QATAR UNIVERSITY

COLLEGE OF ENGINEERING

COMBINED HEAT AND POWER SYSTEM BASED ON SOLID OXIDE FUEL CELLS FOR HOSPITALS IN HOT AND HUMID ENVIRONMENT.

BY

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ABSTRACT

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Title: Combined Heat and Power System based on Solid Oxide Fuel Cells for hospitals in hot and humid environment.

Supervisor of Thesis: Dr Tarek Y. El Mekkawy & Dr. Ahmad Khalaf Sleiti

One of the most influential trends in today's world is the massive increase in the consumption of the existing natural resources to generate power. Finding optimized and sustainable solutions to the depletion of current resources and the associated CO_2 emissions is one of Qatar's 2030 vision's most essential goals.

One of the most viable solutions to these concerns is utilizing combined cooling, heating, and power (CCHP) distributed systems. One of the CCHP system's benefits is reducing heat losses, as the power is produced on-site. Moreover, the CCHP system can operate on recovered heat from waste heat sources to have domestic hot water, heating, thermal-mechanical refrigeration (TMR)/cooling, and extra power. Consequently, there is a sharp increase in the overall system efficiency by reducing the cost of consumption and a steep decrease in environmental pollution. One of the most promising technologies is the combined heat and power technology with solid oxide fuel cells (CHP-SOFC), which could reach an efficiency of more than sixty percent. Its fuel flexibility makes it viable than fossil fuel technologies since it can operate with hydrogen or natural gas.

Energy Consumption in hospitals is more significant than other private and public buildings (Ayoub et al., 2014). Therefore, it is beneficial to determine energy consumption performance to save electricity. This thesis focuses on implementing and

analyzing the CHP-SOFC system and other energy-saving alternatives in the Cancer Care Hospital in Qatar. The main objective is to investigate how an energy assessment framework can be performed out for a healthcare facility.

Modeling analysis is conducted via eQUEST Simulation software, in which a model of 1,75,190 square-feet and a 200-bed hospital building is developed. The Cancer Care Hospital's energy consumption model is developed by keeping account of all existing construction policies and current market utility rates, such as ASHRAE 90.1-2010 standard, Qatar Construction Specification (QCS) 2014 and Kahramaa policies. A demo model of the SOFC CHP system is also implemented in the premises of the hospital using eQUEST.

The obtained results of the above model are evaluated to determine the overall system performance. The facility's energy cost is measured annually while assessing the electricity output and the efficient usage of thermal energy. In addition, to give a better picture of possible cost savings, different improvement alternatives are modeled, and their results are compared with the hospital base-case scenario.

The measurement of carbon emissions aims to evaluate the impact of harmful gases on the environment from several alternatives compared to the current energy system in cancer hospital. The findings are shown as environmental safety measures.

In light of the arguments presented in this research work, the base case scenario is compared with different approaches like efficient HVAC systems, additional external building insulation, lighting upgrade, installation of Photovoltaic system, and SOFC CHP system. At the same time, the proposed improvement alternatives resulted in overall lower energy bills and improved the facility's environmental effects. This work analysis has creativity in the methodology approach, the actual collection of hospital data and the outcome as no research has been performed in GCC countries before.

DEDICATION

I allocate my assignment to my

admired Parents, NCCCR hospital management and distinguished Teachers

for their support and supervision.

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First of all, I thank my Creator Almighty Allah, the Beneficent, the Merciful, and the Supreme Source of all, to guide me and give me the strength to think, organize and write my project at every stage, as well as to keep me inspired and determined.

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LIST OF ABBREVIATIONS

BESS – Backup Energy Storage System

BOP – Balance of Power

CCHP – Combined Cooling, Heating and Power

CHP – Combined Heat and Power System

CO_2 – Carbon Dioxide

DDW – Design Development Wizard

FIT – Feed-In-Tariff

GHG – Green-House Gases

HVAC – Heating, Ventilation and Air Conditioning

HOMER – Hybrid Optimization Model for Electric Renewable

LCOE – Levelized Cost of Energy

MILP – Mixed Integer Linear Programming

MINLP – Mixed Integer Non-Linear Programming

MS-EGC – Multi-Stage Exhaust Gas Combustion

NPC – Net Present Cost

PEMFC – Polymer Electrolyte Membrane Fuel Cell

PV – Photovoltaic

SDW – Schematic Design Wizard

SOFC – Solid Oxide Fuel Cells

WWTP – Waste Water Treatment Plant

CHAPTER 1: INTRODUCTION

1.1 Background

Nowadays, countries want to improve their energy quality and production. The demand for energy increases continuously, but present power plants cannot provide enough energy to accomplish the needs. Research has revealed that fossil fuels' accumulation has remained for almost 200 years, gas resources are limited for nearly 60-65 years, and oil resources for roughly 40-45 years (Ellabban et al., 2014).

Qatar's population increases to more than 2.65 million, with a 4.6 increment factor since 1999. Consequently, Qatar's rapid increase in economics is because of an increased number of commercial and industrial buildings. As a result, the production of electricity in Qatar has increased to almost 3.7 times (Ayoub et al., 2014). Qatar is also considered the second-highest per capita energy user country in the Gulf Cooperation Council (GCC) countries (Ayoub et al., 2014).

However, the number of power plants in the world is also growing, but it is a fact that electrical energy is scarce in a large portion of many countries. Solid Oxide Fuel Cells (SOFCs) are indeed taken into consideration a way to resolve the depletion of fossil fuel reserves and high greenhouse gas rates, including CO2 emissions, and to minimize climate impacts and health associated risks. A fuel cell was formulated in 1839 by Sir William Grove, and it is considered the oldest electrical conversion device.

Recently, this technology has turned into the most promising technology to produce power for the future. Various features offered by fuel cells make them promising energy conversion devices. One of the crucial features is the combination of approximately increased efficiency and low environmental influence (Stambouli & Traversa, 2002). SOFCs have been recognized as a technology of viable high-temperature fuel cells.

The powerful temptation towards SOFC is the capability to cope up with an extensive span of hydrocarbon fuels. Furthermore, the high operating temperature of SOFC yields high-grade unintended heat to employ for cogeneration or in the bottoming cycle to make secure competitors for power production. Even though SOFC yields electricity, it generates dc power by employing only processed fuel. Therefore, SOFC based power production needs integration of various equipment along with SOFC stack, too.

Besides, energy availability is essential for healthcare facilities as electricity is used to preserve medicines in good condition and conduct operations, clinical care, screening services, other appliances, and the hospital's network topology (Hostettler et al., 2015). Policies must be adopted to solve power shortages, high electricity prices, environmental concerns, and greenhouse gas emissions, leading to sustainable and practical energy solutions (Adair-Rohani et al., 2013).

Fundamentally, to counter these issues, every society entity should be provided with sustainable, greener, and economically feasible energy. Due to their demand for sustainable and continuous energy for ventilation, lighting, heating, air conditioning, and medical and surgical machinery utilization, hospitals are found to be critical consumers of electricity (Boemi et al., 2015), (Santamouris et al., 1994), (Adair-Rohani et al., 2013).

Access to stable electricity is a significant issue for hospitals that can influence healthcare provisions (Adair-Rohani et al., 2013). Surgical and non-surgical equipment may damage due to the unstable supply of electricity. In the Global South, data was gathered for 33 health cares in 10 countries that indicated that 70% of the malfunction was due to voltage surges mentioned in (Reise & Waller, 2009). Since a hospital located in Cameroon was affected by voltage swelling from the primary grid, such cases would impact drastic consequences, leading to disruption of 50% of clinical and non -clinical devices (Hostettler et al., 2015).

A large number of power plants are now being constructed to provide a cost-effective solution to electricity generation. Non-renewable energy sources have some limitations and provide an unhealthy environment. Reduction in energy consumption and energy cost are significant elements that increase the need to switch towards other alternatives. This research would discover Solid Oxide Fuel Cell (SOFC) technology implementation with Combined Heat & Power and analyze the various energy-efficient scenarios in Cancer Hospital. Reliability, utility costs, and reduced environmental pollution would benefit from this.

1.2 Problem Statement

The most predominant vision of Qatar is to employ the present resources adequately. One of the prevailing concerns is the high utilization of power and greenhouse gas emissions (GHG) as CO_2. The most viable source to cope with this problem is combined heat and power distributed systems (CHP).

Furthermore, the heat released by the system will be re-utilized for different purposes as for domestic hot water systems, heaters, and equipment sterilization. Therefore, the system's SOFC is considered the most efficient CHP technology, yielding improved performance.

This results in a better fossil fuel substitute because it is compatible with natural gas. SOFC technology is utilized for generating electricity. SOFC is incorporated with Combined Heat & Power (CHP) to get better results by utilizing resources according to Qatar’s vision 2030.

In this thesis, solid oxide fuel cell-based combined heat and power systems will be modelled, and alternatives for improving energy efficiency will be proposed. These alternatives will be proposed based on amendments in various internal building components. The analysis will be performed on these changes' effects on annual energy consumption, utility rates, and air pollutants. The selected facility for applying and validating the proposed research work is a Cancer Care Hospital in Doha, Qatar.

Several techniques can be utilized to make the building energy-efficient, and various strategies can be evaluated using energy models. Although energy models are commonly used to design new buildings, they are not often employed to determine buildings' actual efficiency. A Building Energy Model (BEM) is a simulation tool used for measuring a building's thermal loads and energy usage. BEMs are used by several specialists, including architects, designers, engineers, energy inspectors.

Considering for actual building materials and existing HVAC systems, BEMs can estimate power consumption. BEMs also account for the impact occupants of buildings effect on energy usage by establishing schedules for occupants. This research uses an energy simulation tool called eQUEST to model and evaluate a 175,190 square-feet hospital facility's efficiency.

This research's primary goal is to employ a tool for energy modelling to predict electricity consumption in the building and compare it with actual utility data. One of the most efficient and economical ways to reduce CO_2 emission on a wide scale is to enhance buildings' energy performance (Zaidi et al., 2016). The objectives of the research work are presented below.

1.3 Research Objectives

The following are the main goals of this thesis:

a) To serve as a set of guidelines for organizations wishing to perform integrated assessment analyses at a health care facility

b) To implement and analyze the SOFC-CHP system in Cancer Care Hospital in Qatar.

c) To collect the energy consumption data for said targeted location and to conduct modelling analysis using eQUEST software.

d) Suggest alternative changes to the existing hospital system and observe the potential for energy impacts and tradeoffs. Inbuilt graphics can be seen in the results of our presented model equivalents.

e) To analyze the overall environmental, the technical, and economic feasibility of solid oxide fuel cell (SOFC) with Combined Heat & Power systems (CHP) and other implemented alternatives on hospital building.

1.4 Research Questions

The following questions will be explored in this research work:

a) What are the present technologies used for power production?

b) What is the viability of introducing SOFC-CHP and other alternatives in terms of system efficiency?

c) What are the advantages of SOFC technology and other alternatives as compared to the baseline scenario?

d) How the CO_2 Emission differs for each implemented scenario concerning the base case model?

1.5 Thesis Outline

The layout of this research work is as under,

Chapter 1: This chapter has introductory sections related to solid oxide fuel cell-based combined heat and power systems (SOFC-CHP) applied for National Care Cancer Hospital, Qatar. The objectives and goals of the research are also mentioned in this chapter.

Chapter 2: This chapter deals with a brief discussion of literature in which the study is made related to the SOFC-CHP model in commercial buildings. Further, a comparison is made based on energy-saving strategies in hospitals.

Chapter 3: This chapter has some background information on eQUEST software used in this research, and the proposed methodology portion is discussed in detail. The hospital building model is developed in eQUEST software, and detailed information related to this model like baseline case and other improvement alternatives are also discussed.

Chapters 4 and 5: A model using eQUEST software will be simulated, and its comprehensive analysis as a viable source of power generation at high efficiency will be presented in these chapters. Economic analysis based on simulation results is also made.

Chapter 6: A conclusion is formulated based on the simulated model, and recommendations are also given in this chapter.

CHAPTER 2: LITERATURE REVIEW

This chapter summarizes the literature in which a discussion is made related to the SOFC-CHP model in commercial buildings, and energy-saving techniques are also discussed in this chapter. Moreover, a comparison is made for energy simulation tools discussed in the literature.

A solid oxide fuel cell (SOFC) is a highly efficient electrochemical device. It converts hydrogen and carbon monoxide from hydrocarbon fuels directly into electricity. Solid Oxide Fuel Cells employ dense solid oxide as electrolyte material that conducts negative oxygen ions from the cathode to anode. At the anode, electrochemical oxidation of hydrogen (H2) or carbon monoxide (CO) takes place. At the cathode, an oxygen reduction reaction occurs. They operate at temperatures having a range from 600°C to 1000°C (Technology – H2E Power, n.d.). This description is shown in Figure 1.

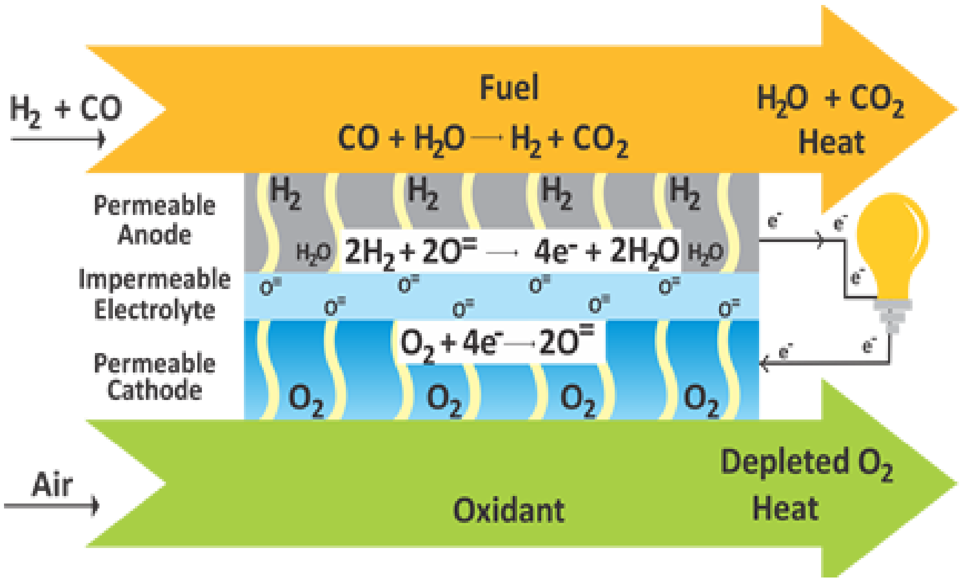


Figure 1. Basic Principle of SOFC (Technology – H2E Power, n.d.)

2.1 Solid Oxide Fuel Cell (SOFC) – Combined Heat and Power (CHP) in Commercial Buildings

Fuel cells directly transform the chemical energy of fuel gas into electrical work and are efficient and environmentally clean, as no combustion is necessary. SOFCs provide pollution-free electricity generation with combined thermal and electrical efficiencies of even more than 70%, as mentioned in (Stambouli & Traversa, 2002).

In (Braun et al., 2006), research work was analyzed for assessing multiple SOFC-CHP models for domestic loads. Optimal thermal to the electric ratio (TER) and the nature of fuels are evaluated by five different designs. Their TER does optimization of the SOFC-CHP model; however, there were not considered building loads.

The presented system's stack model is an estimated scenario of a substantiated steady-state, single-dimensional, single-cell energy balance structure. The working conditions mentioned in (Braun et al., 2006) are 85% of fuel consumption, Balance of Power (BOP) components simulated in this work, and no SOFC part-load performance. Consequently, electrical efficiency advantages are not noticed by using hydrogen fuel instead of natural gas fuel.

(Alanne et al., 2006) explored the feasibility of the 5kW CHP system depends upon natural gas for house building situated in Ottawa and Vancouver, Canada. This study deals with the maximum acceptable capital cost and electricity and gas prices for the selected sites mentioned in this paper.

The SOFC-CHP system is established for stacks of SOFC and other units as a handling unit, a seasonal storage tank for thermal energy, and a fuel processing unit. The power of the SOFC stack is altered between 1 to 5 kW. It is assumed to require a production power of 6% for additional equipment. Further, it is also assumed to have a maintenance cost of 0.01/kWh and an interest rate of 3-10%.

Results show that only a 1-2kW system yields an economic perspective in Ottawa. However, lower costs of electric and natural gas yield no economic benefits by the SOFC-CHP system. The above shows the value of utility rate frames to the SOFC-CHP system's capacity to save power.

According to (Frimodt & Mygind, 2010), research is done to determine the prospect of combining the SOFC system and absorption cooling modules. Various assumptions for this study are that the system of SOFC has an efficiency of 0.5. The COP of an electric chiller is 0.4, 0.032 $/kWh is the gas price, 0.12 $/kWh is electricity price, 500$/kW is the SOFC capital price of the system's life duration is ten years.

Based on these assumptions, it is determined that this module can suit Distributed Generators (DG) implementations in hotels and may also produce economic benefits. Moreover, for system’s feasibility, a theoretical zero-dimensional steady-state structure is established. The results describe an optimum double-stage absorption cycle if the absorption chiller's heat preheats the SOFC inlet air. Furthermore, when the surrounding temperature increases above 20 degrees, then the wet cooling tower is mandatory. Otherwise, various materials will be needed to cope with this situation.

(Pruitt et al., 2014) discussed the retrofit of a commercial building having a CHP distributed generation model. The optimization model is presented to evaluate the CHP system's configuration and working scheme to fulfill power and heat requirements. This demand meets at a lower total cost, comprehensively. Moreover, the result is a nonconvex mixed-integer nonlinear programming structure and resolved by purpose-devised solution methods.

In (Naimaster & Sleiti, 2013), a solid oxide fuel cell-combined heat and power (SOFC-

CHP) model is implemented. The model is established for an office building of medium size (7000, meter-square). This implementation is done on commercial buildings in three recognized Charlotte, Miami, and Minneapolis locations. SOFC model presented in this study is depicted in Figure 2 (Naimaster & Sleiti, 2013).

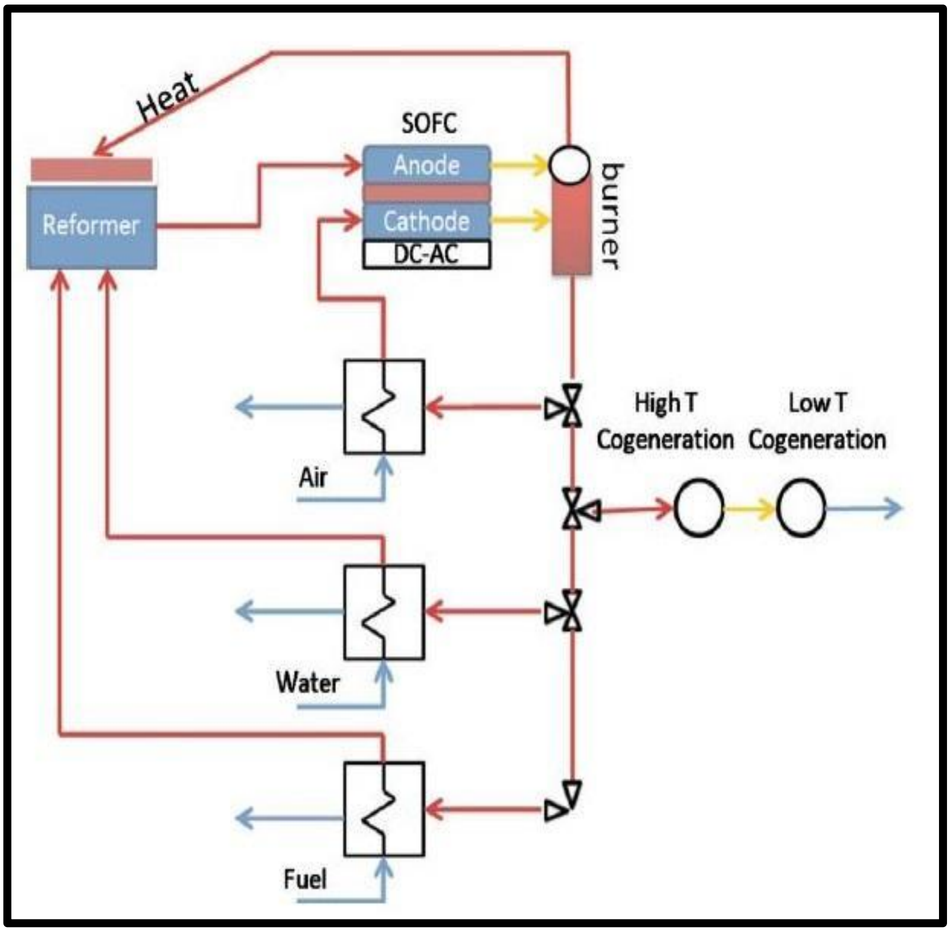


Figure 2. SOFC Cogeneration System (Naimaster & Sleiti, 2013)

In this model, the SOFC-CHP system is comprised of SOFC stack fueled with natural gas, which provides electric energy for the buildings. Moreover, exhaust gas waste thermal energy is utilized to heat space that flows through the boiler. To analyze the optimized system for the office building, the range of power capacities is 25kW to

250kW for the SOFC-CHP model. In eQUEST, the generic electric generator module is used to simulate a SOFC stack model.

Hence, obtained results consist of annually consumed energy by consumers for each site: the base case HVAC system and the month's utility costs for each location. Further, the comparison is made among three locations based on annual utility savings and SOFC CHP efficiency. However, Charlotte and Minneapolis's 175kW SOFC-CHP system's payback duration is far away from the system's lifetime.

According to (Fong & Lee, 2014)), a Combined Cooling, Heating, and Power (CCHP) model is presented depending on a fuel cell. This model is analyzed for an office building. These two zero grid-electricity techniques are used to save electricity of 7.1% and 2.8%. When this system is worked for grid off way, the device's installed capacity and system performance are analyzed for monthly gaps.

(Pellegrino et al., 2015) focused on a fuel cell based on the micro CHP system. This study is done for residential areas in the European Union by implementing various working strategies. Moreover, results show the influence of these different strategies mentioned in this work to encourage fuel-cell technology. Finally, an adapted Feed-in Tariff (FIT) scheme is presented to stimulate on-site utilization despite export to the utility.

(Adam et al., 2015) also analyzed a study of fuel cells, which is based on the micro-CHP system. The evaluation of recovery heat from various process units of fuel cells is determined. The combination of fuel cells based on a micro-CHP system with a supply system of heating was analyzed. This study provides the basis for temperature and cascade usage of heat. For now, multiple objective-based optimizations are also recognized as a useful feature and tool for system design.

In (Gholamian & Zare, 2016), research is done on the organic Rankin cycle and Kalina cycle in SOFC or Gas Turbine System. Methane is used to fuel up the system.

To analyze the performance and parameters of this system, a thermodynamically model is established. These following features indicate the noted parameters:

a) Energy efficiency decreases by increasing current density because of an increase in the consumption of fuel by SOFC.
b) Energy efficiency and total output power are maximized when the bottom cycle has optimized inlet pressure.

Furthermore, an analysis of environmental influence has also been conducted. The results show that using the Organic Rankine Cycle increases exergy efficiency by up to 62.35%. Moreover, implementing Kaline Cycle enhances exergy efficiency by up to 59.53%.

(Pisello et al., 2014) showed essential considerations about the presented system's feasibility when a comparison was made with other CHP technologies. The proposed model can gain thermal and electric efficiencies up to 80% and 8%. It saves 4000 kWh/y/kW of energy and 3000€/ kW of allowable costs. The mentioned ranges are considered effective and favorable compared to other micro-CHP technologies as micro Rankine cycle, Stirling engines, or microturbine systems.

(Facci et al., 2018) studied the technical and economic strategies of a trigeneration power plant. This work is relied on SOFC and analyzed for a domestic collection of almost ten apartments. This energy model consists of a boiler, natural gas SOFC, and thermal storage. Here, a comparison is made with various power plant layouts mentioned in this paper.

This research is done by changing fuel cell sizes and refrigeration technology to meet chilling demand that is considered critical in this type of application. An optimal control strategy evaluates the performance of the plant. This strategy is taken various energy demand trends, electricity prices, and load efficiencies. The methodology of graph theory is developed to optimize the energy system.

Results are furnished as electrical and thermal efficiencies, operating schemes, cost-saving, reduction in primary energy utilization, and payback duration. This analysis is evaluated by taking different capital prices of the SOFC. However, the SOFC's capital cost is a crucial point that yields an issue influencing the optimal layout of Combined Heating and Cooling Power (CHCP). Here, sensitivity analysis focuses on a critical point that SOFC based distributed generation plants are considered more optimal for capital costs of the SOFC. The proposed model is shown in Figure 3.

(Zhang et al., 2017) developed a SOFC-CHP system combined with a multi-stage exhaust energy recycling system. Accordingly, the exhausts of both thermal and chemical energy are employed effectively. The main feature is that the multi-stage combustion exhaust gas (MS-EGC) system will reduce its operating temperature from 1149 to 830 degrees. This feature results in the enhancement of system operation safety factors and mitigating the need for material.

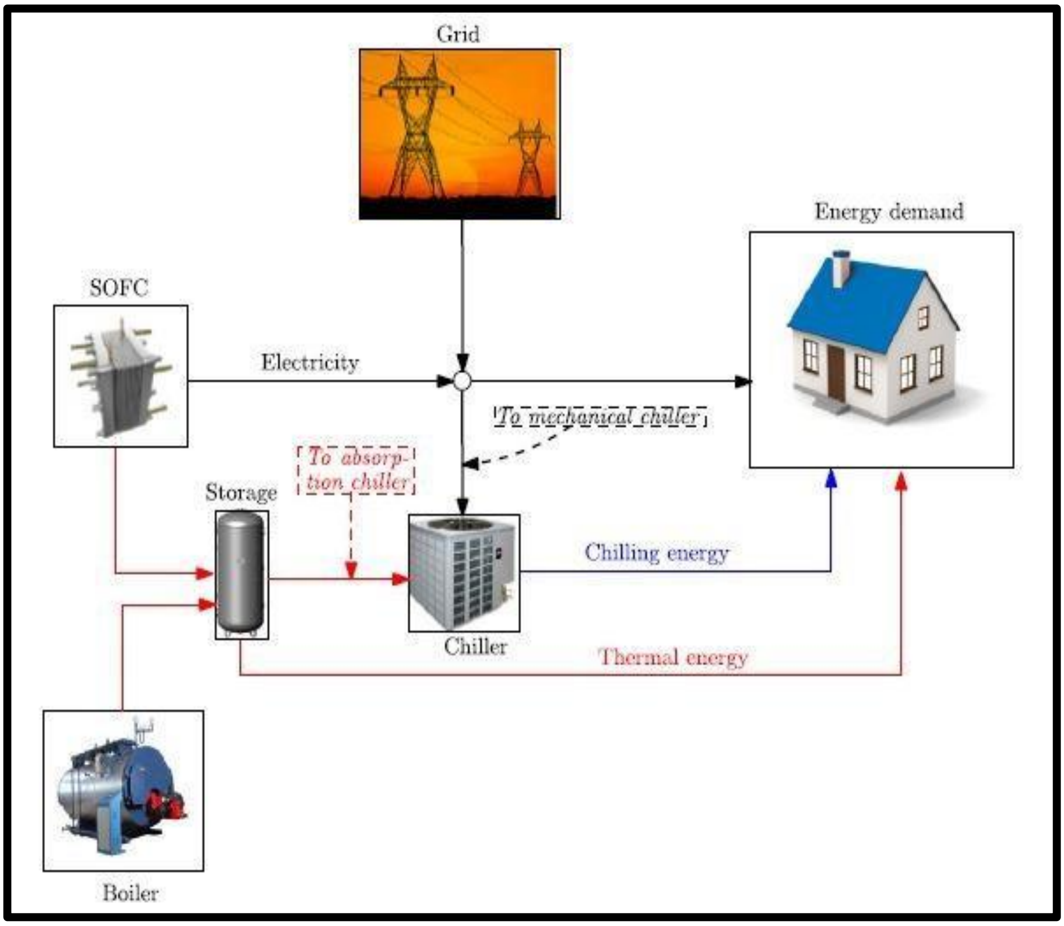


Figure 3. Representation of the Combined Heating and Cooling (CHCP) Plant (Zhang et al., 2017)

Multi-Stage Exhaust Energy Recycling technique is developed. This work is done to increase the system's performance and execution of SOFC-CHP. Designing and experimental studies are done for a 1kW SOFC-CHP system. The system yields co-generation efficiency of almost 92%.

The results reveal that thermal energy recycled infrequently influences the utilization of chemical energy in later stages during the first stage. Moreover, this work will furnish intense perception for the future recommendation of an efficient SOFC-CHP model.

(Sorace et al., 2017) Compared to low-temperature polymer electrolyte fuel cell membrane (PEMFC) and SOFC, considered to be the prime mover. This analysis is focused on residential CHP systems having economic outlook as well as environmental viewpoint. A feasibility analysis is also considered to evaluate the influence of capital cost. The outcomes show that a lower electricity cost is realized by employing the SOFC system with greater efficiency. This yields more significant energy saving compared to standard cases. However, the higher capital cost still causes a hurdle.

(Palomba et al., 2018) described the combined experimental and numerical consideration of a novel small size multigeneration system. The presented idea is established on a high-efficiency SOFC-CHP. This model is coupled with absorption chillers driven by thermal energy, elaborated in Figure 4.

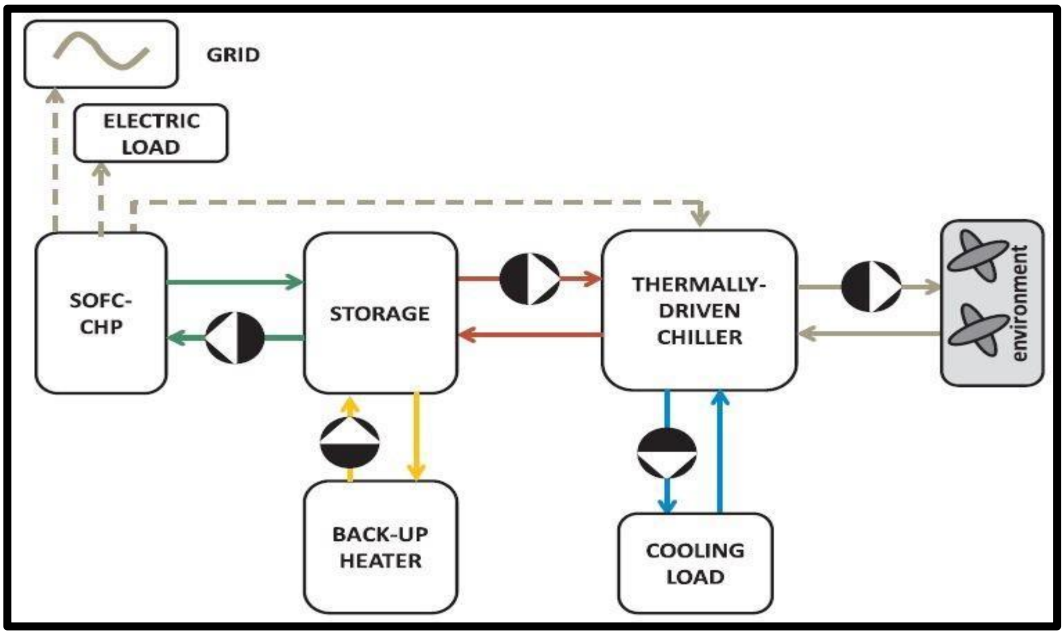


Figure 4. Structure of the Multi-Generation Model (Palomba et al., 2018)

The presented model is employed to explore the effect of each component's sizing. This work's main objective is to estimate the advantages emerging from the utilization of the multigeneration system. These benefits are considered savings of primary energy and minimization of CO_2 emissions. The presented multi-generation system's global efficiency can be taken as promising and useful.

Energy and environmental inspection are supported to approximate the benefits deriving from presented conception over a standard grid-connected system. However, further efforts are required to optimize the system and decrease the required space for installation purposes and results.

According to (Roshandel et al., 2018), research work is done to perform a case study on a greenhouse that is situated in Mahabad, Iran was done. The objective is to examine the execution of a SOFC as the prime mover of a combined heat and power (CHP) system. Here, four hybrid systems are presented to enhance the CHP efficiency. Inclusively, to select the optimal techniques of supplying energy, this study supports making policies in environmental and energy associated regions as a powerful decision tool.

Multi-objective optimization is presented to observe both environmental and techno-economic objective functions together. Further, this gives a robust decision support tool. MATLAB software is utilized to develop a technical, economic, and environmental model of SOFC based CHP. SOFC system presented in this study is indicated in Figure 5.

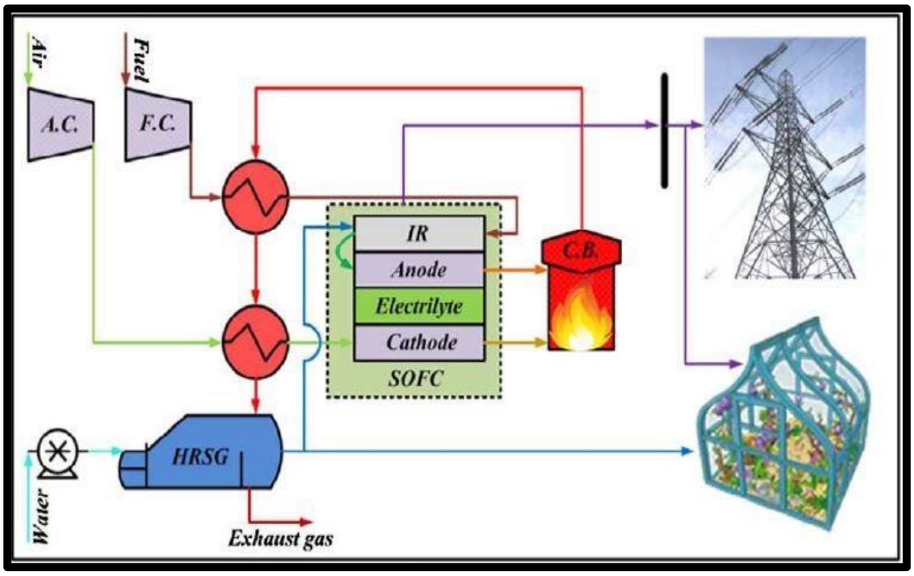


Figure 5. SOFC Based CHP Hybrid System (Roshandel et al., 2018)

Conclusion, this work's outcomes reveal that annual carbon dioxide emissions for SOFC based CHP hybrid models are almost 62%, less in amount than conventional systems. To examine the influences of future electricity costs and carbon dioxide tax, the Levelized Cost of Energy (LCOE) reduction is supported out in three cases. These three cases are regional prices of energy in Iran without carbon dioxide tax, regional prices of energy in Iran with carbon dioxide tax, and world average energy prices with CO_2 tax.

(Giarola et al., 2018) focused on the execution of a wastewater treatment facility's economics, which is integrated with a solid oxide fuel cell (SOFC) and CHP plant. An optimization structure is prepared and pertained to specify cost, energy, and emissions execution of the retrofitted system compared with conventional systems. The proposed frameworks are analyzed in terms of equivalent annual costs and the Levelized cost of electricity. Integrated Waste Water Treatment Plant (WWTP) CHP plant structure is shown in Figure 6.

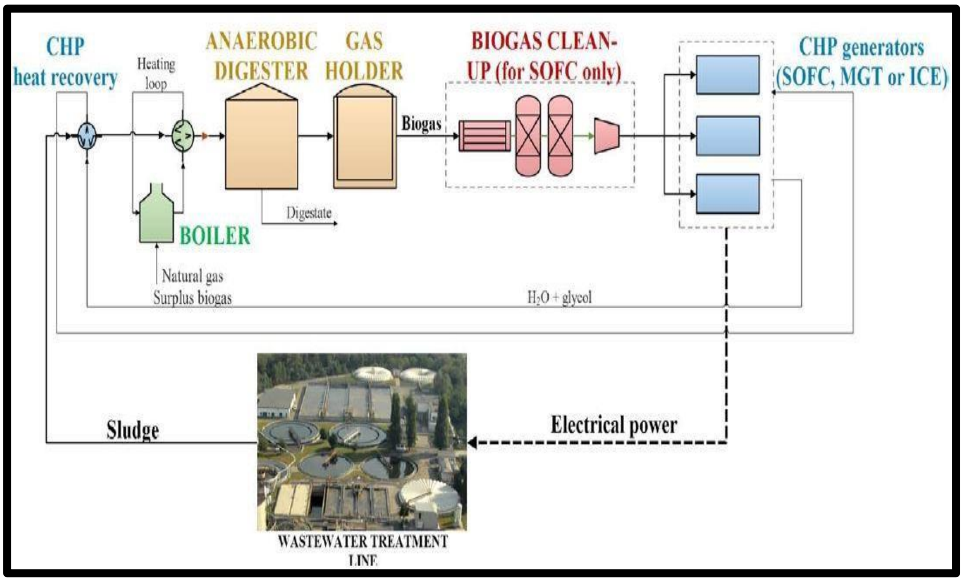


Figure 6. Integrated Waste Water Treatment Plant (WWTP) CHP model (Giarola et al., 2018)

The mathematical Mixed Integer Linear Programming MILP modelling structure is employed for the WWTP's minimum cost unit commitment retrofitted with a SOFC-CHP system. Results describe the present-day capital costs of SOFC technology, which represent its lower strength to compete with conventional energy systems. However, it can become a practical and feasible scheme if executed with thermally-optimized WWTP systems.

2.2 Energy Savings Studies in Hospitals

(Isa et al., 2016) employed the cogeneration of renewable energy sources with fuel cells. The presented cogeneration system comprises the grid on photovoltaic (PV), fuel cell, and battery. It is suitable for large - scale areas, such as hospital buildings, where electrical and heat loads are to be supplied. The research's main goal presented in this paper was to assess the cogeneration system's feasibility for a hospital building in

Malaysia. The Hybrid Optimization Model for Electrical Renewable (HOMER) software is used to render a techno-economic analysis. The cogeneration system is expressed in Figure 7.

A comparison of the presented model is made with five different configurations formulated by HOMER software to evaluate the feasibility. These five models are a standalone diesel system, grid-connected PV system, grid-connected PV-fuel cell system, grid-connected PV-battery system, and grid-connected PV-fuel cell battery system. The results revealed that the proposed model was suitable for fulfilling the load demand and low yield emissions. By installing the presented model, a 30% cost for power generation could be saved.

(Jing et al., 2017) focused on a study to elaborate on high energy performance benefits and reduced carbon dioxide emissions for SOFCs. This study shows an effective prime mover's mechanics for Combined cooling, heating, and power system (CCHP). This structure is shown in Figure 8.

The presented framework is applied to a hospital in Shanghai, China, as a case study. This case study considers state-of-the-art technical features, emissions factors, and energy pricing signal using the time of use scheme. Mixed Integer Non-linear Programming (MINLP) technique is employed for a SOFC based CCHP system.

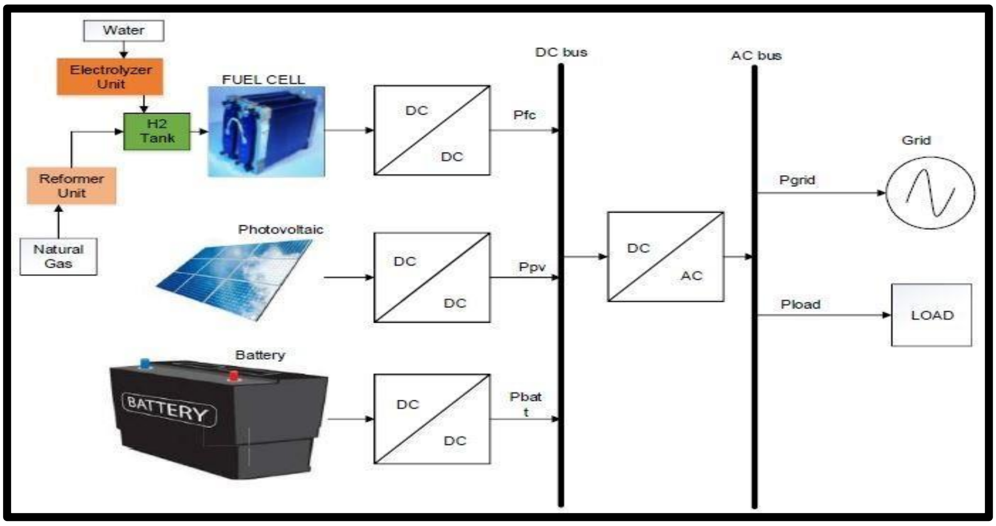


Figure 7. Cogeneration System (Isa et al., 2016)

This representation gives two capacity options for sizing: fixed size (user-defined) and the optimal sizing. Further, the Ɛ-constraint method is utilized for multi-objective optimizations in order to optimize two conflicting objectives. Pareto frontiers show optimal results, and the most realistic outcomes had been specified and confirmed by employing decision-making techniques. The results describe the environmental benefits of the SOFC based CCHP system.

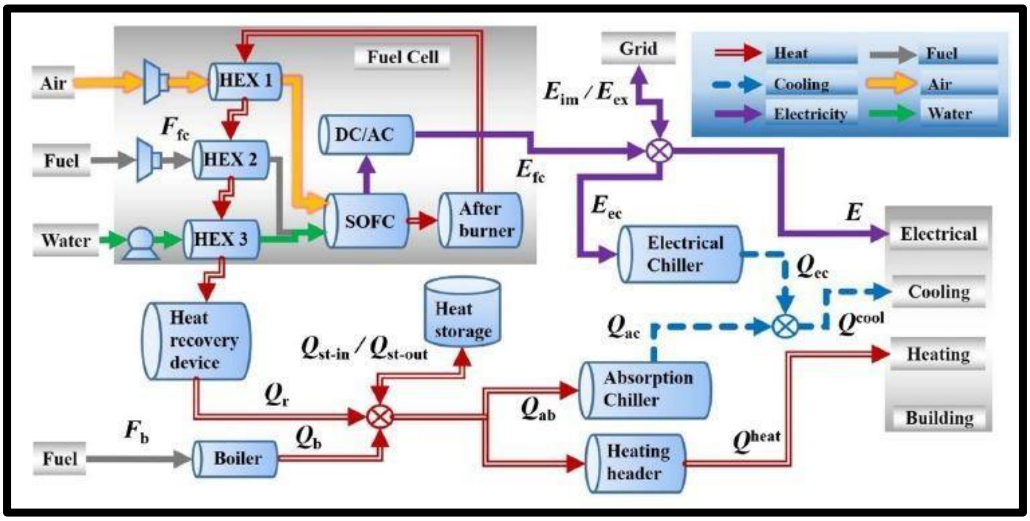


Figure 8. SOFC-CCHP Building Energy Model (Jing et al., 2017)

Further, the Levelized cost of energy (LCOE) defined by the presented optimal design and dispatch system, has a cost of 0.17$/kWh. This cost is high as compared to the cost of the conventional energy system. Moreover, future study may appraise the system to integrate it with renewable energy sources. This feature will result in a further reduction in the environmental impact and reduce the system's overall cost.

(Howard & Modi, 2017) explained the idea of CHP models. This work is done by exploring different criteria as a function of greenhouse gas (GHG) emissions, e.g., CO_2 & NO_2 etc. from the fundamental electricity source, type of building, and climate. Fuel cell-based CHP models are analyzed to observe the benefits of GHG emissions.

The optimization technique is used to consider prototypical hospital, office, and residential buildings' energy demands in different climate types. This analysis is based on three circumstances: ‘‘High”, ‘‘Low,” and ‘‘Present” GHG emissions rates for a particular location.

This research aims to elaborate on the outcomes of building type, building size, climate, and GHG emissions from grid electricity to reduce GHG emissions. The reductions are evaluated for hospitals, offices, and residential buildings formulated in 16 different cities. The results are also evaluated to perceive the changes in system sizing and operation.

According to (Gimelli et al., 2019), cogeneration plants play a dominant role in the hospital sections. As the availability of power is also confirmed during faults in the grid. This feature also saves costs towards the public healthcare system. Integrating the battery energy storage system and the CHP system may enhance the benefits of ensuring flexible operating approaches. Further, it increases the reliability of energy and reduces operating costs.

Moreover, an evolutionary algorithm has been proposed, which is integrated with an evolutionary genetic algorithm. Further, a solution to the vector optimization problem is discussed to evaluate the cogeneration plant's optimal layouts. This solution enhances the immediate savings of energy by reducing the payback duration. Based on a hospital facility's energy and heat demand, results assess the Pareto frontier's shifting frontier assigned by a battery energy storage system to get optimal outcomes.

The presented study in this thesis provides a useful framework for the optimal layout. This study yields full investigations of CHP plants combined with an electrochemical energy storage system. Further, technical constraints with economic parameters are also taken into account to enhance the lifetime of batteries.

Future research will also yield an optimal operation for the Combined Heat and Power (CHP) and the Backup Energy Storage System (BESS). Peak shaving performed in this research is considered a BESS property. Further, optimization for the CHP-BESS can be done to increase the benefits of end consumers. This model is shown in Figure 9.

In light of the viewpoints mentioned in the literature review, background facts, and figures, it can be decided that the SOFC-CHP system is the feasible generation of energy sources for Qatar.

2.3 Energy Simulation Tools

Energy simulation tools are extensively employed to analyze the building energy efficiency and the thermal comfort level as well. Nowadays, various building performance energy simulation tools have distinct user interfaces and different engines for simulations. It is critical for simulation software to determine restrictions for these tools and the complications to their simulations. The accuracy of exchanging data and interfaces, which are considered user-friendly, is considered a feature of these programs' practical utilization. The large size of data has to feed and to analyze the performance of simulation tools. Consequently, there are critical factors for the availability of rich 3D geometry rendering engines, effective information exchange, and software interfaces.

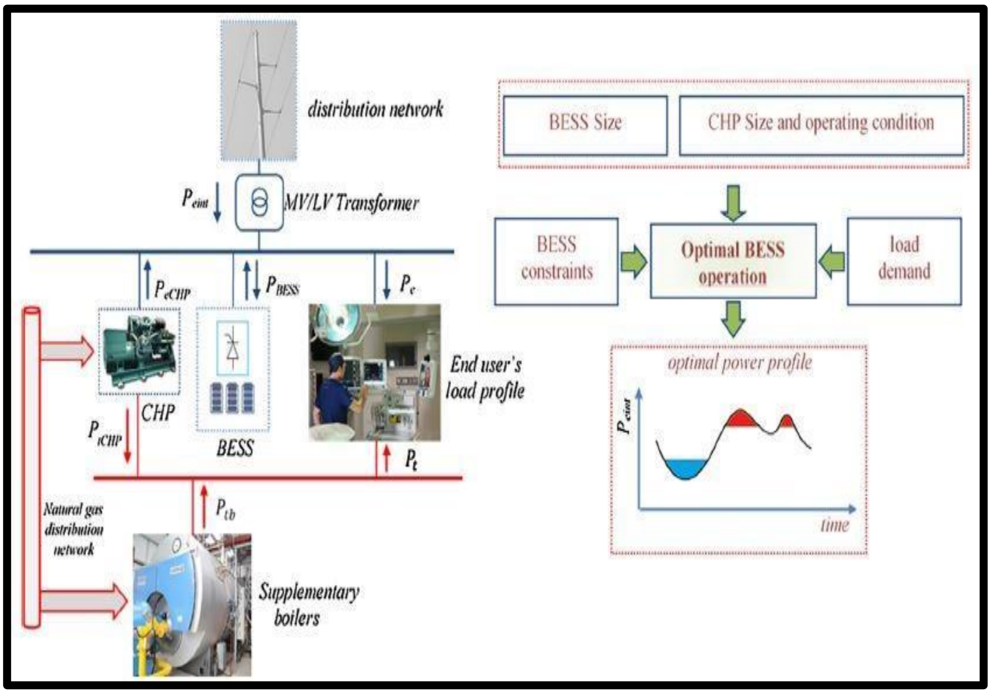


Figure 9. Battery Energy Storage System (BESS) – CHP System Under Observation (Gimelli et al., 2019)

Software programs that incorporate graphical representations are expected to own the most interest for architects. Indifference, engineers require such programs that deal with the conceptual designing when more critical information is not familiar with the system; and in the last step of designing, when project descriptions are established. Different software, such as eQUEST, EnergyPlus, EcoTect and IES integrate clarified input wizards and detailed simulation tools. This integration yields the most strength in order to accomplish requirements at different steps of the design process.

2.3.1 Comparison of Simulation Tools

Multiple software has been evolved from the last few decades. US Department of Energy has determined 240 simulation tools. This department runs the web page of building energy simulation tools, and it is enhancing from research-grade software to commercial products. Significant research is analyzed on some of these programs that are elaborated here.

Autodesk Ecotect Analysis is a tool to execute building performance. EcoTect is considered good software for the necessary work. However, this software is not reliable for detailed investigations ("Ecotect Analysis - Sustainable Building Design Software - Autodesk," n.d.). Furthermore, IES Virtual Environment is a tool for energy analysis and modelling performance of the building. IES ASHRAE 140 was used to test this simulation software. This tool is useful to represent HVAC controls. However, simulation analysis is considered inconsistent between various toolkits (Sousa, 2012).

(Pasqualetto et al., 1998) proposed a detailed study in terms of various authentication steps under consideration to validate the MICRO-DOE2.1E too. (Zhou et al., 2007) determined the efficiency of the variable air volume air-conditioning model, a new tool is appeared and confirmed experimentally in this research work. This work is based on the building energy simulation tool, EnergyPlus.

U.S Department of Energy capitalized the development of a new building tool that started from 1996, i.e., EnergyPlus. This tool comprises multiple innovative characteristics, together with sub hourly basis, user-configuration model HVAC systems, and input and output data frameworks that can smoothen the third-party module and interface development. EnergyPlus was used for the first time in April

2001.

The utilization of energy simulation tools is enhancing to analyze the building performance, efficiency, and thermal relief to their inhabitants. Nowadays, there are multiple tools to analyze building performance, along with various user interfaces and multiple simulation engines. eQUEST is considered one of the most approved tools by the community of building simulation. This software is fast one as it takes almost a minute to compile the yearly simulations of large buildings. This software is efficient computationally and provides results from hourly calculations. Table 1 shows a comparison of energy simulation tools studied by (Crawley et al., 2008).

Table 1. Comparison of Energy Simulation Tools (Crawley et al., 2008)

Description	eQUEST	EnergyPlus
Load Calculations on Hourly Basis	✓	✓
Absorption Chiller of HVAC	✓	✓
Seasonal heat and cold Storage of HVAC	✓	×
Analysis of Life Cycle Cost	✓	×
Availability of Weather Data with Program	✓	✓

In comparison to eQUEST, EnergyPlus takes much time in execution. (Hong et al., 2008) determined a study having a time step of 15-minute, EnergyPlus takes substantial time compared to eQUEST having a factor of 105, which is considered for the large office building and factor of 196 for the hospital's building.

(Chen & Kan, 2014) It has proposed a study to analyze energy-efficient ways in green hospital buildings of Taiwan. The eQUEST software is used to perform an energy-saving analysis. The validation process shows that simulation results are within a 7%

error margin in comparison to actual energy consumption. It is recommended that project efficiency can be enhanced by feeding automatic data input in eQUEST.

(Xing et al., 2015) presented an energy efficiency analysis for hotel buildings. This energy performance analysis is made by using eQUEST Software. The calibrated system analyzes the capability to save energy. Furthermore, the consumption of energy and costs was calculated to analyze the efficient ways of energy-saving and the eQUEST simulation's accuracy. The outcomes of research show that scheduling of internal loads yields the most remarkable influence on the model accuracy for buildings. Based on the above discussion, in this research work, we are using eQUEST software to analyze the energy performance for the hospital building.

CHAPTER 3: RESEARCH METHODOLOGY

In this section, the Hospital model has been designed in eQUEST software. The description of this hospital model is represented here in detail. Specifically, information about the model's location, weather conditions, and specifications of construction is considered for the baseline system case and SOFC-CHP system case. Further, analysis is also made in term of economic and emissions point of view.

In this research work, we are working at the National Center for Cancer Care and Research (NCCCR). The NCCCR is the leading cancer hospital for Qatar State. It is the part of Hamad Medical Corporation (HMC) and takes care of cancer patients.

3.1 Description of eQUEST Software

Simulation tools of energy forecast a provided building model's energy efficiency and tell about its occupiers' thermal comfort. Generally, they hold up the concern of building operation according to specific requirements and allow comparisons with various design scenarios. Every tool has to face some restrictions, so it is compulsory to acknowledge specific basic rules related to energy simulation tools.

In the first place, simulation outcomes can be as precise and detailed as the simulation's input details. The input comprises the building's geometry, weather data, internal loads, HVAC modules, operating schedules and schemes, and particular simulation parameters. Since thermal procedures in a building are more complicated and difficult to understand, energy simulation tools estimate their predictions and detailed mathematics and techniques. Consequently, results can be casually inaccurate if individual predictions and suppositions are incorrectly taken in the simulation or not gone with a real-life scenario. The general layout of data can for simulation engines is shown in Figure 10.

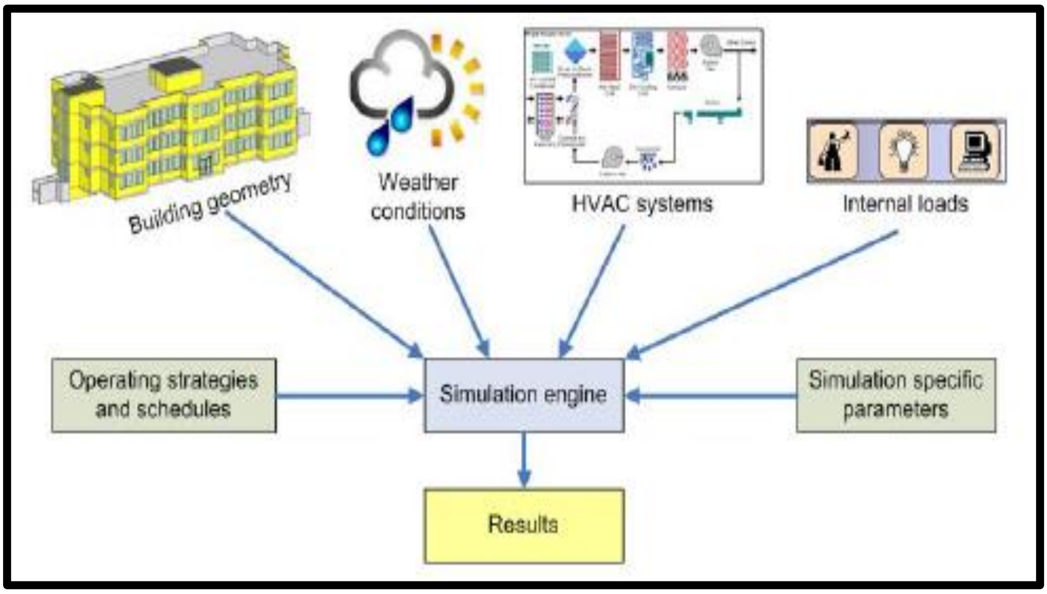


Figure 10. Data Layout of Simulation Engines (Birdsall et al., 1990)

eQUEST is considered an easy-to-simulate program to analyze building energy, which gives qualitative results. These results are achieved by employing a building modelling wizard, an energy-efficient computing wizard, and a graphical display. The building modelling wizard starts the process of creation of the building model. This software has an engine DOE-2.2, which provides hourly basis results of the building model.

These simulations are based on windows, walls, loads, and other occupants. It also provides analysis for the performance of chillers, pumps, and other various devices. Furthermore, it facilitates an efficient environment to make multiple simulations in one run, and all results can be seen in side-by-side visualization. It furnishes with an estimation of energy cost and analysis of energy-efficient evaluation.

There is a DOE-2 engine's ability to execute the thermal behavior of spaces in a building, where different heating loads can be designed and executed with the engine. The building geometry for execution purposes should be in the simple form corresponding to the actual building geometry (Birdsall et al., 1990). The flow of data for the DOE-2 engine is shown in Figure 11.

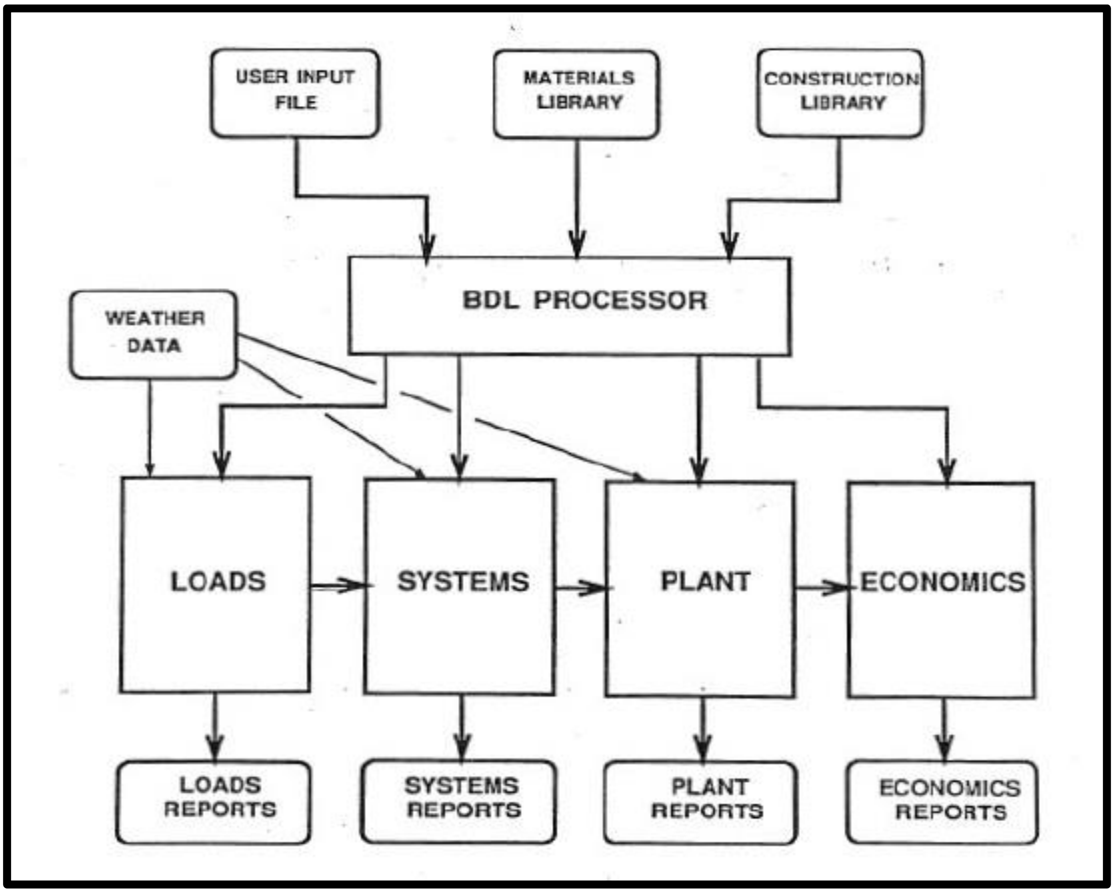


Figure 11. Data Flow of DOE-2.1 Engine (Birdsall et al., 1990)

BDL input processor provides a platform to integrate user input with the materials, layers, and construction library. Computer-readable format is generated by the Building Description Language (BDL) processor using the input further utilized by the four simulation modules, i.e., LOADS, SYSTEMS, PLANT ECONOMICS.

These subprograms are simulated consecutively. The simulation module of LOADS employs this description of BDL and weather data. Then, it performs calculation of heat loss and heat gain, which are relied on assumption loads of heating and cooling systems. The second simulation module, i.e., SYSTEMS, elaborates additional requirements of heating or cooling systems for space.

At long last, the ECONOMICS module determines the cost that relies on utility's fuel needs and pricing schemes. Firstly, external and internal loads are calculated by DOE-2 in a space. Based on the temperature difference between two adjoining spaces, the weight factor method is utilized to determine heat transfer for thermal mass. After that, the HVAC system calculations as inputs are attained by the emerging loads. These defined HVAC systems are used by the simulation engine to satisfy space loads.

3.1.1 Integrated Energy Analysis Design

eQUEST configuration allows the user to execute a brief survey of today's building energy management. This is only possible due to the combined nature of this software's DOE-2-extracted engine with a building modeling wizard, a wizard for analyzing energy efficiency, and a display feature. It starts with modeling a thorough building model and enables the yield of parametric modeling of design. It provides automatic graphics that make a comparison with the performance of design alternatives. Reliable and brief simulations get easier through this software.

eQUEST measures are building energy consumption based on hour by hour for an entire year, i.e., 8760 hours along with hour-by-hour information of weather for specified locations. A detailed data of building that is under consideration has to input to it. This data includes in hourly basis scheduling of habitats, equipment, and other settings. This yields an efficient simulation for different factors of building as interior and envelope building mass, shading, and other air and heating systems.

The process of simulation starts by evolving a model of a specified building. In order to provide a base for estimating energy savings, a baseline building model has emerged.

Then, some changes corresponding to various energy performance measures are pertained to the model to make an alternative analysis. These analyses provide yearly consumption and savings of cost in order to regulate the best solutions for alternatives. Important building area features comprises of latitude, longitude, and elevation. Further, it needs data of adjacent structure or landscape yielding shadows on the presented building.

Weather data of that location is also needed. Moreover, it needs data of walls, roof, and floor of the building's presented model. Structures and construction statistics of each surface that transfers heat are also required of the proposed model. This software gives the users an efficient, user-friendly, and free selections for each of them. Internal loads are considered people, equipment, and lights, etc. These internal loads can model the buildings insensitive to weather. These loads can impact on utility requirements directly or indirectly.

Accurate data for the efficiency of HVAC equipment is necessary to yield accurate and efficient energy simulation. eQUEST manages default HAVAC system efficiency. This can also be obtained from design engineers or manufacturers of equipment.

3.1.2 Detailed Interface Model vs. Wizard Model

This section elaborates on a brief description of the interface model and wizard model of eQUEST. This software deals with two design wizards, which are termed as Schematic Design (SDW) and Design Development Wizards (DDW). These design wizards show recognized steps during design, and these steps have significantly different details. Default parameters can be taken as simple data input in both wizards. The simple layout of both wizards is shown in Figure 12.

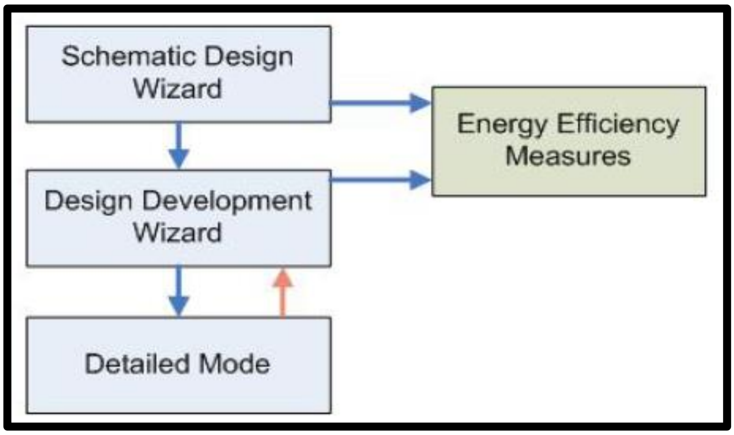


Figure 12. Wizard Mode in eQUEST (Wood, 2011)

Moreover, there is an option to convert from a less detailed wizard mode to a more detailed building illustration. In the detailed mode of this software, the DOE-2 engine provides a feature to apply changes and modifications to the system's available parameters. Once in the detailed mode, the user can convert back only to DDW and lose any detailed information modified in the detailed model.

Another capability of this program is the Energy-Efficiency Measures, which empowers fast analysis of specific input parameters (e.g., coil capacity values). This wizard has the feature of applying modifications in every parameter of the wizard, but can only be employed in SDW or DDW mode. The layout of the schematic design wizard is mentioned in Figure 13.

Now that we have analyzed much about the DD Wizard and EEM's, there is another feature of advanced energy modeling in this tool, i.e., Detail Edit Mode. This Mode should be employed after using either of the two wizards. This model is utilized to input extensive detail about the model or building components. One of the walls can be edited by using detailed edit mode throughout the exterior of the building. This has a more precise design that is independent of others. Each building unit is individualized and can be modified independently of the other modules.

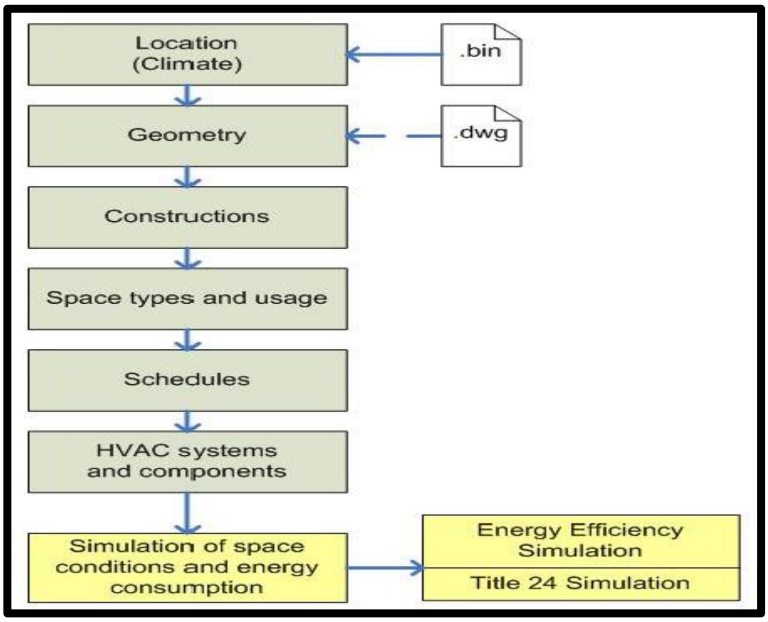


Figure 13. Layout in Schematic Design Wizard of eQUEST (Wood, 2011)

Detail edit mode provides more control to enter data of schedules, loads, zones, building construction, and HVAC systems. All the provided information to wizards is considered a baseline, and more data can be added, but switching back to wizards is not allowed. So, accurate information should be entered into wizards in order to make a baseline scenario.

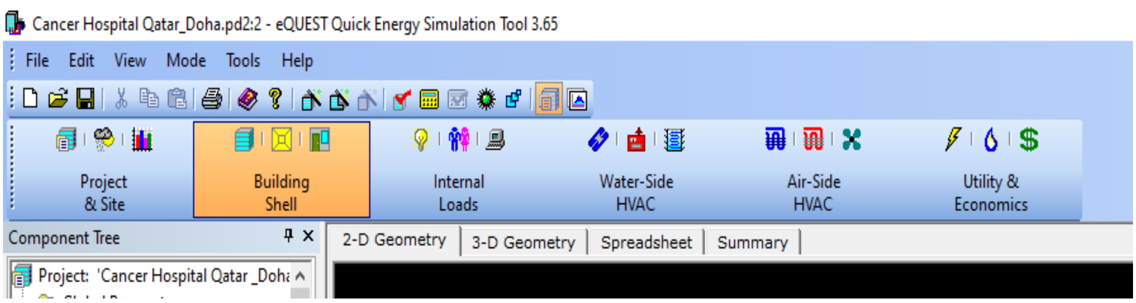


Figure 14. Main Modules of eQUEST

New model components are created in Detailed Interface, and this task is done by modifying or copying the components. For example, the CHILLER command elaborates on all functional features of a chiller. According to the last program version, the same type of chiller, such as open centrifugal, comprises similar features; except the chiller's size, which can be changed from chiller to chiller. Now, the tool takes each chiller as an individual that is different from other chillers.

Furthermore, there are different properties for building structure in Detailed Interface. Figures 15 and 16 show the building's original view and the eQUEST 3-D geometry of the actual Cancer Hospital Building.

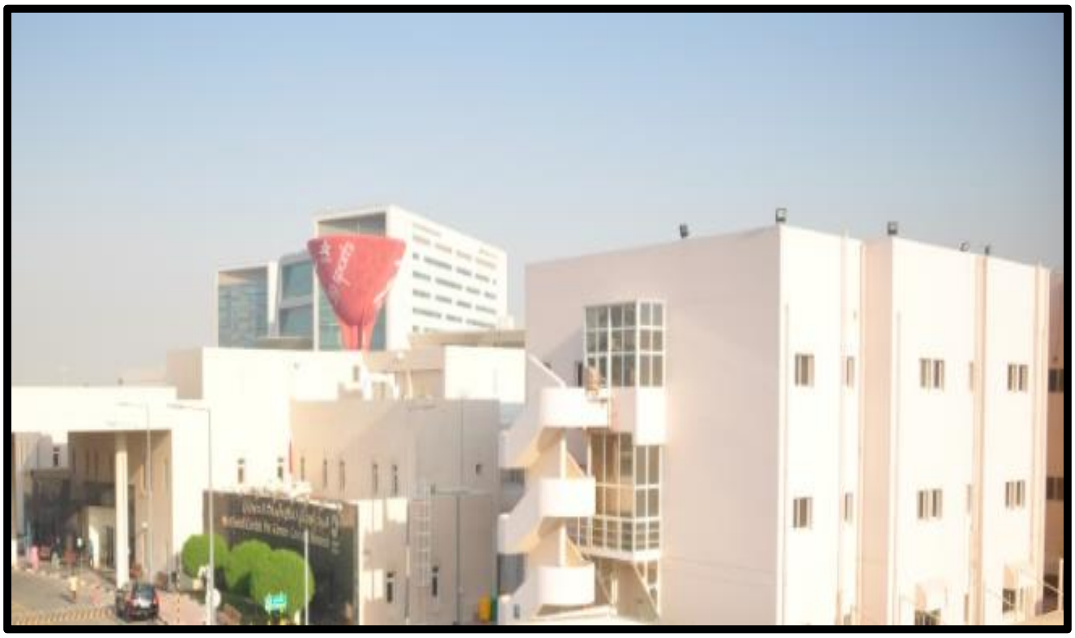


Figure 15. Original View of Cancer Hospital Building

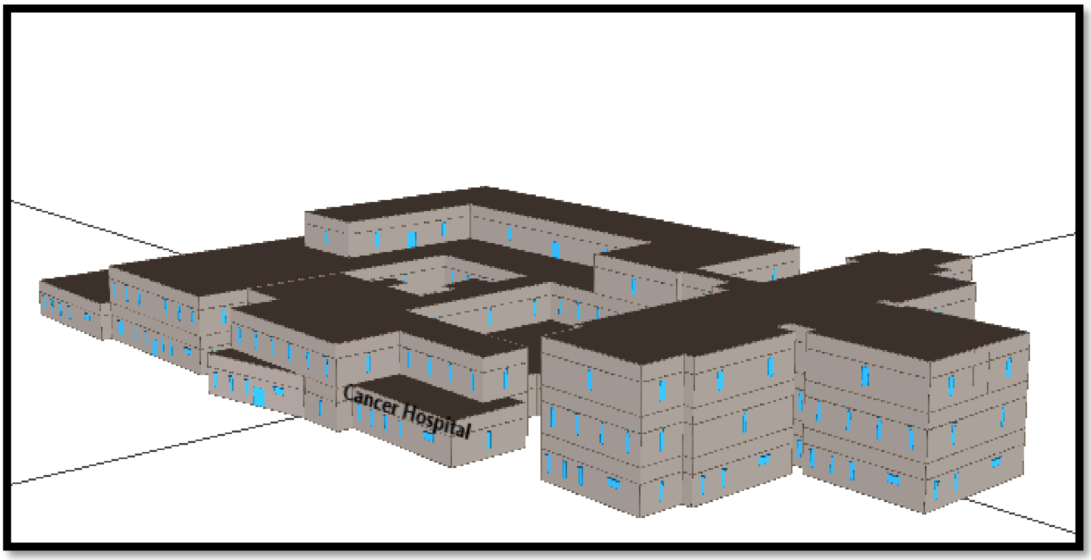


Figure 16. 3D View of the Cancer Hospital Building Model in eQUEST

Using the AutoCAD's existing drawings, the hospital’s 3-D geometry is recreated, as shown in Figures 16 and 17.

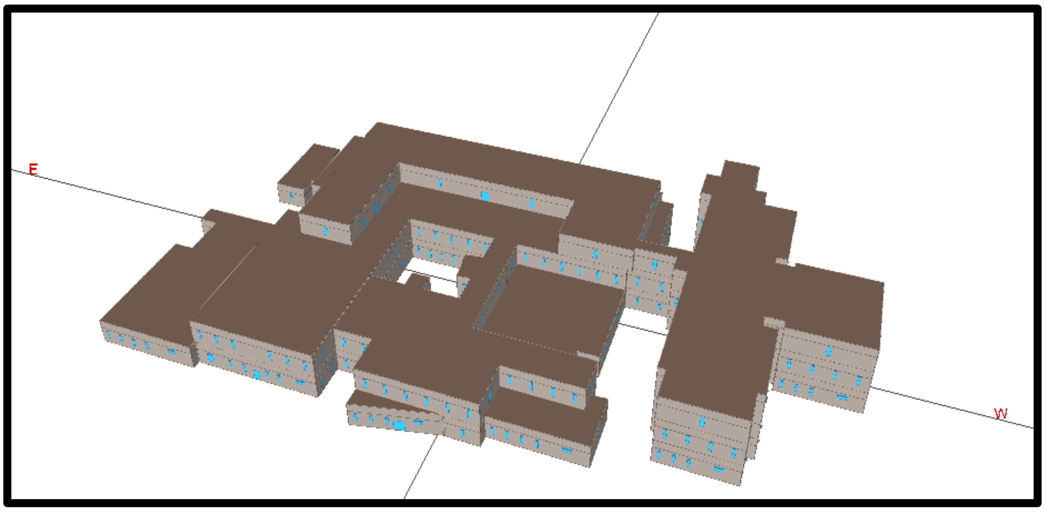


Figure 17. Building Shell View in Detailed Interface

Representational diagrams for the front, backside and top view for the hospital building model are shown in Figure 18, Figure 19, and Figure 20, respectively.

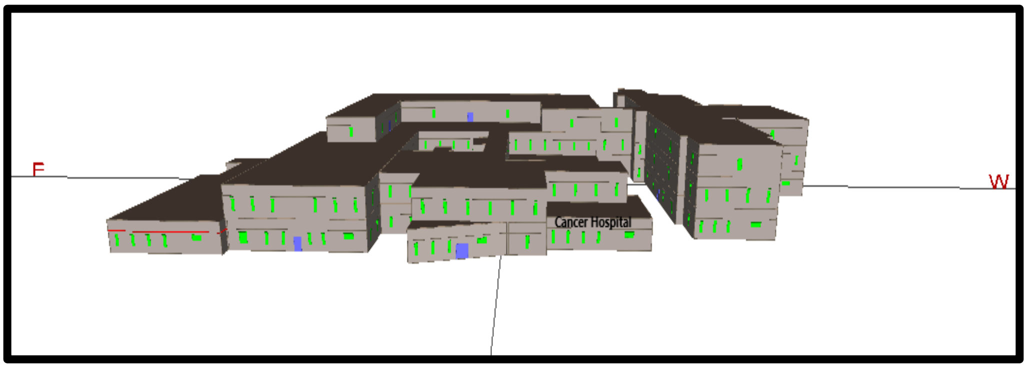


Figure 18. eQUEST Front Side View for the Hospital Building Model

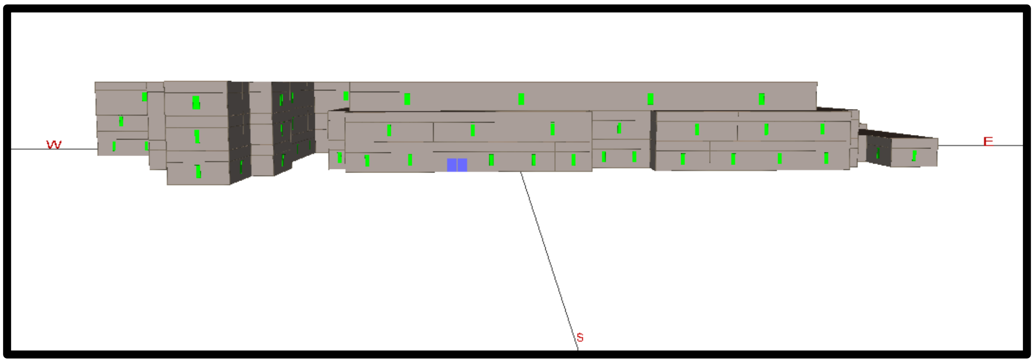


Figure 19. eQUEST Back Side View for the Hospital Building Model

Figure 20. eQUEST Top View for the Hospital Building Model

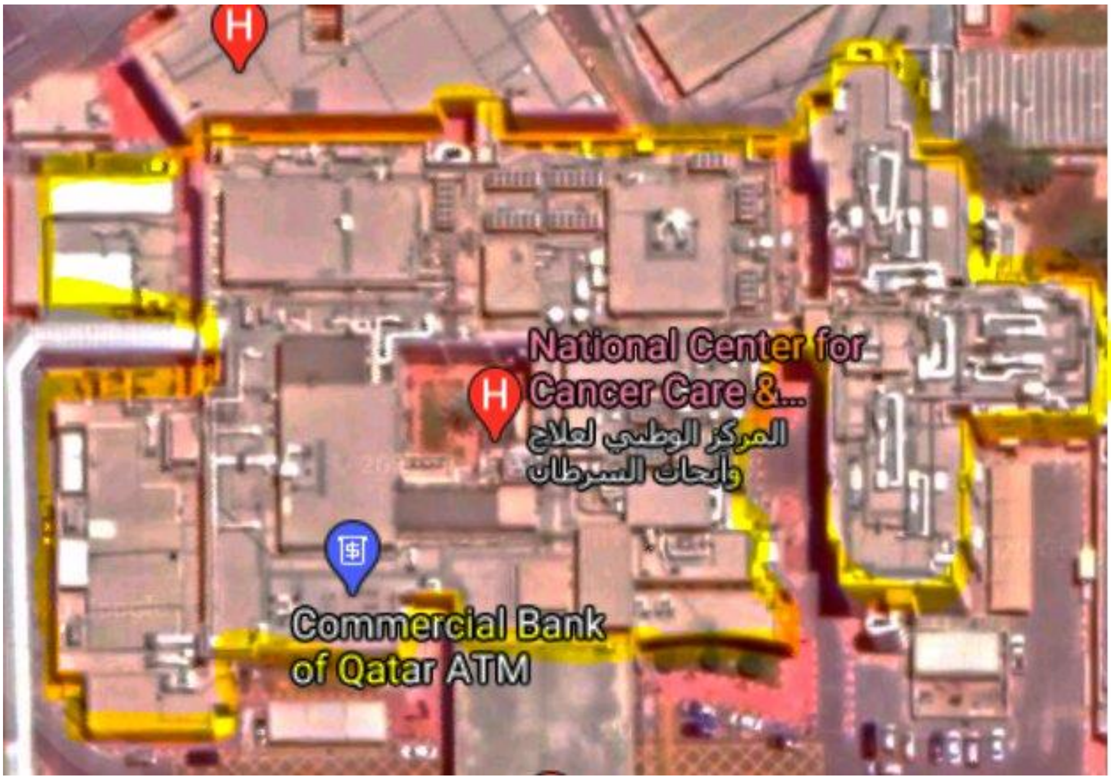


Figure 21. Satellite View of Cancer Hospital from Google Maps

Moreover, space gives information on specific areas. This component describes internal loads. These loads comprise people, lighting, equipment and process loads, zone type, infiltration, and loads calculations for space. The states are considered as specific to their maximum values and their schedules and occupancy.

Moreover, the Air-side HVAC module describes the secondary HVAC distribution system. The provided data consists of various options in-built in this tool as scheduling periods, temperature setpoints, type of system, etc.

Modeling of opaque building constructions requires a two-step method in Detailed Interface of eQUEST, i.e., defining one or multiple constructions and assigning them to specific heat transfer surfaces in the structure. On the other hand, wizard mode mitigates the two-step procedure into one step of defining constructions for the whole model and automatically assigning as the DOE-2 INP file.

3.2 Project Site Module

The type of building is a commercial that is designed for this research work having three stories. The total area of the building is 175,190 ft^2. The eQUEST framework for the cancer hospital building ground floor, as shown in Figure 22.

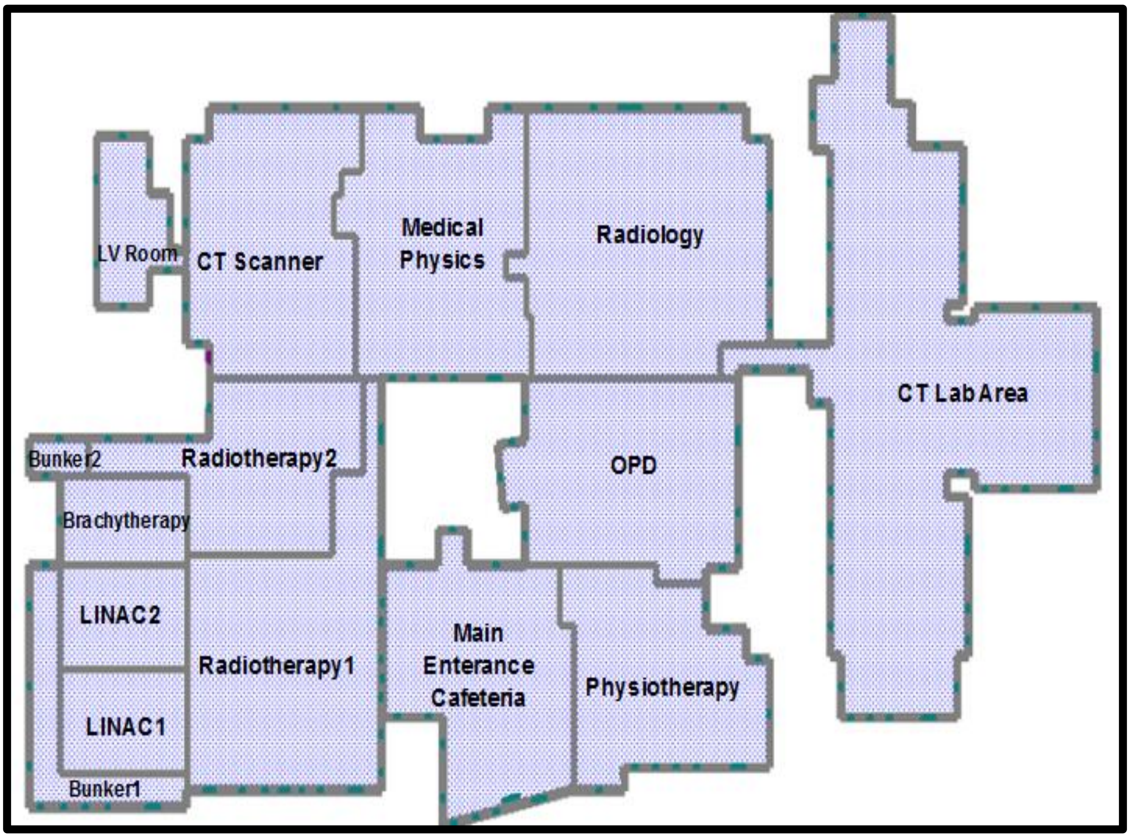


Figure 22(a). eQUEST 2D representation of the Hospital Ground Floor

The building construction comprises buildings' envelope materials, lighting loads, and HVAC modules that fulfill the ASHRAE 90.1-2010 standards.

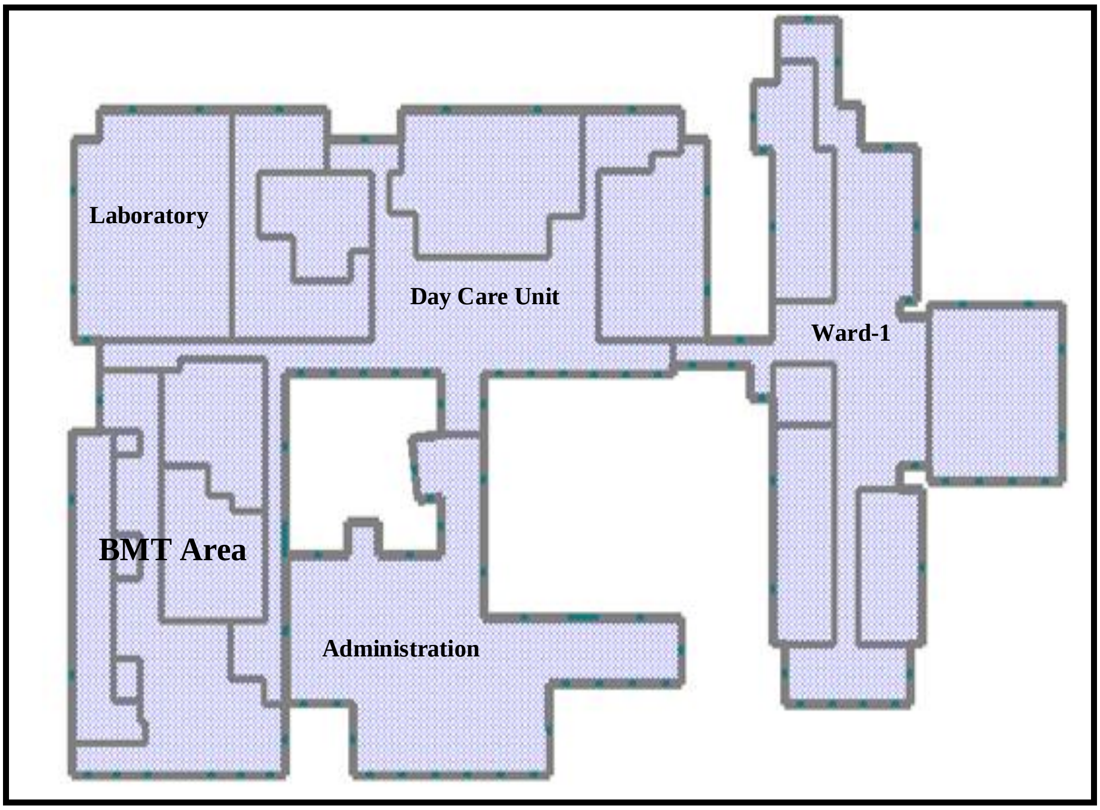


Figure 22(b). eQUEST 2D representation of the Hospital First Floor

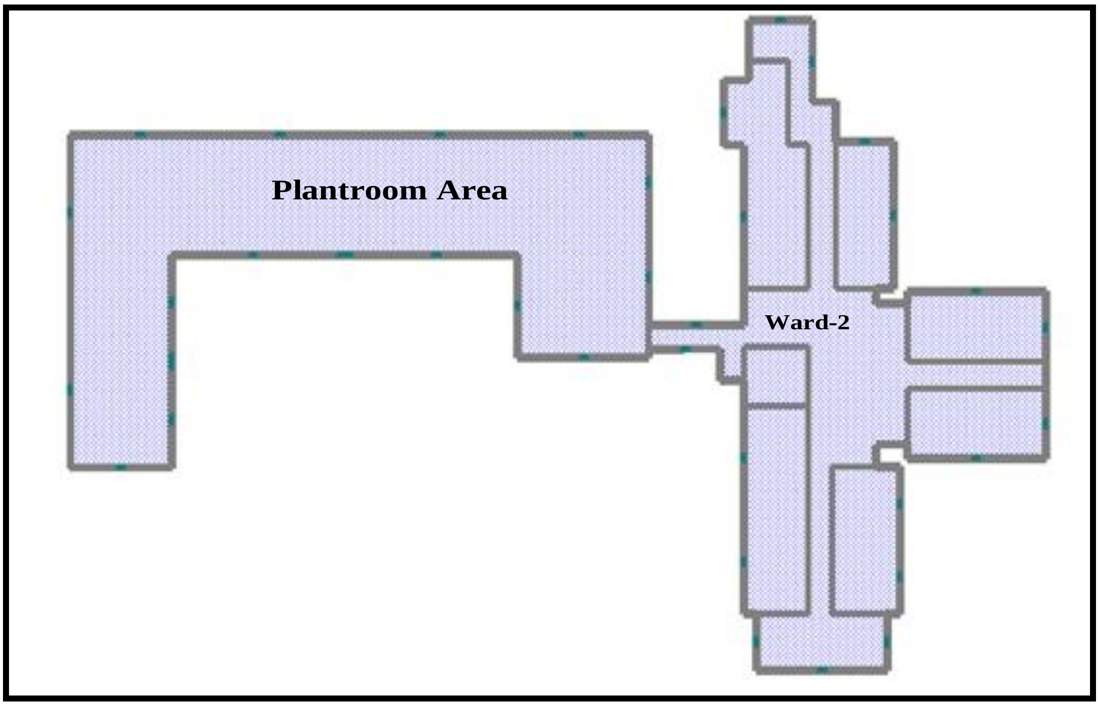


Figure 22(c). eQUEST 2D representation of the Hospital Second Floor

Table 2. Cancer Hospital Building Detail

Content	Detail
Project	Cancer Hospital Qatar _Doha
Climate	Abu Dhabi
Orientation	S-N
Floor	3
Area of ground Floor	80,662 ft^2
Area of first Floor	62,301 ft^2
Area of second Floor	32,227 ft^2
Total Area	175,190 ft^2

3.2.1 Weather Profile and Data

This is an essential module for all hourly simulation models. Weather data of Abu Dhabi is used in this research work. According to historical climate data, Abu Dhabi has a desert climate. On average, the temperatures are considered as always high. January and August are taken as the warmest and coldest months. In Abu Dhabi, the average annual temperature is taken at 26.8 °C or 80.3 °F. The annual rainfall is measured as 75 mm or 3.0 inches. Figure 23 shows the maximum and minimum temperature in Doha (Statistics, n.d.).

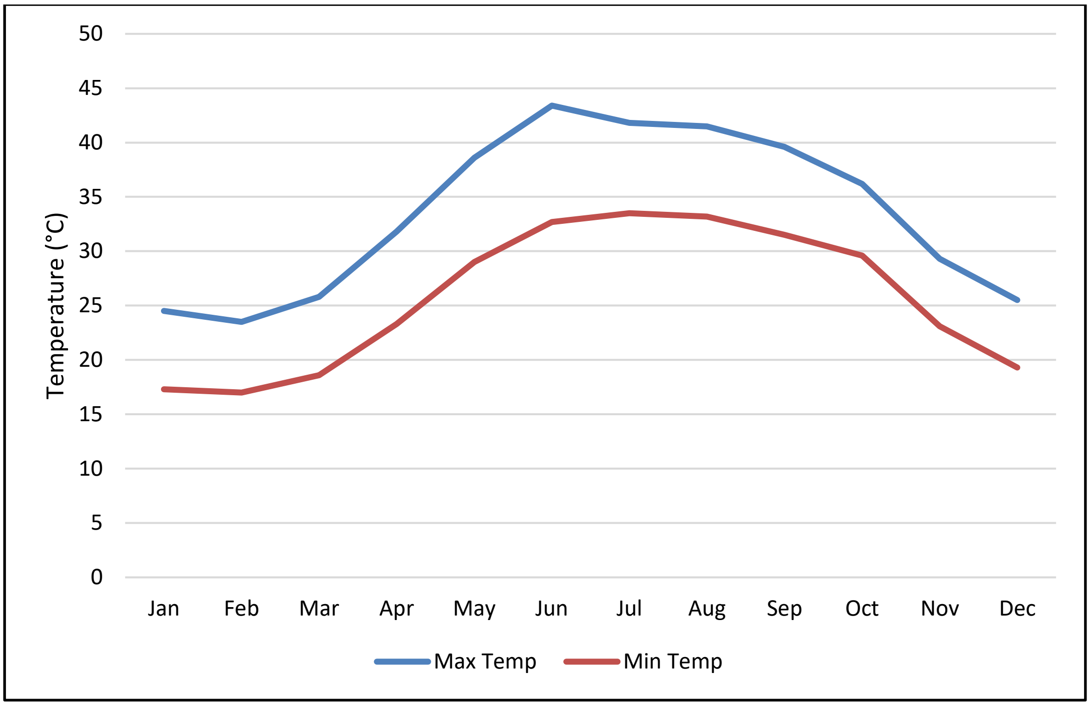


Figure 23. Average Minimum and Maximum Temperature throughout the Year (Statistics, n.d.)

The Average monthly humidity throughout the year is shown in Figure 24.

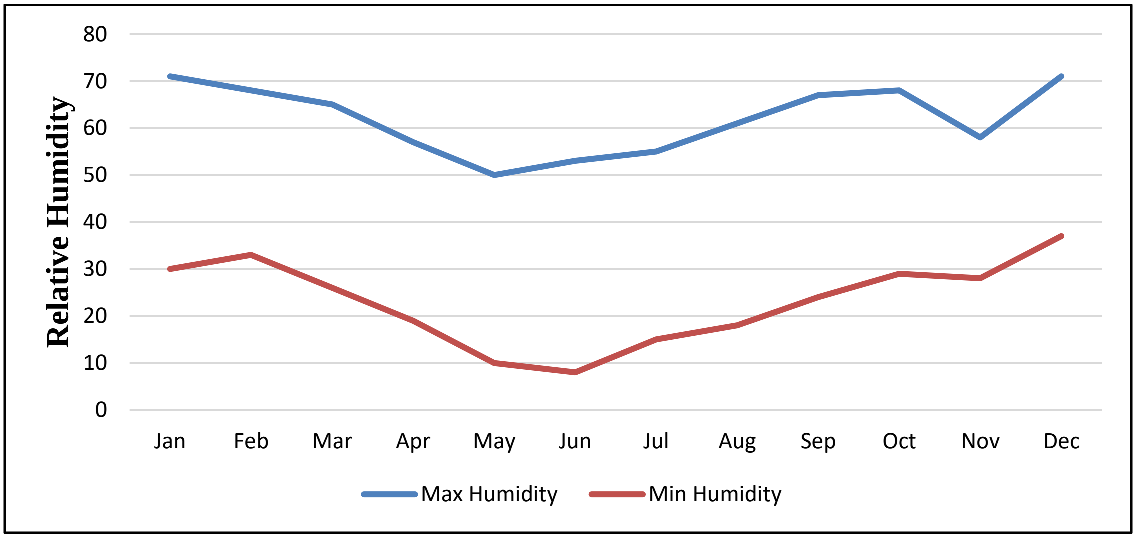


Figure 24. Average Relative Humidity Throughout the Year (Statistics, n.d.)

Similarly, in Qatar, the climate is very hot in summer, and winter is mild. The annual rainfall is measured as 80 mm or 3.14 inch relevant to Abu Dhabi. The max temperature during summer is measured at 43.4°C. As the climate in Qatar and Abu Dhabi is almost similar, so weather data of Abu Dhabi is chosen in our simulations.

3.2.2 Hospital Activity Areas

The cancer hospital building consists of 3 story building. Each floor has its own activity areas. The following table shows the activity areas on the ground floor, first floor, and second floor.

Table 3. Activity Areas of Cancer Hospital

Ground Floor	First Floor	Second Floor
Cyberknife & bunker1	BMT	Plant Rooms
Radiotherapy1	BMT1	Ward-2 Corridor
LINAC1	DCU Hallways	Ward-2 Right wing 3
LINAC2	ICU	Ward-2 Right Wing 2
Brachytherapy	OT	Ward-2 Right Wing
Bunker2	Laboratory	Ward-2 Center wing 2
Radiotherapy2	Pharmacy	Ward-2 Center Wing
CT Scanner	Pharmacy cleanroom	Ward-2 Left Wing 2
LV Room	Administration	Ward-2 Left Wing
Medical Physics	DCU	
Main Entrance & Cafeteria	Nuclear medicine	
Physiotherapy	Ward-1 Isolation Rooms	
OPD	Ward-1 (Palliative)	
Radiology	Ward-1 Right Wing	
CTL Lab Area	Ward-1 Right Wing 2	
EL1 Plnm (G.16	Ward-1 CenteWing	

Figure 25 shows the areas of each zone in cancer hospital in square feet.

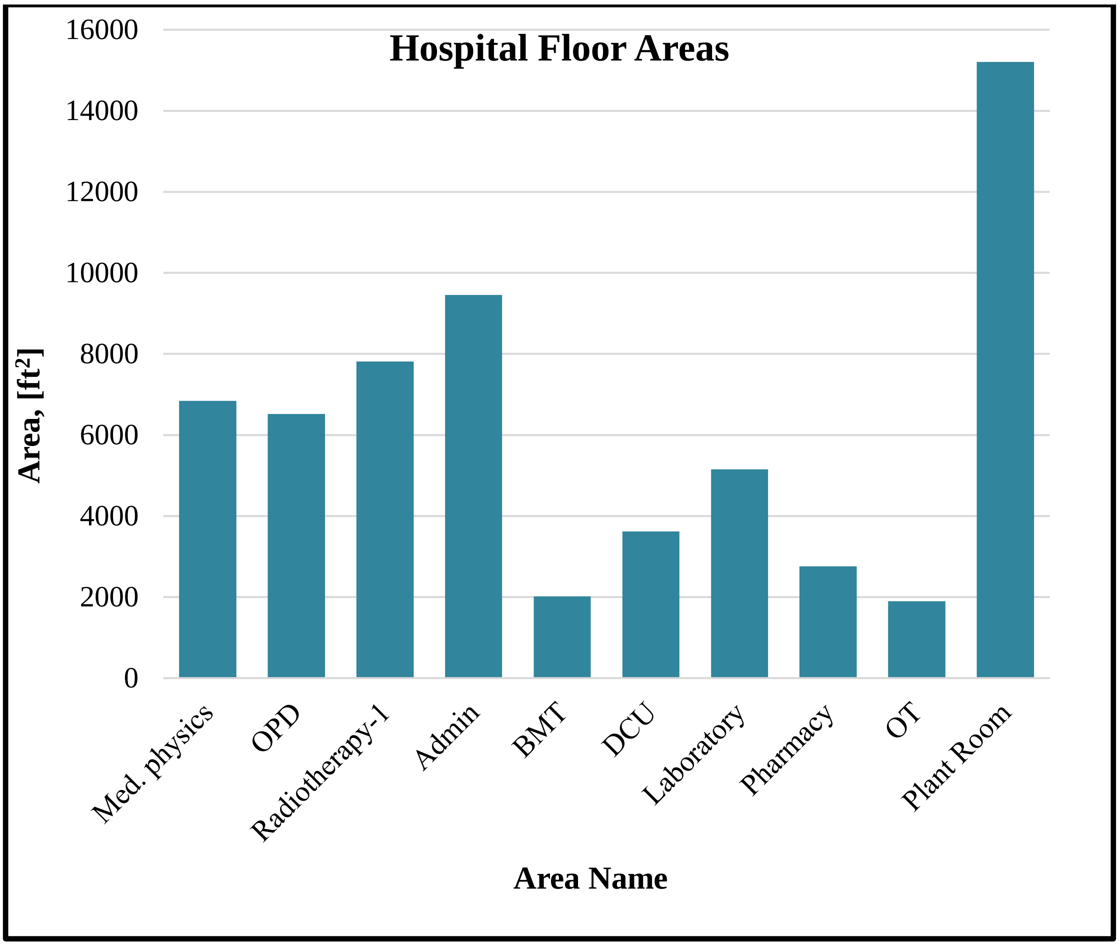


Figure 25. Areas of Spaces in Cancer Hospital

3.3 Hospital Energy Modeling in eQUEST

In order to explore the outcomes of a SOFC-CHP model on yearly building energy utilization and utility costs, a 3-story, 175,190 ft^2rectangular hospital building model has originated and executed by employing eQUEST software. Table 4 shows the data collection technique for a cancer hospital.

Table 4. Data Collection Sheet

Item	Source	Updated Documents/Drawings	Construction Documents
Building and zone areas	Plan sheets	x	✓
Envelop construction materials	Wall sections	x	✓
Surface areas	Building elevations	x	✓
Fenestration areas	Building elevations	x	x
Fenestration u-value & SC	window schedule	x	x
	or specifications	✓	x
HVAC zoning	HVAC plans	✓	x
Design flow rate	HVAC plans	✓	x
Equipment description	equipment schedules	x	x
	or specifications	✓	x
Control sequences	Control diagrams or	✓	x
	Specification	✓	x
Lighting equipment	Lighting layout or	✓	x
	Lighting specification	✓	x
Peak occupancy (by zone)	owner or BMS operator	✓	x
Office equipment (by zone)	Power layout plans or	✓	x
	Equipment specification	✓	x
Medical equip. load (by zone)	Power layout plans or	✓	x
	Equipment specification	✓	x
Pantry Load (by zone)	Power layout plans or	✓	x
	Equipment specification	✓	x
Refrigeration (by zone)	Power layout plans or	x	x
	Equipment specification	✓	x
Misc. load (by zone)	Power layout plans or	x	x
	Equipment specification	✓	x
Per zone			
Occupancy, Lights, Equip sched	owner or operator	x	x
Thermostat schedules	owner or operator	x	x
Per terminal system			
Outside air operations	HVAC equip schedule	✓	x
Fan Schedule	owner or operator	x	x
Fan kw	Equipment specification	✓	x
Utilities schedules	Utility representative	x	x

3.3.1 Baseline Model

3.3.1.1 Building Footprint and Constructions

There are three major sections of the building envelope design, i.e. roof surfaces, floor to ceiling and the ground floor. There are five additional features of roof surfaces and upper walls, i.e. architecture, exterior and paint finishes, exterior insulation, external insulation and interior insulation. Various cases can be adapted from the eQUEST library for design features such as regular wood frames, wood frames 24 in, wood frames > 24 in, metal frames 24 in and metal frames > 24 in can be costumed layer by layer.

For Our Buildings, the following parameters, mentioned in the Table 5, have input under Surface Constructions, Layers, and Material Properties. For Qatar, building construction is outlined to fulfill Qatar Construction Specifications and Kahramaa standards' requirements and the building envelope materials.

3.3.1.2 Internal Load Calculation

There are different loads in cancel hospital associated with all floors. We have surveyed each area of the hospital in order to calculate the internal loads by using the formula:

$$Lighting\ Power\ Density = total\ Power\ in\ watts/Area.$$

Table 5. Parameters for Hospital Building

Layers (GF, FF, SF)	Material Name	Thickness (ft)	Conductivity (Btu/h-ft-F)	Density (lb./ft3)	Specific Heat (Btu/lb.-F)
EL1 & EL2 Ewall Cons Layers	Conc HW 140lb 6in (CC04)	0.5	0.7576	140	0.2
	Gypsum LW Agg 3/4in (GP04)	0.063	0.133	45	0.2
	Air Lay > 4in Horiz (AL33)	n/a	n/a	n/a	n/a
EL1 Ceilg Cons Layers	Conc HW 140lb 6in (CC04)	0.5	0.7576	140	0.2
	Light Soil 12in	1	0.5	100	0.25
	Cmt Mortar 1in(CM01)	0.083	0.4167	116	0.2
	Hol Clay Tile 3in (CT01)	0.25	0.3125	70	0.2
EL2 GFlr Cons Layers	Conc HW 140lb 8in (CC05)	0.667	0.75	140	0.2

Lighting power density is an essential screening measure that shows provisions of opportunities to save energy. Lighting Power Density (LPD) is described as watts of lighting per square foot of room floor area (W/sf). The table 6 shows the calculation of LPD for cancer hospital areas.

Table 6. Site Power Density Calculation

Area Name	Site Lighting Fixture	Fixture Power (Watts)	Total Fixture (Qty)	Area in sqft	LPD W/sqft
Administration office	60x60 Ceiling lights	40	151	9459	0.65
	Down lights	52	1		
	Mirror light	9.6	4		
Laboratory	60x60 Ceiling lights	40	95	5149	0.78
	Mirror lights	9.5	4		
	Exit light	50	4		
Ward-2 Left wing	60x60 Ceiling lights	40	38	3322	0.61
	Mirror lights	15	10		
	Exit Lights	50	2		
	Examination light	50	5		
BMT	39Wx4 ceiling lights	156	20	4717	2.35
	29Wx4 ceiling lights	116	4		
	24Wx4 ceiling lights	96	61		
	14Wx4 ceiling lights	56	29		
	2.5W mirror lights	2.5	8		

Table 7 shows the LPD for medical physics and laboratory areas.

Table 7. Site Lighting Power Density

Area Name	Laboratory					
Equipment type	Total watts	Watts/sqft	Equipment Name	Total watts	Watts/sqft	Equipment Name
Office Equipment	2700	0.39	Computer, Printer, Scanner, Fax Machine	5400	1.05	Computer, Printer, Scanner
Medical Equipment	20000	2.92	MRI machine, CT Scanner Machine,	10000	1.94	Centrifuges, Incubators,
Pantry Equipment	1200	0.18	Water Heater, Coffee Machine,	1200	0.23	Water Heater, Microwave oven,
Refrigerators	250	0.04	Medical fridges	1750	0.34	Domestic Refrigerators/ Medical fridge
MISC. Load	2000	0.29	Access control system, Room AC Split Units, IDF Panels, UPS Load, Biometric Machines	1200	0.23	HEPA Filters, Access control System, Video Conference System, CCTV Load, Fire Fighting Equipment

There is an elaboration of the electrical portion for load calculation.

a) *Electrical: Designing of Lighting*

This is considered as an essential item for all hourly simulation projects. The space-by-space method is used to perform lighting analyses. Modeled spaces are used to accomplish lighting takeoffs.

b) *Electrical: Lighting Occupancy Sensor Controls*

This is considered as another essential item for all hourly simulation projects. Lighting controls based on occupancy decrease lighting power density by 10% uniformly during operation hours.

Lighting power is shown in watts. The dimensions are taken as watts of lighting power per unit space floor area. As per ASHRAE 90.1-2013, each thermal block's lighting power or lighting power density should be fed into the program. Inputting an average lighting power density by space type or building is acceptable in earlier stages of the model/design when no plan exists. The same method (space-by-space or whole building average) shall be used in the design and baseline models. All non-corridor Room-Cavity Ratio (RCR) corrections shall be explicitly documented for review when using the space-by-space method.

The Room Cavity Ratio is a factor that features room configuration as a ratio between the walls and ceiling. This ratio depends upon the room dimensions. The space-by-space method is recommended where practical, to provide with better feedback on the breakdown of design lighting power. Different types of lighting have different efficiencies. Incandescent lights create much heat; LEDs create practically no heat. Fluorescent is somewhere in between but creates much less heat than incandescent. All lights in hospital building areas are LED types except for the BMT area. Some of the lighting loads linked with the ground floor, first floor, and second floor are shown in Figure 26.

Waterside components incorporate the chillers, boilers, pumps, circulation-loops, etc. employed to develop the central heating or cooling plant. No stand-by equipment shall be included in the model. For chilled water loops, primary pumps shall be attached to the chiller, and secondary pumps, if present, shall be connected to the loop. For hot water loops with primary-only pumps, the pumps shall be associated with the loop. If the hot water loop has primary and secondary pumps, the primary pumps shall be attached to the boiler, and the secondary pumps shall be associated with the loop. A brief data of the water-side HVAC system is shown in the Table 8.

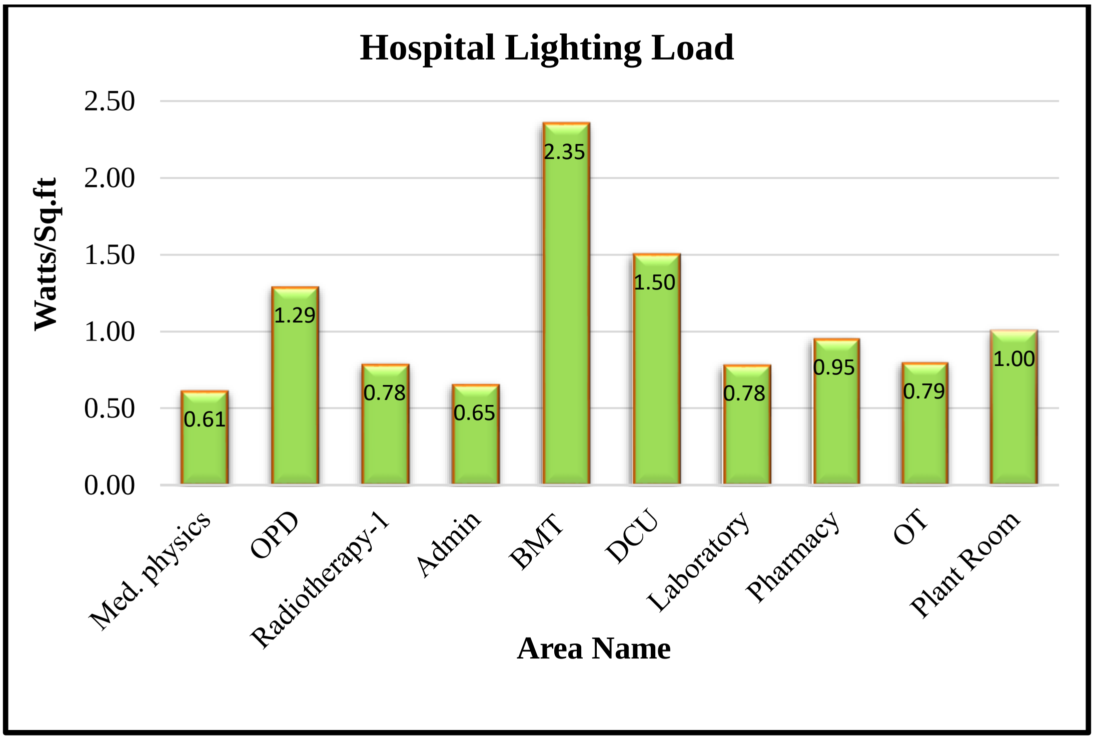


Figure 26. Lighting Load of Some of The Areas of Hospital

Table 8. Information about Water-Side HVAC

Chiller Loop	Chiller Name	Types	TR	COP	Pump KW	Pump Head in FT
Chilled Water loop (Oncology)	Chiller-1a	Electric Hermonic Reciprocating	182.5	2.33	37 KW	100
	Chiller-1b		182.5	2.33		
	Chiller-1c		182.5	2.33		
	Chiller-1d		182.5	2.33		
	Chiller-1e		182.5	2.33		
Circulation Loop (CTL LAB)	Chiller CTL-1	Electric Screw	90	2.7	5.5KW	53
	Chiller CTL-2		90	2.7		
Circulation Loop (Inpatient)	Inpatient Chiller-1	Electric Hermonic Reciprocating	115	2.33	22KW	110
	Inpatient Chiller-2		115	2.33		

This section describes the default system types provided in the template. It may be necessary to model more than one of any type of system, and not all systems apply to all buildings. Air side HVAC components consist of fans, heating and cooling coils, economizers, ducts, terminal units, thermostats, etc. Some of the air-side HVAC systems linked with the ground floor, first floor, and second floor are shown in Figure 27.

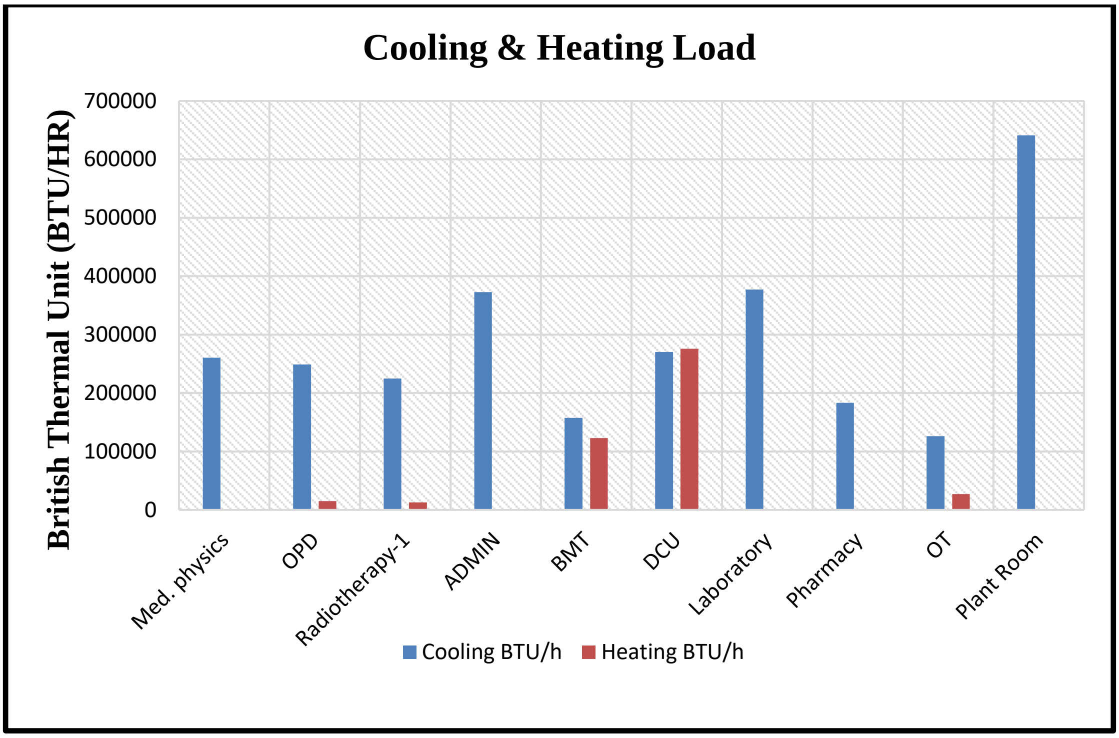


Figure 27. Information of Air-Side HVAC inside Hospital Areas

Moreover, there are four types of equipment in cancer hospitals, i.e., pantry load, medical equipment, office equipment, and miscellaneous load. These loads are associated with each floor, and data for some of the loads are described in Figure 28.

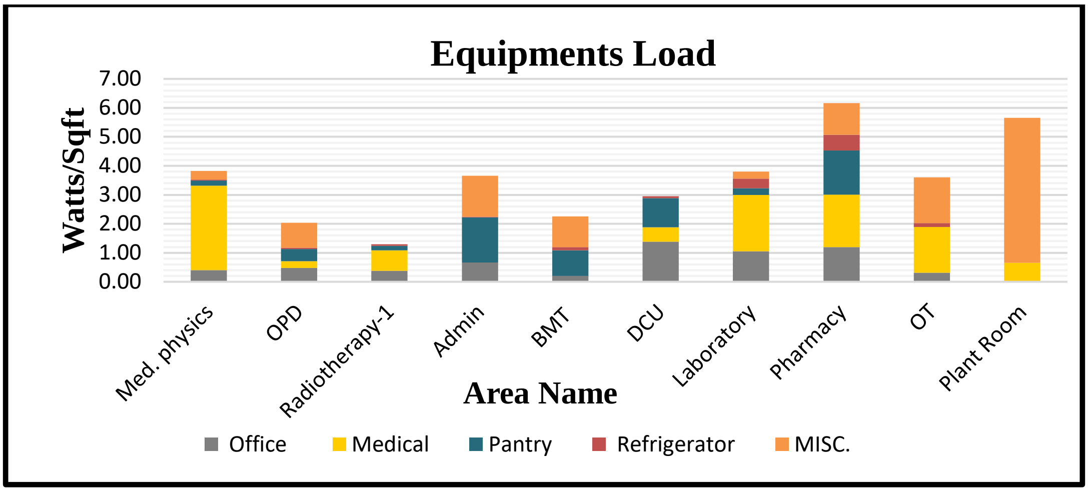


Figure 28. Information about Equipment Load

3.3.1.3 General Occupancy

Occupancy describes the statistics about the number of people present in a specific area, their sensible and latent heat gains, and occupancy schedules. Figure 29 shows the occupancy mode.

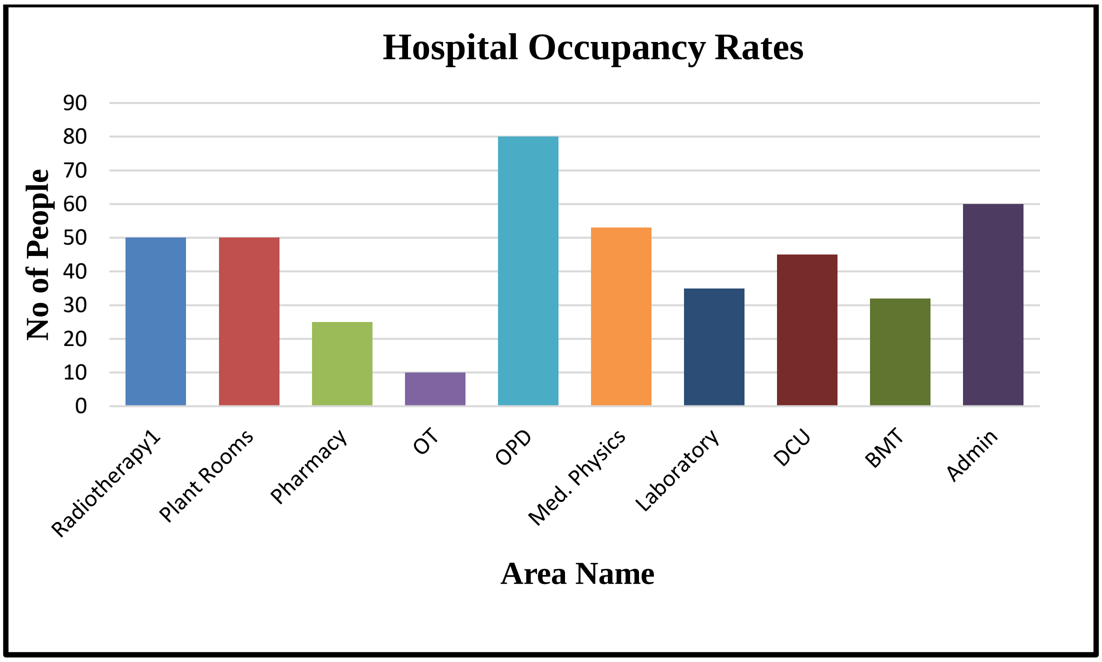


Figure 29. Occupancy of People

Occupancy shows the area occupied by per person; for example, the space of Cyber knife & bunker1 has a total area of 1,779.3ft^2 and area per person is 80 ft^2. In this total area of space, the number of people can be 50, and the occupancy schedule is from 7 am to 3 pm. Moreover, latent heat gain values, sensible heat gain, and total heat gain by a person are also elaborated for each space. Figure 30 shows the data for Cyber knife & bunker1.

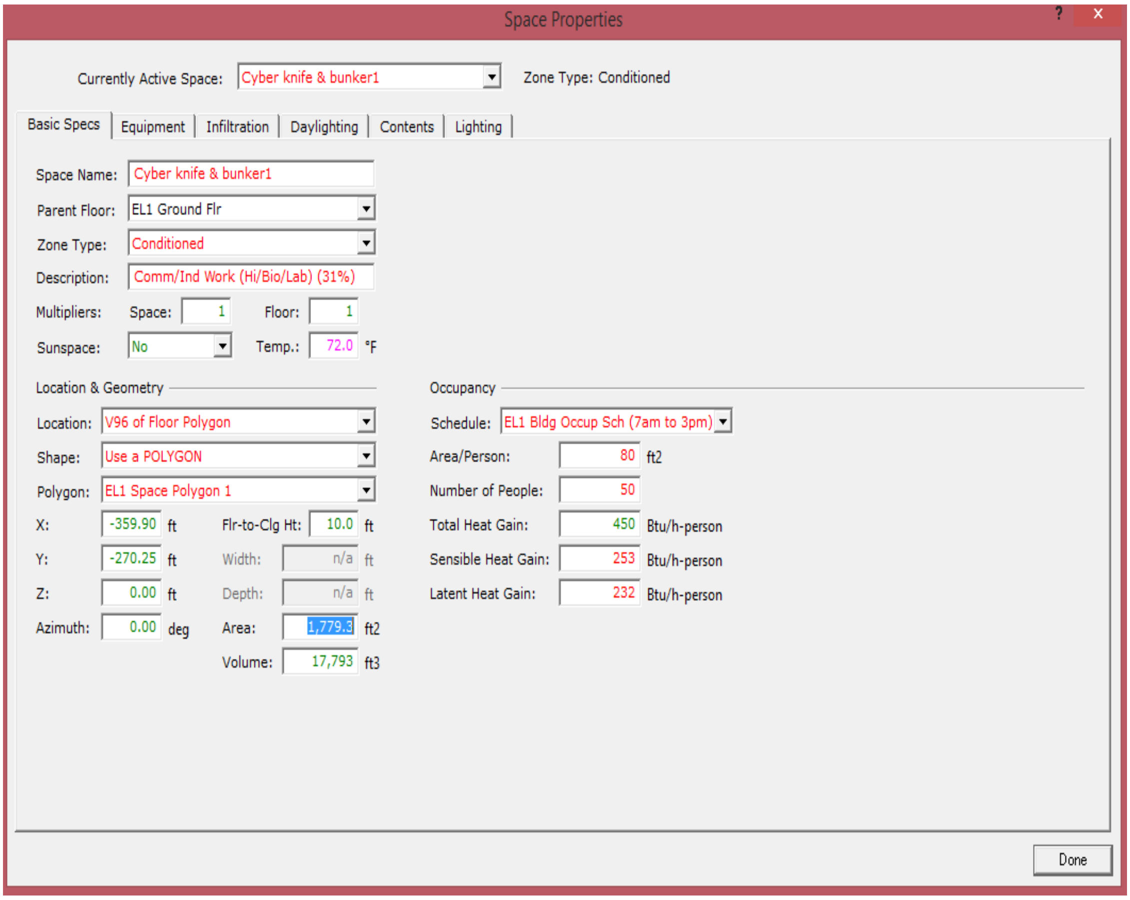


Figure 30. Properties of an Active Space for Occupancy

Furthermore, various spaces on all floors have shown in the table 9, which describes the activity description of various units, their schedule details, and occupied area by each individual.

3.3.1.4 Mapping of HVAC Equipment & Zoning

Zoning provides details on secondary HVAC distribution system features specified to a thermal region. The “SYSTEMS” and “PLANT” tools in DOE-2.1 are joined to form a single unit named as HVAC. This can enhance loads' association due to the secondary HVAC systems such as air handler and reheat coils and the primary HVAC systems as chillers. Therefore, circulation loops have been introduced. A circulation loop enables the system's connection with a thermal demand to the thermal supplier, i.e., boiler. Figure 31 shows the circulation loop.

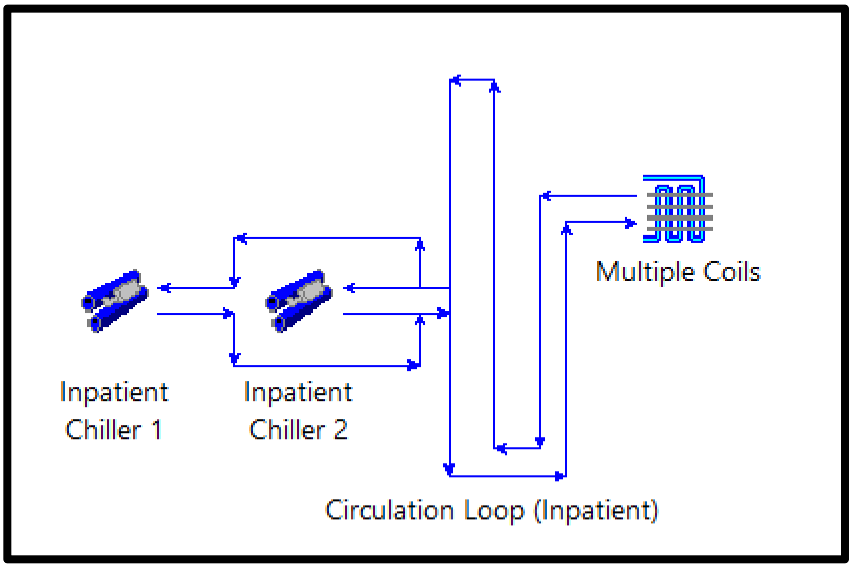


Figure 31. Circulation Loop of Inpatient Chiller

A chilled water loop delivers the chilled water to cooling coils. Furthermore, a chilled water loop may be given to deal with a process cooling load, for example, a computer room module load. Chilled water loops pass their load onto one or multiple chillers. Figure 32 shows the chilled water loop.

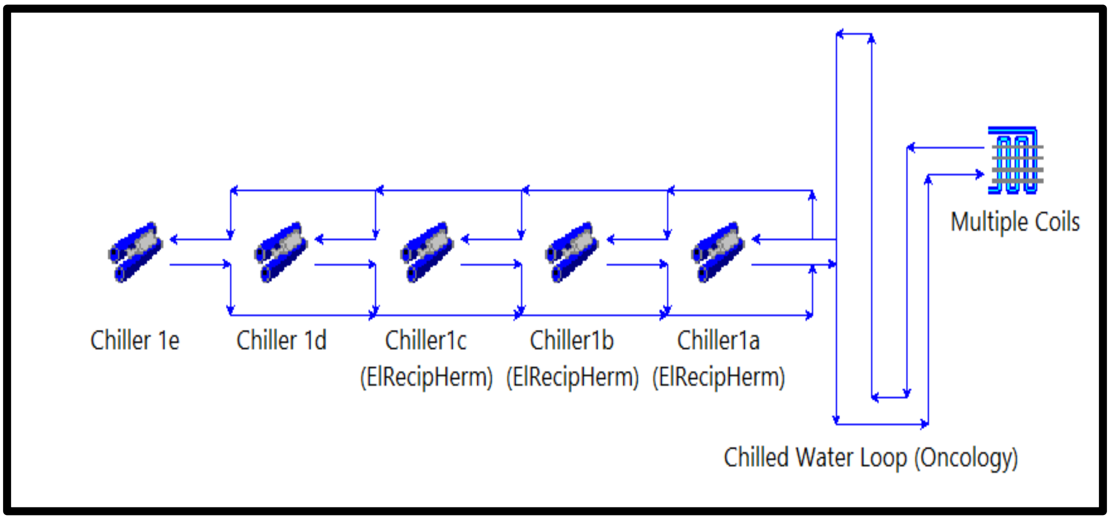


Figure 32(a). Chilled Water Loop oncology

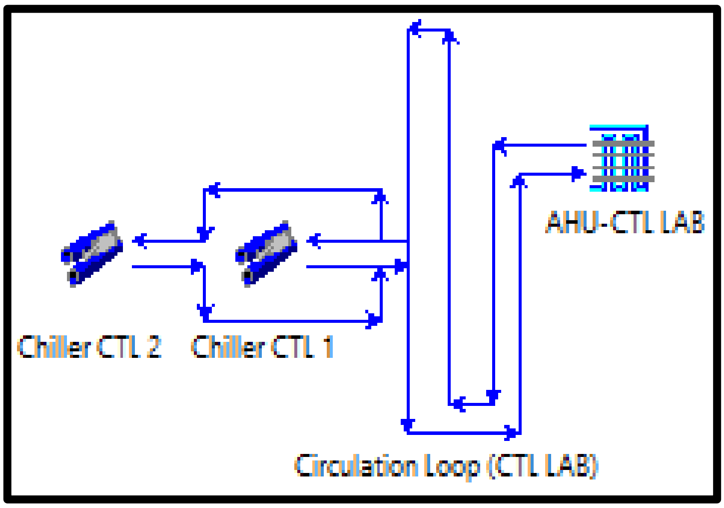


Figure 32(b). Chilled Water Loop CTL

A hot water loop provides hot water to heating coils. The coil types comprise preheating, central heating, reheat, baseboards, heat pumps, and radiant floor panel systems. Mainly, hot water coils employed for space heating are connected to a circulation loop. Figure 33 shows the HW pump and Oncology unit.

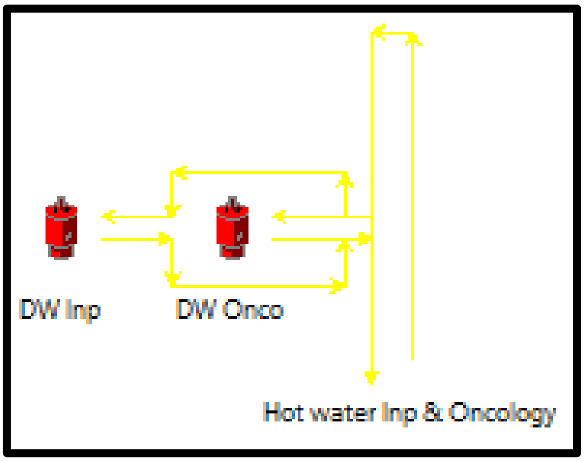


Figure 33. Hot Water Pump for Oncology

3.3.1.5 Assignment of Hospital Main Schedules & Alternative Schedules

Schedules define the profiles on an hourly basis for lighting power, occupancy, and thermostat setpoint. Formats of schedules for LOADS, HVAC, and ECONOMICS input remain the same. DAY-SCHEDULE describes the hourly profile for a specific day type. Figure 34 shows the schedule properties.

3.3.1.6 Utility Charges

Qatar General Electricity & Water Corporation (KAHRAMAA) is a well-known government organization that is associated with sustainable distribution and transmission of electricity & water across the Qatar State. Utility rates describe the basic characteristics of a tariff. The utility rate command is described for every kind of fuel or energy and defined prices concerning time, not by quantity. For charges varying by quantity, for example, block rate tariff, utility rate points for one or more BLOCK-CHARGE commands.

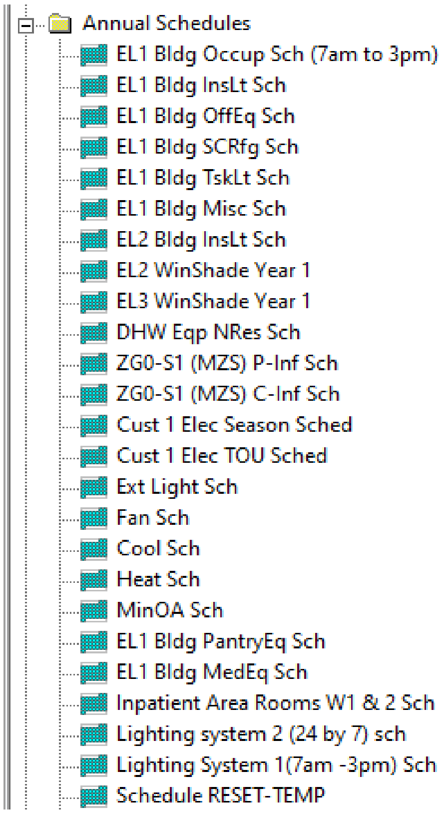


Figure 34. Hospital Annual Schedules

For the time of use tariffs, the hourly basis values are multiplied by the scheduled values. Then attained values are summed for the billing period. The fixed rate of tariff for Government buildings is 0.32 in Qatari Riyal. As eQUEST is USA based software, so we have converted the Qatari riyal into cents. The cost of energy consumption will be attained by

$$Cost = Total\ Energy\ Consumtion\ \times Tariff$$

3.3.1.7 Review of Simulation Run

Simulations for cancer hospital show the total energy consumption of each month. Figure 35 shows the electric consumption.

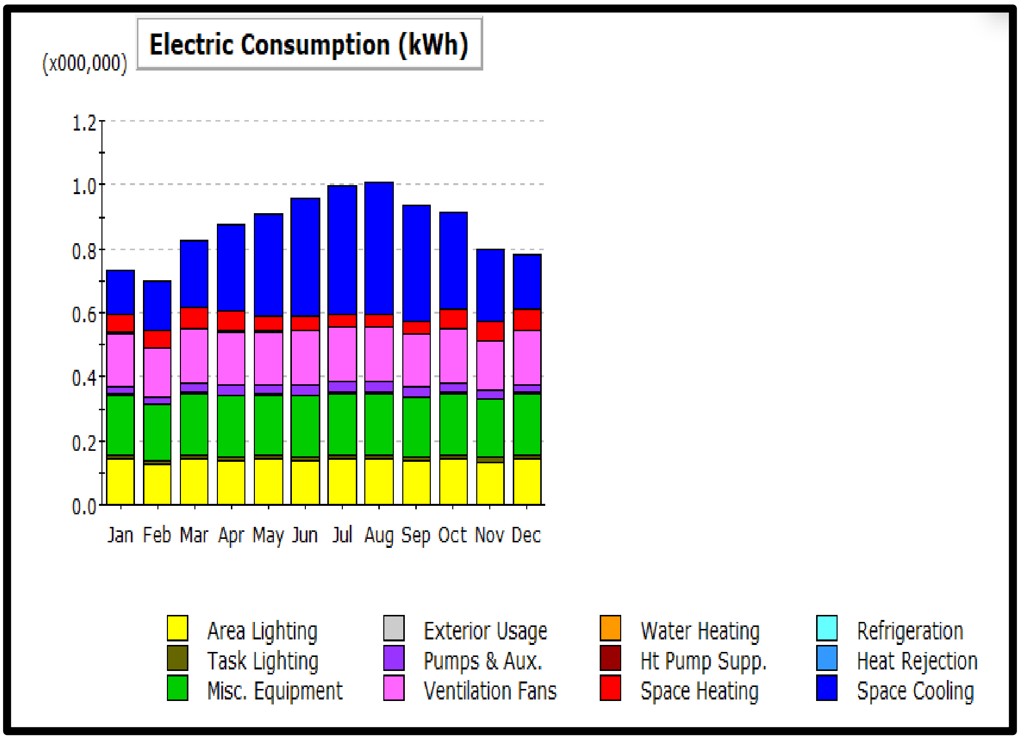


Figure 35. Electric Consumption

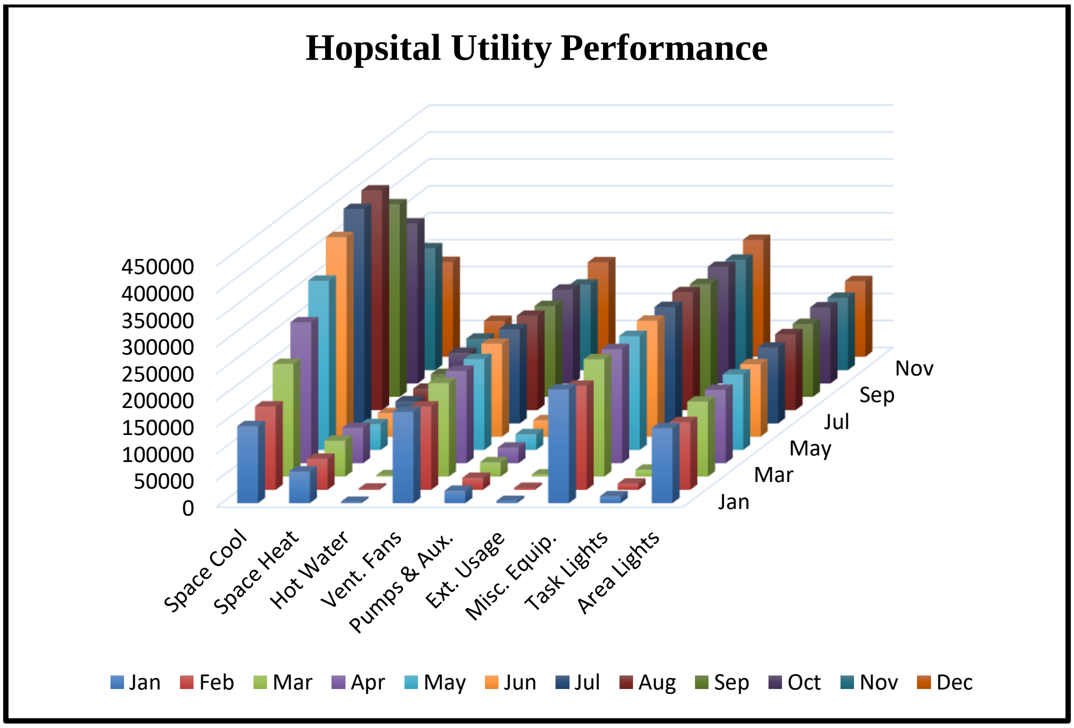


Figure 36. Hospital Utility Performance

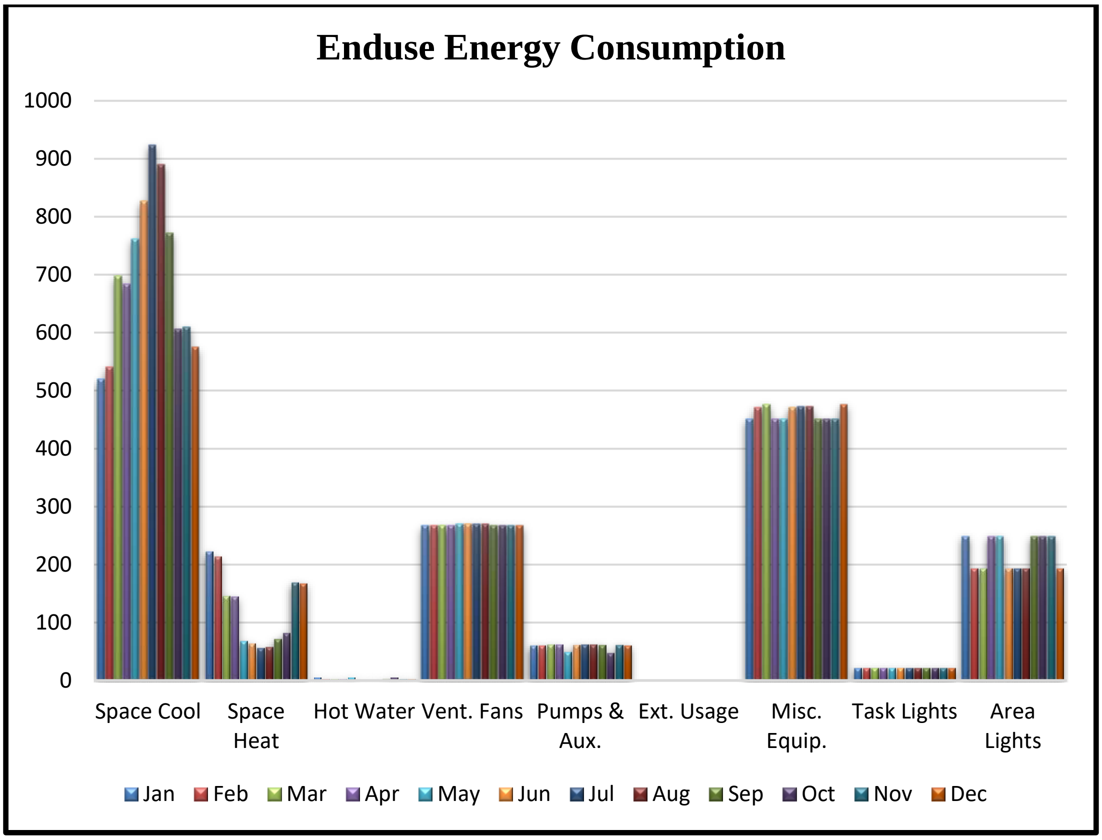


Figure 37. End Use Electric Consumption

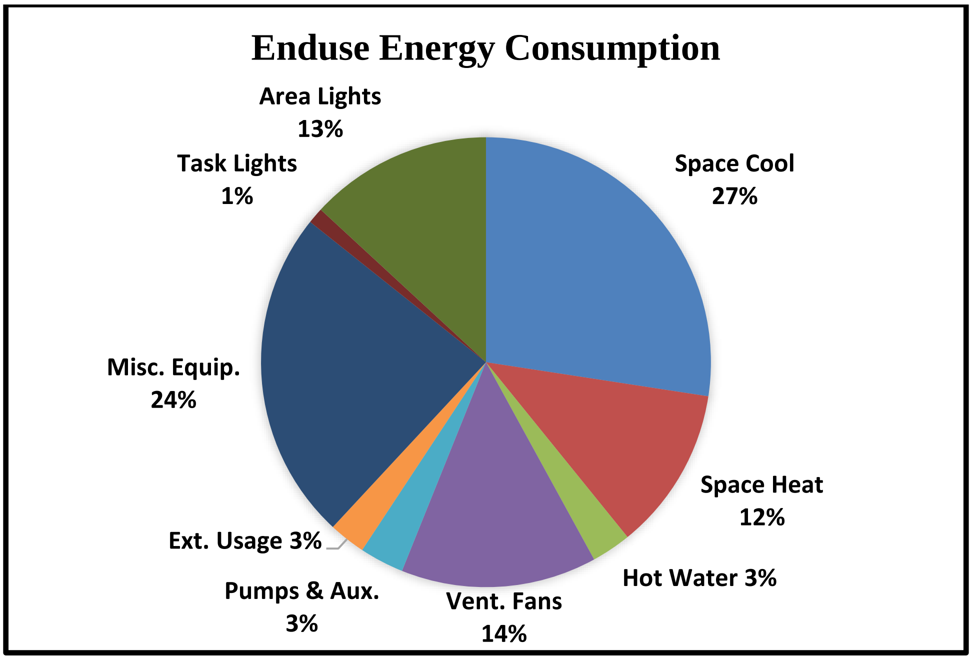


Figure 38. Percentage of End-use Consumption of Electricity

3.3.2 Validation & Verification of Baseline Model

The actual data of the cancer hospital contains the average electricity consumption of each month for 2019. Simulation results show that they exist within the margin of error. This ensures that eQUEST can perform reliable simulation results with an entire perception of the model's operation and suitable data assumptions. The actual electric consumption throughout the year is 11.05MWh. The actual monthly consumption is shown in Figure 39.

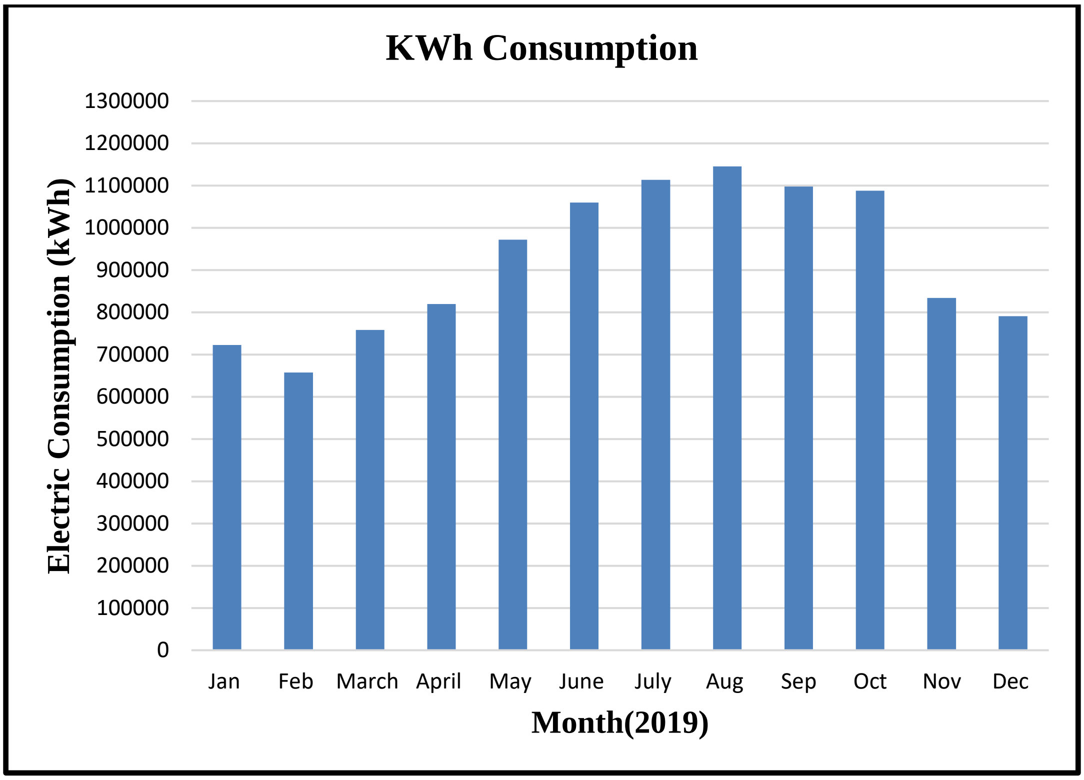


Figure 39. Consumption of Electricity on Monthly Basis

The electrical maintenance team collects this actual data by each month through kahramma electric meters installed on each low voltage panel inside the substation room, and this is 100% accurate data based on real values. This data is taken for our research work consideration. This data is compared with our simulated results. After performing the baseline model for a cancer hospital, monthly consumption becomes less than actual consumption. The verification and validation results of the hospital are shown in Figure 40.

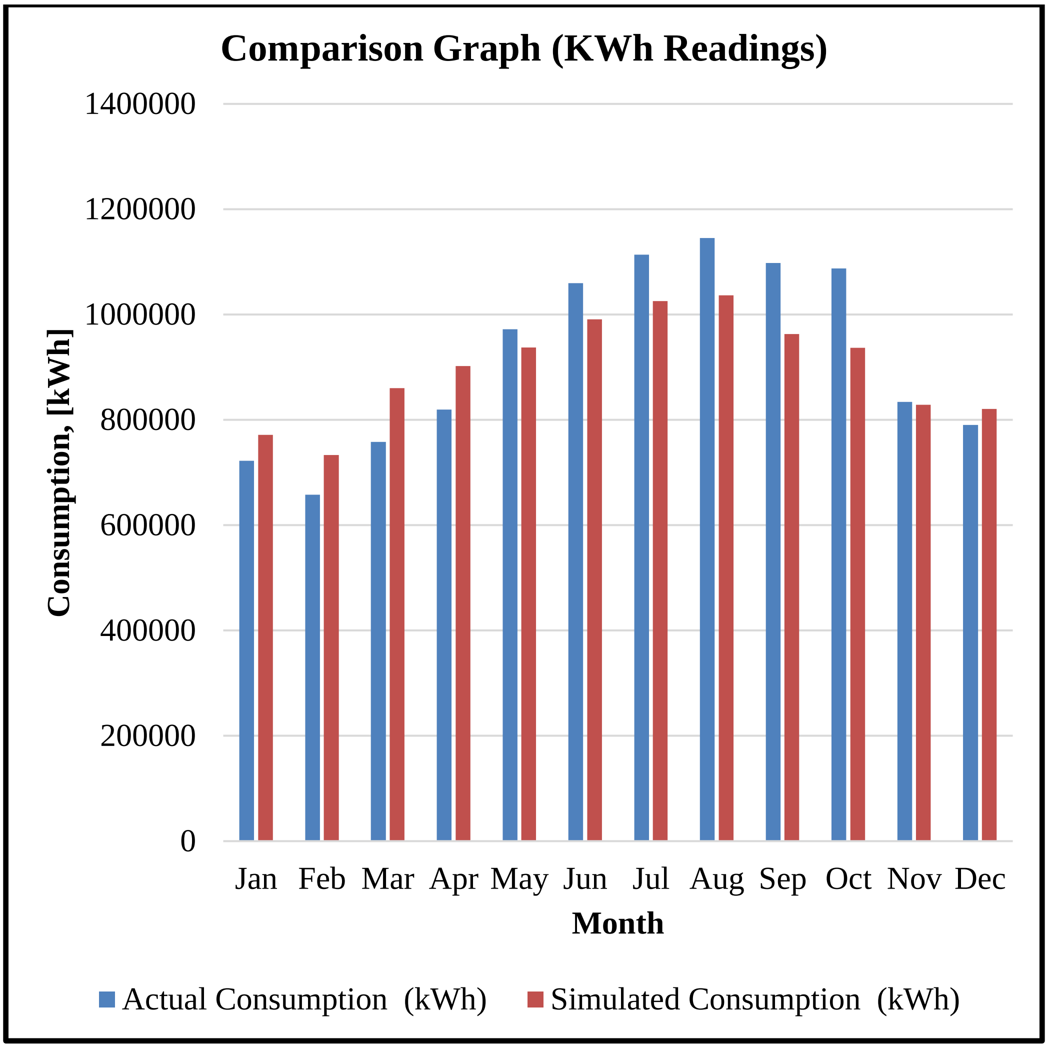


Figure 40. Verification of Consumption of Electricity for Actual and Simulated Data

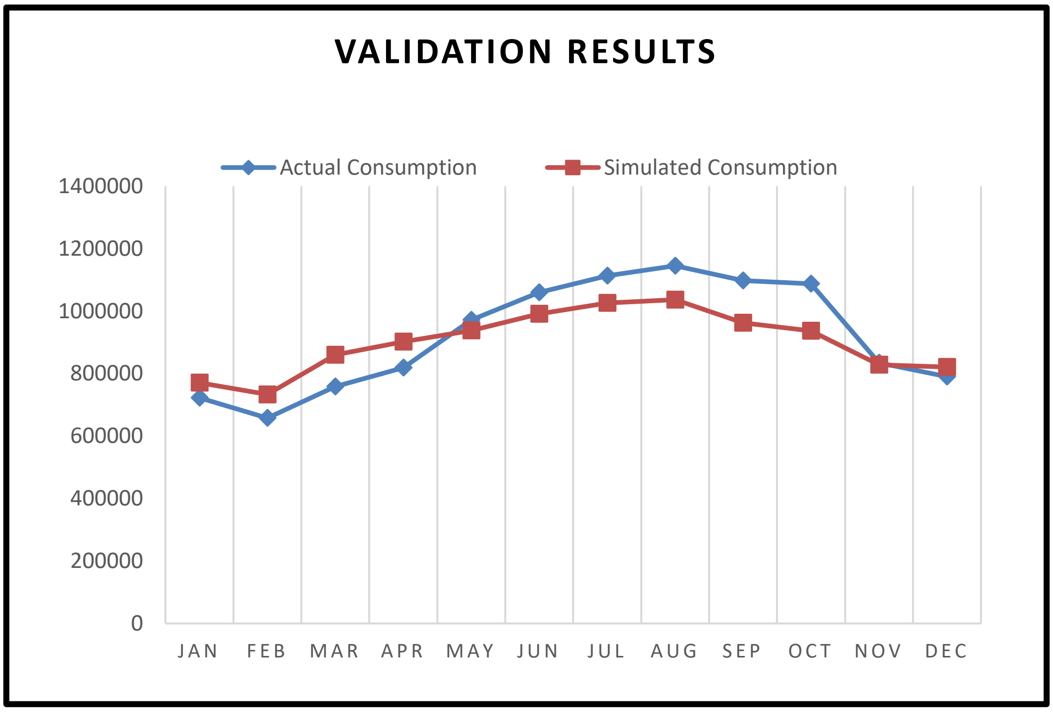


Figure 41. Validation of Electricity Consumption for Actual and Simulated Data

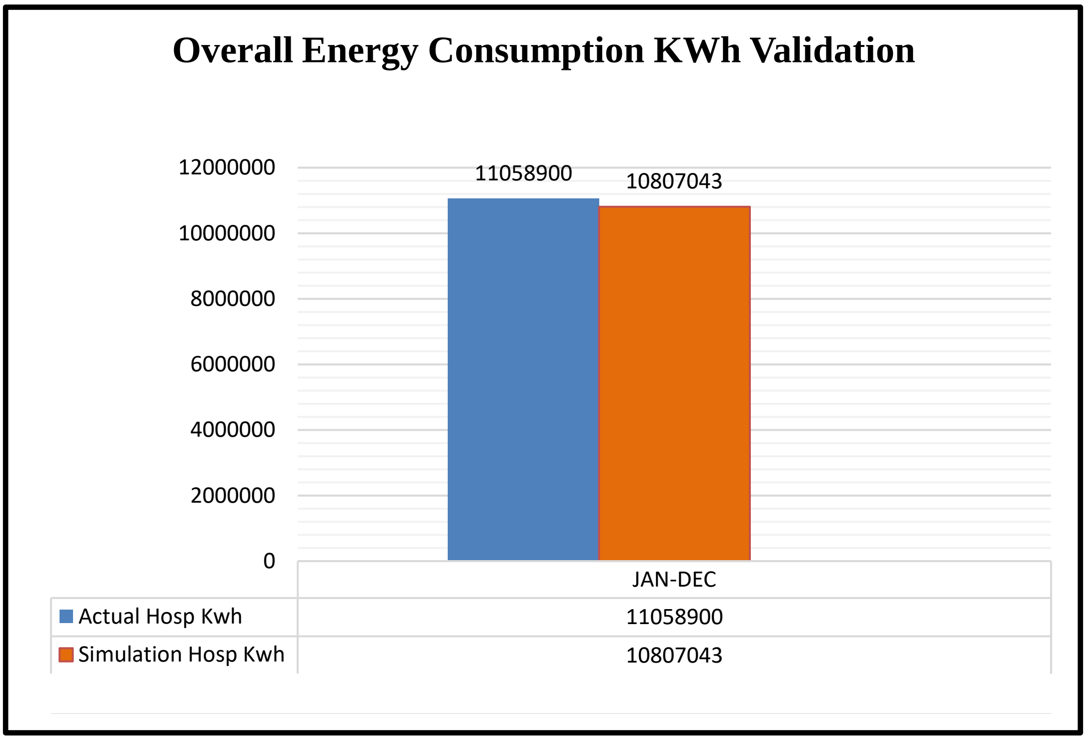


Figure 42: Overall Electricity Consumption for Actual and Simulated Data

CHAPTER 4: ENERGY SAVINGS ALTERNATIVES TO BASELINE CASE

4.1 Implementation of Alternatives

eQUEST/DOE-2 deals with two alternatives, the 'EEM Wizard' and 'Parametric Runs.' These methods are used to analyze energy-efficient design alternatives by simulating several alternative simulation design scenarios.

4.2 Creating Parametric Studies

The parametric studies of eQUEST deals with alternative simulation scenarios. In these scenarios, each new scenario is considered as a parametric variation of the base scenario. Parametric analysis needs more detailed input and control as compared to EEM analysis. Generally, Parametric Runs are considered as more flexible and detailed version than EEM wizard mode. These studies need more steps to elaborate on the whole structure. Parametric Runs can change existing building components but no components can be created by employing this.

There are six steps in creating Parametric runs.

a) Defining the global parameters
b) Assigning them values
c) Define the Parametric Runs
d) Define Parametric Components
e) Execution of parametric simulations
f) Analysis of parametric results

This creation depends on the user's preferred technique. The first technique needs to define global parameters. Parametric runs and components are explained in the second technique. These components apply directly to BDL commands and keywords. In the case of the numeric parameter value, global parameters are recommended to use. Figure 43 shows the flow of steps involved in Parametric Runs.

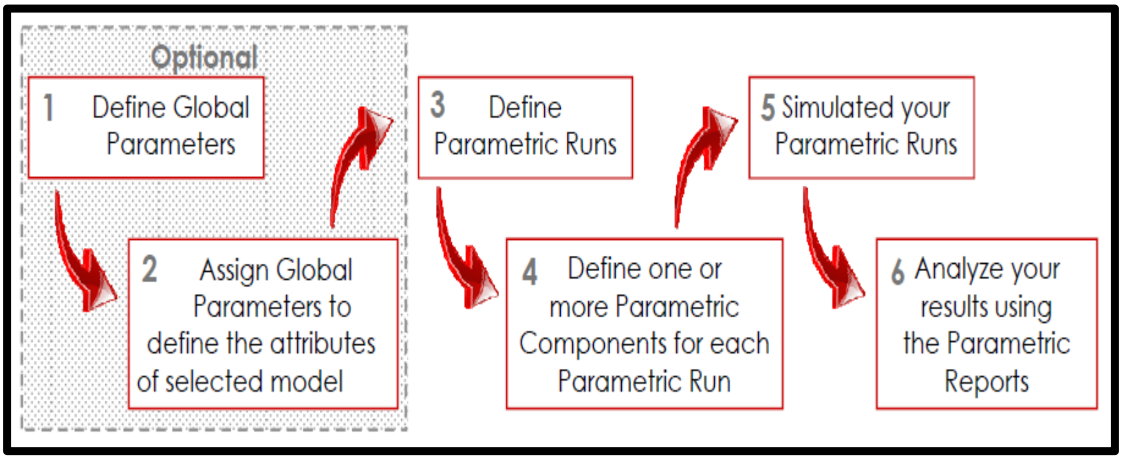


Figure 43. Flow Diagram of Parametric Runs (Wood, 2011)

A fundamental limitation in eQUEST remains that when defining parametric runs, parametric components can only refer to existing components in the project; therefore, parametric runs can only be used to modify features of objects that exist in memory for the current project.

In version 3.65, parametric runs can reference other external projects (i.e., INP files saved as part of other projects). To take advantage of this new capability, users must perform a ‘save as’ and modify the new project in any way preferred. The newly created (saved) file can then be referenced in the original project's parametric run sequence. The most straightforward way to accomplish this is to run all simulations, use File, and open the INP file for the last (fourth parametric run).

Note that when performing a File Open, the browse dialog expects to find PD2 files, not INP files. Set the File Type on the browse dialog to search for INP files, then open the INP file created for the last parametric run, i.e., "Cancer Hospital Qatar Doha Package unit.inp." This action will present the "Create Project from BDL File" dialog. Confirm the desired weather file (defaults to the last weather file used). Perform a 'save as' and rename the new project "Parametric (Package VAV)". Figure 44 shows the existing parametric runs in eQUEST.

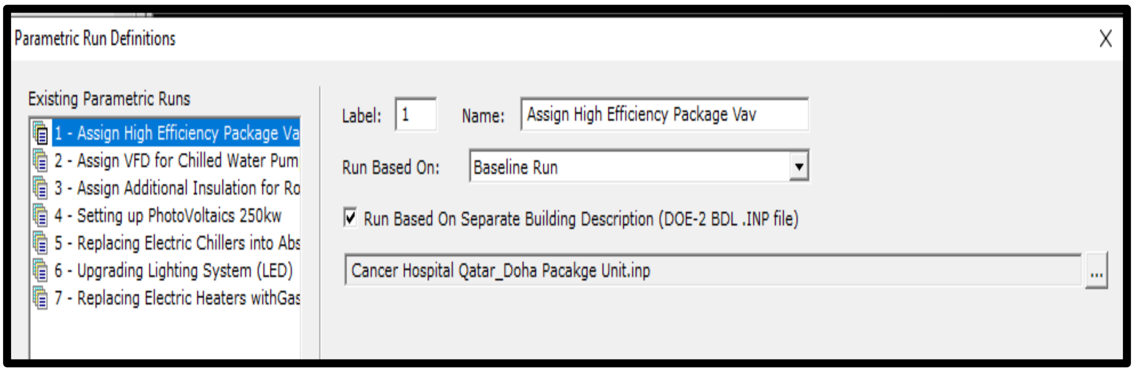


Figure 44. Parametric Runs for Proposed Work

4.3 Examples of Alternative Scenarios with Base case Model

4.3.1 Replacing All Chillers with Package Unit VAV

Conclusion: there are prominent features of an efficient system for the HVAC model, better performance, cost, and optimized energy use. The selection of equipment must validate ASHRAE Standard 90.1. various selection criteria have been discussed for the HVAC system. The air conditioning system is categorized into two main types, i.e., Centralized air conditioning systems and Decentralized air conditioning systems.

As per our base case, we have Central air conditioning systems that serve multiple spaces from one base location. As a cooling medium, these systems employ chilled water and utilize extensive ductwork for air distribution. Figure 45 shows the chilled water central system. The system is categorized into three main subs categories which are

1) The chilled water plant,
2) The condenser water model and
3) The air-delivery model.

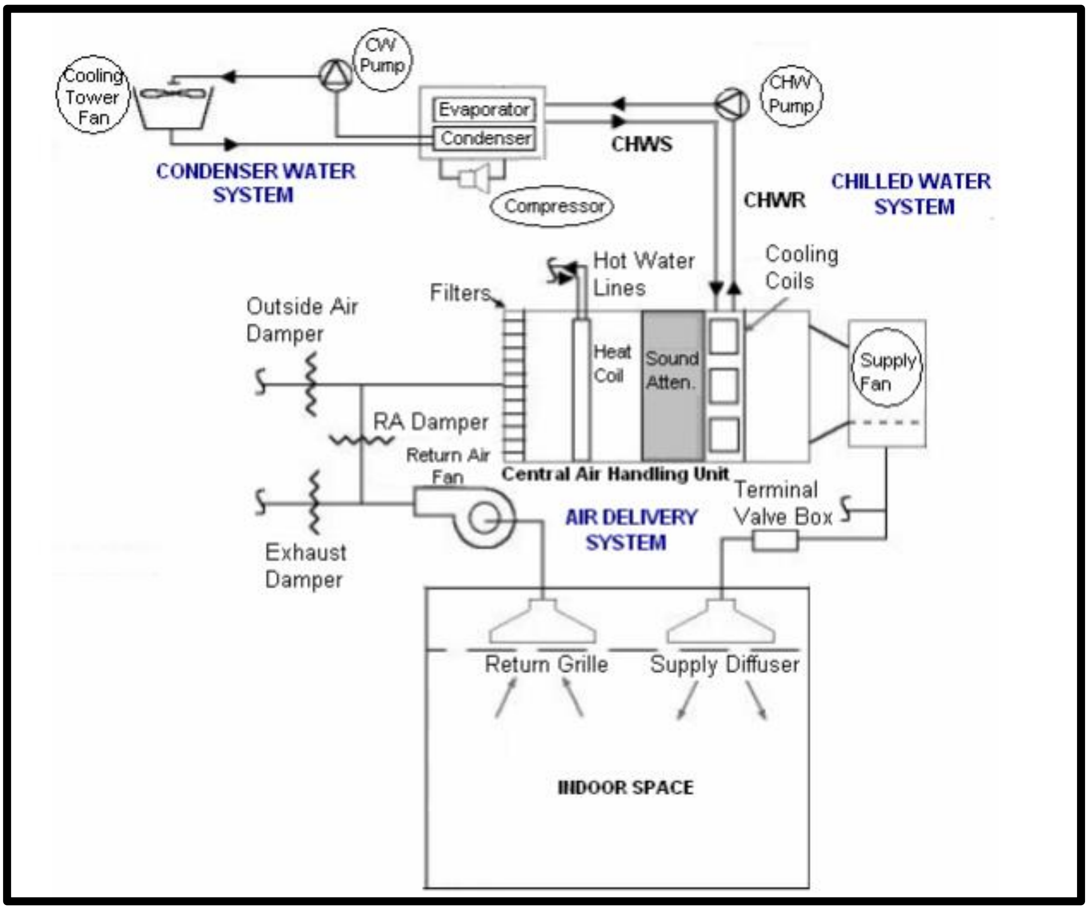


Figure 45. Chilled Water Central System (TRANE, 2012)

Decentralized air conditioning systems are termed multiple names as local systems or packaged systems supply cooling to a single room or spaces rather than the building.

These modules consist of all mechanical parts of the HVAC system, compressors, condensers, and evaporators.

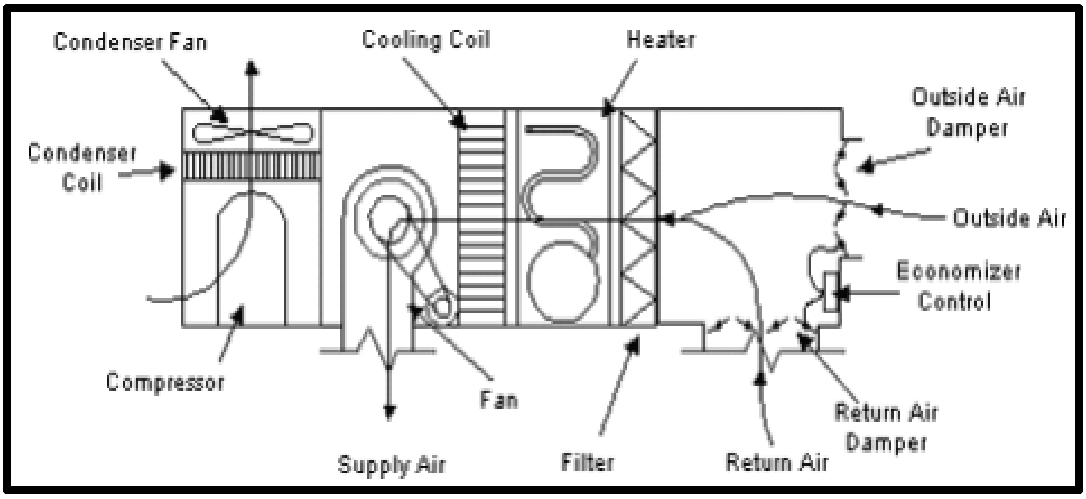


Figure 46. Typical Single-Package Rooftop System (TRANE, 2012)

Decentralized systems are considered suitable for medium buildings or for less occupied buildings at any specific time. These systems may be given a priority because of shutting down in unoccupied spaces. Therefore, they provide potential energy savings. Decentralized systems offer room-by-room control and give occupants a higher comfort level because of individualized control features. Whereas Central systems are distinguished by:

1) High-pressure loss in the distribution system;
2) High area requirements for the air distribution system;
3) High efficiency of fans.

The central plant chilled water system and built-up Variable Air Volume (VAV) air handler unit are changed along with hot water reheating with rooftop package unit VAV systems. VAV is a highly efficient package unit. The VAV systems are selected because of their advantage over constant-volume systems, which has more precise control on temperature, decreased compressor wear, lower energy utilization by system fans, and reduced noise. Decentralized models are considered as simple systems which can be operated easily, together with easy maintenance.

For each air-side system in the project, on the Basics tab of the Air-Side Systems tabbed dialog, change the System Type from “Variable Air Volume” (i.e., CHW-based single duct VAV) to “Pkgd Var Vol” (i.e., DX single duct VAV). To delete the CHW pumps (Oncology, Inpatient & CTL), in the Water-Side HVAC module, right-click on the CHW Loop Pump and select “Delete…”. From the Delete Pump dialog, confirm the CHW pump's deletion by clicking on the “delete” button. To delete the chiller (still in the Water-Side HVAC module), right-click on the chiller and select “Delete…”.

From the Delete Chiller dialog, confirm the chiller's deletion by clicking on the “delete” button. To delete the chilled water loop (still in the Water-Side HVAC module) right-click on the Chilled Water Loop and select “Delete…”. From the Delete Circulation Loop dialog, confirm the CHW loop's deletion by clicking on the “delete” button. Save the packaged VAV version of the project and reopen the original version (i.e., the version with built-up CHW VAV).

After selecting “Create Parametric Run,” name the parametric run as preferred, “Packaged VAV.” Select Run Based On = “Baseline.” This will cause this specific parametric case to be run on top of (i.e., cascaded on top) the six preceding parametric cases. Place a checkmark next to Run Based on Separate Building Description (DOE-2 BDL.INP file. Click on the ellipse button and browse to select the DOE-2 BDL.INP file from the Packaged VAV project, then click “Open”.

Confirm that the correct file name appears immediately left of the ellipse button. Press the Grid View button near the Parametric Run Definitions screen's lower right-hand corner to view all parametric runs defined. This completes defining a Parametric Run for the packaged VAV case. Figure 47 shows the selection of the baseline scenario along with the alternative of packaged VAV.

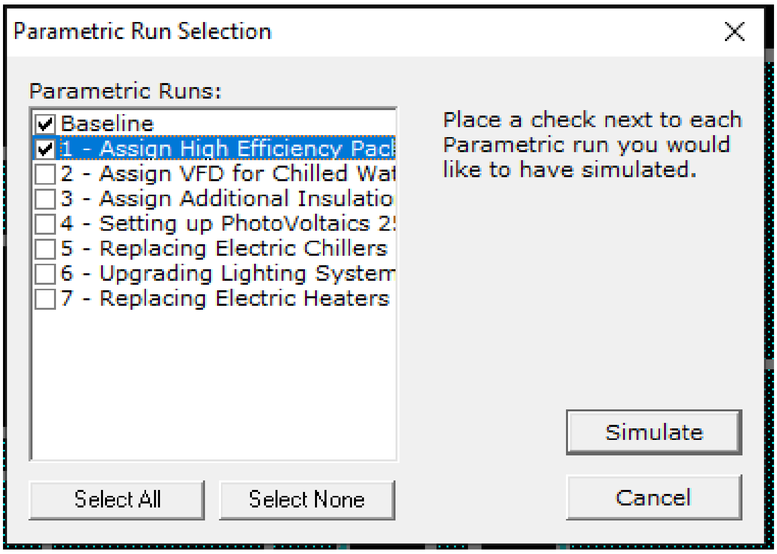


Figure 47. View for Selection of Baseline and Packaged VAV

By using the VAV system, energy consumption becomes less than the baseline case. Outcome results by changing chillers with the VAV package unit are shown in Figure 48.

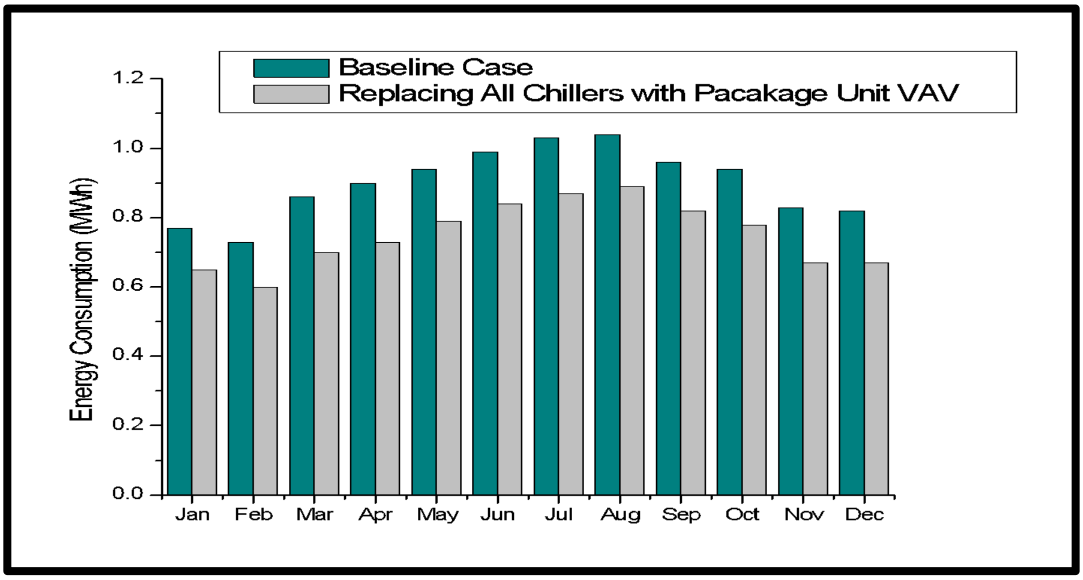


Figure 48. Electricity Consumption for Baseline and Alternative Case

The total energy consumption of both cases, i.e., baseline design and alternative case of replacing chillers, is shown in Figure 49. This verifies that electric consumption becomes less than the baseline case by changing chillers with the VAV unit.

4.3.2 Replacing CHW Single Speed Pumps (Secondary) with Variable Speed Drive

The chilled-water (CHW) pumps have a constant speed. The flow of water is changed by cycling off a chiller and its pump for capacity design. In a constant power flow (CPF) configuration, load changes are considered to alter delta-T.

The high pump energy consumption reflects the primary disadvantage of CPF designs. A de-coupler pipe hadronically separates the two loops, by permitting temperature exchange, but independent pressures and flows. In the process, the energy consumption of the pump is decreased. Because the reduction in horsepower changes along with reduction of distribution flow. The resultant savings could be from 50 to 60 percent — in comparison of CPF arrangement.

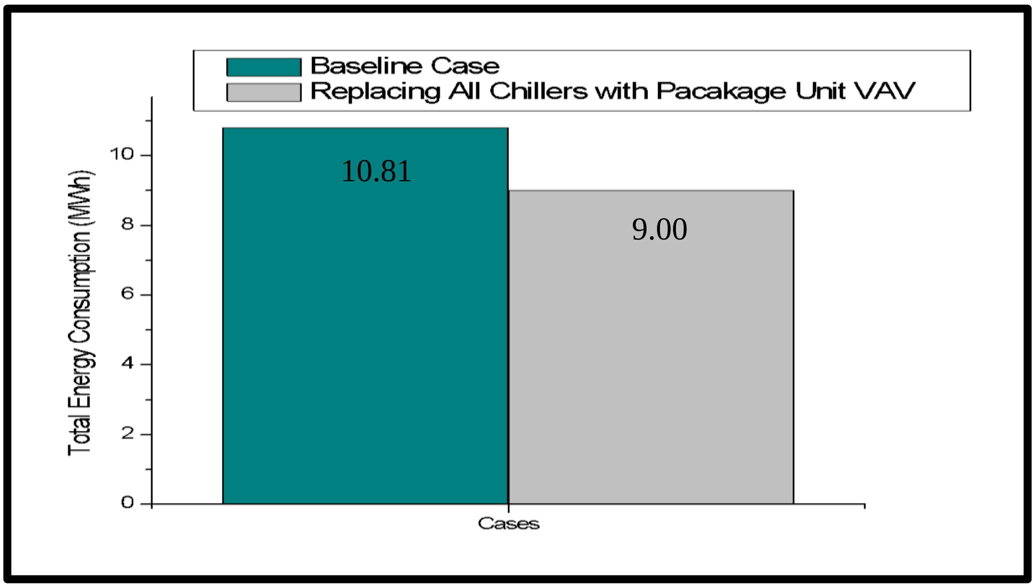


Figure 49. Overall Electricity Consumption

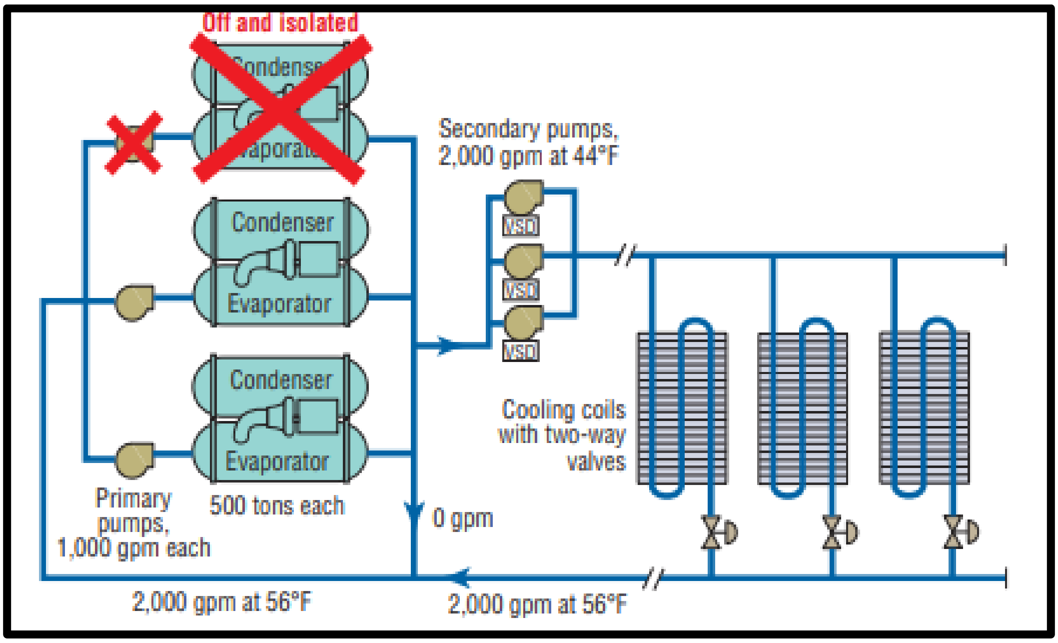


Figure 50. Variable Speed Drive (TRANE, 2012)

Outcome results by changing pumps with VSDs are shown in Figure 51.

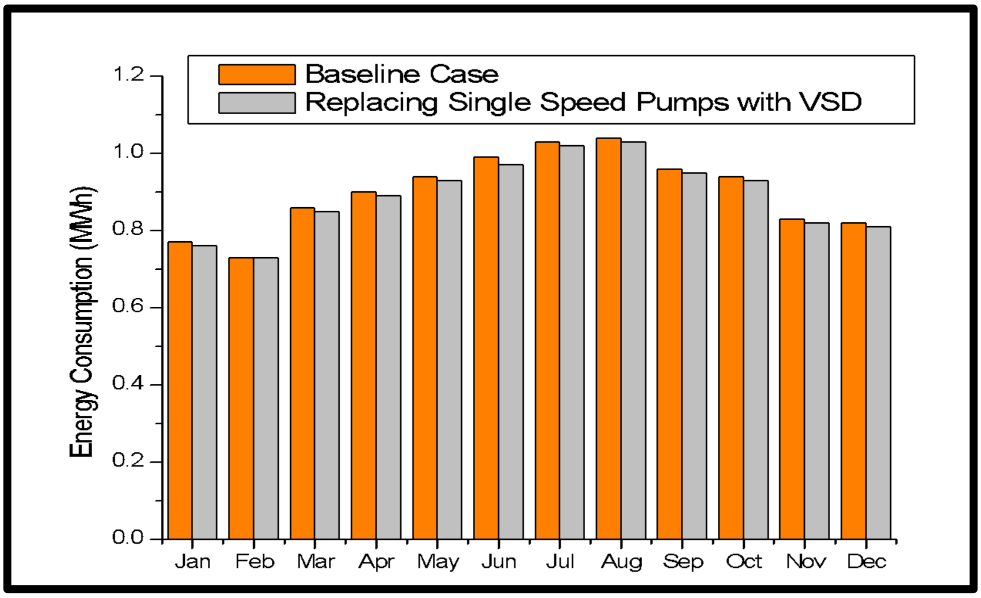


Figure 51. Comparison of Electricity Consumption for Baseline and Alternative Case

The total energy consumption of both cases, i.e., baseline design and the alternative case of replacing single-speed pumps with variable speed drives, is shown in Figure 52. This verifies that electric consumption becomes less than the baseline case by changing single-speed pumps with the VSD unit, but this reduction is not considerable.

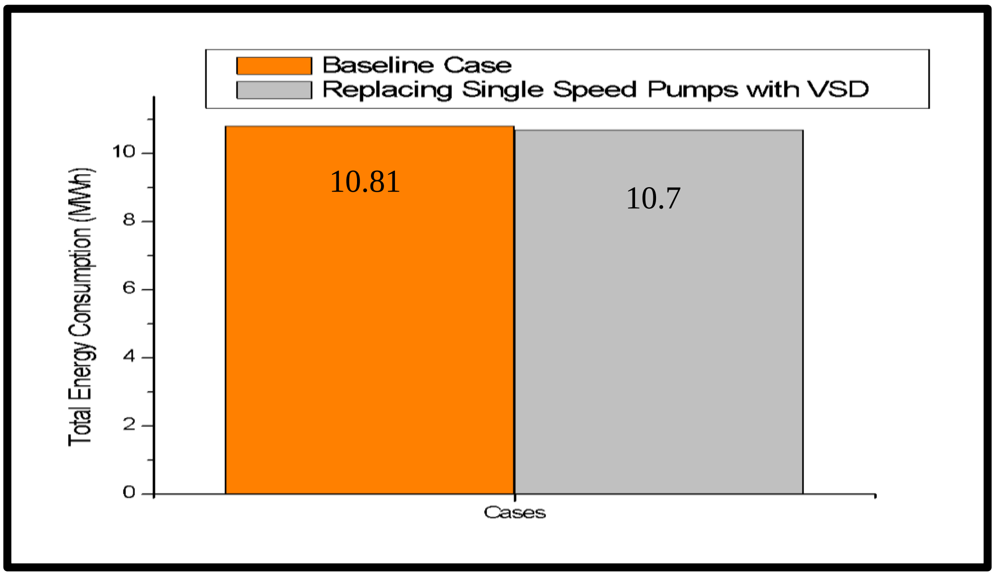


Figure 52. Overall Electricity Consumption

4.3.3 Adding Additional External Wall & Roof Insulation

The concrete wall can be protected with insulation of the external solid wall. The insulation purpose is to decrease the motion of heat tendency out of the walls, considerably minimizing the heating demand. When solid wall insulation is installed on the building's external walls, it must stick to building regulations. With lengthening polystyrene, this results in that minimum 90mm of insulation requires to be utilized–as the thicker the material, the better its insulating accomplishment and efficiency (Energy in Buildings, n.d.) (R-Value (Insulation), n.d.).

There are multiple benefits of external wall insulation.

1) External wall insulation terminates penetrating damp.

2) It can also provide help by reducing noise entering the building.

Figure 53 shows the construction of the wall surface, layers, and material properties. The material specifications have been taken as default values from eQUEST DOE 2.2 library file (eQ-lib.dat).

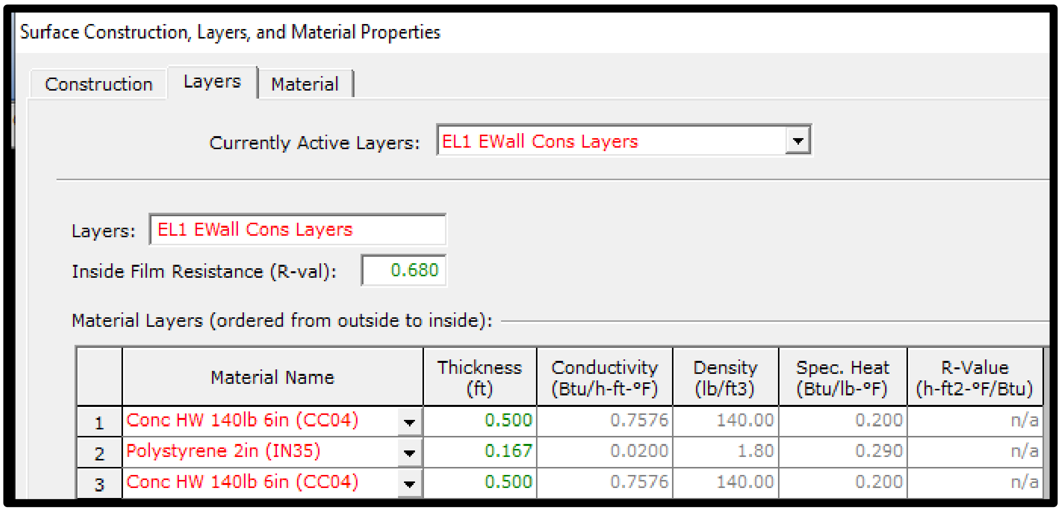
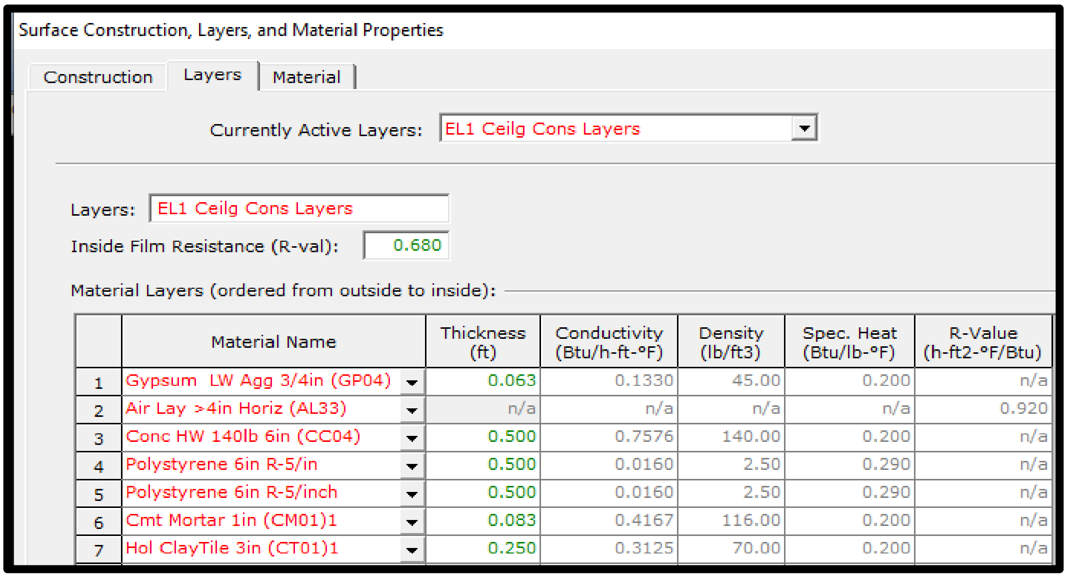


Figure 53. Properties of Wall Construction Layers

Furthermore, enormous heat is lost through the roof in an uninsulated building. Insulating a building roof is an effective way to decrease heat loss and minimize the heating bills. Figure 54 shows the ceiling construction layer's properties.



	Material Name	Thickness (ft)	Conductivity (Btu/h-ft-°F)	Density (lb/ft3)	Spec. Heat (Btu/lb-°F)	R-Value (h-ft2-°F/Btu)
1	Gypsum LW Agg 3/4in (GP04)	0.063	0.1330	45.00	0.200	n/a
2	Air Lay >4in Horiz (AL33)	n/a	n/a	n/a	n/a	0.920
3	Conc HW 140lb 6in (CC04)	0.500	0.7576	140.00	0.200	n/a
4	Polystyrene 6in R-5/in	0.500	0.0160	2.50	0.290	n/a
5	Polystyrene 6in R-5/inch	0.500	0.0160	2.50	0.290	n/a
6	Cmt Mortar 1in (CM01)1	0.083	0.4167	116.00	0.200	n/a
7	Hol ClayTile 3in (CT01)1	0.250	0.3125	70.00	0.200	n/a

Figure 54. Properties of Ceiling Construction Layers

A comparison of electricity consumption is made with baseline design and by adding an external wall and roof insulation to the hospital building, shown in Figure 55. Electricity consumption is reduced by adding an external wall and roof insulation.

The total energy consumption of both cases, i.e., baseline design and alternative case of adding an external wall and roof insulation, are shown in Figure 56. This verifies the outcomes that electric consumption becomes less than the baseline case by adding insulation.

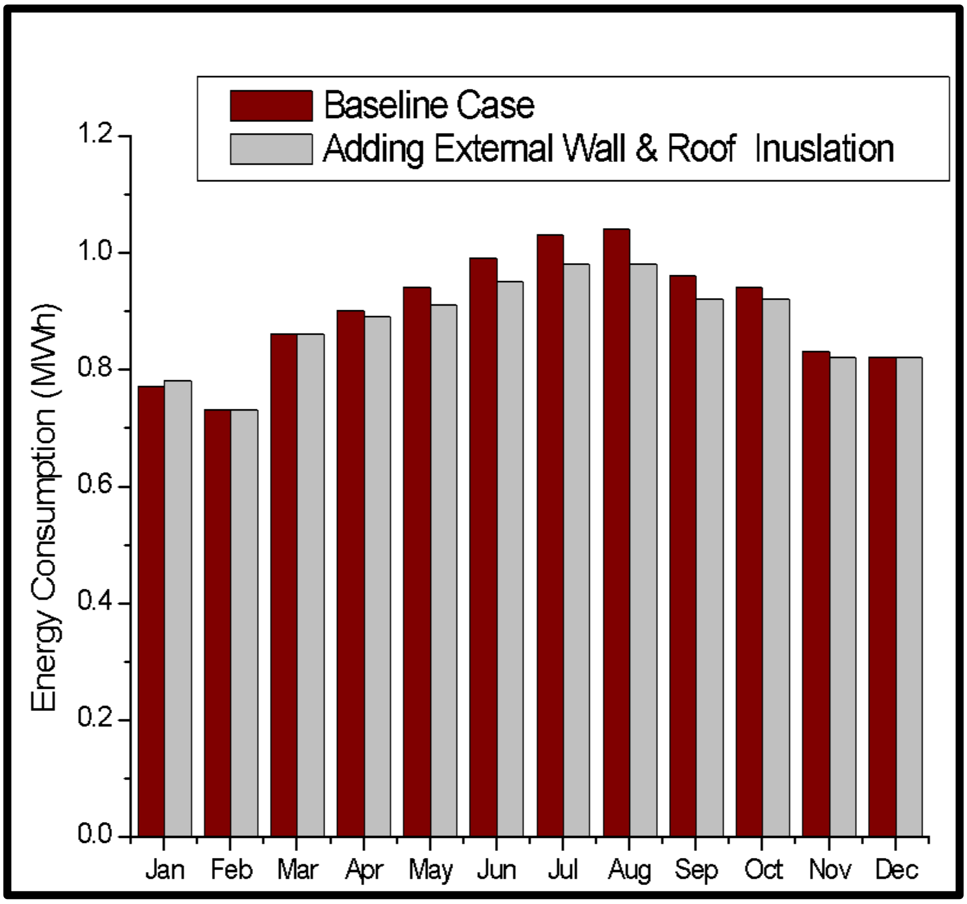


Figure 55. Comparison of Electricity Consumption for Baseline and Alternative Case

The proposed retrofit can reduce total annual Electricity consumption from 10.81MWh to 10.56MWh.

4.3.4 Setting up a Photovoltaic Array

Solar energy provides a better solution to meet energy requirements as compared to other resources. The prominent phenomenon for energy from the sun is called the photovoltaic effect. The photovoltaic system comprises of PV cells or modules. These modules can change the sunlight into electricity. To attain the maximum power from these modules, maximum power point tracking is used. The DC-DC converter is employed to stabilize the voltage level that must be synchronized with voltages of equipment.

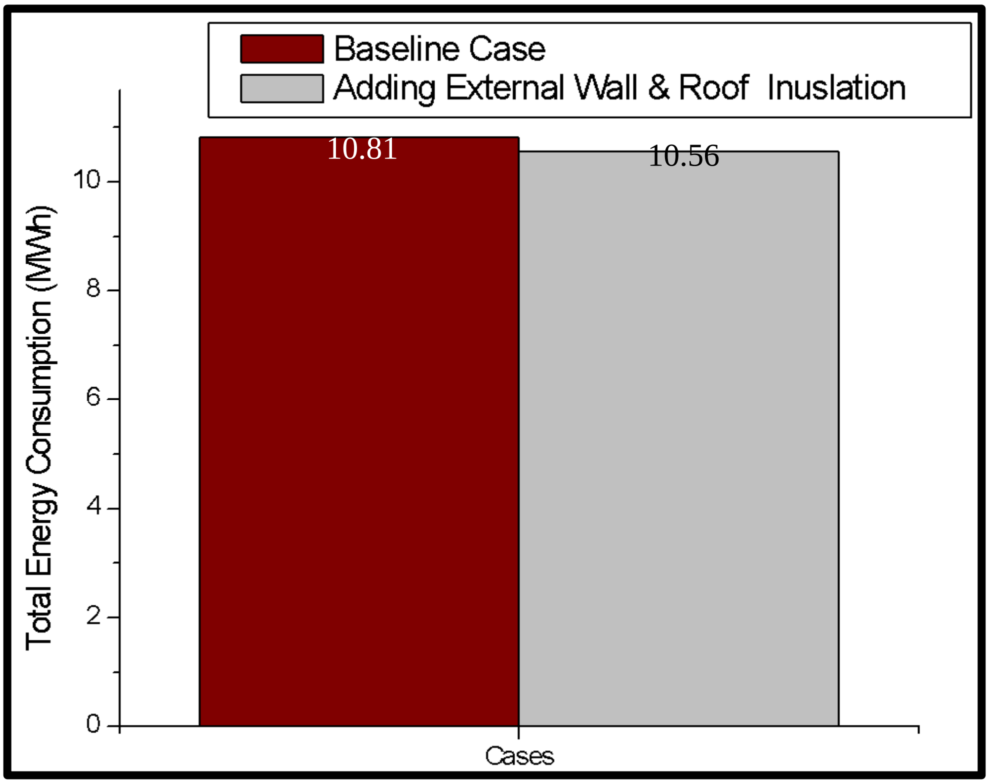


Figure 56. Overall Electricity Consumption

PV panel comprises one or more photovoltaic modules. In a pre-wired setup, these panels are linked and can be easily mounted in the field. Modules are combined to create the PV arrays to meet the necessary power demand. Monocrystalline PV panels are used here. Technical data has been taken from the monocrystalline data sheet (Quality & Warranty, n.d.). Figure 57 shows the steps of arranging PV in eQUEST.

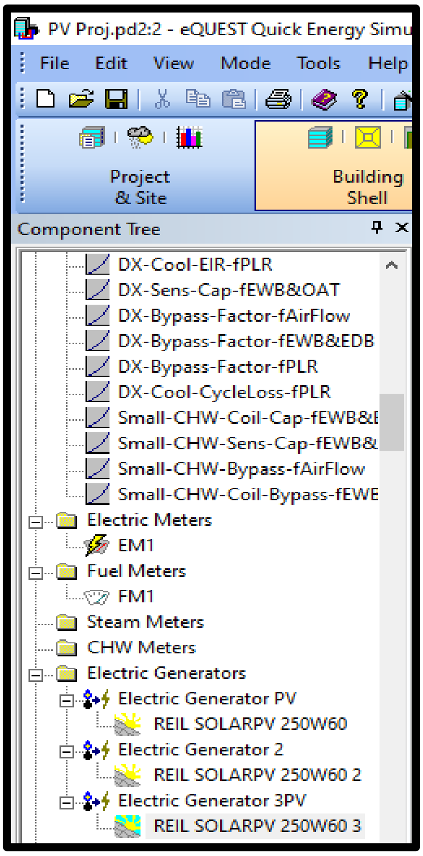


Figure 57. Component Tree for PV in eQUEST

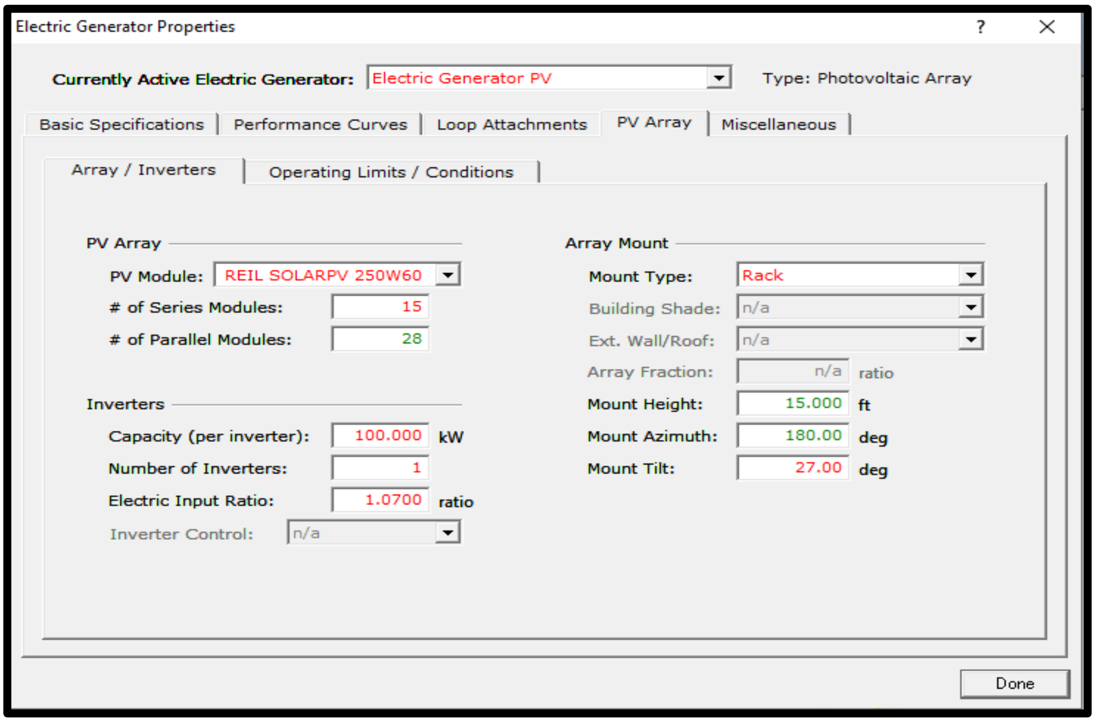


Figure 58. Properties of Electric Generator for PV in eQUEST

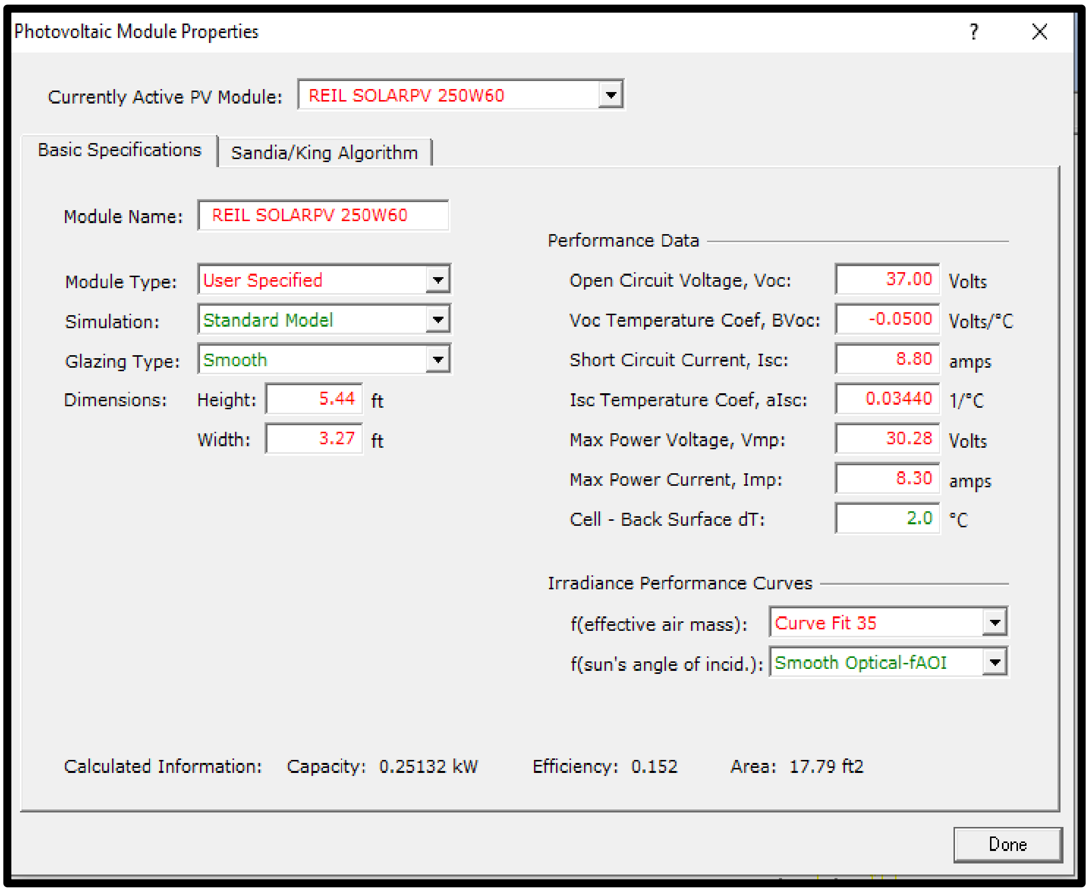


Figure 59. Properties of PV module in eQUEST

Figure 60 shows the comparison of energy consumption between the baseline design and the alternative case using the photovoltaic system. Electricity consumption is reduced by adding a Photovoltaic system from grid supply. As partial energy is being independently supplied by PV Generators which shows decrement of electricity consumption.

The total energy consumption of both cases, i.e., baseline design and alternative case of adding a photovoltaic system, are shown in Figure 61. This verifies the outcomes that electric consumption becomes less than the baseline case by adding PV.

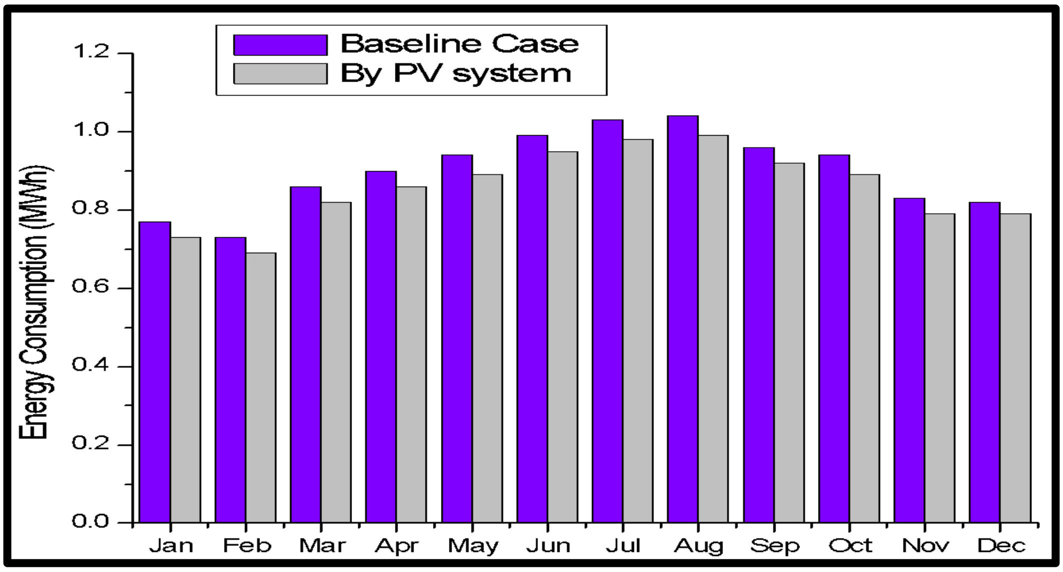


Figure 60. Comparison of Electricity Consumption for Baseline and PV

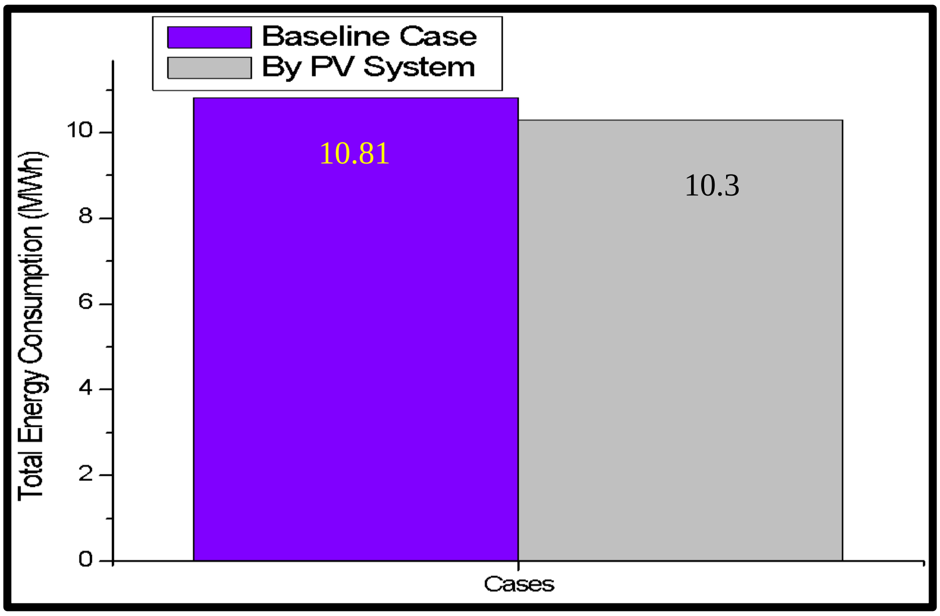


Figure 61. Total Electricity Consumption

4.3.5 Replacing Oncology 2 No's of Chillers from Electric to Absorption Chiller Type

A chiller is a source of eliminating heat from a space or process load by employing a vapor compression cycle. Ideally, the chiller comprises four primary parts: i.e., compressor, condenser, expansion valve, and evaporator. After compression, the working fluid or refrigerant is a superheated vapor condensed by condenser coils or tubes, employing air or water for cooling purposes. Absorption chillers provide an alternative to the compressor-based chillers.

The heat cycle is added in absorption chillers and replaced with a compressor. Absorption chillers employing hot water need almost temperature between 160-230 degrees F. The following points show the comparison between absorption chiller and electric chiller:

1) Absorption chillers deal with the coefficient of performance (COP) of almost 0.54–1.1, and it contends imperfectly with electric chillers (rotary compressor chillers). Contradictorily, electric chillers possess COP from 1.0 ~ 8.0.
2) Absorption chillers engage around 50% more space in an HVAC system than the comparable electric chillers (vapor compression chillers).
3) Absorption water chillers occasionally need an emergency power source if power failures are often anticipated; however, as absorption chiller takes significantly less electric energy, that is why a small back-up generator can offer for this purpose very well.
4) Absorption water chiller or lithium bromide chiller employs natural refrigerants such as water and rejects the requirement of CFC or HCFC refrigerants with high global warming tendency.

Despite several possible drawbacks of absorption chillers, they prefer compression chiller when a considerable amount of waste heat is readily obtainable. Figure 62 shows the replacement of electric chillers with absorption chillers in eQUEST.

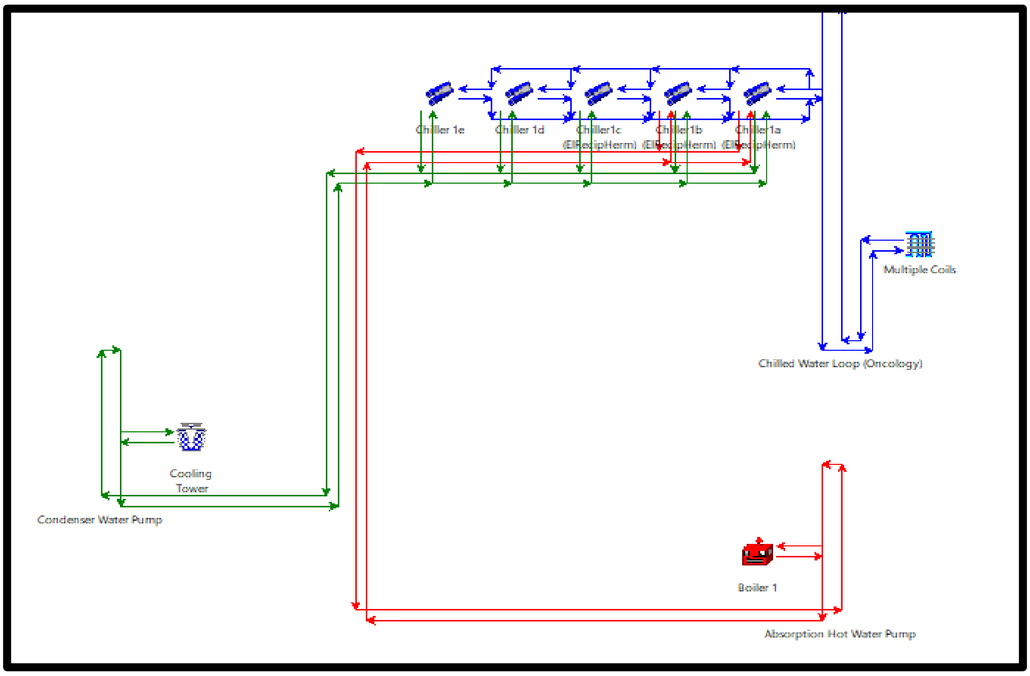


Figure 62. Single Line Diagram of Chiller 1a and 1b with Absorption Chillers

Figure 63 shows the hermetric reciprocating chiller properties.

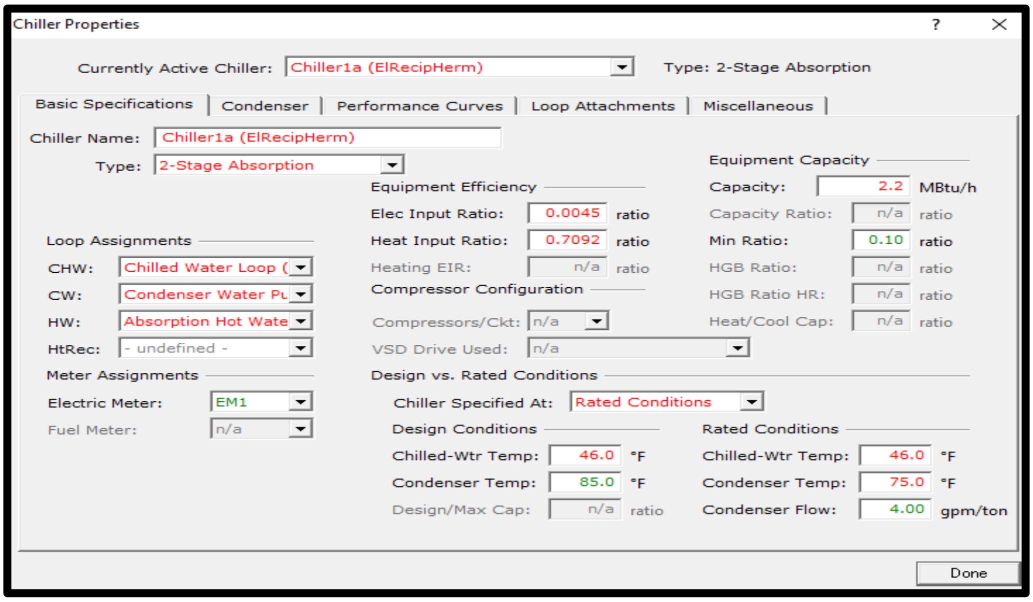


Figure 63. Chiller Properties

By replacing electric chillers with absorption chillers, electric consumption becomes greater, shown in Figure 64. Therefore, the use of electric chillers is fair and cost-effective as compared to absorption chillers. Furthermore, only an absorption chiller is not feasible and practical because of having very low COP.

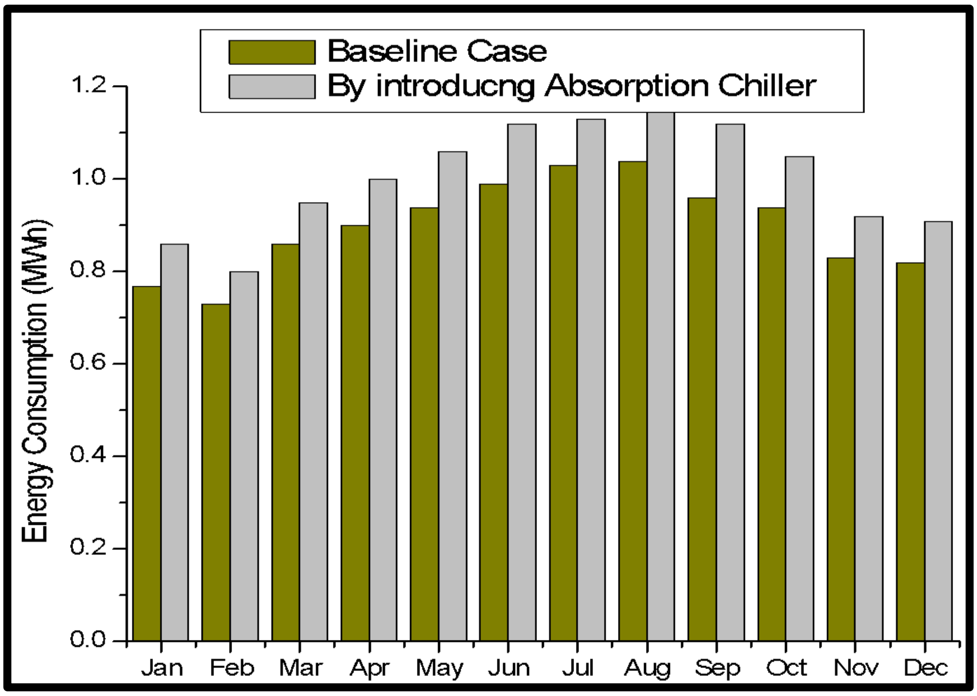


Figure 64. Comparison of Electricity Consumption for both Cases

Annually electric consumption is enhanced due to absorption chillers, shown in Figure 65.

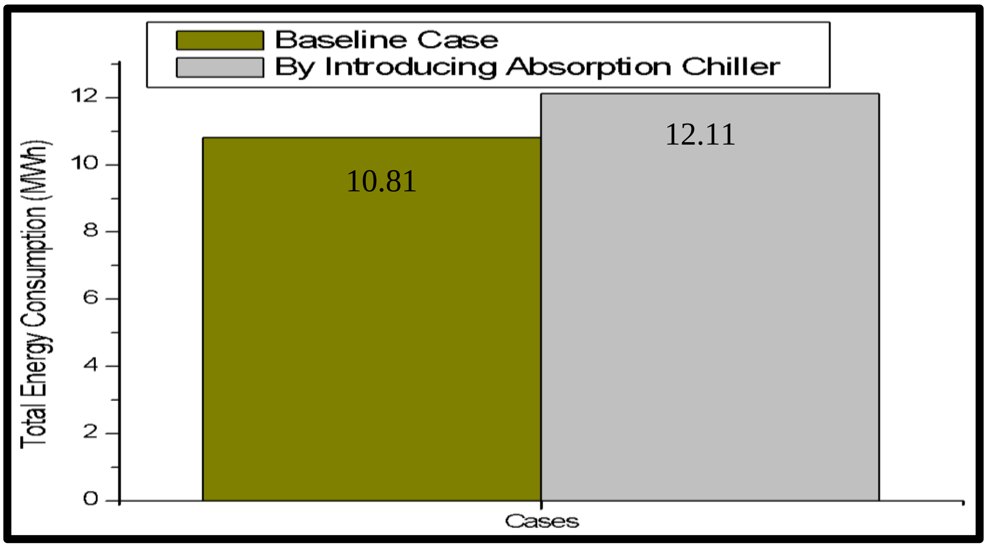


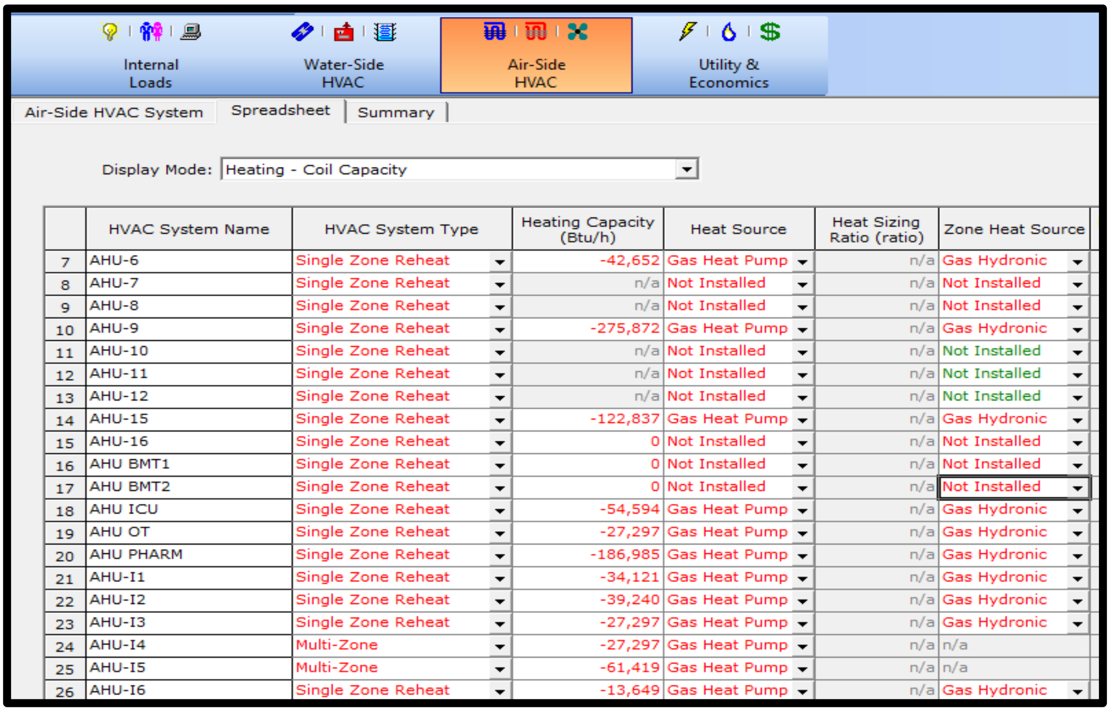
Figure 65. Overall Electricity Consumption

4.4 Altering the Electric Heaters with Heat Pumps for Space Heating

Electrical Heaters are typically 100% efficient because all of the electrical energy employed is converted into heat. Further, combustion losses and piping losses are negligible. Electrical heater efficiency is much better than the boiler. However, the heat pump's efficiency can reach as high as 350%, depending on the liquid temperature.

Due to this reason, the heat pumps are better than the heat pump. The electric heater consumes more energy to generate thermal energy than the heat pump. The installation of a heat pump provides a price benefit of almost 50%, which is greater than electric heaters. The heat pumps are more efficient and have a high capability for cost-saving.

Figure 66 shows the installation of the gas heat pump in the replacement of electric heaters.



	HVAC System Name	HVAC System Type	Heating Capacity (Btu/h)	Heat Source	Heat Sizing Ratio (ratio)	Zone Heat Source
7	AHU-6	Single Zone Reheat	-42,652	Gas Heat Pump	n/a	Gas Hydronic
8	AHU-7	Single Zone Reheat	n/a	Not Installed	n/a	Not Installed
9	AHU-8	Single Zone Reheat	n/a	Not Installed	n/a	Not Installed
10	AHU-9	Single Zone Reheat	-275,872	Gas Heat Pump	n/a	Gas Hydronic
11	AHU-10	Single Zone Reheat	n/a	Not Installed	n/a	Not Installed
12	AHU-11	Single Zone Reheat	n/a	Not Installed	n/a	Not Installed
13	AHU-12	Single Zone Reheat	n/a	Not Installed	n/a	Not Installed
14	AHU-15	Single Zone Reheat	-122,837	Gas Heat Pump	n/a	Gas Hydronic
15	AHU-16	Single Zone Reheat	0	Not Installed	n/a	Not Installed
16	AHU BMT1	Single Zone Reheat	0	Not Installed	n/a	Not Installed
17	AHU BMT2	Single Zone Reheat	0	Not Installed	n/a	Not Installed
18	AHU ICU	Single Zone Reheat	-54,594	Gas Heat Pump	n/a	Gas Hydronic
19	AHU OT	Single Zone Reheat	-27,297	Gas Heat Pump	n/a	Gas Hydronic
20	AHU PHARM	Single Zone Reheat	-186,985	Gas Heat Pump	n/a	Gas Hydronic
21	AHU-I1	Single Zone Reheat	-34,121	Gas Heat Pump	n/a	Gas Hydronic
22	AHU-I2	Single Zone Reheat	-39,240	Gas Heat Pump	n/a	Gas Hydronic
23	AHU-I3	Single Zone Reheat	-27,297	Gas Heat Pump	n/a	Gas Hydronic
24	AHU-I4	Multi-Zone	-27,297	Gas Heat Pump	n/a	n/a
25	AHU-I5	Multi-Zone	-61,419	Gas Heat Pump	n/a	n/a
26	AHU-I6	Single Zone Reheat	-13,649	Gas Heat Pump	n/a	Gas Hydronic

Figure 66. Installation of Gas Heat Pump

A comparison of electricity consumption is made with baseline design and altering the electric heaters with heat pumps for space heating, shown in Figure 67. Electricity consumption is reduced by adding heat pumps for space heating.

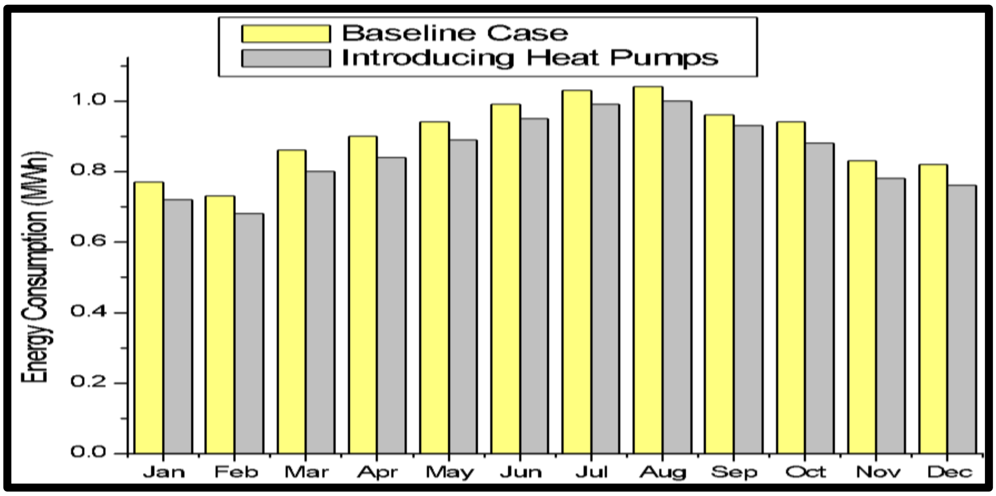


Figure 67. Comparison of Energy Consumption along Baseline and Alternative

The total energy consumption of both cases, i.e., baseline design and alternative case of altering the electric heaters with heat pumps for space heating, is shown in Figure 68. This verifies the outcomes that electric consumption becomes less than the baseline case by adding heat pumps.

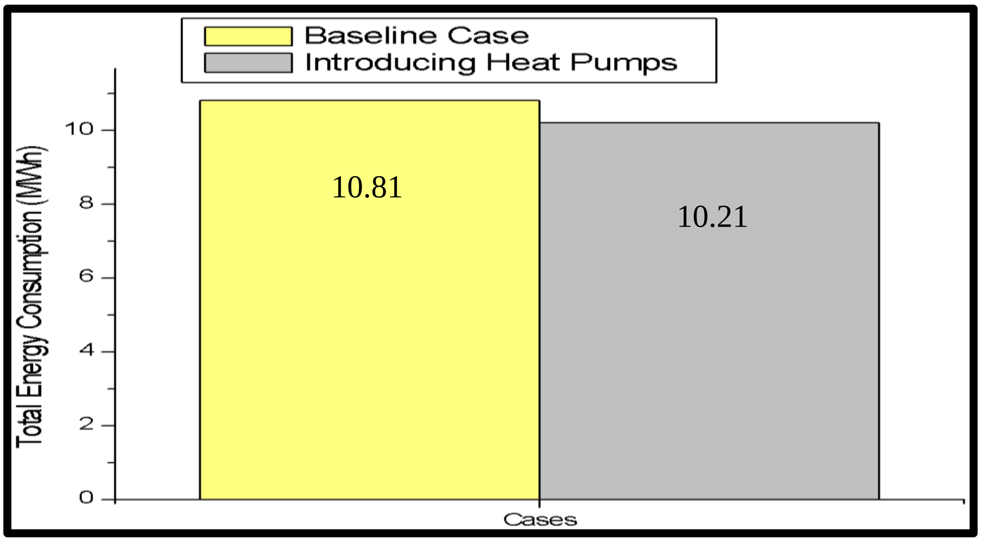


Figure 68. Total Energy Consumption along Baseline and Alternative

4.5 Installation of High-Efficiency Lights in BMT Area & Plantroom

Energy-efficient lights in the BMT area and plant room are installed. In the comparison of traditional incandescent, energy-efficient lights such as light-emitting diodes (LEDs) provide the following benefits:

1) They utilize less energy to almost 25%-80% and save more money than traditional lights.

2) These lights have a longer life of 3-25 times than traditional lights.

A brief comparison of traditional lights and energy-efficient lights is shown in the following table 9 (Williams, 2017).

Table 9. Comparisons between Traditional Incandescent, Halogen Incandescent, compact fluorescent lamps (CFLs), and LEDs

Factors	60W Traditional Incandescent	43W Energy-Saving Incandescent	15W CFL		12W LED	
			60W Traditional	43W Halogen	60W Traditional	43W Halogen
Energy $ Saved (%)	–	~25%	~75%	~65%	~75%-80%	~72%
Annual Energy Cost*	$4.80	$3.50	$1.20		$1.00	
Bulb Life	1000 hours	1000 to 3000 hours	10,000 hours		25,000 hours	

Figure 69 shows the lighting power density in BMT and plant rooms.

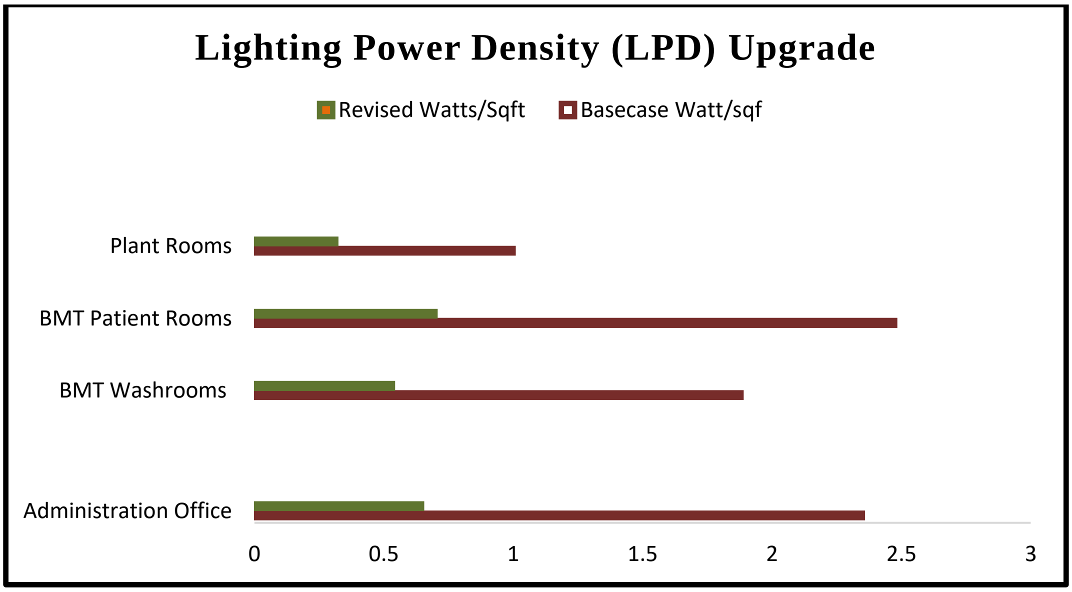


Figure 69. Lighting Power Density (LPD) Upgrade in BMT & Plant Rooms

A comparison of electricity consumption is made with baseline design and energy-efficient LEDs, shown in Figure 70. Electricity consumption is reduced by installing energy, efficient lights.

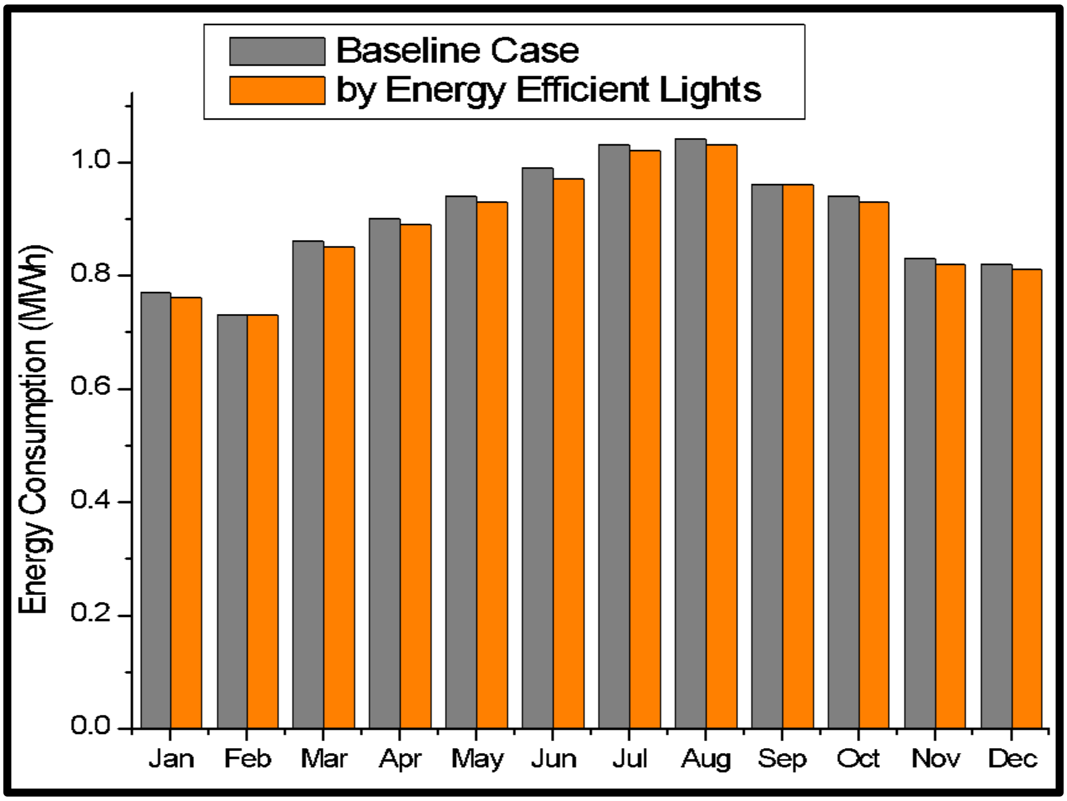


Figure 70. Comparison of Energy Consumption by Base Case and Energy-Efficient Lights

The total energy consumption of both cases, i.e., baseline design and alternative case, is shown in Figure 71. This verifies the outcomes that electric consumption becomes less than the baseline case by installing energy-efficient lights.

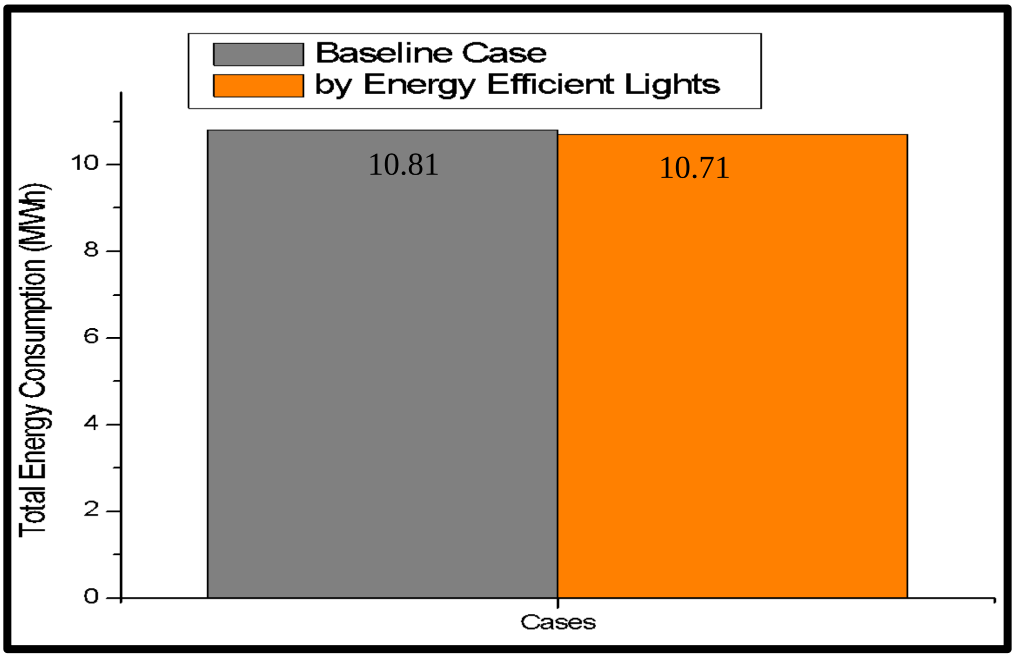


Figure 71. Comparison of total energy consumption

4.6 SOFC-CHP System Implementation

The SOFC-CHP system comprises SOFC stacks having natural gas. This system generates electricity and yields space heating from the exhaust gas waste thermal energy present in the heating system's boiler hot water loop. The natural gas-fired boilers will get functional when exhaust heat from the SOFC stack is not enough to sustain the hot water loop temperature.

The SOFC stack is mentioned in eQUEST by employing a generic electric generator unit. In this program, there is no specific fuel cell model available. The part-load heat input ratio (HIR) is utilized to introduce fuel consumption of the SOFC stack. This HIR is defined in terms of the ratio between designed system fuel consumption at the higher heating value (HHV) and the designed output electrical power. The component tree of integrating SOFC into the model is shown in Figure 72.

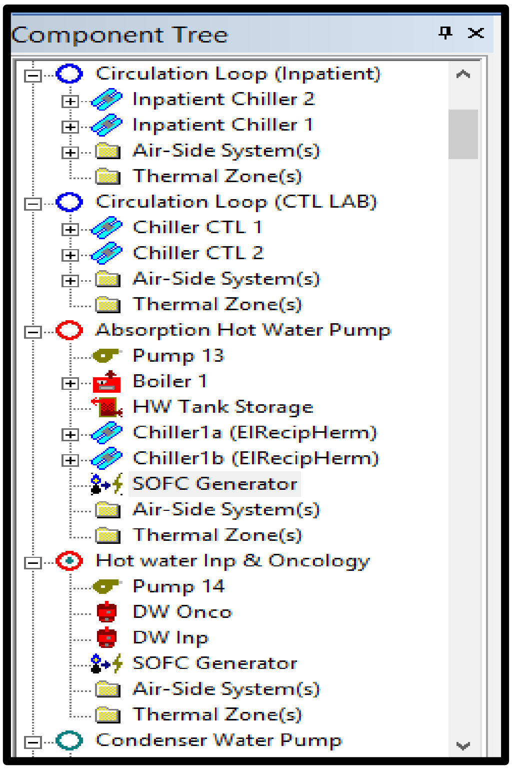


Figure 72. Component Tree for Hospital HVAC System with SOFC Generator

ELEC-GENERATOR has its performance characteristics and specifications in eQUEST. The capacity of the generator is accepted in kW in this software. Here, the capacity of the electric generator is taken as 200kW.

The type of generator is an engine-driven generator. The entry of minimum ratio elaborates the ratio of the minimum possible output to the hourly operating capacity. Figure 73 shows the electric generator properties in eQUEST.

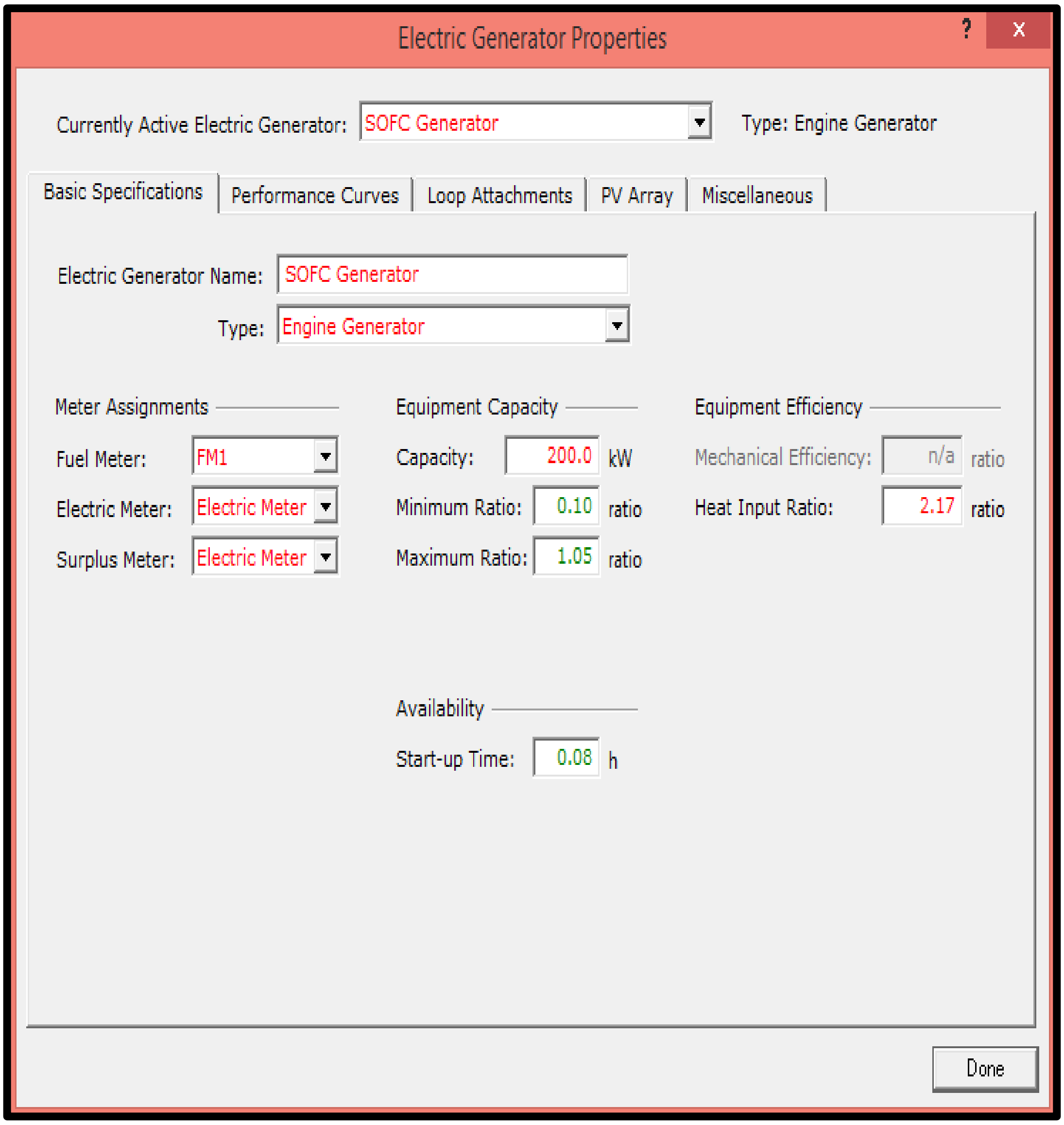


Figure 73. Properties of Electric Generator in eQUEST

Moreover, an electric meter is a meter attached to the end-user site and provides information about energy consumption and demand for the consumer associated with it. Further, a utility rate schedule can also associate with the meter so that the ECONOMICS program can calculate the energy cost.

There are three meters, i.e., UTILITY, BUILDING, and SUB-METER. These meters belong to three different stages; UTILITY is considered the highest one, BUILDING being the middle, and SUB-METER is on the lowest level.

There is also another meter type that is ELECTRIC-SALE METER. This meter gets the output of electric generators in the form of electricity sale to a utility. Two alternatives are simulated with baseline cases which are

1) Installation of Solid Oxide Fuel Cell with Hospital HVAC System -Electric + Absorption Chillers
2) Installation of Solid Oxide Fuel Cell with Hospital HVAC System -Electric Chillers

4.6.1 Installation of Solid Oxide Fuel Cell with Hospital HVAC System -Electric + Absorption Chillers

Each chiller relies on some external force from a low temperature to transfer heat to a high-temperature medium. Electric chillers, for example, have compressors. Absorption chillers substitute steam, hot water, or some other external source of heat for the compressor. Absorption chillers rely on heat energy to chill water, making a perfect mix with CHP systems. Combining a cooling absorption device with a SOFC cogeneration plant allows excess heat to be used. Hot water is produced by the plant, which in turn drives the absorption chiller.

This section deals with the technical characteristics of SOFC-CHP building installations. The integration of SOFC-CHP/CCHP systems within the building needs networking with the building HVAC models.

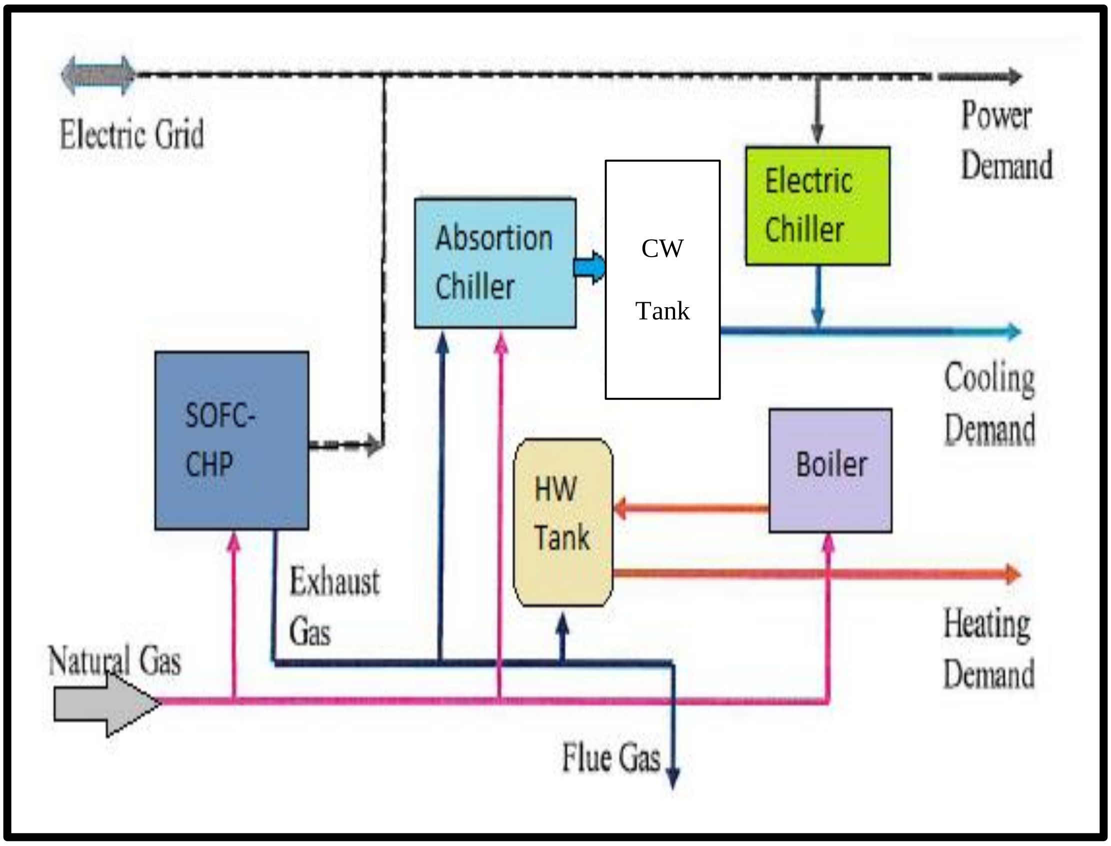


Figure 74. Schematic diagram of SOFC-CHP System with Electric and Absorption Chiller (Abdulla Alns and Ahmad K. Sleiti, 2020, Accepted)

Even though SOFC systems show high electrical performance, nearly half of the fuel energy is transformed to heat. The SOFC high-temperature heat can be utilized as the fundamental thermal energy source to reserve cooling or heating or generate extra energy. In this research, the fuel cell's waste heat is utilized by an absorption chiller to supply cooling to meet the cooling demand.

Preliminary outcomes from the dynamic system of the SOFC represent that the SOFC exhaust keeps adequate quality heat to employ in an absorption chiller.

Sometimes, the cogeneration system cannot meet the building's actual demand and cooling supply, so additional electrical chillers or utility power may have to be utilized to supply during peak hours.

For this case, out of five oncology electric chiller, Chiller 1a and 1b were replaced with a two-stage absorption chiller with a water-cooled condenser.

Three water loops are attached to the system, which is (1) Absorption hot water loop (assigned for the absorption chiller), (2) condenser water loop, (3) chilled water loop. Installation of SOFC by using electric chillers and absorption chillers is presented based on the following aspects:

1) The efficiency of electric chillers is high, so they furnish most of the cooling energy
2) SOFC exhaust thermal energy is employed to operate the absorption chiller to furnish extensive cooling energy.

As for hospital end-uses other than domestic hot water, a more heating load requirement was observed, including room space heating. This case can optimize the usage of the SOFC system as it utilizes the thermal energy available at the exhaust of the SOFC Generator, which will be fed to the absorption Chiller generator as well to the Domestic hot water loop (Inpatient and Oncology). The Model Drawn of Case-1 for the SOFC Generator along with Oncology Electric Chillers +Absorption Chiller is shown in Figure 75.

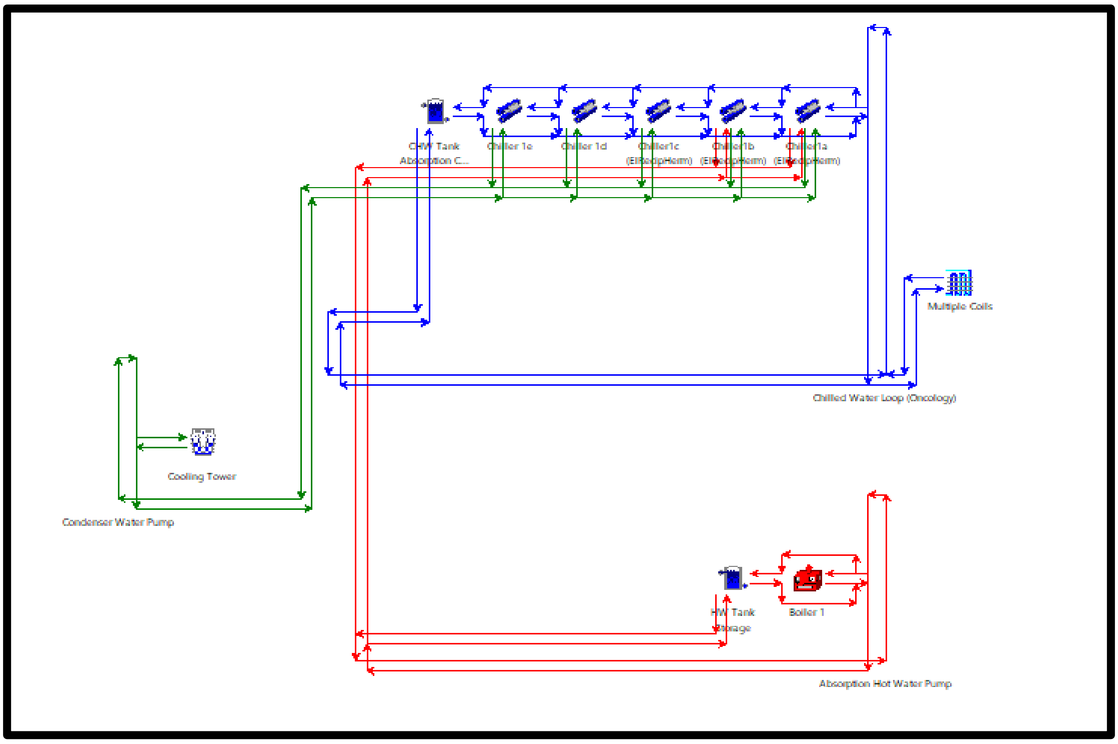


Figure 75. SOFC Generator along with Oncology Electric Chillers +Absorption Chiller

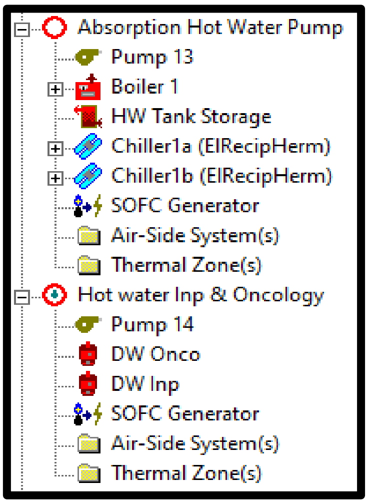


Figure 76. Component Tree Oncology Electric Chillers +Absorption Chiller

Besides, Hot water outputs from the storage will be attached to Domestic Hot water used for oncology and inpatient Areas. In contrast, the Chilled Water tank is attached to store excessive Cooling Energy released from this efficient integrated system. It can be used to expand and supply additional cooling load requirements inside hospital spaces. Graphical results of electric and gas consumption are shown in Figures 77 and 78.

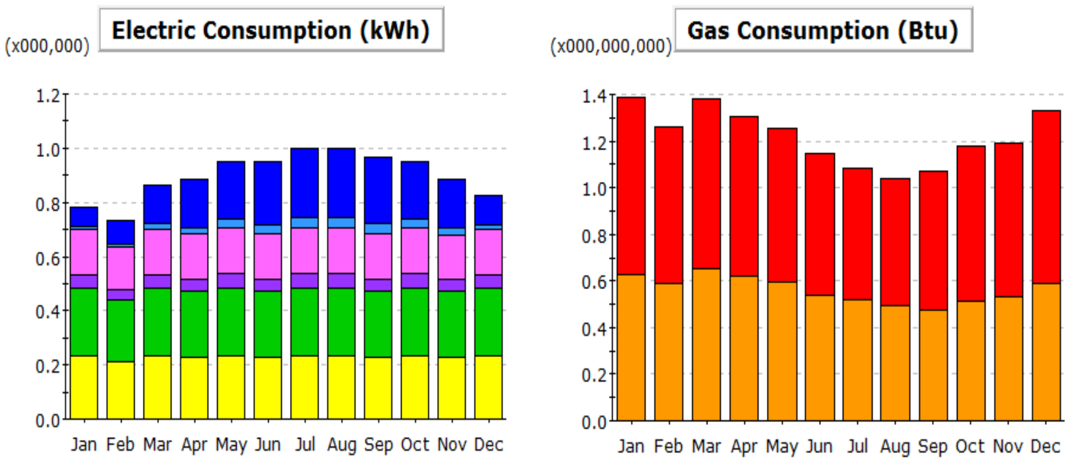


Figure 77. Monthly Electricity Consumption & Monthly Gas consumption of SOFC-CHP System

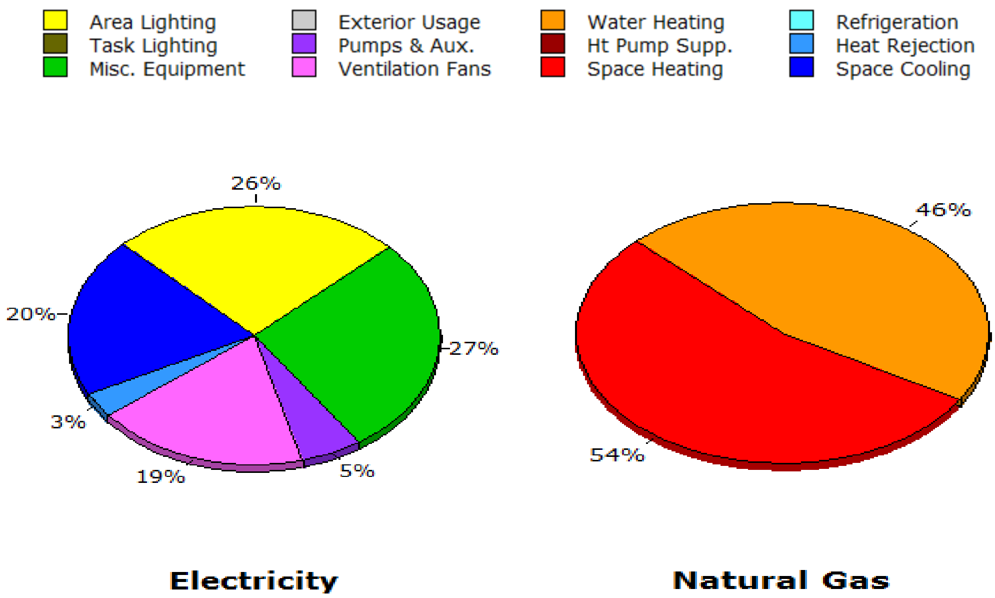


Figure 78. Annual (a) Electricity consumption by End-use (b) Gas consumption of SOFC-CHP System

4.6.2 Installation of Solid Oxide Fuel Cell with Hospital HVAC System -Electric Chillers

In this case, one medium electric chiller is taken in eQuest. Two loops of water are attached to the electric chiller, the condenser water loop, and the chilled water loop. A cooling tower circulates the condenser water loop to furnish condensing purposes; the chiller water loop is directed to the cooling coils to furnish space cooling as per the requirement of each zone. Electric chillers have greater efficiency so they can provide most of the cooling energy.

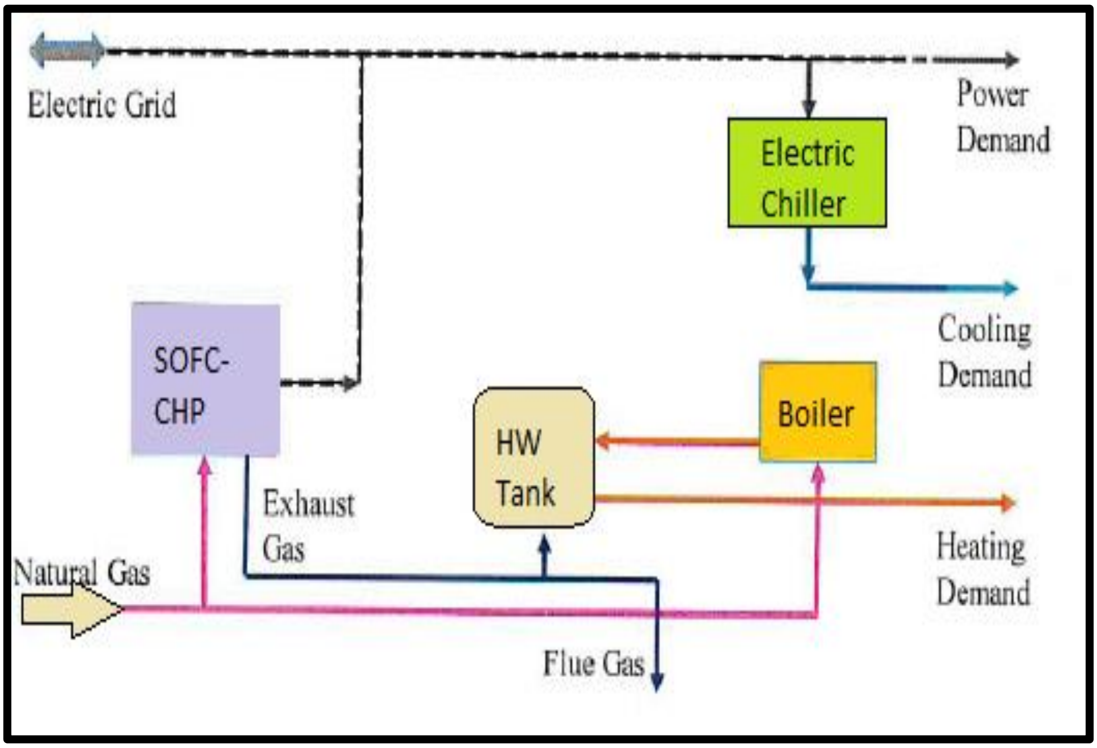


Figure 79. Schematic diagram of SOFC-CHP System with Electric Chiller (Abdulla Alns and Ahmad K. Sleiti, 2020)

Utilizing a cogeneration plant of combined heat and power (CHP) in a hospital is optimal for attaining an energy-efficient system by reducing carbon dioxide emissions. It helps in saving the limited resources of the hospital. CHP plant corporates with the use of high-efficiency natural gas as a fuel by regenerating electricity and heat.

4.7 CO2 Emissions

Another technique of energy production adapted to Qatar's cancer hospital building is primarily utilizing SOFC-CHP system for space heating, domestic hot water and employing electricity for lighting, cooling, and equipment. This study shows that the annual amount of air pollution due to energy consumption under the traditional method in a commercial building, which supplies both SOFC-CHP and electricity to the building, was compared with the annual amount of air pollution referable to supplying only electricity. The outcomes revealed that the building using only electricity emits much more air pollution than the building using electricity and the SOFC-CHP system.

In order to analyze the value of the reduction of CO2 emissions by the SOFC-CHP system, a comparison is made for the base case and SOFC-CHP case. The emissions of CO_2 linked with consumption of electricity from the utility is attained (Ayoub et al., 2014).This shows the value of 1.89 kg-CO2/kWh. Moreover, CO_2 emissions may also be attained by utilizing the concept of (Naimaster & Sleiti, 2013). In section 5.3, further detailed calculations have been done.

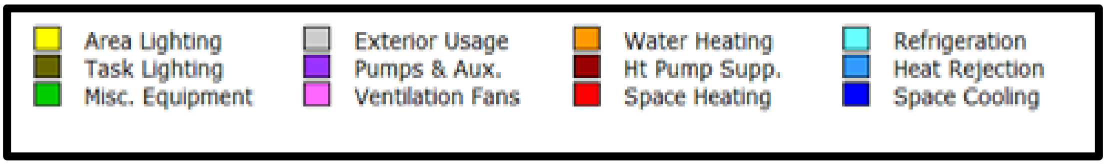
5.1 Analyzing Base case Graphical Reports

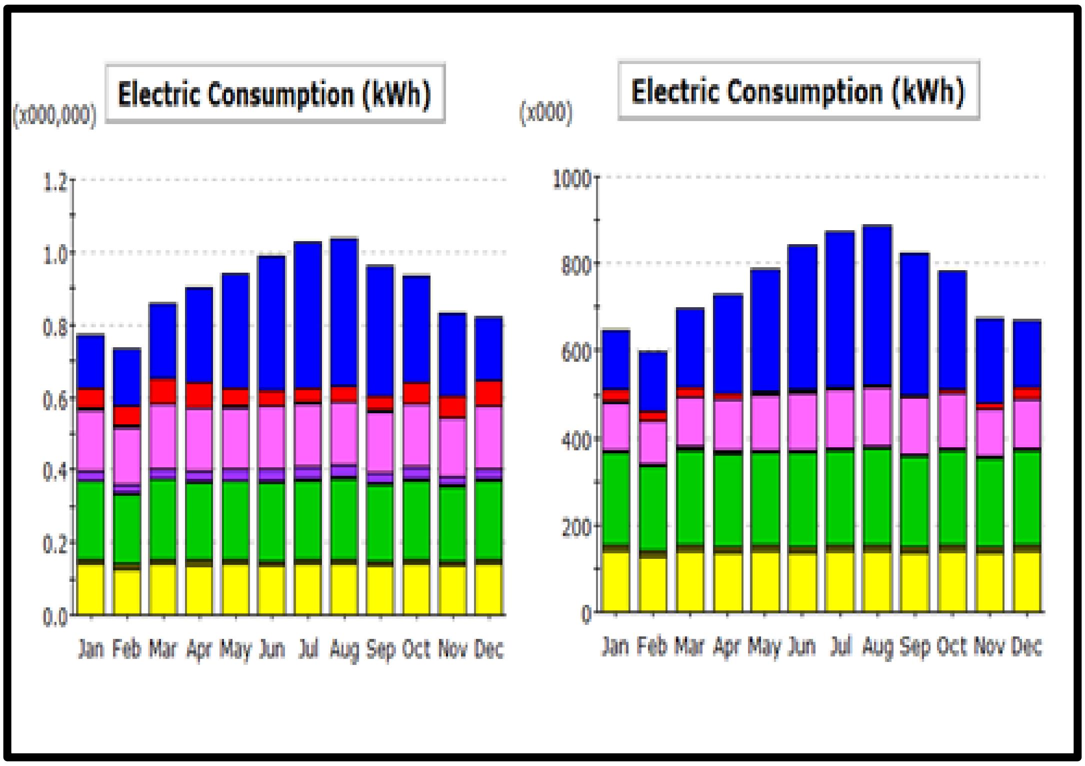
To have better insight, a graphical representation of the base case, along with each alternative, is given in this section.

5.1.1 Monthly Consumption by End-Use

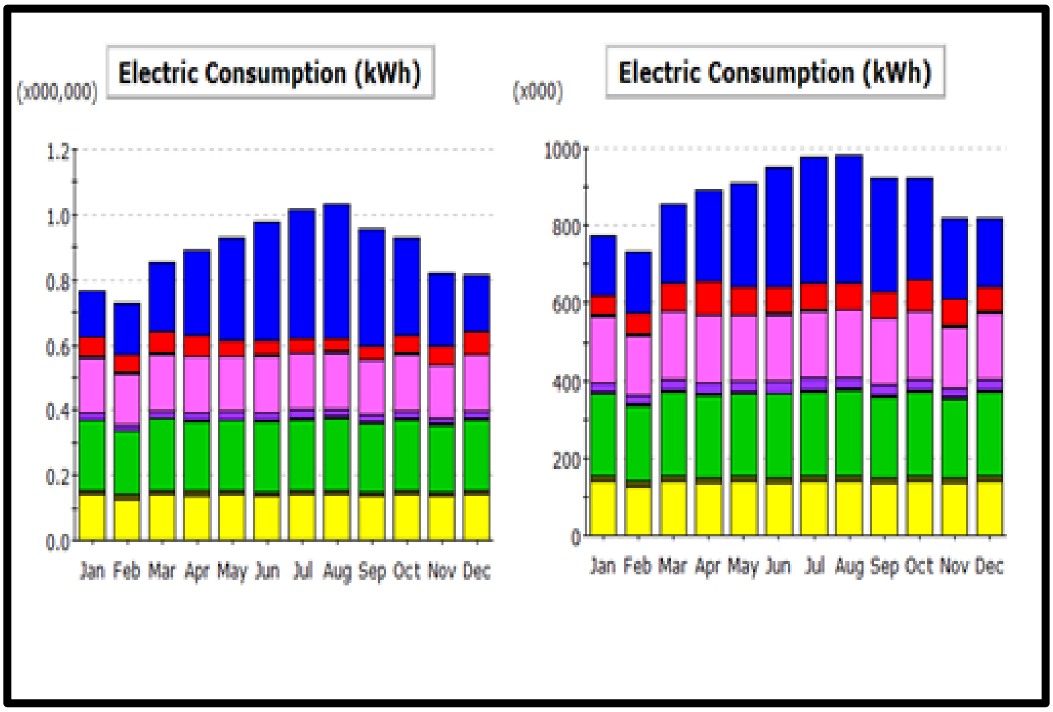
The monthly consumption of each alternative by the end-user is represented in Figures 80 and 81.

This given legend is common for all mentioned graphs below.



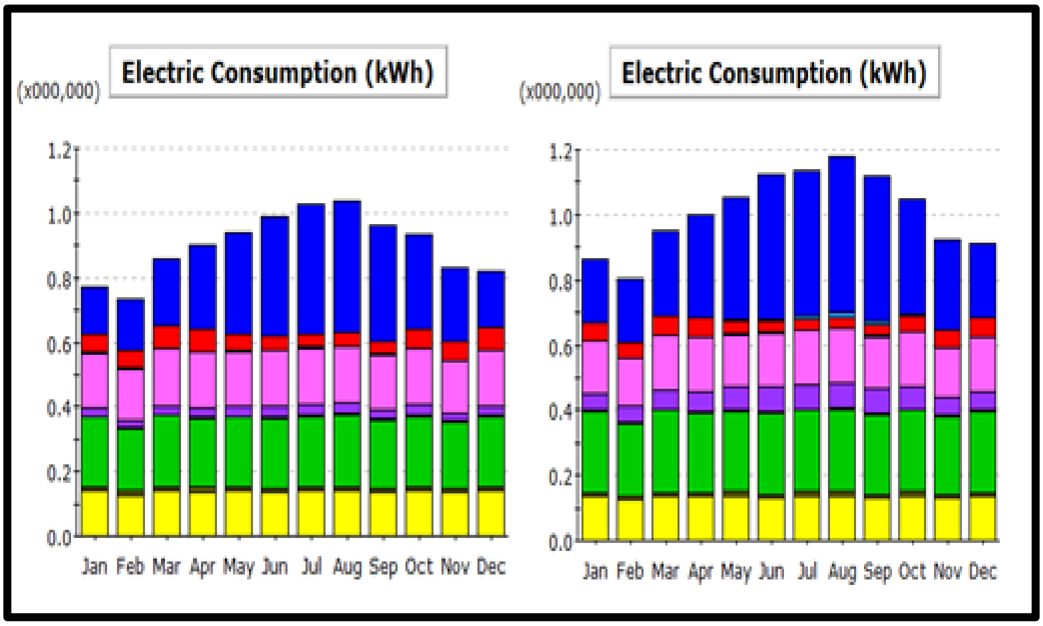


(a) (b)

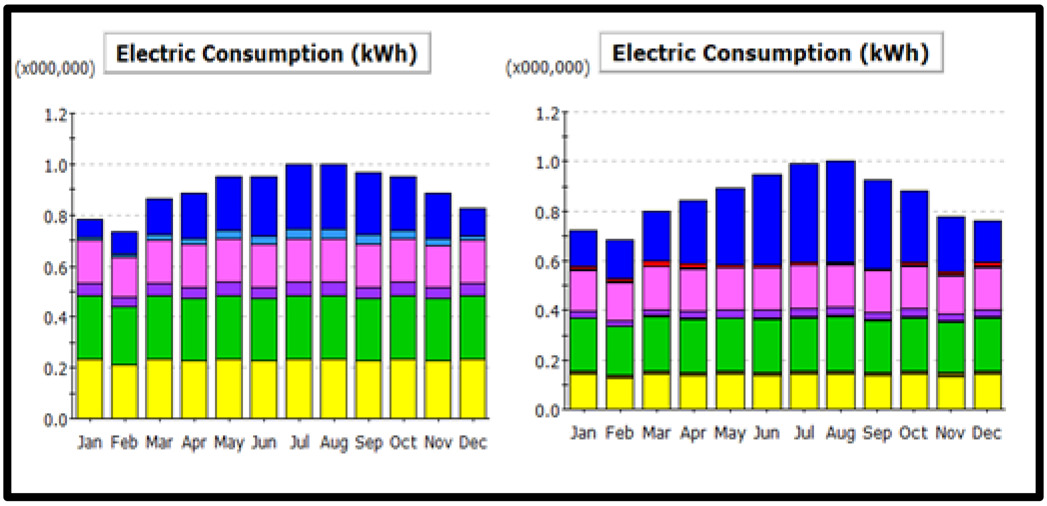


(c) (d)

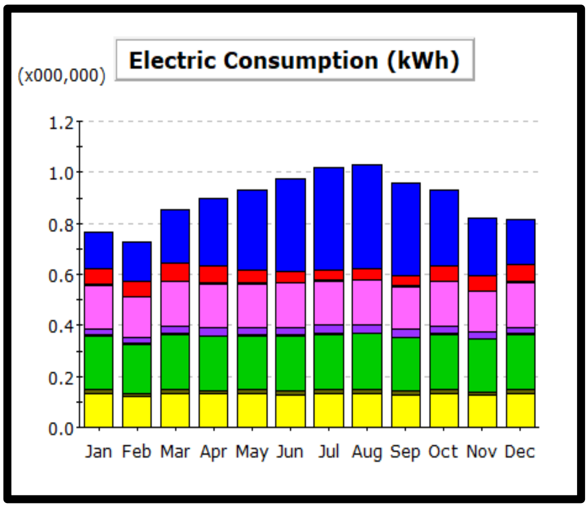
Figure 80. Monthly Energy Consumption for (a) Baseline Case (b) for High Efficiency Package VAV (c) Applying VFD (d) Energy Consumption by Additional Insulation



(a) (b)



(c) (d)

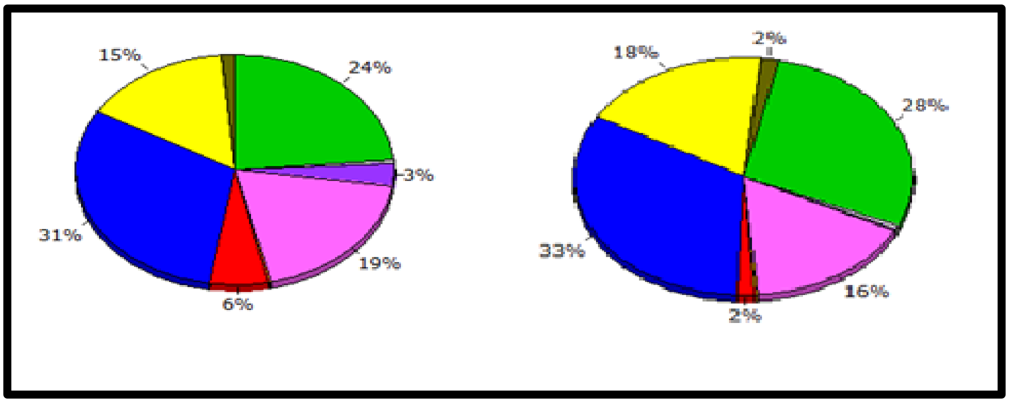


(e)

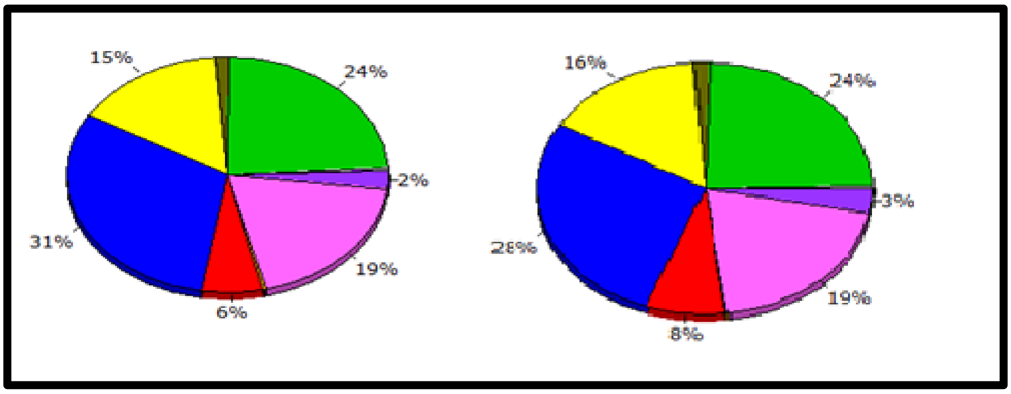
Figure 81. Monthly Energy Consumption (a) using Photovoltaic (b) by Replacing Electric Chillers into Absorption Chillers (c) by SOFC (d) by Replacing Electric heaters with Gas Heat Pump (e) by Installation of Energy Efficient Lights

5.1.2 Annual Energy Consumption by End Use

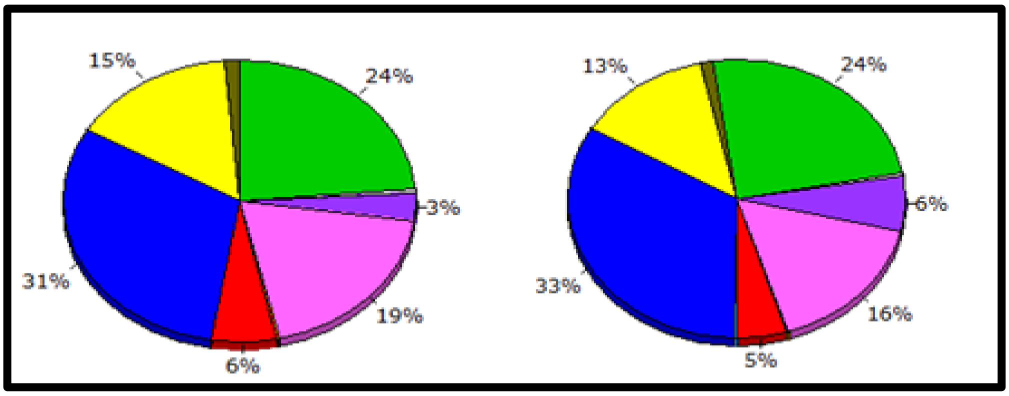
This section shows the annual energy consumption of Cancer Hospital for each alternative along with base case.



(a) (b)

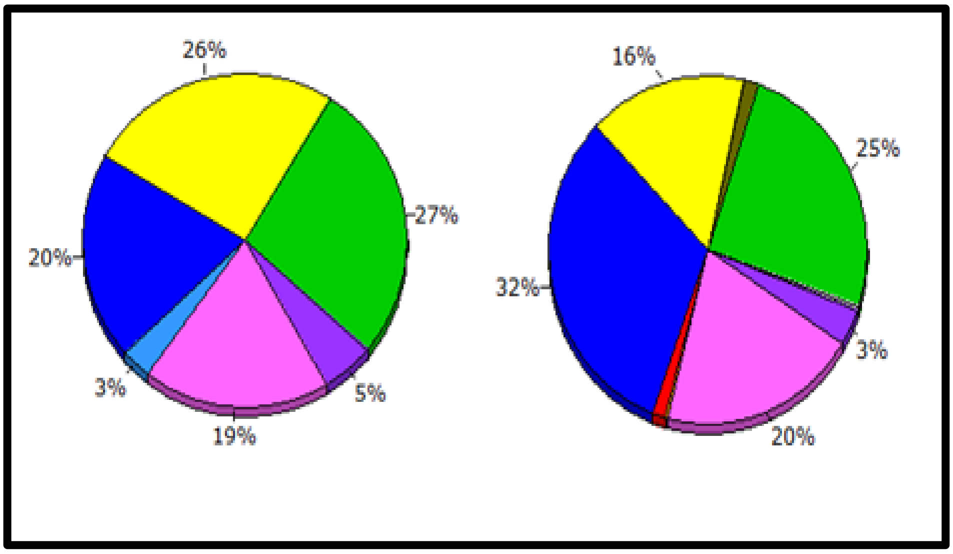


(c) (d)

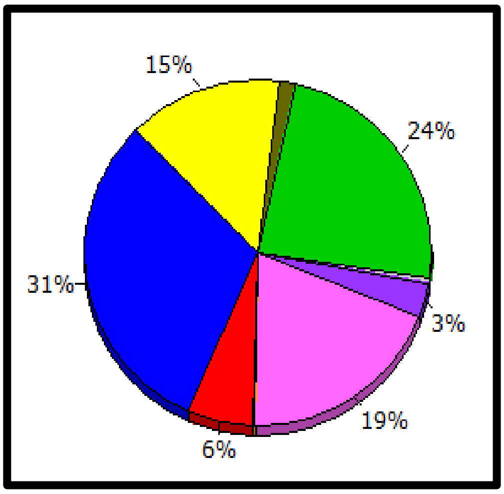


(e) (f)

Figure 82. Annual Energy Consumption for (a) Baseline Case (b) for High Efficiency Package VAV (c) applying VFD (d) Energy Consumption by Additional Insulation (e) using Photovoltaic (f) by Replacing Electric Chillers into Absorption Chillers



(a) (b)

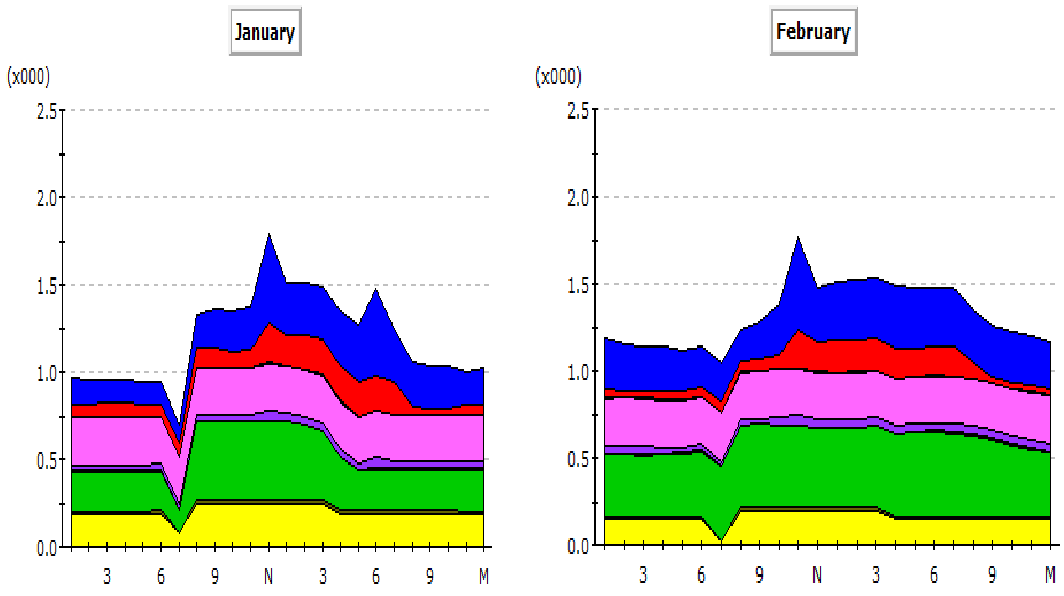


(c)

Figure 83. Annual Energy Consumption (a) by SOFC (b) by Replacing Electric Heaters with Gas Heat Pump (c) by Installation of Energy Efficient Lights

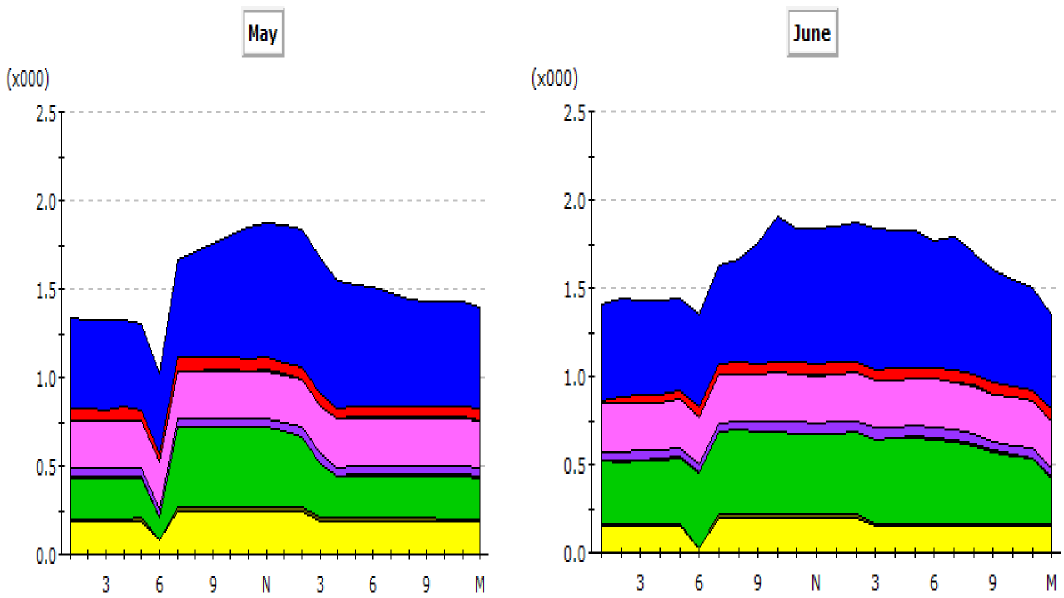
5.1.3 Monthly Peak Day Electric Load Profiles

A load profile shows the graphical representation in the variation of electrical load and time. Monthly peak day load profiles for different months are shown in Figure 84.



(a) (b)

Figure 84. Peak Day Load Profile in (a) January (b) February for Base Case



(a) (b)

Figure 85. Peak Day Load Profile in (a) May (b) June for Base Case

5.1.4 Utility Bill Analysis

This section shows the cost analysis for each case. This represents that base line scenario yields a larger utility bill as compared to other alternatives. By introducing additional insulation yield less utility bill and saves more money for the hospital building.

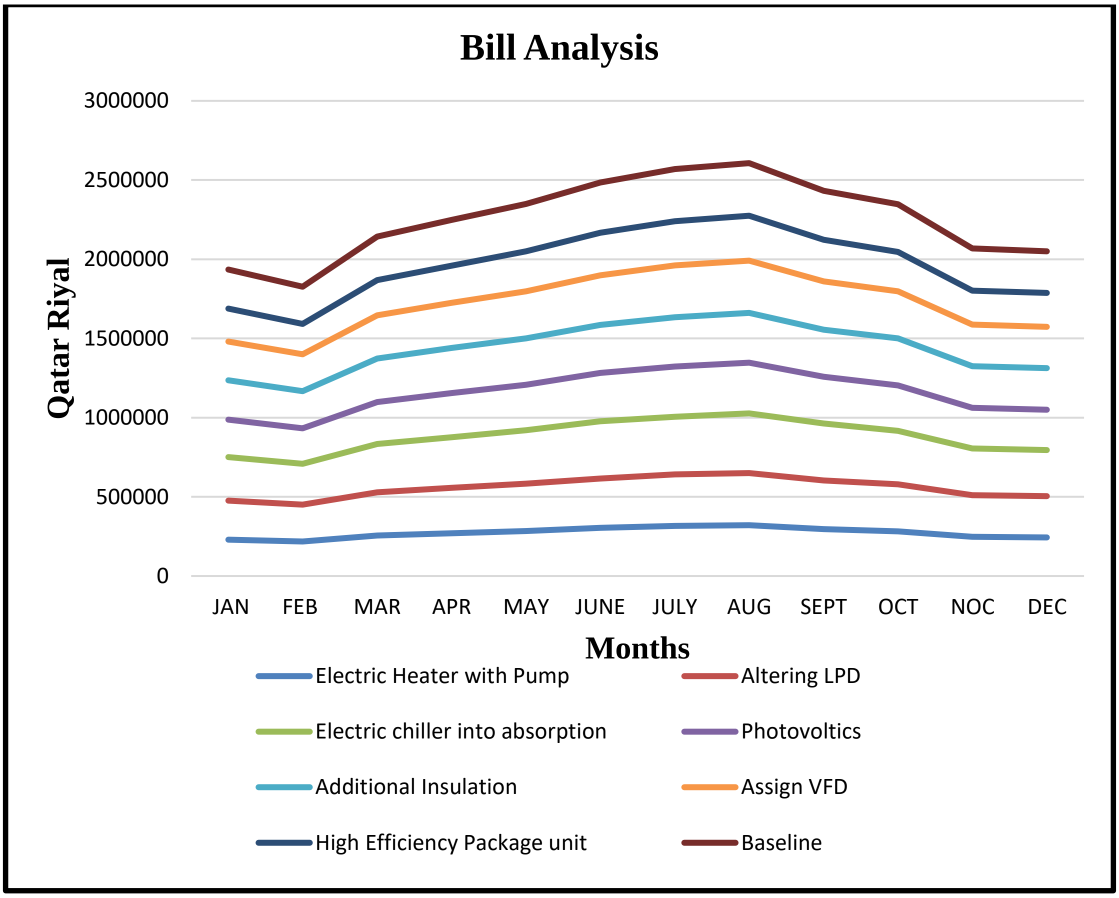


Figure 86. Annual Tariff Rates Comparison for Each Alternative

5.2 SOFC-CHP System Case

5.2.1 Effect on Overall Energy Consumption

From the analysis of the results from eQuest Software building Energy performance, SOFC and base-case results are shown in Figures 87 and Figure 88.

Sofc Testing DOE-2.2-50a 9/29/2020 12:36:23 BDL RUN 2

REPORT- BEPU Building Utility Performance WEATHER FILE- EPW ABU DHABI,-,ARE

	LIGHTS	TASK LIGHTS	MISC EQUIP	SPACE HEATING	SPACE COOLING	HEAT REJECT	PUMPS & AUX	VENT FANS	REFRIG DISPLAY	HT PUMP SUPPLEM	DOMEST HOT WTR	EXT USAGE	TOTAL
EM1 ELECTRICITY													
KWH	2759430.	0.	2956527.	0.	2169398.	330837.	565167.	2003292.	0.	0.	0.	0.	10784661.
FM1 NATURAL-GAS													
THERM	0.	0.	0.	78941.	0.	0.	0.	0.	0.	0.	67347.	0.	146288.

TOTAL ELECTRICITY 10784661. KWH 43.138 KWH /SQFT-YR GROSS-AREA 43.138 KWH /SQFT-YR NET-AREA
TOTAL NATURAL-GAS 146288. THERM 0.585 THERM /SQFT-YR GROSS-AREA 0.585 THERM /SQFT-YR NET-AREA

Figure 87. Overall Building Utility Performance Analysis with SOFC-CHP System

Cancer Hospital DOE-2.2-50a 9/29/2020 13:06:36 BDL RUN 1

REPORT- BEPU Building Utility Performance WEATHER FILE- EPW ABU DHABI,-,ARE

	LIGHTS	TASK LIGHTS	MISC EQUIP	SPACE HEATING	SPACE COOLING	HEAT REJECT	PUMPS & AUX	VENT FANS	REFRIG DISPLAY	HT PUMP SUPPLEM	DOMEST HOT WTR	EXT USAGE	TOTAL
EM1 ELECTRICITY													
KWH	1658564.	152668.	2556372.	650827.	3327625.	0.	340403.	2048727.	0.	0.	24407.	47450.	10807044.
FM1 NATURAL-GAS													
THERM	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.	0.

TOTAL ELECTRICITY 10807044. KWH 61.809 KWH /SQFT-YR GROSS-AREA 61.809 KWH /SQFT-YR NET-AREA

Figure 88. Baseline Results

It can be clearly analyzed from the Results that Space Heating and Domestic Hot water consumption (KWH) has been fulfilled through SOFC Generator Powered by Natural Gas, which results in the reduction of overall kWh from 10.81MW TO 10.78MW. While as per the base case, the kWh/sqft reduces from 61.8 to 43.18kWh/sqft. Reduction appears because the thermal energy is being supplied from the SOFC in the simulation model through the SOFC Generator. Apart from heating, the SOFC–CGS deals with providing electricity and hot water to the cancer hospital. This results in the reduction of greenhouse gas emissions (CO_2, CH_4, NO_x).

Moreover, the following are advantages of using SOFC-CHP systems for Hospital:

1) An energy-efficient system helps in energy savings, and these savings can be used to treat cancer patients and their financial support
2) Savings of financial resources on an annual basis
3) It benefits in reducing carbon emissions in terms of environmental and economic outcomes.
4) It provides Flexibility in generating electricity, heating, and cooling implemented through several techniques

5.3 CO2 Emission Analysis

Annual carbon dioxide (CO_2) emissions of Qatar, as of 2018, is measured in 100 million tons per year. Each country has a share of global carbon dioxide (CO_2) emissions. This share is measured as each country's emissions are divided by the sum of all countries' emissions in a given year and 'statistical differences' in carbon accounts. This interactive chart in Figure 89 shows Qatar's annual emissions as a percentage of the global total in a given year.

When regulating targets, measure, or analyze CO2 emissions, they mainly concentrate on production-based CO_2 emissions emitted within a country. Consumption-based CO_2 emissions can be estimated by correcting for trade. These production-based and consumption-based emissions are shown in Figure 90 (Roser, n.d.).

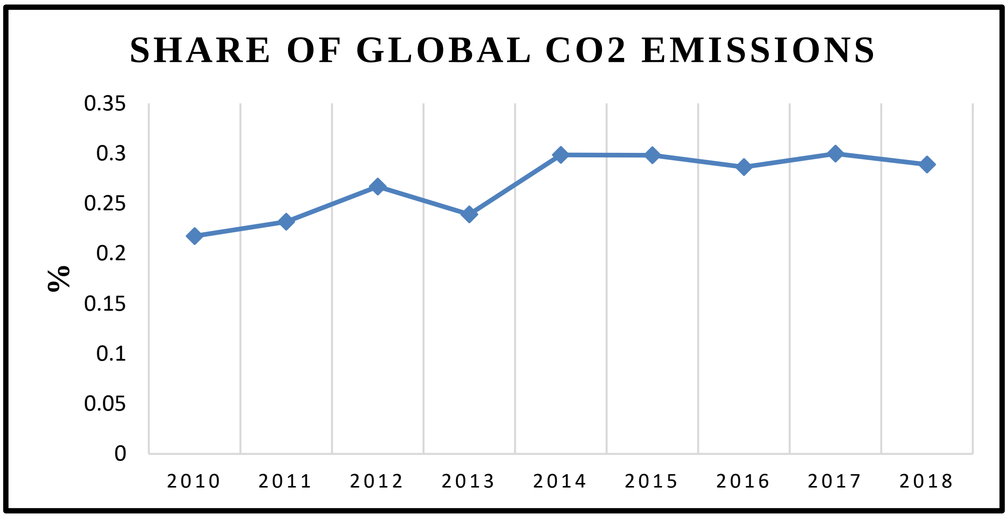


Figure 89. Annual Share of Global CO_2 Emissions (Roser, n.d.)

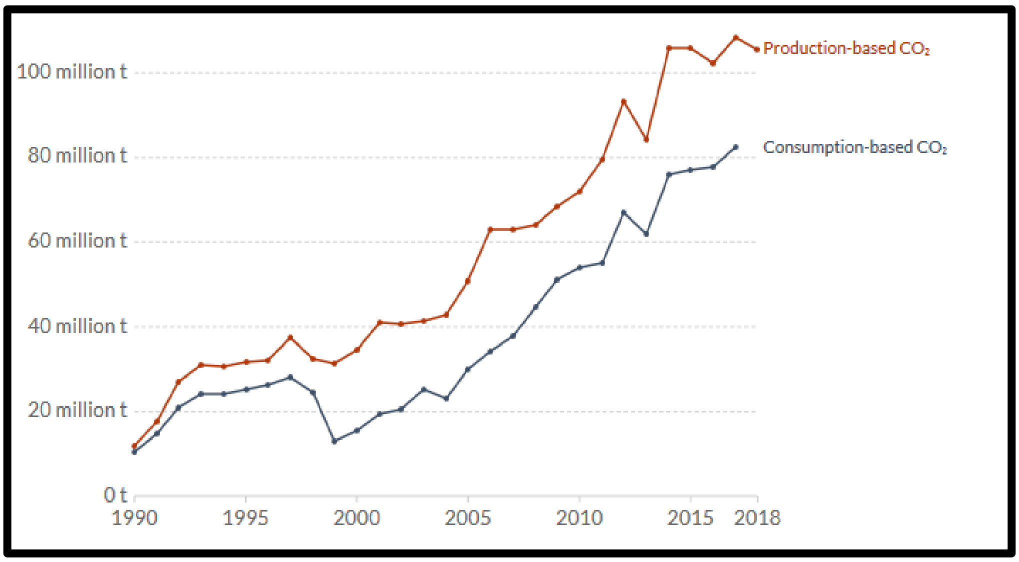


Figure 90. Production Vs. Consumption-Based CO_2 Emissions, Qatar (Roser, n.d.)

Consumption-based CO_2 emissions from 2010 to 2017 are shown in Figure 91. We have used the numeric value of CO_2 emission of 2016, i.e., 77.93million tons. This value of million ton is converted into kilograms.

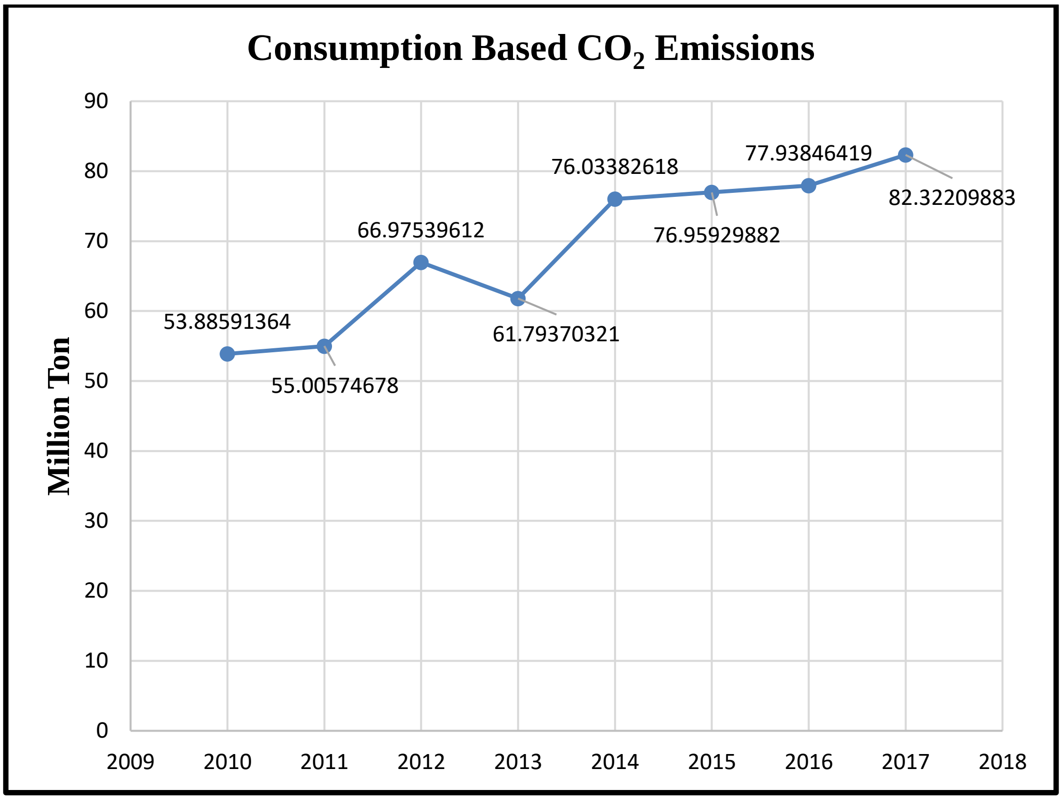


Figure 91. Consumption Based CO_2 Emissions, Qatar (Roser, n.d.)

CO_2 emission for base-case and all other alternatives is calculated by considering research works, as mentioned in the above section. The table shows the electricity consumption for each option, and the Co2 emission coefficient is computed using the equation as given below:

$$Emission\ factor = \frac{kgCo2}{Qatar\ Electricity\ Consumption\ (kWh)}$$

By converting 77.93million tons into kilograms, 70704585200kg is attained. Electricity consumption of Qatar in 201 was 37.24 billion kWh (Roser, n.d.). So, emission factor would be,

$$Emission\ factor = \frac{70,704,585,200}{37,240,000,000} = 1.898$$

CO_2 emission per year for each case is calculated by

$$= Emission\ factor * \ Total\ Electricity\ Consumption\ (kWh)$$

A comparison for each alternative with the base scenario can be seen from the Table 10.

Table 10. CO_2 Emission of Base case vs Alternatives

Alternatives	Total kWh Consumed	Emission in kgC02/kwh	kg/CO2/Year	mtCO2/Country
Base Case	10807044	1.89	20425313.16	20425.31316
Assign High Efficiency Package Vav	9003024	1.89	17015715.36	17015.71536
Assign VFD for Chilled Water Pumps	10701527	1.89	20225886.03	20225.88603
Assign Additional Insulation for Roof & External walls	10559329	1.89	19957131.81	19957.13181
Setting up Photovoltaics	10385584	1.89	19628753.76	19628.75376
Replacing Electric Chillers into Absorption Chiller	12105522	1.89	22879436.58	22879.43658
Applying SOFC for Oncology Chillers (Electric+ Absorption Type)	10784661	1.89	20383009.29	20383.00929
Lighting Power Density Change in BMT and Plantroom	10708400	1.89	20238876	20238.876
Replacing AHU Electric Heaters with Gas Heat Pump and Gas Hydronic	10214181	1.89	19304802.09	19304.80209

A complete comparison for the emission of CO2 for the base case and other alternatives is shown in the figure. Figure 92 shows that the alternative of intruding absorption chiller yields a more massive CO2 emission than other alternatives.

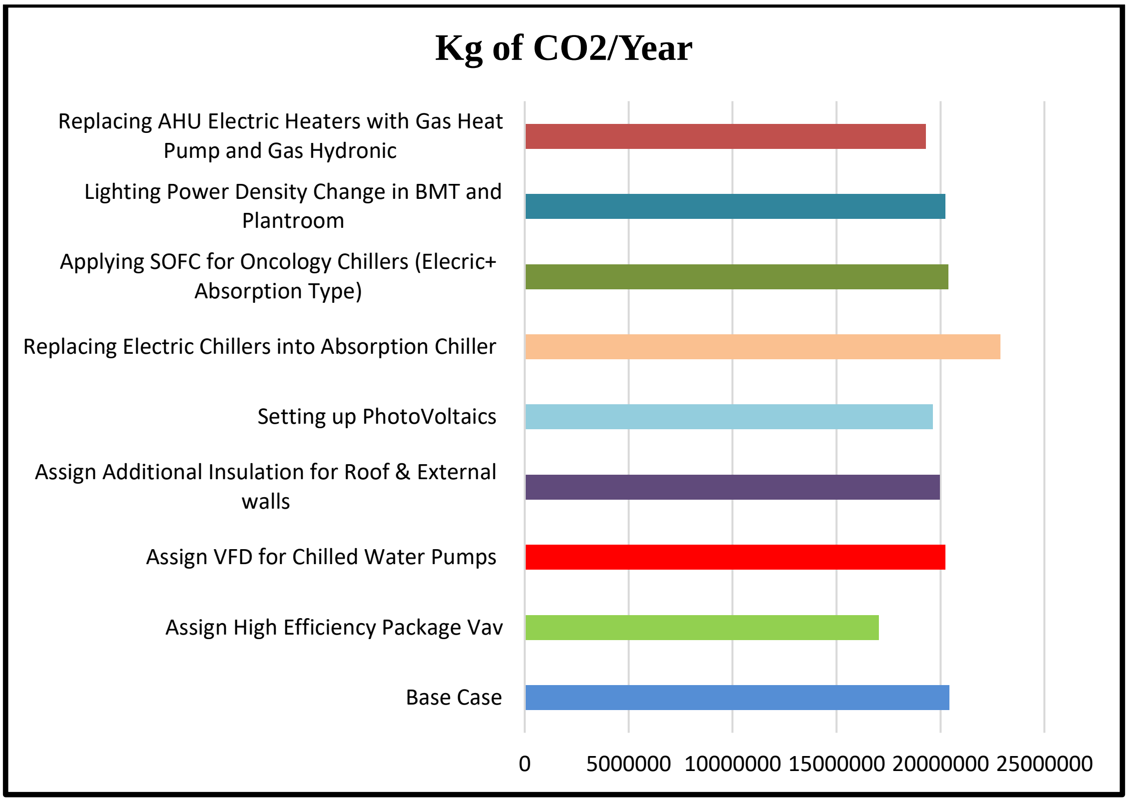


Figure 92. Comparison of Emission of CO_2 For Each Case

5.4 Economic Analysis

So far, we have dealt with the SOFC-CHP system's performance and other alternatives for hospital building, which represent the system sustainability and feasibility. This section has a discussion of the consequences of the economic analysis directed for the system. This analysis would assist the owners of building in having a decision about the credibility of the system.

Life-Cycle Cost Analysis is also termed as LCCA or LCC analysis. It is the analysis process that considers the first cost of construction for a building or system. After considering construction costs, it makes a comparison with building life-cycle costs. LCC analysis has raised the perception of the system's energy consumption and performance, construction costs and techniques, and various general costs of savings.

LCC analysis is a complicated process due to having an economic nature. Following is an overview of the whole process of performing LCC analysis in eQUEST.

1) The energy model project is a build-up in eQUEST.
2) Parametric runs are added to the eQUEST model.
3) Building simulation is executed in this tool.
4) Outcomes of LCC analysis are analyzed through Software default settings, and results are displayed.

In this analysis, the important required information is given during the creation of the building's energy model. After data input, go to the Simulation Detailed Results Report and open the LCC results.

Summary of Life-Cycle Costs depicts the breakdown of the life-cycle costs for each alternative individually. This analysis is started from the base. In Incremental Life-Cycle SAVINGS, a comparison is made for each alternative to the previous run. The base case scenario is compared to the first alternative. The results of LCC analysis are compared to the base case on a run-by-run basis. Cumulative Life-Cycle SAVINGS shows the cumulative savings. These statistics help analyze various factors such as window glazing, overhangs, HVAC systems, additional SOFC operated generators. This also helps to analyze the cost-effective factors for the system.

Total LCC PV$ provides the most dominant values for the analysis because of expressing the overall LCC costs for each alternative. An optimal alternative is considered to have the lowest LCC value for the system. The Figure 93 shows the life cycle cost summary for each alternative.

Life-Cycle Costs Summary

		One-Time Costs		Total Utility		Maintenance		Total
		1st year	LCC	1st year	LCC	1st year	LCC	LCC
Case	Description	$	PV$	$	PV$	$	PV$	PV$
Life-Cycle COSTS								
Base	Base	$0	$0	$951020	$6388257	$0	$0	$5810331
Alt 1	Assign High Efficiency Package Vav	$0	$0	$792266	$5321864	$0	$0	$4840411
Alt 2	Assign VFD for Chilled Water Pumps	$0	$0	$941734	$6325881	$0	$0	$5753597
Alt 3	Assign Additional Insulation for Roof & External	$0	$0	$929221	$6241827	$0	$0	$5677148
Alt 4	Setting up PhotoVoltaics	$0	$0	$913932	$6139127	$0	$0	$5583739
Alt 5	Replacing Electric Chillers into Absorption Chill	$0	$0	$1065286	$7155813	$0	$0	$6508448
Alt 6	Applying SOFC for Oncology Chillers (Elecric+	$0	$0	$898848	$6037804	$0	$0	$5491582
Alt 7	Altering LPD in BMT & Plantroom Area	$0	$0	$942339	$6329945	$0	$0	$5757293

Figure 93. Summary of Life-Cycle Cost

The charts that appeared on the following pages show additional data for analysis.

5.4.1 Life-Cycle Savings Graph

This graph in Figure 94 provides a comparison for the overall net savings in present value dollars. This graph shows the breakeven point for each alternative. This graph provides the fastest way of analyzing which alternative has the most incredible life-cycle cost savings compared to the base case. The following figure compares life-cycle cost savings for each alternative, which shows that the alternative of assigning high-efficiency package unit VAV provides the most incredible life-cycle cost savings compared to other scenarios.

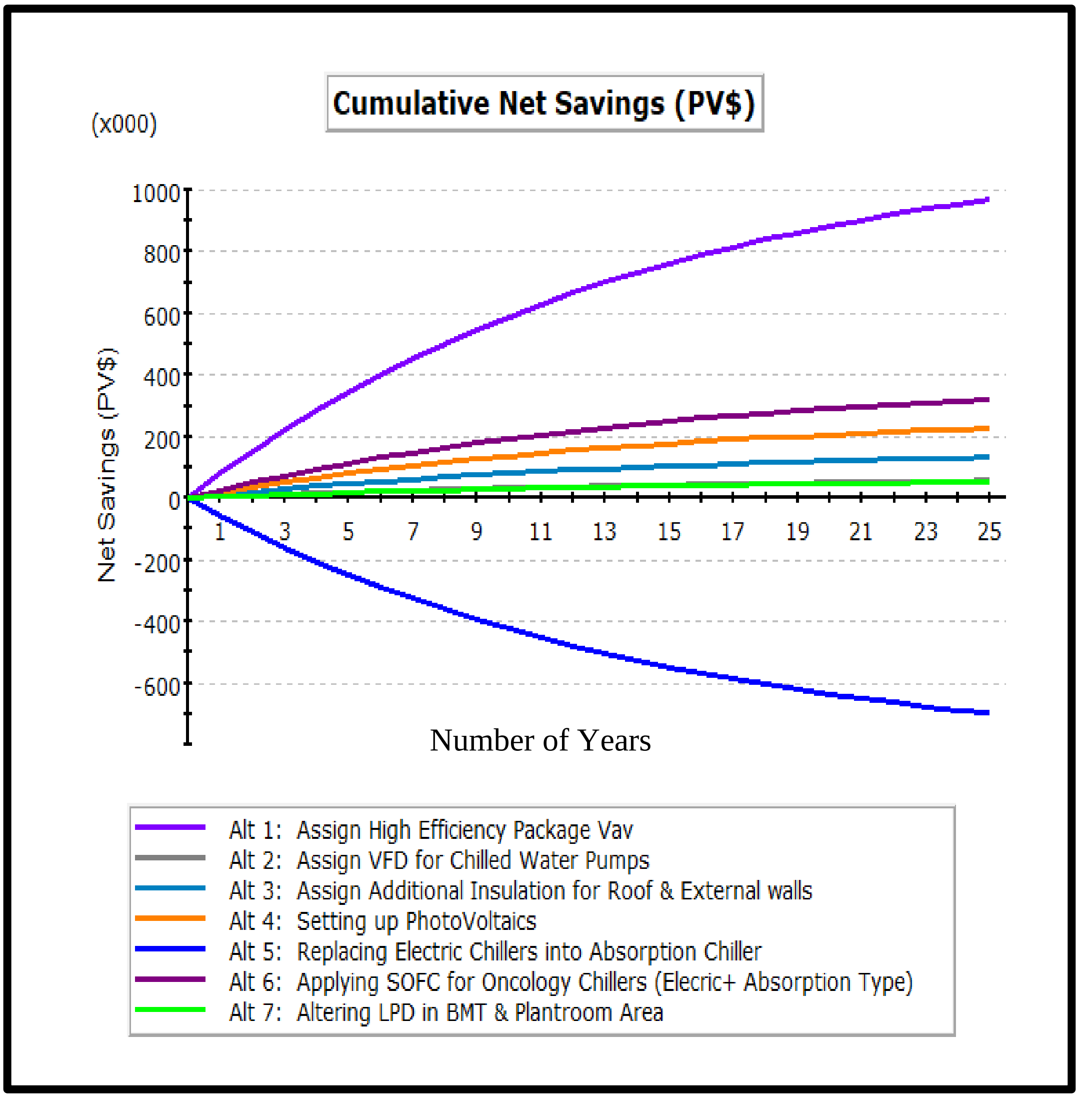


Figure 94. Net Saving Comparison of All Alternatives

5.4.2 Life-Cycle Savings Comparison

This comparison categorizes the LCC analysis into some specifics. These particulars are taken from the portion of Cumulative Life-Cycle Savings of LCC Summary Report. By considering and determining multiple projects or alternatives together, this comparison is considered as a useful tool. Savings comparison of the base case with each alternative is shown in Figure 95.

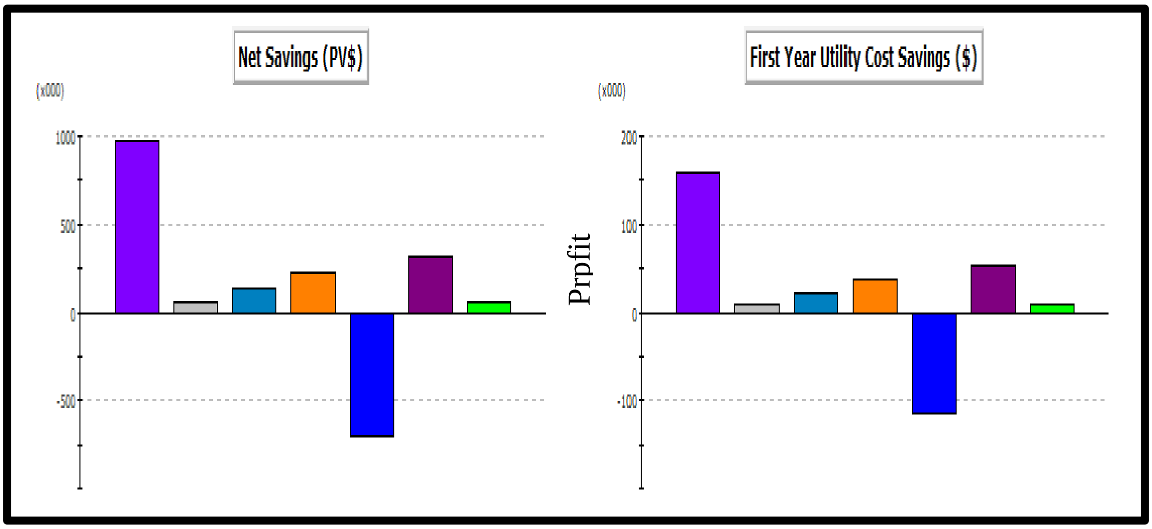


Figure 95. Life Cycle Savings Comparison for Each Alternative

5.4.3 Net Savings (PV$):

The overall savings can be seen through this graph for each alternative in the LCC analysis. It considers the time value of money along with the overall expense of every other alternative. Essentially, it graphically shows the cost you would save (or lose) compared to the base case ($0 net savings).

5.4.4 First Year Utility Cost Savings ($)

The graph presented in this section shows about first-year utility cost savings in comparison to the base case.

Summary report of Life-Cycle Costs elaborates that the lowest Total LCC alternative is the first one, packaged unit VAV ($4840411). Moreover, further verification of this alternative is made by Life-Cycle Savings Comparison. First-year utility savings of this alternative has the most significant value among all alternatives. All-inclusively, the reports make sure that the optimal choice of LCC is alternative #1. However, this shows a fundamental analysis, and other more variables make some influence than those that eQUEST needed that is the satisfaction of occupant and productivity, risk, value, etc.

CHAPTER 6: CONCLUSION AND RECOMMENDATIONS

In this thesis, a 175,190 ft^2 Cancer Care Hospital building is modeled using eQUEST energy modeling software tool. The model is developed according to standards of ASHRAE 90.1-2010 and as per the policies and using the tariffs of Qatar General Electricity & Water Corporation (KAHRAMAA).

Furthermore, according to Qatar's local markets, utility costs of electricity and natural gas have been established in this framework. Simulations for energy and cost are performed, and results of energy consumption profiles and annual energy costs are obtained and analyzed. Afterward, SOFC cogeneration models are added to the model based on (Chiappini et al., 2011). This integration is done in order to explore the SOFC-CHP system efficiency in the cancer hospital building.

This research work is done by using the climate of Abu Dhabi, which is similar to Qatar weather conditions. Eight alternatives are proposed and analyzed to attain an energy-efficient and optimized system for the hospital building. The proposed alternatives are (1) assigning high-efficiency VAV, (2) by using VFD, (3) by adding insulation, (4) by inserting PV panels, (5) by introducing absorption chillers, (6) by integrating SOFC, (7) by introducing energy-efficient lights, and (8) by adding heat pumps. The baseline scenario of the cancer hospital building is compared with the proposed alternatives. Performance curves are examined for a 200kW capacity of SOFC CHP system in terms of production of energy, utilization of thermal energy, and overall efficiency of the system.

The SOFC Generator powered by Natural Gas reduces electricity's overall consumption from 10.81MW to 10.78MW. This Reduction seems because of SOFC supplying heat energy in the simulation model through the SOFC Generator. An environmental influenced evaluation is analyzed with respect to CO2 emissions. It is observed that the alternative of Packaged unit VAV provides maximum reductions in CO2 emissions as compared to other cases. Consequently, based on all information and results analysis, it can be concluded that the SOFC-CHP system is efficient for the cancer hospital building.

This proposed system provides the patients with a clean and healthy environment based on SOFC-CHP & PV System results analysis. Cost analysis shows that a high cost can be saved by integrating the proposed system into a cancer hospital building. However, the performance of the proposed model can be analyzed by practical implementation in the near future. The following are the recommendation points which can provide future work in this area:

a) The proposed model was successfully implemented for energy analysis for a hospital and therefore, can be implemented for hospitals in general.

b) Other operational alternatives and technologies, such as the Internet of Things (IoT), smart grid and digital twin, which include energy management and savings capabilities, can be introduced to make the system more efficient and cost-effective.

c) It is recommended to include to introduce the capital cost of the system in future work for the proposed strategies to make it more realistic.

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