Modeling a Hospital in South Louisiana for Evaluation of Potential Energy Savings

A Thesis

Presented to the

Graduate Faculty of the

University of Louisiana at Lafayette

In Partial Fulfillment of the

Requirements for the Degree

Master of Science

Zahra Sardoueinasab

Summer 2017

Modeling a Hospital in South Louisiana for Evaluation of Potential Energy Savings

Zahra Sardoueiansab

APPROVED

Sally Anne McInerny, Chair
Professor and Head of Mechanical Engineering

Terrence Chambers
Associate Professor of Mechanical Engineering

John Guillory
Associate Professor of Mechanical Engineering

Peng Yin
Assistant Professor of Mechanical Engineering

Mary Farmer-Kaiser
Dean of the Graduate School

ACKNOWLEDGMENTS

I would first like express the deepest appreciation to my advisor, Dr. Sally Anne McInerny, for her continuous support, guidance, and encouragement throughout my graduate studies and research. Her guidance helped me during the research and writing of this thesis. Without her help, this thesis would not have been realized.

I am also grateful to Mr. Chris Morgan. I greatly benefited from his keen scientific insight, knowledge, and expertise.

I would like to thank Dr. Peng Yin for his support. He spent a substantial amount of time instructing me in how to do this research, and I have learned many things from him since I started this project.

I would like to thank my committee members, Dr. Guillory and Dr. Chambers, for serving on my thesis committee.

I am thankful for the funding source Louisiana Department of Natural Resource (LA DNR) that allowed me to pursue my graduate studies, and for the Department of Mechanical Engineering at University of Louisiana at Lafayette.

Finally, I must express my very profound gratitude to my brothers for providing me with unfailing support and continuous encouragement throughout my years of study.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGUERS

LIST OF ABBREVIATIONS

ASHRAE	American Society of Heating, Refrigerating, and Air-Conditioning Engineers
AUH	Air Handling Unit
CAV	Constant Air Volume
CBECS	Commercial Building Energy Consumption Survey
DCV	Demand Controlled Ventilation
DOE	Department of Energy
DOAS	Dedicated Outdoor Air System
DNR	Department of Natural Resource
DV	Displacement Ventilation
EPA	Environmental Protection Agency
ERV	Energy Recovery Ventilation
EUI	Energy Use Intensity
FCU	Fan Coil Unit
HPHX	Heat Pipe Heat Exchanger
IAC	Industrial Assessment Center
ID/DEC	Indirect/Direct Evaporative
LED	Light-Emitting Diodes
LPD	Lighting Power Density
MST	Mechanical System Technologies
NREL	National Renewable Energy Laboratory
OR	Operating Rooms
RAMEE	Run-Around Member Energy Exchanger

SHGC	Solar Heat Gain Coefficient
TSD	Technical Support Document
UFAD	Under Floor Air Ventilation
VAV	Variable Air Volume

INTRODUCTION

The Department of Energy (DOE) funded an Industrial Assessment Center (IAC) at the University of Louisiana at Lafayette (UL Lafayette) for over a decade starting in the year 2000. IACs provide no-cost energy audits/ assessments to small- and medium-sized manufacturers within the standard industrial code range of 20-39;(DOE 2017). After the UL Lafayette IAC was phased out and the lead faculty member retired, the Department of Mechanical Engineering at UL received a grant from the Louisiana Department of Natural Resources (DNR) to support a continuation of the energy audit work. This grant allowed the new team to look beyond the manufacturing sector for energy audit opportunities.

In the United States, the energy consumption of commercial buildings in 2016 accounted for 20% of the total site energy used by the four end-use sectors, namely residential, commercial, industrial, and transportation (EIA 2017). To compare the energy use of different building types, building energy consumption is frequently characterized in terms of energy use intensity (EUI) as measured in kBtu/ft^2 or GJ/m^2. Figure 1 shows the EUI for different types of commercial buildings. As can be seen in Figure 1, the EUI of inpatient healthcare facilities or hospitals is second only to that of food service buildings, and well above the EUIs of the other building types. Given the fact of high EUIs in hospitals and the large quantity of hospitals located in the South Louisiana, it is necessary to investigate the energy use in hospitals and evaluate the energy savings potential.

In 2016, commercial buildings consumed 20% of the total energy (in the U.S.) used by the four end-use sectors: residential, commercial, industrial, and transportation (EIA 2017). When electrical consumption is converted from site to source energy (EPA 2013), this increases to 25%. Figure 1 shows that the site energy use intensity (EUI), as measured in kBtu/ft^2 or GJ/m^2, varies substantially by property type within the building sector. This figure is based on 2003 and 2012 Commercial Building Energy Consumption Survey (CBECS) data published by the Energy Information Agency (EIA 2016a). The property types with the highest site EUIs are food service and inpatient healthcare or hospitals. Given the high site EUI of hospitals, the fact that healthcare is a growth business, and the availability of a local hospital – interested in working with the university – the UL energy audit team chose to develop greater expertise in hospital energy usage and potential energy-saving measures, together with an alumnus specializing in hospital HVAC design.

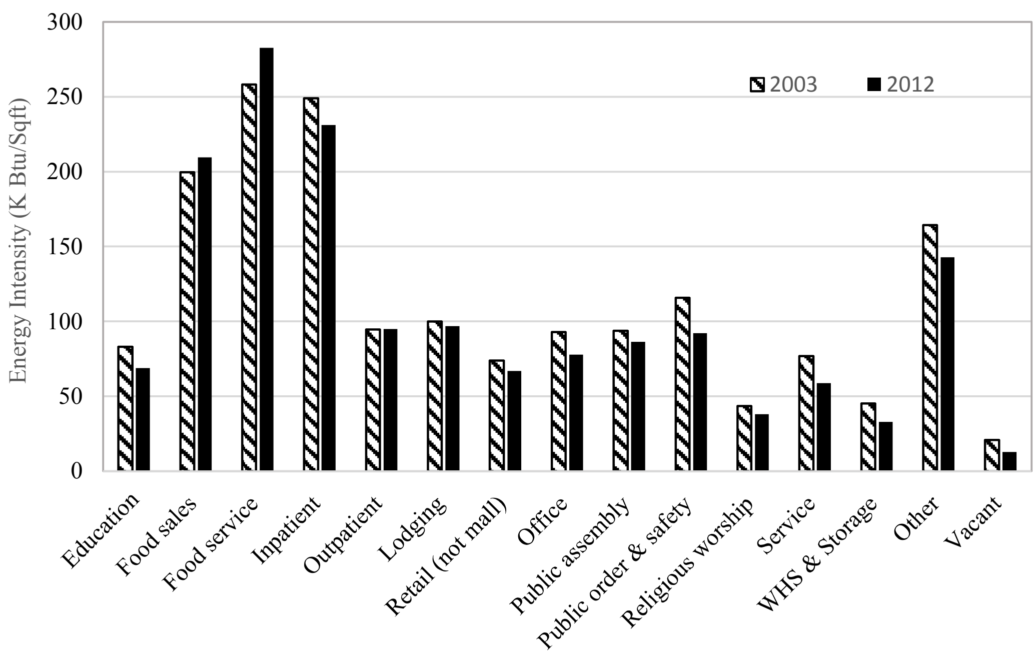


Figure 1. Site Energy Intensity by Commercial Building Type in 2003 & 2012 (EIA 2016a)

The purpose of this work is twofold. It provides a summary of hospital energy use and, based on prior work on the topic of reducing energy consumption in hospitals, develops and validates a model of a hospital located in South Louisiana with one year of utility data. A series of building energy simulations were performed to evaluate three energy efficient measures, namely reducing lighting power density, installing high efficiency windows, and the combination of both approaches.

LITERATURE REVIEW

In order to increase energy efficiency in buildings, numerous measures need to be implemented. However, in hospitals and healthcare facility, selection of energy saving recommendations should be undertaken carefully while conserving and improving healthcare delivery. Energy-saving measures could range from simple and inexpensive actions to significant, enormously cost-effective actions. Energy-saving measures based on different groups of renovations can be implemented to the building envelope, HVAC system, and energy conversion transfer systems (Buonomano 2014).

Building Envelope

Building retrofit plays an important role in increasing indoor microclimate stability, reduction of energy demand, and pollution emission. The influence of improving the building envelope has been investigated in a university hospital in Italy. In this analysis, roof thermal insulation has been improved by adding 0.098ft (3.0 cm) and 0.026ft (8.0 cm) polyurethane. This recommendation along with several recommendations on the HVAC system has been analyzed. Results from this study proved that marginal savings were achieved for summer and winter by applying this recommendation. However, this action is expensive with a long simple payback period (Buonomano et al. 2014).

A significant amount of building energy is related to the cooling load required to offset heat gain through roofs. The common solution for reducing that cooling load is to install a cool roof that leads to an increase in solar reflectance. Testa and Moncef. (2017) investigated the associated energy-saving of installing a dynamic cool roof for U.S. Commercial and residential buildings. According to this study, poorly-insulated and old buildings are good candidates for this recommendation, as energy saving increases with a decrease in insulation level.

In another study, reduction in the cooling and heating demand of Iranian hospitals is investigated. In the study, different approaches were applied consisting of increasing envelope thermal insulation, adding shade to the buildings, and applying thermal mass, along with a combination of the mentioned methods. According to this study, by improving building fabric, the heating and cooling demand can be reduced while indoor air temperature is kept in the required range. Also, the combination method is the best solution for reduction of the heating and cooling demand (Khodakarami et al. 2009).

Lighting

One of the main energy consumers using 20-45% of commercial buildings' electricity demand is lighting. This amount diverges a lot from one building to another, and in some buildings, up to 40% of the gross energy consumption is used for lighting (Dubois and Blomsterberg 2011). However, for hospitals, lighting consumes a considerable amount of energy which varies from 26% to about 36%, and it would be desirable to reduce this usage (Maleetipwan-Mattsson et al. 2016).

In order to reduce lighting energy in hospitals, the following recommendations are suggested: replace incandescent lamps with fluorescent in hospital rooms, hallways, and elevators, install energy efficient lights in other places, replace T-12 fixtures with T-8 and T-5 fixtures, install automatic lighting controls, install LED exit lights, and upgrade parking lighting. (Kapour and Kumar 2009). However, the first and least expensive approach to minimize lighting energy usage is lighting power optimization.

Proper lighting design results in lower operating and maintenance costs, as well as reduction in energy use and internal cooling load. At first, lighting power should be measured and compared with standards to ensure that required illumination is provided without over-lighting. The metric used is lighting power density (LPD) which is calculated by dividing lighting power by space area (W/ft^2). This approach is listed as the first recommendation in order to achieve lighting energy savings in the document titled "Large Hospitals 50% Energy Saving," provided by the National Renewable Energy Laboratory (Bonnema et al. 2010). In this study, reducing LPD is suggested along with installing occupancy sensors in applicable zones, such as restrooms and office areas, which leads to an additional 10% energy reduction. Interior LPD for each space type has been changed from the ASHREA (2004b) standard in the baseline model to a standard developed by Bonnema et al. (2010) in a low energy model for each space. Based on the results, by reducing lighting power density, lighting energy usage intensity can be reduced from 21.1 to 15.3 $kBtu/ft^2yr$ (240 to 174 MJ/m^2yr) which is equal to a 38% reduction of lighting energy (Bonnema et al. 2010).

Another method for reducing lighting energy is to install high performance lighting such as solid-state, light-emitting diodes (LED) and linear fluorescent lights. Based on ASHRAE/IESNA Standard 90.1 requirements, lighting power can be reduced by 20% by using these technologies (ASHRAE 2012). In 2004, St. Mary's Hospital in Leonardtown, Maryland upgraded its lighting system by installing more efficient lighting, which led to annual savings of $20,000 after a 4.35-year payback period.

The third suggested approach is to use exit signs with energy-efficient lights. Hospitals are used by many patients and visitors every day; therefore, exit signs are used often in hospitals, and using exit signs with high efficiency lighting saves a considerable amount of energy. For a typical hospital with 300 exit signs, replacing the light source in exit sign with LEDs results in annual savings of $14,755 with a payback period of 1.15 year (Health Research and Educational Trust 2014).

Another application of installing high efficiency lighting has been done for a 12-story clinical building in New Zealand, by replacing all 3,450 fluorescent lights with high efficiency lights. Also, three tube lights have been replaced with one tube light in all corridors, which results in a 75% energy savings and illumination improvement of 300 LUX. For this project, an annual electricity savings of $2.5x10^6$ kBtu ($2.7x10^6$ MJ) with a payback period of 3.5 years is estimated (Brochure 1997).

Heating Ventilating and Air Conditioning Systems (HVAC)

Various energy efficiency measures are available to increase HVAC savings. In healthcare facilities, to save energy and reduce cost, various types of energy-saving measures need to be applied in terms of the design condition of each hospital and flow of energy or production system. Moreover, air quality in hospitals is a very important issue for visitors and working staff due to the use of cleaning solution and a medical detergent used for sterilizing (Noie-Baghban and Majideian 2000).

HVAC systems play an important role in providing building thermal comfort, and are among the most energy-intensive consumers. By looking at the energy consumed by HVAC systems around the world, it is clear that a considerable amount of energy is used by them. For example, in the U.S., over 50% of energy is used by HVAC. This amount is 70% for Australia, 32% for India, 33% for Hong Kong, and 70% in the Middle East. Additionally, the need and usage of HVAC systems is increasing, especially in summer time. Therefore, enhancing HVAC systems reduces HVAC energy consumption and improves their performance. (Vakiloroaya et al. 2014). However, because of continuous operation of HVAC systems in hospitals, their energy intensity is relatively high, 130 kBtu/ft^2 (1472 MJ/m^2, which is greater than the total energy usage of educational buildings, i.e. 83 kBtu/ ft^2 (944 MJ/m^2), and office buildings, i.e. 93 kBtu/ft^2 (1055 MJ/m^2) (Rasouli et al. 2014).

There are many different techniques and recommendations available for improving HVAC systems, such as: improving the air distribution system, and using a Dedicated Outdoor Air System (DOAS) and heat recovery application. These recommendations count as the most commonly used, and are applicable for almost each case.

Improving Air Distribution

In HAVC systems of healthcare facilities, fans consume about 8% of the total building energy. According to the U.S. Environmental Protection Agency (EPA), almost 60% of fans are oversized by 10%. Therefore, right sizing and reducing fan usage can save a large amount of energy. One of the proposed approaches for reducing fan energy is to install a variable frequency drive on all fan motors, which reduces the fan power by 50% (DOE 2011). In Bonnema et al. (2010), constant air volume systems (CAV) are used in air handling units (AUH). In this report, one of the approaches for reducing energy usage by 50% is to change the CAV system to a variable air volume system (VAV) in the low energy model. This change results in a 76% reduction in fan energy (fan energy intensity has been decreased from 60.45 to 14.4 kBtu/ft^{2}yr (686-163.5Mj/m^{2}yr).

Installing Dedicated Outdoor Air System

Installing a DOAS is another technique used in hospitals to reduce energy usage. DOAS introduces fresh air to the building, which can improve indoor air quality (IAQ) and reduce poor ventilation problems. The DOAS system handles both latent and sensible load of conditioning outdoor air and can work in parallel or series with the zone local terminal unit which can be a fan coil units (FCU), heat pumps, CAV systems, and passive chilled beams. In parallel configuration, conditioned DOAS introduces conditioned air directly to the zones, but in the series configuration, conditioned air is sent either to local terminal unit intake or to the supply duct of the terminal unit.

There is a study conducted by the National Center for Energy Management and Building Technologies (Chimack et al. 2009) which investigated the energy saving associated to different Mechanical System Technologies (MSTs) including DOAS, Energy Recovery Ventilation (ERV), Indirect/Direct Evaporative Cooling (ID/DEC), Demand Controlled Ventilation (DCV), Displacement Ventilation (DV), and Under Floor Air Ventilation (UFAD). That was using EnergyPlus simulation software for four different types of buildings (office, school, hotel, hospital) and for five different U.S. climates (Chicago, Denver, Houston, Las Vegas, and Phoenix). Results of this study proved that using DOAS in hospitals results in energy intensity reduction of 12% in Los Angeles to 32% in Chicago (4.34 and 28.22 kBtu/ft^{2}yr (49.2 and 320 MJ/m^{2}yr). Based on this study, the application of DOAS in hot and humid climates produces more savings than in other climates. Besides that, according to this work DOAS has the shortest payback period, as compared to other MSTs (Chimack et al. 2009).

In a master's thesis titled "Energy Benefits of Different Dedicated Outdoor Air System Configuration in Various Climates" (Deng 2014), the energy benefits of utilizing a DOAS system for an office building in seven different U.S. climate zones is investigated. In this study, a baseline model using a VAV system is compared with three different configurations of DOAS including 1) FCU as terminal unit while DOAS supplies conditioned outdoor air to each FCU intake, 2) FCU as terminal unit and DOAS introduces conditioned outdoor air to each occupied space, and 3) DOAS with active chilled beam. According to this work, application of all three configurations results in energy savings which varies from 7.1% in Chicago to 26% in Albuquerque. However, DOAS requires a bigger unit in the first configuration (when it supplies conditioned outdoor air to FCU intake) than in the second configuration because it is recirculating more air. Lastly, the maximum amount of energy savings is achieved when DOAS is used in conjunction with a chilled beam system, especially in hot climates (Deng 2014).

Using Energy Recovery Ventilators

Another approach for saving energy in hospitals is to use energy recovery ventilators (ERVs), which have been used a lot recently. The aim of using ERVs, which transfer heat or heat and moisture between conditioned exhaust air and supply air, is to decrease energy required for conditioning outdoor air. Rasouli et al. (2014) simulated a hospital building and its HVAC system by means of the TRNSYS building energy simulation tool and the MATLB computer program. In this case, a Run-Around Member Energy Exchanger (RAMEE), which is a heat and moisture recovery system, is simulated for four different North America climates including Saskatoon (cold and dry), Chicago (cool and humid), Phoenix (hot and dry), and Miami (hot and humid). This study proved that using RAMEE accomplished a heating energy reduction of about 58% and 90%, as well as a cooling energy reduction between 4% and 18% in Saskatoon and Miami, respectively. This means that cold climate heating energy savings are more than hot climate cooling energy savings. Also, results of this study have been compared with another approach in which application of RAMEE has been studied for an office building. According to this work, installing RAMEE saves more energy in hospitals than in office buildings. Total heating, cooling, and fan energy saved in hospitals varies from 48% in Saskatoon to 8% in Miami, while the amounts for office buildings are 30% and 5%.

Ahmadzadehtalatapeh and Yau (2011) investigated the application of Heat Pipe Heat Exchanger (HPHXs) for improving air quality of a hospital ward in Malaysia. Reduction of the energy usage of the air conditioning system is studied by using the TRNSYS building energy simulation tool, in which HPHXs are used to preheat or precool the supply air of two AHUs. Simulation results of this study proved that by adding eight-row HPHXs, desired indoor conditions recommended by ASHRAE will be achieved along with an energy usage reduction of the air conditioning system. Based on the simulation results, a total amount of 455MWh energy was saved, which is equal to $42,227 USD with a payback period of 1.6 years.

DESIGN AND RETROFIT FOR EFFICIENCY

Large Hospital 50% Energy Savings Report

In 2010, a Technical Support Document (TSD) was developed by the Commercial Buildings Group at the National Renewable Energy Laboratory (NREL) under the direction of the DOE Building Technologies Program (Bonnema et al. 2010). This report documents the technical analysis applied and design guidelines that help large hospitals to accomplish at least of 50% energy savings over ANSI/ASHRAE/IESNA Standard 90.1-2004 for all U.S. climate zones. EnergyPlus software is used as a simulation engine to model baseline and low energy buildings. In this report, a prototype model is created in which design features not addressed by Standard 90.1-2004 are used, and then a baseline model is fashioned by taking the prototype model and applying design features addressed by Standard 90.1-2004. A low energy model is generated by using the prototype model and applying energy design measures addressed by the TSD.

Building Feature

The model is a seven-story hospital of steel-frame construction and roof with insulation above deck. The area of the hospital is 527,000 ft^2 (49,000 m^2) with a 40% fraction of fenestration to gross wall area. Baseline heating, ventilation, and air conditioning equipment consists of central air handling units, chillers, boilers, and constant air volume terminal units with hot water reheat coils.

Development of Low Energy Model

The following recommendations are applied to a prototype model and to create a low energy model.

1 Reduced lighting power densities.

2 Daylighting and occupancy sensors in applicable zones.

3 More insulative envelope (opaque exterior and fenestration).

4 Overhangs on south-facing fenestrations.

5 A multizone variable air volume dedicated outdoor air system with zone-level water-to-air heat pumps.

6 High-efficiency chillers, boilers, pumps, and water heaters.

7 Demand controlled ventilation.

8 Reduced infiltration through tighter envelope construction.

Results

According to this report, the biggest source of savings is due to changes in the HVAC system. The highest percentage of savings is achieved in marine and cold climates (62.7%), and the least is achieved in hot and humid climates (50.9%).

SOFTWARE SELECTION

Reasons for Using Simulation Software

Building simulation software provides the possibility of modeling a building before renovation or before the building is built. Also, simulation is less expensive and takes less time than experiments, which allows for the investigation and comparison of different energy alternatives. One of the facility manager's concerns is to manage building energy usage by evaluating energy end users (lighting, HVAC, and electrical equipment), and take actions to reduce energy associated with each of them. This fact persuades researchers to develop strategies to reduce building energy usage and environmental impact by analyzing and controlling building energy usage and performance.

In order to reduce building energy consumption, various energy conservation measures are recommended, but not all of them are applicable and operative. Practical energy conservation measures could be implemented to reduce operational costs, if facility mangers could predict the energy demand profile and building energy consumption, which is doable by using building simulation software tools (Siddharth et al. 2011). Computer simulation and modeling tools have been developed and heavily used by engineers and architects recently. The effective use of building simulation is affected by three major factors: complexity, accuracy, and validity (Hui 2003).

Another reason that engineers use building simulation tools is because retrofitting existing buildings, which need to be modeled by energy simulation software, results in a significant amount of footprint energy reduction. Also, using energy simulation software aids in specifying variables that help designers to choose the best energy efficiency measures. These measures need to be applied for new and existing buildings in order to make buildings more efficient. Several factors affect selecting a building energy analysis program including its application, experience of the user, and hardware available to run it (Harish et al. 2016).

On the other hand, HVAC systems along with lighting consume a significant amount of building energy usage. Therefore, understanding and optimizing the performance of building services through the use of simulation software leads to reducing building energy usage. It is worth noting that the building energy requirement is dependent on the performance of the building envelope, HVAC system, and lighting as an integrated system in each unique building. Also, for large commercial buildings, the interaction between the building and its environment need to be analyzed and modeled by building simulation software (Hong et al. 2000).

One of the main purposes of using simulation software is to obtain quantitative data to help in evaluating compliance, which is necessary due to the increase in the number of building performance codes and standards. Also, designers use simulation software tools to design the most efficient buildings, to track the effect of building components on building performance, and to consider individual buildings as single or integrated systems (Software Tools for Energy Efficient Buildings 1999).

Simulation Software Available

There is various building energy simulation software available in market ranges from simple to detailed and complicated. Building designers usually choose software based on their experiences, required detail level, and familiarity with the software (Hui. 2003).

Crawley et al. (2008) introduce the following as the most important and most widely-used simulation tools: BLAST, BSim, Designer's simulation ToolKit (DeST), DOE-2, ECOTECT, Ener-Win, Energy Express, Energy 10, EnrrgyPlus, eQUEST, ESP-r, Hourly

Analysis Program (HAP), HEED, IDA, Indoor Climate and Energy (IDA, ICE), IES, Power Domus, SUNREL, Tas, TRACE, and TRNSYS.

Reasons for Selecting EnergyPlus

For this project, EnergyPlus simulation software is selected because it is a freely available software supported by the U.S. government and has been extensively applied in academic and commercial settings. EnergyPlus is developed by the United States Department of Energy (DOE) and it has both features and capabilities of BLAST and DOE-2 software. Since EnergyPlus is a thermal simulation software tool, energy can be analyzed through the building and thermal zone (Sousa 2012). Users can implement building geometry and materials as well as internal loads and HVAC systems in EnergyPlus. Also, design day and annual simulation are two different kinds of simulation available in EnergyPlus which provide annual and design day outputs such as heating/cooling load, zone temperature, and building energy consumption by using a weather file (Neto et al. 2008). In general, EnergyPlus is a tool for application of energy simulation, load calculation, building performance, energy performance, and heat and mass balance. However, using text input makes graphical interface more difficult in EnergyPlus.

In a study done by Harish et al. (2016), nine building simulation software tools including TRNSYS, EnergyPlus, DOE-2, BLAS, DeST, BSim, ECOTECT, ESP-r , and eQuest have been compared on the capability of performing software characteristics such as simulation solution, time step approach, geometric description, solar gain, shading and sky consideration, and occupant comfort. This study shows that EnergyPlus has 9 out of 12 of the mentioned characteristics, which makes it a good candidate for choosing simulation software. Part of the table developed by Harish et al. (2016) is illustrated below (Harish et al. 2016).

Table 1. Comparison of Different Simulation Software

Modeling Characteristics	BLAST	DOE-2.1e	EnergyPlus	eQuest	TRNSYS
Time Step Approach	PI	NI	CI	PI	PI
Geometric Description	CI	NI	PI	CI	CI
Simultaneous Radiation & Convection	CI	CI	CI	CI	CI
Combined Envelope Heat & Mass Transfer	CI	NI	CI	NI	CI
Internal Mass Considerations	CI	CI	CI	CI	CI
Occupant Comfort	CI	NI	CI	NI	PI
Solar Gain, Shading & Sky Considerations	NI	NI	CI	PI	CI
Variable Construction Element Properties	NI	NI	NI	NI	NI

Nomenclature: CI: Completely/wholly implemented, PI: Partially implemented, OI: Optionally implemented, NI: Not/Negligibly implemented.

In another study, a comparison of 20 simulation tools was performed in terms of zone load, building envelope, daylighting and solar, ventilation and infiltration, HVAC system, and economic evaluation. According to this work, EnergyPlus has the highest number of capabilities or features in common versions among all simulation tools (Crawley et al. 2008).

Jaric et al. (2013) introduced EnergyPlus (Energy Simulation Software tool), IDA ICE (Indoor Climate Energy), IES-VE (Integrated Environmental Solutions – Virtual Environment), and TRNSYS as the most complete software tools. In this study, a comparison of seven simulation tools including EnergyPlus, EDA-ICE, IES-VE, TRNSYS, ECO Design, GBS, and ECOTEC was done in terms of simulation solution, duration of time calculation, complete geometric disruption, electrical and renewable energy system, and HVAC system. Based on this study, EnergyPlus and TRNSYS have 40 out of 48 features in mentioned categories.

OVERVIEW OF REFERNCE MODEL DEVELOPMENT

St. Elizabeth Hospital

For this project, St. Elizabeth Hospital is selected since information about an actual hospital is required in order to make an EnergyPlus model. Located in Gonzales, Louisiana, St. Elizabeth Hospital is a two-story building and a member of the FMOL (Franciscan Missionaries of Our Lady).

The purpose of this research is to use EnergyPlus software to model a hospital in southern Louisiana in order to explore possible energy efficiency measures for this climate, implement them in the model, and discover what amount of energy could be saved by these recommendations. However, for this purpose, an actual hospital located in this climate condition was required for modeling. All building details, such as architectural and mechanical plans as well as information about end users, are required. Also, for model validation, results from the EnergyPlus model including energy usage intensity along with central plant equipment size must be compared with an actual hospital.

The following are reasons for choosing St. Elizabeth Hospital:

1. Geographical conditions of plant (i.e. its location in Southern Louisiana).
2. Possibility of access to new and old architectural and mechanical plans which are necessary elements for making a model in Energy plus.
3. Possibility of access to utility bills (electricity and gas) in order to compare energy usage intensity in the Energy Plus model with that of the actual hospital.
4. Possibility of conducting electrical equipment (plug load) survey in order to estimate internal heat gain due to electrical equipment.

5 Possibility of access to central plant equipment size information in order to compare Energy plus model with actual hospital.

Figure 2. St. Elizabeth Hospital Location

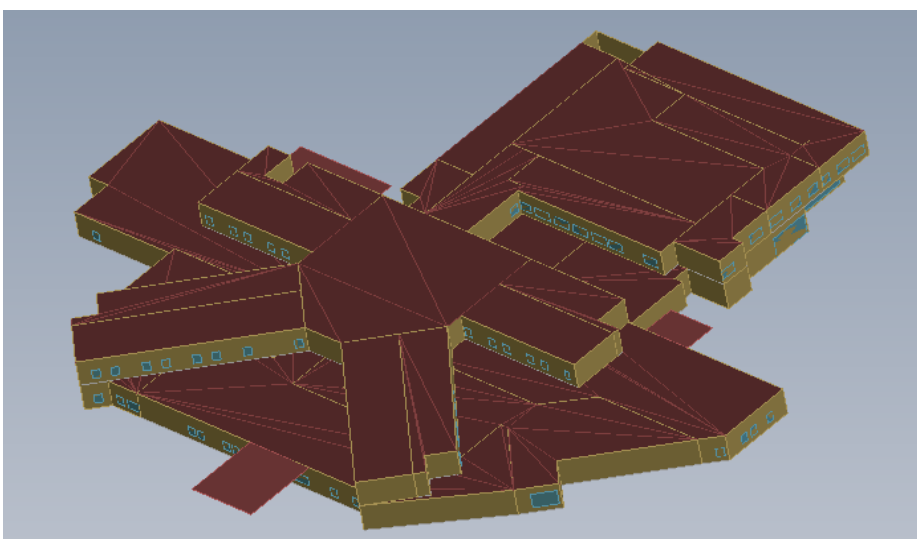


Figure 3. EnergyPlus Model Geometry Based on St. Elizabeth's Hospital

Elements of Model

Building Envelope. The geometry of the reference model simulated in EnergyPlus was based on the actual hospital blueprint and includes a 120,000 ft^2 (11160 m^2) two-story hospital building consisting of an old section and a new two-story wing which was added in

2009. The floor-to-floor height was modeled as 10 ft (3.05 m). The model is divided into 30 zones, and each zone has its own space condition and equipment requirement.

The material used for the envelope of the reference model created in EnergyPlus is the same as the material used for the actual hospital. The building envelope consists of the following components: exterior walls, interior walls, second floor, first floor, roof, and ceiling. The following table details material used for each component.

Table 2. Surface Martial Exclusive of Windows

	Roof	Ceiling	Exterior wall	2nd Floor	1st Floor
Outside Layer	Asphalt Roll Roofing	Carpet	Stucco	Carpet	Carpet or Tile
Layer2	Insulation BD	Insulation BD	Metal Lath	Insulation BD	Concrete
Layer 3	Concrete	Concrete	Insulation BD	Concrete	
Layer 4	Metal Decking	Metal Decking	Gypsum Board	Metal Decking	
Layer 5	Ceiling Air Space	Ceiling Air Space		Ceiling Air Space	
Layer 6	Acoustical Tile	Acoustical Tile			

Building Fenestration. Building fenestration encompasses all penetrations of the envelope used for access and egress, such as windows and doors. In this project, all windows are considered as double-pane ½ inch air space aluminum frame. Location and size of all fenestrations are the same as the actual hospital fenestrations driven from architectural plans. Fenestration details are included in the following table.

Table3. Windows

Total Windows Area $ft^2(m^2)$	Window to Wall Ratio (%)	U value Btu/h-ft2-F(W/m-K)	SHGC
5167 (480)	13	0.81 (1.4)	0.59

Internal Gains

People. There are 30 zones for this hospital; therefore, 30 associated people objects are considered. For each zone, the number of occupants depends on the zone application obtained from ANSI/ASHRAE standard 62-2001.

Lights. Interior lighting includes all electric lighting inside the building envelope. It includes hard-wired light fixtures. Lighting from task lights or moveable fixtures was not considered as interior lighting. The lighting power density was taken as 2.5 W/ft^2 (27 W/m^2) based on a local rule of thumb used for initial hospital HVAC system sizing.

Electric Equipment. A complete site survey of the hospital was done in order to take into account all electrical equipment in each hospital room. A list of all electrical equipment used in each room is gathered. For each zone, total electrical and usage is a summation of electricity usage of all equipment, which is taken from the 2001 ASHRAE Fundamentals Handbook (SI). The team was not able to visit the surgical suites, so the equipment loads for the surgical suite are based on the "HealthCare Energy End-Use Monitoring" document provided by National Renewable Energy Laboratory (NREL) (Sheppy 2014).

Air Flow and Schedules

Ventilation. In this project, for each of the 30 zones based on the zone application, required ventilation rates are taken from ANSI/ASHRAE Standard 62-2001.

Infiltration. Infiltration rate is taken from Infiltration Modeling Guidelines for Commercial Building Energy Analysis documents prepared by the U.S. Department of Energy (DOE). According to this document, an infiltration rate of 1.8 cfm/ ft^2 (0.00915 $m^3/s/m^2$) is calculated for above-grade envelope surface areas, and this amount is used for this project (Gowri et al. 2009).

Schedules. The hospital is the kind of building to be open 24 hours per day, 7 days per week. However, not all spaces in the building have to operate on this schedule. Commonly, spaces like office areas or some clinics are not open 24 hours per week. For this project, two different types of schedules are used: one for office areas and one for the rest of the hospital, referred to as Hospital 24/7.

Schedules for this project are taken from commercial prototype building models for hospitals provided by the DOE (DOE 2016).

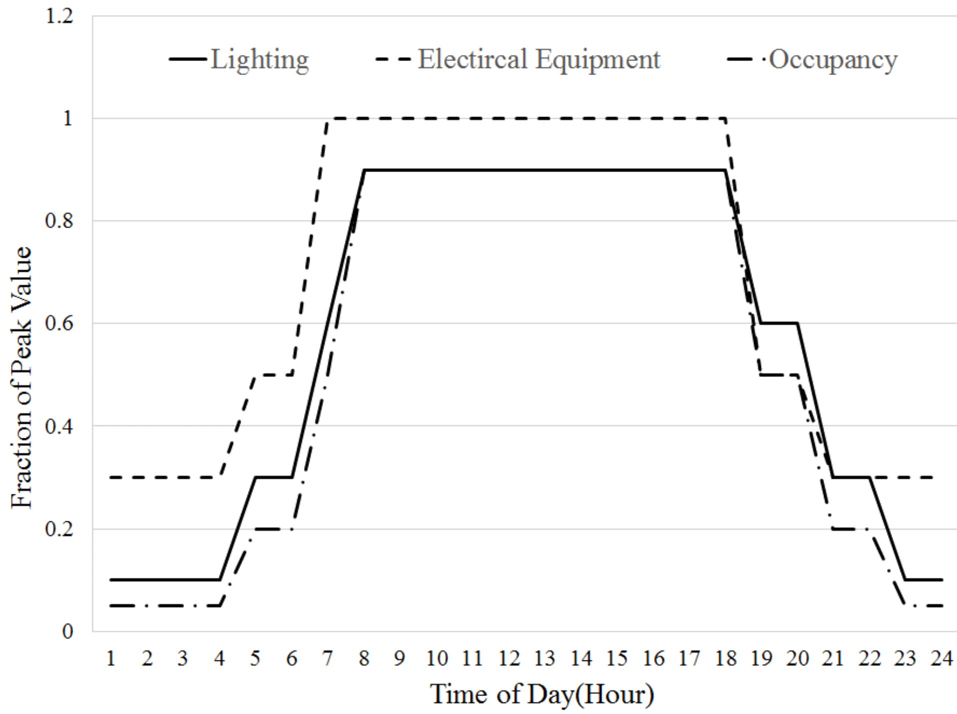


Figure 4. Office Schedule

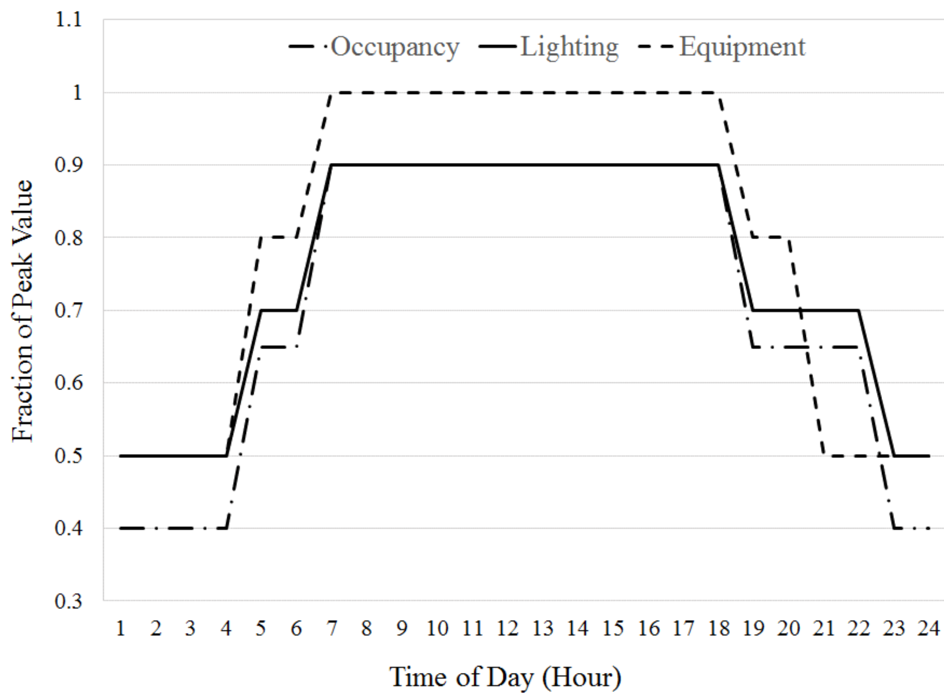


Figure 5. Hospital 24/7 Schedule

Temperature and Humidity Specifications

For controlling temperature, a dual setpoint with Dead Band is chosen. Temperature and relative humidity settings are taken from "Large Hospital, 50% Energy Saving: Technical Support Document." Table 4 shows the cooling and heating set point, as well as minimum and maximum relative humidity considered for the Energy Plus model.

Table 4. EnergyPlus Model Temperature and Humidity Level

Cooling SetPoint F (C)	Heating SetPoint F (C)	Minimum Relative humidity (%)	Maximum Relative Humidity (%)
72 (22.2)	70 (21.1)	30	60

Heating Ventilation and Air Conditioning System (HVAC)

The HVAC system used for the EnergyPlus model is the same as the HVAC system used for the actual hospital. The HVAC system for St. Elizabeth consists of VAV systems and FCUs. There are 14 AHUs providing conditioned air. The following table shows the type of air conditioning system used.

Table 5. Zones and Their HVAC Type

Zone Name	HAVC system
River1-1Through River1-9	VAV Box
River 2-1 Through River 2-9	Fan Coil Units
ST1-1 Through ST1-4	VAV Box
ST2-1 Through ST2-5	Fan Coil Units
ST2-6 Through ST2-8	VAV Box

HVAC System: Fan Coil Units. As mentioned before, the HVAC system used for the Energy Plus model is the same as the actual. Thirteen out of 30 zones have fan coil units. Entering water temperature to cooling and heating temperature are obtained from St. Elizabeth Hospital mechanical plans.

HVAC System: Variable Air Volume System (VAV). There are 14 air handling units (AUH) serving St. Elizabeth Hospital. There is a zone assigned to each air handling unit except some of AUH that serves several zones instead one zone. Cold and hot air generated in AHUs are provided by chilled water and hot water produced by chiller and boiler. Required information for making VAV systems are taken from St. Elizabeth Hospital mechanical plans.

Chilled and Hot Water Loops

Water temperature of chilled and hot water loops are driven from mechanical plans of St. Elizabeth Hospital. Chilled water and hot water temperatures are considered as 45 F (7.22 C) and 180 F (82.2 C), respectively.

Detailed Model Inputs

To generate a model in EnergyPlus, a building has to be made from scratch. There is a lot of information required by the software to make the model such as simulation parameter, location and climates, schedules, construction and surface details, thermal zone, internal gain, zone airflow, HVAC templates and outputs. All steps of making the model and all inputs are documented in Appendix A and B. Details of how to start working with EnergyPlus are provided in a Getting Started Guide attached in Appendix C. This document helps a beginner who does not know anything about EnergyPlus learn what the EnergyPlus features are, and how to input the data, run simulation, and get desired outputs.

MODEL VALIDATION

The EnergyPlus model needs to be validated after completion. In fact, validation is required to show that the model is a reasonable representation of an actual system. The EnergyPlus model has been validated by following methods.

1 Large Hospital 50% Energy Saving Technical Support Document (TDS)

2 St. Elizabeth Hospital annual energy usage

3 St. Elizabeth Hospital central plant equipment size

Comparison with Large Hospital 50% Energy Saving Report

Initial validation efforts concentrate on the output of the model, therefore energy usage intensity (EUI) of the EnergyPlus model and “Large Hospital 50% Energy Saving Technical Support Document” have been compared. In this project, TSD is called baseline model and more details of this TSD is available in Design and Retrofit for Efficiency section

Energy Usage Intensity (EUI). Building EUIs is one of the recognized energy performance metrics for designing energy modeling and assessing the performance of building energy. Energy Usage intensity is expressed as energy per square foot per year and expresses the energy usage of a building as a function of its size. To calculate EUI total building energy consumption during a year should be divided by total floor area (EnergyStar 2017).

EUI Comparison. Energy usage intensity of a baseline hospital across all U.S. climate zones is available in TSD. In order to make a reasonable comparison, the EUI of baseline model of Houston is chosen because of similarity in climate condition.

Table 6. Energy Usage Intensity Comparison

Model	Metric	Amount
Baseline	$kBtu/ft^2.yr$ ($MJ/m^2.yr$)	413.5 (4698)
Reference	$kBtu/ft^2.yr$ ($MJ/m^2.yr$)	270(3100)

The above table shows that EUI of the baseline model (413.5 $kBtu/ft^2.yr$) is higher than that of the reference model which is 270 $kBtu/ft^2.yr$ (3100 $MJ/m^2.yr$). The main reason for higher EUI is the type of HVAC system used in baseline model. CAV system is the type of HVAC used in baseline model, while the HVAC system of reference model is either a VAV system or FCU. Therefore, we changed the VAV system in the reference model to CAV system for further comparison. The result from changing the HVAC system simulation are illustrated in table 7 which shows that the EUI of the baseline model is 413.5 kBtu/ft2.yr (4698 $MJ/m^2.yr$) and reference model EUI is 446.5 $kBtu/ft^2.yr$. However, the EUI of the reference model is slightly higher than that of the baseline model. The main reason is because the average LPD of the reference model is 2.5 W/ft^2 (26.9 W/m^2) while this amount for the baseline model is 1.2 W/ft^2 (12.9 W/m^2) which is half of the reference model LPD. There is only a 7 %difference between energy usage intensity (EUI) of the baseline and reference model, which proves the validity of the simulated model.

Table 7. Energy Usage Intensity Comparison with CAV System

Model	Metric	Amount
Baseline	$kBtu/ft^2.yr$ ($MJ/m^2.yr$)	413.5 (4698)
Reference	$kBtu/ft^2.yr$ ($MJ/m^2.yr$)	446.5(5072)

Compare with Actual Hospital Annual Energy Usage

Electricity. For the second method of validation, simulation results of the reference model have been compared with the actual hospital. For this purpose, energy usage of the reference model has been compared with actual hospital annual energy usage obtained from utility bills, including three years of electricity bills along with one year of gas bills.

The difference between each year's annual electricity usages of actual hospital with reference model usage varies between 25% in 2014 to 15% in 2016. Simulation results show that the difference is slightly high; therefore, electricity usage of electric equipment of the reference model has been compared with usage of electric equipment of Healthcare Energy End-Use Monitoring Document. Comparison of high electricity consumers like MRI and CT scan machines is done because this equipment uses a considerable amount of electricity, and also, in this project, the maximum amount of power that this equipment could use is considered for these imaging machines. The mentioned document shows that, primarily, these imaging machines do not always work at maximum power but they work at the average rate of power (Sheppy et al. 2014). Therefore, the average power usage of these imaging machines was applied, electricity usage of the reference model was calculated again and found to be equal to 22.8×10^6 kBtu ($24x10^6$ MJ).

Table 8. Annual Electricity Usage Comparison

Year	Actual kBtu(MJ)	Reference Model before Changes kBtu(MJ)	Reference Model after Changes kBtu(MJ)
2016	22.5×10^6 ($23.7x10^6$)	26.6×10^6 ($28x10^6$)	22.8×10^6 ($24x10^6$)
2015	20.5×10^6 ($2.16\ x10^6$)		
2014	19.8×10^6 ($20.8\ x10^6$)		

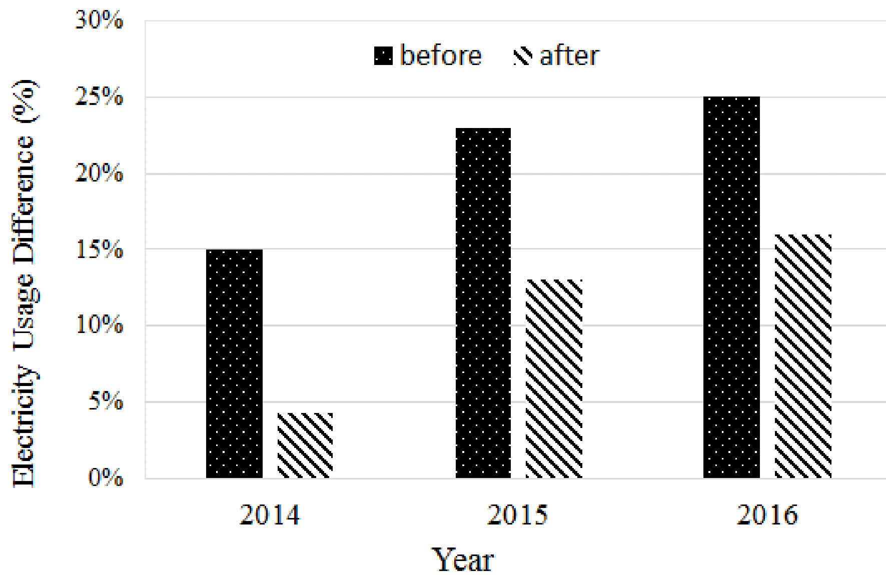


Figure 6. Electricity Usage Difference of Reference Model and the Actual Before and After Change

After making changes in electrical equipment usage, the energy per total building area of the new reference model is calculated again and compared with the baseline model, and results are illustrated in the following table

Table 9. Energy Usage Intensity Comparison after Changes

Model	Metric	Amount
Baseline	$kBtu/ft^2.yr$ ($MJ/m^2.yr$)	413.5 (4698)
Reference	$kBtu/ft^2.yr$ ($MJ/m^2.yr$)	247 (2800)

Natural Gas. In the second method of comparing energy usage, gas usage of the reference model and actual hospital have been compared. The calculated gas usage of reference model is about 14.7 million CCF used for air conditioning and water heating purposes. Gas usage of the actual hospital, obtained from utility bills, is about 13.8 million CCF; by comparing with the reference model, a difference of 6.1% is obtained.

Table 10. Annual Gas Usage Comparison

Year	Actual Usage CCF (m^3)	Reference Model Usage CCF (m^3)	Difference (%)
2016	13,800,000 (39×10^6)	14,700,000 (41.7×10^6)	6.1

Central Plant Equipment Comparison

In the third comparison, central plant equipment size including that of the chiller, cooling tower, and boiler have been compared with the actual hospital. As is seen from the table, the size of the chiller and cooling tower is almost half of those in the actual hospital and the size of the boiler is about 67% of the actual boiler size. However, it is worth mentioning that central plant equipment is made in 50% redundancy.

Table 11. Central Plant Equipment Comparison

	Energy Plus Model	Actual
Boiler Size Bhp (MJ/s)	200 (1.96)	290 (2845)
Chiller tons(GJ)	640 (2677)	800 (3347)
Cooling Tower tons(GJ)	640 (2677)	800 (3347)

EVALUATION OF ENERGY SAVING RECOMMENDATIONS

Many authors have done studies regarding efficient use of energy and possible energy savings measures in hospitals. Energy efficiency measures can be applied with respect to the building envelope by applying thermal insulation and reducing building leakage, with respect to heating and cooling systems by using heat exchangers and air-cooled chillers with centrifugal compressors, and with respect to ventilation system by applying advanced strategies. For this project, five major and practical energy saving measures are recommended including

1. Reducing lighting power density (LPD)
2. Installing high efficiency windows
3. Combination of LPD reduction and window changing
4. Installing a separate Glycol chiller for operating rooms
5. Combination of LPD reduction and chiller separation

Reducing Lighting Power Density (LPD)

In this project, an average LPD of 2.5 watt/ft^2 (26.9 W/m^2) has been applied to all 30 zones of the reference model, as the HVAC engineer of St. Elizabeth hospital proved. By comparing the LPD of the reference model with ANSI/ASHRAE /IESNA Standard 90.1-2007, it is realized that this amount is higher than the standard level. Therefore, the LPD of each zone based on zone application has been decreased to the standard level of ANSI/ASHRAE /IESNA Standard 90.1-2007 for each zone. As can be seen from the table, lighting electricity deceased by 58%, energy per total building area decreased from 247 to 217 kBtu/ft^2 (2.8 to 2.46MJ/m^2), and 12% reduction in total building energy usage is achieved.

Table 12. Lighting Power Density Reduction Simulation Results

	Average Lighting power density W/ft^2 (W/m^2)	Electricity of Interior Lighting kBtu (MJ)	Energy Per Total Building Area kBtu/ft^2 (MJ/m^2)	Total Energy kBtu(MJ)
Before Reduction	2.5 (26.9)	5.1×10^6 (5.3×10^6)	247 (2800)	29.6×10^6 (31.2×10^6)
After Reduction	0.86 (9.2)	2.1×10^6 (2.2×10^6)	217 (2480)	26×10^6 (27.4×10^6)

Installing High Efficiency Windows

In this project, all windows are considered as double pane ½ inch air space aluminum frame. For energy saving purposes and to reduce energy transferred through windows, thermal insulation of windows is increased. We used the heat transmission coefficient (U-value) and Solar Heat Gain Coefficient (SHGC) recommended for saving 50% energy in hospitals in “Large Hospital 50% Energy Savings: Technical Support.” Therefore, for calculating energy saved by applying high efficiency windows, the U-value and SHGC have been decreased from 0.81 to 0.43 Btu/h-ft^2-F and 0.59 to 0.26, respectively. Based on information results, energy per total building area decreased from 247to 244kBtu/ft^2 (2800-2770 MJ/m^2) and total energy was reduced by 1 %.

Table 13. Window Change Simulation Results

	U value Btu/h-ft^2-F (W/m^2-k)	SHGC	Energy Per Total Building Area kBtu/ft^2(MJ/m^2)	Total Energy kBtu(MJ)
Before change	0.81 (1.4)	0.59	247(2800)	29.6×10^6 (31.2×10^6)
After change	0.43 (0.74)	0.26	244 (2770)	29.3×10^6 (31×10^6)

Combination of LPD Reduction and Window Changing

In this section two previous methods are combined to see how much energy will be saved, and results are presented in Table 13. Based on simulation results, by reducing LPD and improving window thermal insulation, electricity consumption will be decreased by 20%, energy per total building reduced from 247 to 215 kBtu/ft^2 (2800-2440 MJ/m^2), and total energy usage of hospital reduced by about 13%.

Table 14. Combination of LPD Reduction and Window Changing Simulation Results

	Total Electricity kBtu (MJ)	Energy Per Total Building Area kBtu/ft^2 (MJ/m^2)	Total Energy kBtu (MJ)
Before Reduction	24×10^6 (25.3×10^6)	247 (2800)	29.6×10^6 (31.2×10^6)
After Reduction	19.8×10^6 (20.8×10^6)	215 (2450)	25.9×10^6 (27.3 ×10^6)

Installing Separate Glycol Chiller for Operating Rooms

The third recommendation is to install a separate Glycol chiller for hospital operation rooms (ORs) because of low ORs temperature required compared to other hospital areas. When one chiller is used for the whole hospital, the chilled water temperature must be low enough to provide required OR temperature, which leads to increase chiller energy consumption. Therefore, by separating ORs chiller, the chilled water temperature used for the rest of the hospital could be increased by 3-4 F while the ORs temperature still remains as low as needed. Also, a Glycol chiller has been used in this model for ORs since Glycol added in water prevents water freezing in chiller when the water temperature has been decreased. By making this change energy per total building area has been decreased from 247 to 229 kBtu/ft^2 (2800-2600 MJ/m^2) as well as 8% reduction in total energy consumption.

Table 15. Chiller Separation Simulation Results

	Energy Per Total Building Area kBtu/ft^2(MJ/m^2)	Total Energy kBtu (MJ)
Before Installing	247 (2800)	29.6×10^6 (31.2×10^6)
After Installing	229 (2600)	27.2×10^6 (28.6×10^6)

Combination of LPD Reduction and Chiller Separation

In this method two recommendations of reducing lighting power density and separating OR chiller have been applied to the model. Simulation results of these changes are included in the following table.

Table 16. Combination of LPD Reduction and Chiller Separation Simulation Results

	Energy Per Total Building Area kBtu/ft^2 (MJ/m^2)	Total Energy kBtu(MJ)
Before Reduction	247 (2800)	29.6×10^6 (31.2×10^6)
After Reduction	200 (2274)	24.2×10^6 (25.5×10^6)

Figure 7 compares the energy per to total building area (kBtu/ft^2) of the actual hospital and all four energy saving recommendations. According to Figure 7, all energy saving recommendations reduces building energy usage.

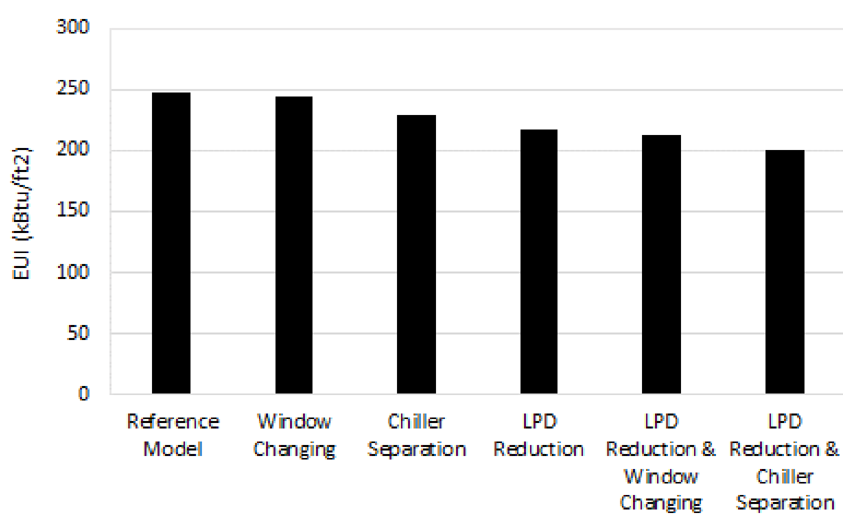


Figure 7 EUI Comparison of Different Recommendations with Reference Model

By comparing energy usage intensity of all methods, it is clear that by applying both a combination method of LPD reduction - chiller separation and LPD reduction - window changing, the highest amount of saving will be achieved. The LPD reduction method alone reduces EUI by 12%, and is the best method after the combination methods. However, results of the simulation show that by installing high-efficiency windows, only 1% EUI reduction will be achieved, which proves that this method is not as valuable as LPD reduction and chiller separation.

CONCLUSION

In this thesis, the need of retrofitting existing buildings in order to reduce energy consumption is highlighted. Also, this work emphasizes the importance of using building energy simulation for evaluating building energy consumption and amount of energy saved by implementing energy saving recommendations. As one of the most used building simulation tools, EnergyPlus simulation software is selected to model a hospital in southern Louisiana. For modeling in EnergyPlus, all information required is taken from architectural and mechanical hospital plans.

In this thesis, the results of the simulation have been validated by comparing the EUI of the reference model and baseline model included in a technical support document for large hospitals. Also, annual energy usage of the reference model is compared with actual hospital energy usage. In addition, the size of central plant equipment calculated by EnergyPlus has been compared with the actual hospital.

Five energy-saving recommendations are implemented including lowering LPD, installing high-efficiency windows, separating OR chillers from the hospital's major chiller, combination methods of LPD reduction and Window changing, and, lastly, LPD reduction and chiller separation. According to the simulation results, total hospital energy usage has been decreased by 18% after reducing the LPD and separating the OR chiller, and 12% of total building energy reduction is achieved by reducing LPD and installing high-efficiency windows. Reducing LPD will bring down the total building energy by 12%. The total building energy will be decreased by 8% and 1% after separating chillers and installing high-efficiency windows, respectively.

RECOMMENDATIONS

Using the existing model for St. Elizabeth Hospital, future analyses could include evaluation of a dedicated outdoor air system. Two other possible measures that have not yet been evaluated are the installation of daylighting control and occupancy sensors for all applicable zones. Most importantly, now that the reference model has been created and validated, further work is needed to translate this model and the required model input so that it can be readily used to assess energy savings potential (e.g. for lighting and/or HVAC changes) in any hospital in southern Louisiana. This requires a means of readily scaling the square footage of each space usage type as well as modifying the HVAC system types, lighting power densities, and plug loads before running the model simulations.

REFRENCES

Ahmadzadehtalatapeh, M., and Yau, Y. H. 2011. The application of heat pipe heat exchangers to improve the air quality and reduce the energy consumption of the air conditioning system in a hospital ward—A full year model simulation. *Energy and Buildings* 43: 2344-2355.

Alexis, G. K., and Liakos, P. 2013. A case study of a cogeneration system for a hospital in Greece. Economic and environmental impacts. *Applied Thermal Engineering*, 54: 488-496.

ASHRAE 62-2001. *Energy Standard Ventilation for Acceptable Indoor Air Quality*. Atlanta: ASHRAE.

AHSRAE 2012. Advanced energy design guide for large hospitals: achieving 50% energy savings toward a net zero energy building. https://www.ashrae.org/standards-research--technology/advanced-energy-design-guides

Bonnema, E. Studer, D., Parker, A., Pless, S, and Torcellini, P. 2010. *Large Hospital 50% Energy Savings:*Report NREL TP-550-47867. Golden. CO. National Renewable Energy Laboratory.

Brochure, M. 1997. Saving energy with Energy Efficiency in Hospitals. Center for the. Sittard: Analysis and Dissemination of Demonstrated Energy Technology.

Building Energy Initiative. 2010. Why Focus on Existing Buildings? http://www.buildingefficiencyinitiative.org/articles/why-focus-existing-buildings

Buonomano, A., Calise, F., Ferruzzi, G., and Palombo, A. 2014. Dynamic energy performance analysis: Case study for energy efficiency retrofits of hospital buildings. *Energy,* 78: 555-572.

Chimack , M. Sheaffer, A., and Davor, N. 2009. Mechanical System Technology Evaluation. Alexandria: National Center for Energy Management and Building Technologies.

Crawley, C. B., Hand, J. W., Kummert, M., and Griffith, B.T. 2008. Contrasting the capabilities of building energy performance simulation programs, *Building and Environment*. 43: 661-673.

Deng, Sh. 2017. *Energy Benefits of Different Dedicated Outdoor Air System Configuration in Various Climates*. M.S Thesis. University of Nebraska.

DOE. 2017. Industrial Assessment Centers (IACs). https://energy.gov/eere/amo/industrial-assessment-centers-iacs

DOE. 2011. Hospitals Save Energy and Money by Optimizing HVAC Performance. *Commercial Buildings Initiative* https://www1.eere.energy.gov/buildings/publications/pdfs/alliances/hea_hvac_fs.pdf

DOE 2016. Commercial Prototype Building Models. https://www.energycodes.gov/development/commercial/prototype_models

Doris, E., Cochran, J., and Vorum, M. 2009. *Energy Efficiency Policy in the United States: Overview of Trends at Different Levels of Government*. Report NREL/TP -6A246532. Golden, CO: National Renewable Energy Laboratory.

Dubois, M.C., Bisenga, F., Gentile, N., and Tetri, E. 2015. Retrofitting the Electric Lighting and Daylighting Systems to Reduce Energy Use in Buildings: A Literature Review. *Energy Research Journal*.

EIA. 2017. Americans use many types of energy. Accssed date 6 July 2017. https://www.eia.gov/energyexplained/?page=us_energy_home

EIA. 2016 a. Commercial Buildings Energy Consumption Survey (CBECS). https://www.eia.gov

EIA. 2007. Energy Characteristics and Energy Consumed in Large Hospital Buildings in the United States in 2007. https://www.eia.gov/consumption/commercial/reports/2007/large-hospital.php

EnrgyStar. 2017. What is energy usage intensity (EUI)? Accessed date 6 July 2017. https://www.energystar.gov/buildings/facility-owners-and-managers/existing-buildings/use-portfolio-manager/understand-metrics/what-energy

EnergyPlus. 2017. Getting Started- EnergyPlus Documentation. Accessed date 6 July 2017. https://energyplus.net/sites/default/files/pdfs_v8.3.0/GettingStarted.pdf

EPA. 2013. Source Energy https://portfoliomanager.energystar.gov/pdf/reference/Source%20Energy.pdf

Gourlis, G., and Kovacic, I. 2016. A study on building performance analysis for energy retrofit of existing industrial facilities. *Applied Energy*. 184: 1389-1399.

Gowri, K., Winiarski, D., and Jarnagin, R. 2009. *Infiltration Modeling Guidelines for Commercial Building Energy Analysis.*PNNL 18898. SpringField, VA. Pcific Northwest National Laboratory.

Harish, V. S. K. V., and Kumar, A. 2016. A review on modeling and simulation of building energy systems. *Renewable and Sustainable Energy Reviews*. 56: 1272-1292.

Hong,. T., Piette, M. A., Chen, Y., Lee, S. H., Taylor-Lange, S. C., Zhang, R., Sun, K., and Price, P. 2015. Commercial Building Energy Saver: An energy retrofit analysis toolkit. *Applied Energy*, 159: 298-309.

Hong, T., Chou, S. K., and Bong, T. Y. 2000. Building simulation: an overview of developments and information sources, *Building and Environment*. 34: 347-361.

Hui, S. C. M. 2003. Effective use of building energy simulation for enhancing building energy codes. *IBPSA Building Simulation Conference.*

Jarik, M., Budimir, N., Pejanovic, M., and Svetel, I. 2013. A Review of Energy Analysis Simulation Tools, *7th International Working Conference.*

Kapour, R, and K. Satish. 2009. Energy Efficiency in Hospitals Bets Practice Guide. New Delhi: International Resource Group.

Khodakarami, J., Knight, I., and Nasrollahi, N. 2009. Reducing the demands of heating and cooling in Iranian hospitals. *Renewable Energy,* 34: 1162-1168.

Maleetipwan-Mattsson, P., Laike, T., and Johansson, M. 2016. Factors affecting optimal lighting use in shared hospital environments: A case-study. *Building and Environment*, 96: 260-269.

Neto, A. H., and Fiorelli, A. F. S. 2008. Comparison between detailed model simulation and artificial neural network for forecasting building energy consumption, *Energy and Buildings*. 40: 2169-2176.

Noie-Baghban, S. H., and Majideian, G. R. 2000. Waste heat recovery using heat pipe heat exchanger (HPHE) for surgery rooms in hospitals, *Applied Thermal Engineering* 20 (14): 1271–1282.

Rasouli, M., Akbari, S., Simonson, G. J., and Besant, R. W. 2014. Energetic, economic and environmental analysis of a health-care facility HVAC system equipped with a run-around membrane energy exchanger. *Energy and Buildings* 69: 112-121.

Siddharth, V., Ramakrishna, P. V., Geetha, T., and Sivasubramaniam, A. 2011. Automatic generation of energy conservation measures in buildings using genetic algorithms. *Energy and Buildings* 43: 2718-2726.

Software Tools for Energy Efficient Buildings, Washington, Buildings for the 21th Century. 1999.

Sousa, J. 2012. Energy simulation software for buildings: Review and comparison. *Proceedings of the international workshop on information technology for energy applications*

Sheppy, M., Pless, Sh., and Kung, F. 2014. *Healthcare Energy End-Use Monitoring* . Report NREL/TP 5500-61064. Golden, CO: National Renewable Energy Laboratory.

Tan, B., Yavuz, Y., Otay, E. N., and Camlibel, E. 2016. Optimal selection of energy efficiency measures for energy sustainability of existing buildings. *Computers and Operations Research*, 66: 258–271.

Testa, J., and Kerarti, M. 2017. Evaluation of energy savings potential of variable reflective roofing systems for US buildings. *Sustainable Cities and Socity,* 31: 62-73.

Vakiloroaya, V., Samali, B., Fakhar, A., and Pishghadam, K. 2014. A review of different strategies for HVAC energy saving*, Energy Conservation and Management*. 77: 738-754.

Wang, T., Li, X., Liao, P. C., and Fang, C. 2016. Building energy efficiency for public hospitals and healthcare facilities in China: Barriers and drivers. *Energy*, 103: 588-597

APPENDIX A

Appendix A provides detailed model input and steps. A word file contains all steps taken to generate a model of St. Elizabeth Hospital in EnergyPlus. In this document, a brief description of each object is given, along with required information for the object. Also, a screenshot of each object is attached to give the user an idea of how the EnergyPlus window looks. At the end of this document, a list of all schedules used is provided in sets of tables. Appendix A is an attached DVD file.

APPENDIX B

Appendix B provides the model files to run the model in EnergyPlus. IDF files of the original model and modified files after applying each energy saving recommendation are included. Appendix B is an attached DVD file.

APPENDIX C

Appendix C is a Getting Started Guide to help new users to start working with EnergyPlus. The guide presents a brief description of the basic EnrgyPlus features, components, and capabilities. An EnergyPlus new user will be able to start work by reading this document. Appendix C is an attached DVD file.

APPENDIX D

Appendix D is an ASHRAE Conference Paper submitted for the January 2018 Winter Annual Meeting. This thesis, "Modeling a Hospital in South Louisiana for Evaluation of Potential Energy Savings," provides a complete overview of the work presented in this thesis, with the exception of two subsequent energy-saving measures evaluated.

Modeling a Hospital in South Louisiana for Evaluation of Potential Energy Savings

Zahra Sardouienasab *Student Member ASHRAE*

Sally Anne M[c]Inerny, P.E., Ph.D. *Member ASHRAE*

Chris Morgan, P.E. *Member ASHRAE*

Peng Yin, Ph.D. *Member ASHRAE*

Abstract

Due to the continuous operation of HVAC systems and stringent requirements for indoor environmental conditions, the total energy use per floor area in healthcare facilities is second only to that of food service buildings and significantly higher than other commercial building types. In order to evaluate potential opportunities for saving energy in healthcare facilities, a model of a hospital located in South Louisiana was developed in a public domain building energy simulation program. Building information required for the model development was taken from the hospital architectural and mechanical plans. A field survey was also conducted to identify plug loads and the central plant equipment. A multizone HVAC system consisting of a variable air volume (VAV) system and fan-coil units was implemented in the developed model. The annual electricity and natural gas consumption

estimated by the developed model was compared with a published study and to actual utility data for model validation. Three energy efficiency measures were evaluated using the developed models, namely reducing lighting power density, installing high efficiency windows, and the combination of both approaches. Simulation results showed a 12% annual energy savings by reducing the assumed average lighting power density from 2.5 Watts/ft^2 (27 Watts/m^2) to zone specific values - based on the applicable ASHRAE standard. Only a 1% savings resulted from using high efficiency windows. The combination of both approaches could reduce the annual energy consumption by 13% based on the simulation results. The development of a validated hospital model enables the further exploration of potential energy-saving opportunities in healthcare facilities in South Louisiana.

Introduction

The Department of Energy (DOE) funded an Industrial Assessment Center (IAC) at the University of Louisiana at Lafayette (UL) for over a decade starting in the year 2000. IACs provide no-cost energy audits/ assessments to small and medium sized manufacturers within the standard industrial code range of 20-39 (DOE 2017). After the UL IAC was phased out and the lead faculty member retired, the department of Mechanical Engineering at UL received a grant from the Louisiana Department of Natural Resources (DNR) to support a continuation of the energy audit work. This grant allowed the new team to look beyond the manufacturing sector for energy audit opportunities.

In the United States, the energy consumption of commercial buildings in 2016 accounted for 20% of the total site energy used by the four end use sectors, namely residential, commercial, industrial, and transportation (EIA, 2017). To compare the energy use of different building types, building energy consumption is frequently characterized in terms of energy use intensity (EUI) as measured in kBtu/ft^2 or GJ/m^2. Figure 1 shows the EUI for different types of commercial building. As can be seen in Figure 1, the EUI of inpatient healthcare facilities or hospitals is second only to that of food service buildings and well above the EUIs of the other building types. Given the fact of high EUIs in hospitals and a large quantity of hospitals located in the South Louisiana, it is necessary to investigate the energy use in hospitals and evaluate the energy savings potential.

In 2016, commercial buildings consumed 20% of the total energy (in the U.S.) used by the four end use sectors: residential, commercial, industrial, and transportation (EIA, 2017). When electrical consumption is converted from site to source energy (EPA 2013) this increases to 25%. Figure 1in main content shows that the site energy use intensity (EUI), as measured in kBtu/ft^2 or GJ/m^2, varies substantially by property type within the building sector. This figure is based on 2003 and 2012 Commercial Building Energy Consumption Survey (CBECS) data published by the Energy Information Agency (EIA 2016a). The property types with the highest site EUIs are food service and inpatient healthcare or hospitals. Given the high site EUI of hospitals, the fact that healthcare is a growth business, and the availability of a local hospital – interested in working with the university - together with an alumnus specializing in hospital HVAC design, we chose to develop greater expertise in hospital energy usage and potential energy saving measures.

The purpose of this paper is twofold. It provides a summary of hospital energy use and the prior work on reducing energy consumption in hospitals, a model of a hospital located in South Louisiana was developed and validated with one-year of utility data. A series of building energy simulations were performed to evaluate three energy efficient measures, namely reducing lighting power density, installing high efficiency windows, and the combination of both approaches.

Energy Use in Hospitals

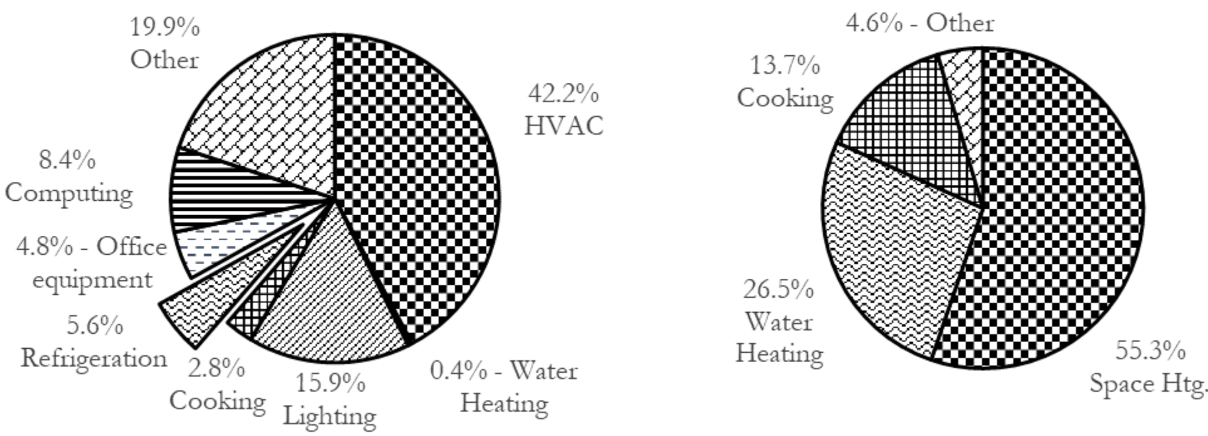
The high EUI of hospitals as shown in Figure 1 is driven by 24-hour, seven-day a week operations coupled with high ventilation, sterilization, and space cooling demands, including those specialized (e.g. surgical suites) spaces with intensive cooling, high demand of outside air, and stringent humidity control. A breakdown of the energy consumed in U.S. hospitals by fuel type in the year 2012 is given in Table 17 (EIA 2016b). Note that while the site totals for electricity and natural gas are close, the source or primary energy use of electricity is far larger than that of natural gas.

Figure 8 provides a breakdown of electrical energy, Fig. 8(a), and natural gas, Fig. 2(b), usage within hospitals (EIA 2016c&d). Space heating, Fig. 8(b), includes the energy for reheat coils, which are common in older hospitals. Reheat energy comprises 20-30% of all of the energy use by hospitals regardless of the climate zone. (ASHRAE 2012) There is little demand for true space heating in southern Louisiana, but humidity control needs are significant. More detailed information on the breakdown of energy use in two hospitals in the northeast can be found in National Renewal Energy Laboratory (NREL) technical report (Sheppy et al 2014).

Between the natural gas usage for space heating in Fig. 8(b) and the electrical usage for HVAC systems in Fig. 8(a), it is clear that HVAC systems are the largest energy user in hospitals. Therefore, increasing the efficiency of HVAC systems offers the greatest energy savings potential. Factoring in the increase in site to source energy for electrical systems, the next major users of primary energy in hospitals are plug loads and lighting. Plug loads include those for medical and diagnostic equipment and instrumentation.

Table 17. Total Energy Consumption By Major Fuels For Hospitals. (EIA 2016b)

Number of Buildings	Floor Space	Sum of Major Fuels	Electricity - Primary/Site	Natural Gas	Fuel Oil	District Heat
10,000	2,380l. Mi Ft^2 (221) (Mil M^2)	549 TBTU (580,000) (TJ)	766/251 TBTU (809,000/265,000) (TJ)	219 TBTU (231,000TJ)	16 TBTU (17,000TJ)	62 TBTU (65,000TJ)



Electrical b) Natural Gas

Figure 8 Breakdown of Hospital Energy Usage (a) Electrical and (b) Natural Gas

Reducing Energy Consumption in Hospitals

Design for New Hospitals Bonnema et al (2010) authored a seminal NREL technical report entitled "Large Hospitals 50% Energy Savings: Technical Support Document" in which they predicted a 50-60% energy savings could be achieved beyond those achieved in a baseline hospital compliant with ASHRAE Standard 90.1-2004. Energy use estimates were obtained from models of the baseline and low energy hospitals using DOE's EnergyPlus software. The additional measures taken to achieve the low energy building included: lighting changes - reduced light power densities, daylighting sensors and occupancy sensors in applicable zones; envelope measures - opaque exterior, windows, overhangs on south facing windows, reduced infiltration; and HVAC systems - multizone variable air volume dedicated outdoor air system with zone level heat pumps, as well as high efficiency chillers, boilers, water heaters, and pumps. The biggest energy savings "by far" resulted from the change of the HVAC system from a constant air volume (CAV) air handlers to a dedicated outside air system with water loop heat pumps (DOAS/WLHP), thereby decoupling the space conditioning and ventilation loads and eliminating reheat. ASHRAE's Advanced Energy Design Guide for Large Hospitals reflects the findings of Bonnema et al 2010 as well as fourteen other relevant reference sources (ASHRAE 2012).

Noorts and Murphy designed a new LEED Gold patient tower for an existing hospital in Park Ridge, Illinois. The major energy savings features were an energy efficient building envelope, a green roof, high efficiency lighting with occupancy sensors where applicable, low velocity air-handling units, multiple smaller air handling units (AHU), and a high efficiency condensing water boiler (Noorts and Murphy 2011). The result was a 23.1% energy savings (21.3% energy cost savings) relative to a 90.1 base case. These estimates were based on baseline and as designed model comparisons performed using eQuest/DOE2.2 software (DOE 2016a). Lawless (2013) and his team designed a new medical center in Grafton, Wis. Their design also targeted the high energy users in hospitals: lighting, fan energy, reheat, and heating and cooling system equipment. Air handling units were designed for maximum face velocities of 350 fpm (1.8 m/s) and energy recovery chillers were used to transfer energy to the hot water loop. Implementation of these and many other measures recommended in ASHRAE's Advanced Energy Design Guide for Large Hospitals resulted in annual savings of $340,000 a year with a payback period of less than four years. Monteiro, Frayne and their design team designed "the first 'fully digital' medical facility in North America (Monteiro and Frayne 2017). This hospital is located in Toronto. Their design incorporated many of the same features as Lawless' team as well as a green roof, electrochromic glass, and DOAS system. eQUEST v3.64 (DOE 2016a) was used to show compliance with the goal of exceeding Standard 90.1-2007 by 40.8%.

Existing Hospital Retrofits and Upgrades. Kafesdjian (2011) wrote about a major upgrade to a psychiatric hospital located in Montreal. Designers identified almost 38 savings measures for the facility of which the hospital selected 18. These measures included a geothermal system for off-peak domestic hot water, heat reclaim from chimney stacks, variable speed boiler feedwater pumps, replacement of pneumatic with direct digital controls, lighting changes (T12 to T8 fluorescent fixtures), and sealing of more than 4,300 windows. The result was a 14.6% reduction in total hospital energy use. Desmarais (2011) summarized the energy savings measures in the retrofit of and expansion to a medical hospital, also in Montreal. A dual-compressor centrifugal chiller was employed to recover heat from the interior of the building and transfer it to low temperature heating loops in the exterior of the building. Other measures included the use of enthalpy wheels and a medium speed air-distribution system. The overall result, estimated using EE4 and DOE2.1e simulation software, was a decrease in energy consumption of 30% in the new addition and of 10% for the "rehabilitated portion of the hospital."

Hanlon et al. (2010) reported on a major retrocommissioning of a hospital in Fort Scott, Kansas. The hospital, while only in operation for three years, had operating costs almost double the average for the hospital system it was in. An energy services team identified 130 energy cost reduction measures of which the system administrators chose 24. All of these were related to the HVAC system and its operations. The largest contribution to excessive energy use was the "simultaneous heating and cooling costs associated with high minimum airflow rates and improper control sequences." The total cost of the measures implemented was $208,000 with an estimated annual cost savings of $181,000.

Even without a major renovation/addition there are many changes that can be made incrementally as part of regular maintenance work and have favorable payback periods. The "Mechanical Systems Handbook for Healthcare Facilities" includes a chapter on HVAC Energy Management Opportunities (Barrick and Holdaway 2014). This chapter provides a checklist of things to look for in existing hospitals. There are three subsections: Building Envelope, Lighting, and Powerhouse. The section on building envelope begins by stating that envelope loads, providing there are no major leaks or roof damage, are generally a relatively insignificant contributor to the overall heating and cooling load. Major changes to the roof, wall insulations, and windows (unless there are major issues) have a long payback period unless undertaken in conjunction with a major renovation or addition. More likely to yield energy savings with reasonable (2 to 3 year) payback are the changes to lighting, HVAC operations and controls, and regular recalibration and tuning of HVAC equipment. Two DOE fact sheets (DOE 2011a and 2011b) also provide recommendations on changes to lighting, HVAC controls, schedules, and balancing.

Reference Hospital Model

Building Modeling Software – EnergyPlus. There are many building simulation packages available that differ in cost, complexity, simulation capabilities, and calculation methods. Of these, DOE's EnergyPlus software is considered to be one of the best choices (Crawley et al. 2008, Harish et al, 2016, Jaric et al. 2013). EnergyPlus incorporates the features and capabilities of DOE-2 and BLAST, two other simulation programs. While EnergyPlus is complex, takes considerable time to learn how to use, and is not very user friendly, it is also free, widely used, and has been extensively applied in published academic studies and in commercial applications.

Model Basis and Details. The authors gratefully acknowledge the assistance provided by the administrators at St. Elizabeth Hospital in Gonzalez, Louisiana, in the development of the reference hospital model. Gonzales is in Ascension Parish and about 20 miles southeast of Baton Rouge. The team was given access to a full set of architectural and mechanical plans, provided with a year's worth of utility bills, and permitted to undertake detailed site audits of the electrical equipment (plug loads) in each zone and of the central plant equipment. St. Elizabeth's Hospital is a member of the Franciscan Missionaries of Our Lady Health System.

An illustration of the hospital model developed in EnergyPlus. It is a two-story 120,000 ft2 (11,200 m2) building that consists of both an older part and a new two-story addition built in 2009. The EnergyPlus model is divided into 30 zones, each with its own space conditioning and equipment requirements. Some of the model details are provided here, while full documentation will be available in the masters' thesis of the first author in late 2017.

Tables 2 and 3 in main content provide information on the surface material and fenestration inputs. The number of people assumed in each zone was based on the zone space usage and ANSI/ASHRAE Standard 62-2001. The lighting power density was taken as 2.5

Watts/ft2 (27 Watts/m2) based on a local rule of thumb used for initial hospital HVAC system sizing. Plug loads were determined based on a site audit and the 2001 ASHRAE Fundamentals Handbook. The team was not able to visit the surgical suites, so the equipment loads for the surgical suite are based on (Sheppy et al 2014).

The HVAC system types in Table 5 in main content are based on the actual hospital systems. There are a total of 14 different air handlers, some of which feed multiple zones. Thirteen of the 30 zones have fan coil units. Chilled and hot water loop temperatures were taken as 45 F (7.22 C) and 180 F (82.2 C), respectively. Room temperatures were set for dual set point control with cooling and heating set point temperatures and the allowable humidity range taken from (Bonnema et al 2010). Ventilation was based on space usage and ANSI/ASHRAE Standard 62-2001, Addendum N. The reference Infiltration Modeling Guidelines for Commercial Building Energy Analysis was used to estimate an infiltration rate of 1.8 cfm/ft2 (9.15x10-3 m3/s/m2) of above grade envelope surface area (Gowri et al 2009). Occupancy, lighting, and equipment schedules are based DOE's Commercial Building Reference model (EnergyPlus files) for a hospital (DOE 2016b).

Model Validation

The first step in the validation of the model was to compare the site EUI calculated with our model to that obtained by Bonnema et al. 2010 for their baseline Standard 90.1-2004 compliant model. Bonnema et al.'s baseline model had a site EUI of 413.5 kBtu/ft^2.yr (4,698 MJ/m^2.yr); whereas our model resulted in a much smaller site EUI of 270 kBtu/ft^2.yr (3,100 MJ/m^2.yr). A review of the differences in assumptions indicated that the Bonnema et al model assumed CAV systems while ours were VAV. When the HVAC systems in our model were changed from VAV to CAV, the result was a site EUI 446.5 kBtu/ft^2.yr (5,072

MJ/m2.yr) or roughly 8% greater than Bonnema et al.'s baseline model. Given that the lighting power density in our model was an average of 2.5 W/ft^2 (26.9 W/m^2) and the corresponding value in the Bonnema baseline model was 1.2 W/ft^2 (12.9 W/m^2), these results are in reasonable agreement.

Next, the annual energy consumption predicted by our model – using the actual VAV systems – was compared to the 2016 total calculated from the utility bills for St. Elizabeth Hospital. The actual electricity 2016 consumption was 22.5x106 kBtu (6.6x10^6 kWh), almost 20% lower than the model prediction of 26.6x10^6 kBtu (7.8x10^6 kWh). At this point, the energy consumption of the medical equipment (plug loads) was further examined. Sheppy et al. (2014) found that high intensity medical equipment, such as MRI and CT scanners, should not be assumed to operate at 100% during peak hours, rather an average operating power should be assumed. When this was adjusted in our model, the result was a total yearly electrical usage of 22.8x10^6 kBtu (6.7x10^6 kWh), a result uncannily (and unexpectedly) close to the actual 2016 actual value. Finally, the actual 2016 gas usage of 13.8x106 CCF (39.1x10^6 m^3) compared well with the model prediction of 14.7x106 CCF (41.7x10^6 m^3).

Primary Evaluation of Two Energy Reduction Measures. Once we had a model in which we had some confidence, the predicted energy savings for changing to high efficiency windows and decreasing the lighting power density were determined. When the windows in the model were changed from to more energy efficient windows – U value decreased from 0.81 Btu/h-ft^2-F (1.4 W/m-K) to 0.43 Btu/h-ft^2-F (0.74 W/m-K) and the SHGC decreased from 0.59 to 0.26, then the annual energy usage decreased by a little over 1%. Separately, the lighting power density was changed from an average of 2.5 watt/ft^2 (26.9 W/m^2) for the entire hospital to zone specific values based on the actual space usage and ANSI/ASHRAE

/IESNA Standard 90.1-2007. The result was an average lighting power density 0.86 (9.2 W/m^2) and annual energy consumption decreased by a little over 12%. The resultant when both measures were applied together, the predicted decrease was close to 13%.

Conclusion

A review of literature on hospital energy reveals that the greatest potential for energy savings in existing hospitals is in the modification and tuning of their HVAC systems. Second to that, changes in lighting generally offer the potential for significant energy savings. An EnergyPlus model of an existing hospital in Gonzales, LA, was developed with the goal of using it as a reference model to estimate savings associated with energy conservation measures generated by energy audits. The model was validated by comparing the EUI obtained for our model with that of a previously published model, and by comparison against actual annual energy use in the Gonzales hospital. Once the model was validated it was exercised to show a very small energy savings of 1% from changing the windows to high efficiency windows and a 12% reduction in energy use when assumed average lighting power density used (based on a local initial design estimate for hospitals) was replaced with zone specific lighting based on actual space usage.

References

ASHRAE 2012. Advanced energy design guide for large hospitals: achieving 50% energy savings toward a net zero energy building. https://www.ashrae.org/standards-research--technology/advanced-energy-design-guides

Barrick, J.R. and R.G. Holdaway. Mechanical System Handbook for Healthcare Facilities. Chicago: ASHE, 2014.

Bonnema, Eric, Studer, Daniel, Parker, Andrew, Pless, Shanti and P. Torcellini. 2010. Large Hospital 50% Energy Savings: Technical Support Document. Golden. National Renewable Energy Laboratory.

Crawley, C.B., Hand, J. W., Kummert, M., and B.T. Griffith. 2008. Contrasting the capabilities of building energy performance simulation programs, *Building and Environment*. 43:661-673.

Desmarais, G. 2011. Hospital Retrofit. *ASHRAE Journal* 53(3): 32-35.

DOE. 2011a. *Energy Efficient Hospital Lighting Strategies Quickly Pay Off. Commercial Buildings Initiative* https://www1.eere.energy.gov/buildings/publications/pdfs/alliances/hea_lighting_fs.pdf

DOE. 2011b. *Hospitals Save Energy and Money by Optimizing HVAC Performance. Commercial Buildings Initiative* https://www1.eere.energy.gov/buildings/publications/pdfs/alliances/hea_hvac_fs.pdf

DOE 2016a. eQuest The Quick Energy Simulation Tool. http://www.doe2.com/equest/

DOE 2016b. Commercial Prototype Building Models. https://www.energycodes.gov/development/commercial/prototype_models

EIA. 2016a. Commercial Buildings Energy Consumption Survey (CBECS). https://www.eia.gov

EIA 2016b. Total energy consumption by major fuel. https://www.eia.gov/consumption/commercial/data/2012/c&e/pdf/c1.pdf

EIA 2016c. Electricity consumption (Btu) by end use https://www.eia.gov/consumption/commercial/data/2012/c&e/pdf/e3.pdf

EIA 2016d. Natural gas consumption and conditional energy intensities (Btu) by end use https:/www.eia.gov/consumption/commercial/data/2012/c&e/pdf/e7.pdf

EIA. 2017. Americans use many types of energy. Accessed 6 July 2017. https://www.eia.gov/energyexplained/?page=us_energy_home.

EnergyPlus 2017. Accessed 6 July 2017. https://energyplus.net

Gowri, K. Winiarski, D., and R. Jarnagin. 2009. Infiltration Modeling Guidelines for Commercial Building Energy Analysis. Pacific Northwest National Laboratory.

Harish, V.S.K.V., and A. Kumar. 2016. A review on modeling and simulation of building energy systems. *Renewable and Sustainable Energy Reviews*. 56:1272-1292.

Hanlon, T. Tinsley, E. and T. Staley. 2010. Commissioning Hospital: Retrocommissioning. ASHRAE Journal 52(5): 46-48.

Jarik, M., Budimir, N., Pejanovic, M., and I. Svetel. 2013. A Review of Energy Analysis Simulation Tools, *7th International Working Conference.*

Kafesdjian, K. 2011. Hospital Upgrade: Heat Recovery, Geothermal Save Energy. ASHRAE Journal 53(8): 44-46.

Lawless, J.M. 2013. Reheat for Medical Center. *ASHRAE Journal* 55(6): 46-50.

Monteiro, K. and B. Frayn. 2017. Actue Care: Lean and Green & Digital. ASHRAE Journal 59(3): 80-86.

Noorts, G. and M.W Murphy. 2011. Creating a Heating Environment: Efficient Hospital. *ASHRAE Journal* 53(11): 52-57.

Sheppy, M., Pless, Sh., and F., Kung. 2014. Healthcare Energy End-Use Monitoring . Technical Report. Golden, National Renewable Energy.

Zahra Sardoueinasab. Bachelor of Science, University of Kerman, 2007; Master of Science, University of Louisiana at Lafayette, summer 2017
Major: Mechanical Engineering
Title of Thesis: Modeling a Hospital in South Louisiana for Evaluation of Potential Energy Savings
Thesis Director: Dr. Sally Anne McInerny
Pages in Thesis: 72; Words in Abstract: 232

ABSTRACT

Due to the continuous operation of HVAC systems and stringent requirements of indoor environmental conditions, the total energy use per floor area in healthcare facilities is second only to that in food service buildings, and significantly higher than that in any other commercial building types. In order to evaluate potential opportunities for saving energy in healthcare facilities, a model of a hospital located in south Louisiana was developed in EnergyPlus simulation software. Building information required for the model development was taken from the hospital architectural and mechanical plans. Two field surveys were also conducted to identify the operating characteristics of electrical equipment and gas equipment. The annual electricity and natural gas consumption estimated by the developed model was compared with utility data for model validation. Five energy efficient measures were evaluated using the developed models, namely reducing LPD, installing high efficiency windows, the combination method of reducing LPD and window changing approaches, installing a separate chiller for OR, and another combination of LPD reduction and chiller separation. Simulation results showed 12% annual energy savings by reducing LPD from 2.5 to 0.86 W/ft^2 while only 1% savings resulted from using high-efficiency windows. The combination of LPD reduction and window changing could reduce the annual energy consumption by 13%. Building energy usage has been decreased by 8% after separating the OR chiller and 18% by the combination method of reducing LPD and separating chillers.

BIOGRAPHICAL SKETCH

Zahra Sardoueinasab was born on April 24th, 1984 in Kerman, Iran. She completed her bachelor's degree in mechanical engineering from the University of Shahid Bahonar, Kerman, Iran in 2007. She worked as a manager of quality of control and gas inspector from 2008-2012.

She joined the Master of Science program in mechanical engineering at the University of Louisiana at Lafayette in January of 2015. She earned her Master of Science in mechanical engineering in August of 2017.