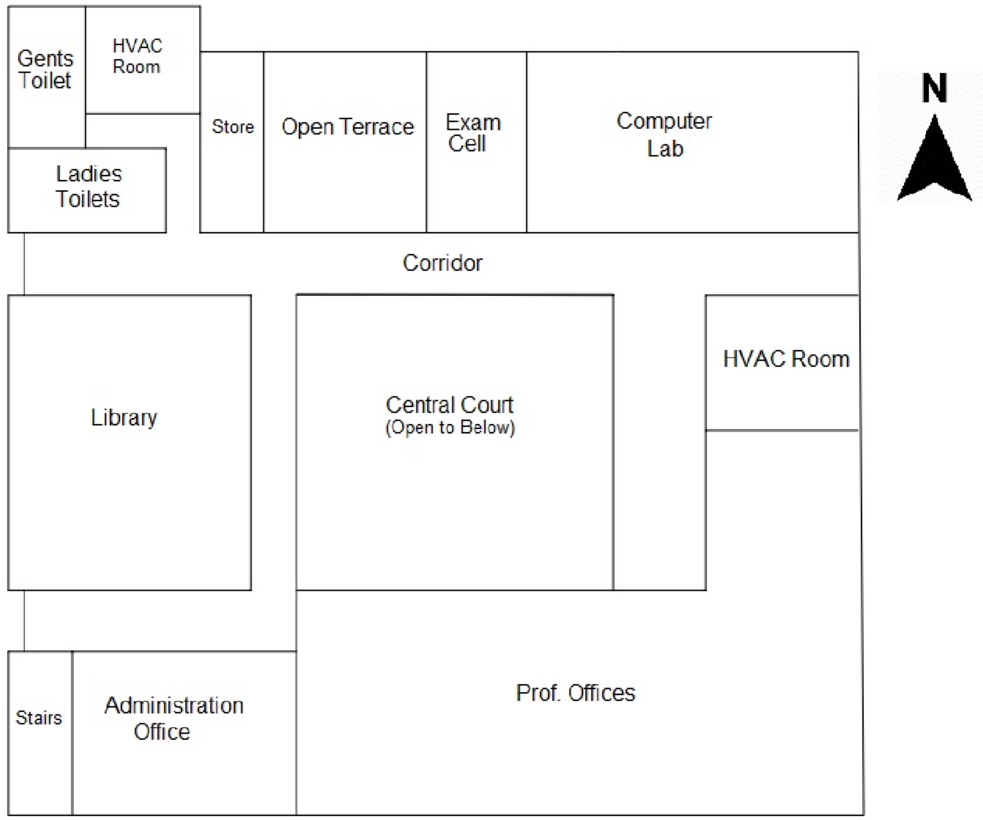
Layout Plan of First Floor

Appendix A3:



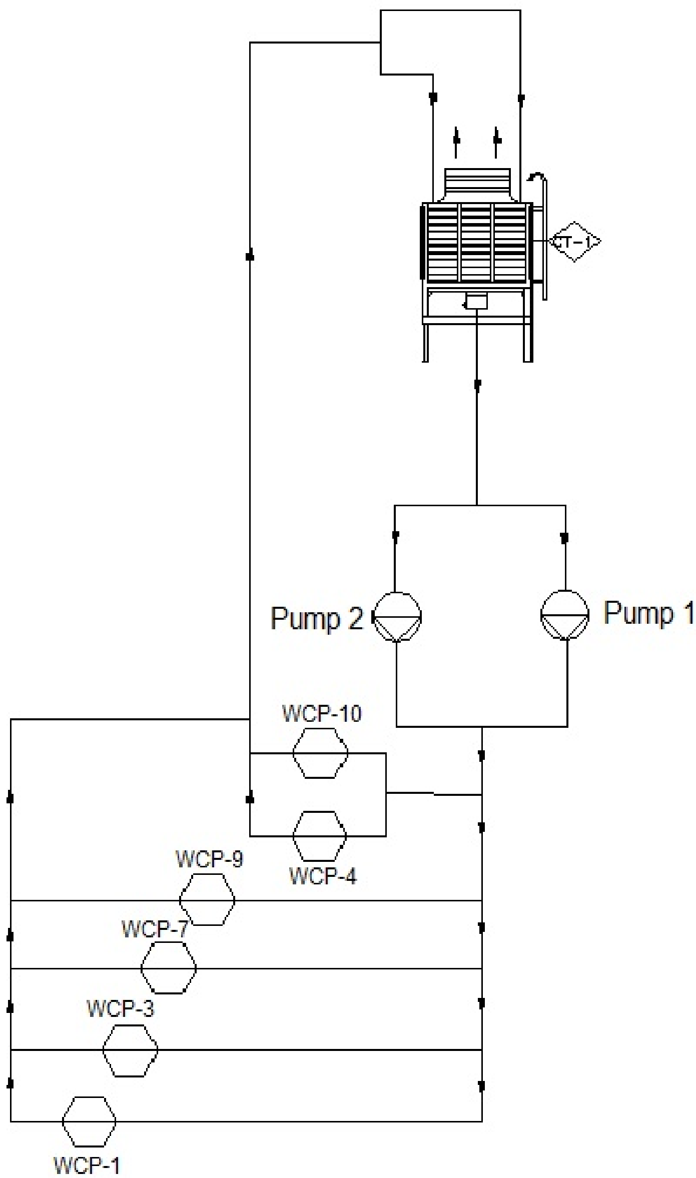
Layout Plan of Second Floor

Appendix A4:



Layout Plan of Third Floor

Appendix B:



Cooling Tower Loop and its Connection with Packaged Units

Energy Performance Analysis of a Commercial Building using eQUEST

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Abstract

Energy consumption in a building largely depends upon the type of materials and design of the buildings. This paper analyses the energy consumption pattern of an academic building located in Karachi using eQUEST. Some common and easy to adopt energy efficiency measures (EEMs) are proposed and applied to the baseline building to evaluate their energy savings potential. Of all the discussed, appropriate selection of air conditioning system has highest energy savings potential. When all the EEMs are applied together, the baseline building shows an energy saving potential of 30.5%.

Keywords

Energy performance analysis, eQUEST, Commercial buildings, Energy efficiency measures

1. Introduction

Recent energy crises and the hazardous impact of fossil fuel burning on environment have alerted the world to find some ways to save energy and use it efficiently. The building sector, others being industrial and transportation sector, is the largest energy-consuming sector contributing one-third to the final energy consumption of the world (Lucon O. et al. 2014). Moreover, energy demand in building sector is rising with higher rates than any other sector. And, if energy efficiency measures are taken, building sector has a potential of annual energy savings up to 14.72×10^{12}kWh by 2050 (IPEEC, 2015).

Similarly in Pakistan, building sector consumes large proportion of total energy consumption. And it is expected to grow due to rapid urbanization, which will cause a widening gap between demand and generation of electricity in future. So, energy efficient strategies for buildings can play an important role to curb the power shortages as well. National Energy Efficiency and Conservation Authority (NEECA), through its pilot project, has found a potential of 30% energy savings in buildings ("Building Sector", 2018). In addition to energy savings, energy efficient buildings do reduce the operational cost of the buildings.

To find the energy saving potential of a building, it is always significant to perform its energy performance analysis. In this paper, the effects of different energy efficiency measures in terms of energy savings for an academic building located in Karachi are studied using eQUEST. Since the energy used for any operations other than space heating, cooling, lighting etc. is not affected by the building designs and materials so these are not considered in this paper.

2. Methodology

In the first place, energy performance analysis of a baseline building is performed using eQUEST. Some common and easy to adopt energy efficiency measures (EEMs) are then applied using control variables method to calculate the energy savings. Some of the possible EEMs may include: the addition of insulations to exterior walls and roof surfaces, replacing one type of window with another, reduction in lighting density, installation of daylight controls and appropriate selection of air conditioning systems. Moreover, the variation in window-to-wall ratio (WWR) of a building may have a positive impact on energy savings.

The baseline building includes two floors above the grade and no floor below the grade. The floor-to-ceiling and floor-to-floor heights for each floor are 9.9 ft and 12.8 ft respectively. The gross floor area of the building is 30500 sq. ft. approximately. The building is of a rectangular shape with approximate total length and width of 138 ft. and 124 ft. respectively. It mainly includes one library, one conference room and one room for faculty offices. It also consists of one photocopy and stationary room, one staff-room, one common room and five class rooms and laboratories. One water-cooled packaged unit with electric resistance heating is installed for each floor to serve the air conditioning. Figure 01 shows the floor layouts of ground and top floor of the building.

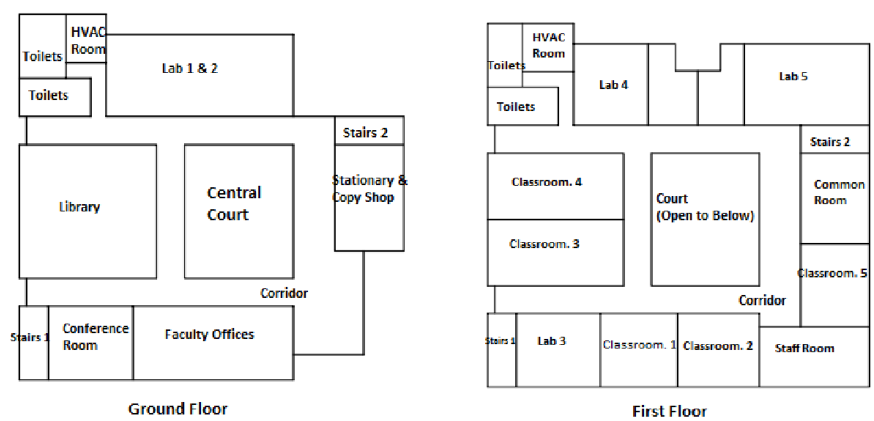

Figure 01: Floor layouts

Exterior walls of the building are made of 8 in. concrete masonry unit (CMU) with external finish of stucco. Exterior roof surfaces are made of 8 in. concrete with roof built-up finish. Windows installed in the buildings are made of single glazed clear glass. Lighting load is set to be 0.6 W/ft.^{2} in library, laboratories, offices, classes and conference room. Similarly, lighting load in corridors and lobby is 0.65 W/ft.^{2} and 0.4 W/ft.^{2} for staff room and common room. Cooling and heating set-points are 24 °C and 22 °C respectively. Figure 02 shows the energy model diagram of the building created by using eQUEST.

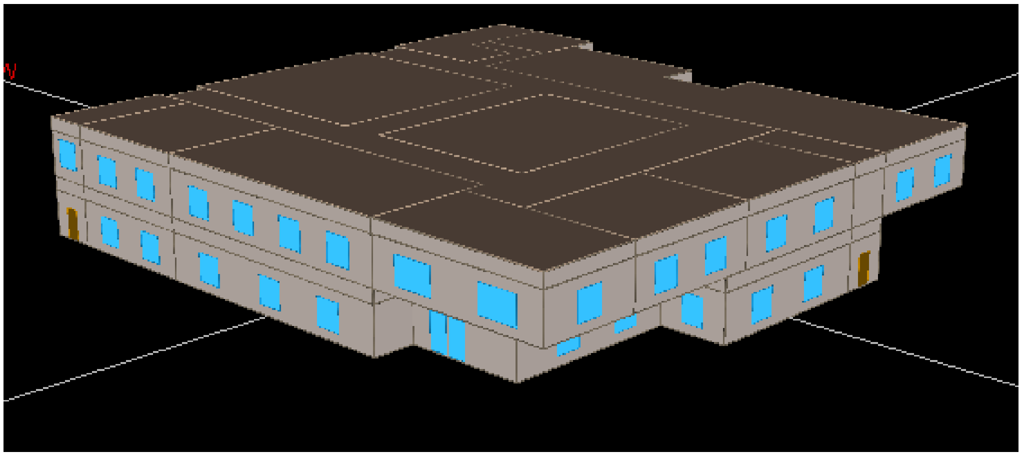

Figure 2: Energy model of the building

The annual operating schedule of the building is mainly divided into two groups. The first group consists of summer and winter vacation (i.e. 01, June to 31, July and 21, December to 31, December) while the other group consists of operational days for all the remaining dates.

3. Results and Discussions

Above data was input to the eQUEST and simulation was performed. Figure 3 shows the simulation results of the baseline building. Results show that the total annual energy consumption for baseline building is 109.58×10^3 kWh and a larger proportion of energy is used for space cooling and area lighting. Furthermore, it can be seen from the figure that the largest energy consumption for an individual month is in the month of August. This may be attributed to higher demand of energy consumption for space cooling in summer. Similarly, the least energy consumption is in the months of summer vacations. It is due to fact that building is not occupied during these months.

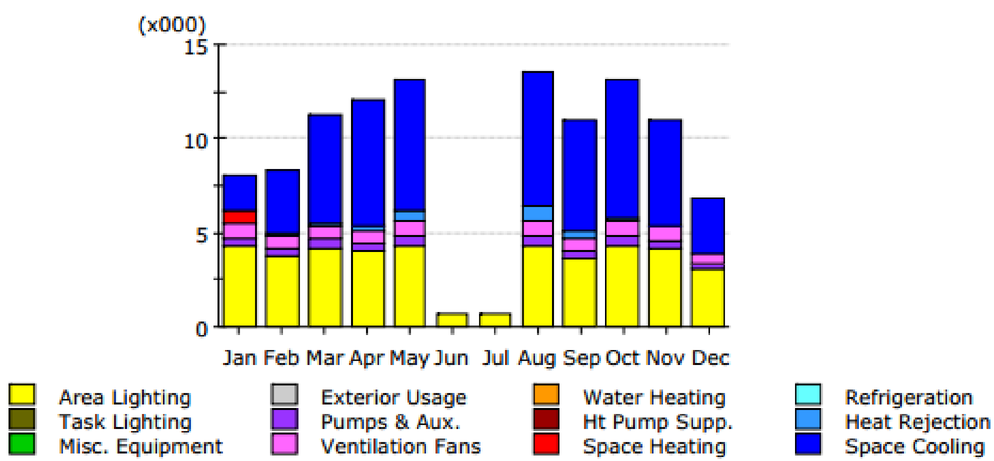

Figure 3: Results of Baseline Building

Since area lighting and space cooling has most contributions towards energy consumption, so EEMs are mainly focused on these areas. Discussed below are the effects of different EEMs applied individually to the baseline building. Table 1 summarizes these effects.

3.1 EEM1: Insulation for exterior surfaces

In order to reduce the heat losses from the building, some insulation materials are added to exterior walls and roof surfaces. Results show that the addition of 1 in. layer of polystyrene insulation to the exposed surfaces decreases the annual energy consumption of baseline building to 107.73×10^3 kWh.

Table 1: Annual energy savings for each EEMs

Energy Efficiency Measures	Annual Energy Savings (kWh)
EEM1	1850
EEM2	4110
EEM3	3110
EEM4	24770
Combined	33530

3.2 EEM2: Double glazed window

High performance windows not only provide better thermal insulation but it also blocks infrared radiations coming from the sunlight to reduce the space cooling load of building. The installation of double glazed clear glass window to the baseline building can reduce the annual energy consumption to 105.47×10^3 kWh.

3.3 EEM3: Daylighting controls

Daylighting in a building with low performance windows may have a negative impact on the energy performance of a building. It is due to the fact that daylighting may reduce lighting load of the building, but on the other hand, with low performance windows it increases space cooling load of the building by allowing some infrared radiations of sunlight. So, daylighting controls can only be studied in integration with windows performance. Implementing daylighting controls to the baseline building with addition of window blinds reduces energy consumption of the baseline building to 106.47×10^3 kWh/year.

3.4 EEM4: Appropriate air conditioning system

Energy consumed by air conditioning system largely depends on the type of the system being used. Selection of variable air volume (VAV) system instead of constant volume (CV) system for building reduces energy consumption to 84.81×10^3 kWh annually.

If the above discussed EEMs are applied together to baseline building, the results show the annual energy savings of 33.53×10^3 kWh. So, the integrated energy efficient baseline building consumes 76.05×10^3 kWh annually.

4. Conclusion

Energy efficient strategies not only lessen the energy consumption of buildings but it largely reduces the operational cost of buildings as well. This paper is aimed at determining the energy savings of some common and easy to adopt energy efficiency measures for an academic building located in Karachi. Simulation results predicted 30.5 % of annual energy savings. Results show that the selection of appropriate type of air conditioning system has highest energy savings potential individually as compared to others discussed in this paper. Similarly, insulation to exterior surfaces has least energy saving potential.

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