SIMULATIONS OF DESIGN MODIFICATIONS IN MILITARY HEALTH FACILITIES

A Thesis

by

CHRISTOPHER WILLIAM KISS

Submitted to the Office of Graduate Studies of
Texas A&M University
in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

May 2011

Major Subject: Construction Management

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Approved by:

Chair of Committee,	Sarel Lavy-Leibovich
Committee Members,	José L. Fernández-Solís
	Jeff S. Haberl
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ABSTRACT

Simulations of Design Modifications in Military Health Facilities. (May 2011)
Christopher William Kiss, B. Arch., Norwich University; M. Arch., Norwich University
Chair of Advisory Committee: Dr. Sarel Lavy-Leibovich

Developments in sustainability and evidence-based design (EBD) have created additional requirements for the design and construction of facilities. Facilities in the Military Health System (MHS) have been directed to undergo restoration and modernization by Department of Defense (DOD) leadership. The hospital building type has one of the highest energy intensities out of all commercial building types. Hospitals have become more energy intense due to the evolution of the deep-plan hospital. The design of the building envelope is the most lasting feature affecting the energy use of a hospital. The building envelope design consists of the shape of the building, material selection, as well as its orientation.

A review of literature identified EBD features which affect the design of the building envelope. An assessment of military medical facilities compiled their location, climate zone, age, size, patient capacity, and wall to floor area ratios. Two case-study hospitals were selected based on their recent construction and location in extreme climate zones. A small community hospital located in Alaska, and a large medical center located in Texas. Incremental simulations of simple hospital building forms were conducted in each climate zone to verify current literature recommendations for design. Benchmark metrics were derived from ASHRAE Standard 90.1-2010 and CBECS 2003 survey data.

The results examined the scale of the impact of increased daylighting features on the energy performance of the facilities. The building shape had the greatest impact on the energy use of the buildings; specifically those shapes which had the largest amount of window area consumed the most energy. The increase in energy consumption, however, was not extraordinary when considering the potential gains in patient care and medical outcomes. Additionally, the building internal loads, mechanical systems such as domestic hot water, represented a large percentage of the energy consumption. The design recommendations were to optimize building envelopes with improved envelope materials and systems, as well as site orientation. The largest areas for potential gains, the internal loads, were identified as largely unaffected by the building envelope. It is recommended that efficient equipment selection be a primary task in design.

ACKNOWLEDGEMENTS

I would like to thank my committee chair, Dr. Sarel Lavy for all his guidance and motivation throughout the course of this research. The rest of my committee, I am grateful to Dr. Jose Fernandez-Solis for his enthusiasm for research and for maintaining my motivation throughout. I am especially thankful to Dr. Jeff Haberl for his ability to provide focus to my study.

I am grateful to Dr. Zofia Rybkowski, for her assistance in developing a thesis topic. I am appreciative of numerous other faculty for their involvement and mentorship during my program of study.

I want to thank my family and friends for sustaining me for these twenty three short months. To my parents, Bill and Sue Kiss, I want to give thanks for all the years of support and encouragement as well as instilling in me the importance of a good work ethic. To my wife, Jill, I want to thank her for her equal amount of effort to ensure that “we” were successful in graduate school and as a family. To my son, Jake, I am grateful for the motivation that he gives me to be a better person and father.

There are too many names to list them all, I am grateful for everyone who has crossed my path. Each and every person has helped me in some way or another.

NOMENCLATURE

ACH	air changes per hour
ACSIEFM	Assistant Chief of Staff for Installation, Environment and Facility Management
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BPS	building performance simulation
Btu	British thermal unit
CBECS	Commercial Buildings Energy Consumption Survey
DOAS	dedicated outdoor air systems
DOD	Department of Defense
DOE	Department of Energy
EBD	evidence-based design
EDM	energy design measure
EIA	U.S. Energy Information Administration
EPA	U.S. Environmental Protection Agency
eQUEST	the quick energy simulation tool (software)
FEMP	Federal Energy Management Program
GGHC	Green Guide for Health Care
GSA	U.S. General Services Administration
GUI	graphic user interface
HVAC	heating, ventilation and air-conditioning
IAQ	indoor air quality
IEQ	indoor environmental quality
IRS	Internal Revenue Service
kBtu	thousand British thermal units
LCCA	life cycle cost analysis
MEDCOM	U. S. Army Medical Command

MHS	Military Health System
MILCON	military construction
NCR	National Capital Region
NIST	National Institute of Standards and Technology
NREL	National Renewable Energy Laboratory
OA	outside air
RMI	Rocky Mountain Institute
sf	square foot
TMA	TRICARE Management Activity
VAV	variable air volume
WWR	window to wall ratio

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1. INTRODUCTION

1.1 Background

One of the most prominent topics within the built environment is sustainability. According to Dell'Isola and Kirk (2003), environmental sustainability is defined as the pursuit of alternate methods of construction that attempt to mitigate harm to the environment. The cost to design and construct facilities, as well as to support their operations and maintenance are growing, largely due to rising energy and material costs (Huang et al. 2009; EIA 2004a). In addition to the decreasing availability of sources of nonrenewable energy, the number of buildings and floor space has steadily increased. According to the Energy Information Administration (EIA 2004b), from 1979 to 2003, the commercial floor space increased almost 30%, and the overall commercial building energy consumption increased by 9%.Heating/cooling, lighting, and communication power demands in facilities are driving up the energy requirements at increasing rates (EIA 2007).

The need for sustainability goes far beyond the initial construction of a building. The costs of initial design and construction are a fraction of the operations and maintenance when compared as life cycle costs of a facility (Dell'Isola and Kirk 2003). The operation costs of a facility are becoming more of a concern in a business world where buildings are looked upon as strategic assets that are either a source of revenue or a liability required for operations. In the healthcare built environment, the business cost of healthcare outcomes is multiple times larger than the construction cost or the operating and maintenance costs combined (Sadler et al. 2008). Of the typical life cycle costs of a hospital, 64 percent are attributed to personnel costs, such as salary and contracted services (Dell'Isola and Kirk 2003). Figure 1: Life cycle cost of ownership, typical hospital (Adapted from Dell'Isola and Kirk 2003), is recreated from Dell'Isola and Kirk's work and shows the heavy weight of personnel costs in hospital ownership.

This thesis follows the style of *Journal of Energy Engineering.*

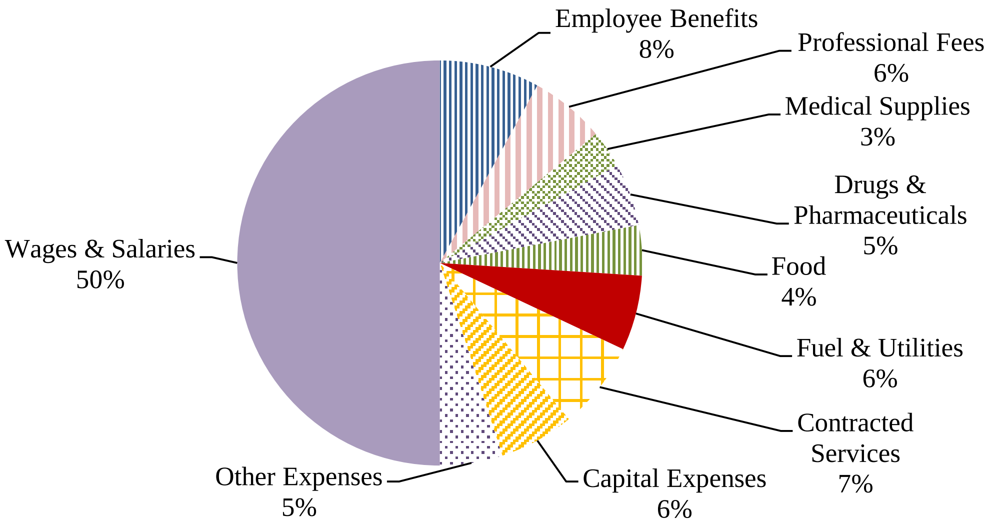


Figure 1: Life cycle cost of ownership, typical hospital (Adapted from Dell'Isola and Kirk 2003)

The capital expenses of hospital ownership consist of initial construction and renovation costs. These costs of ownership amount to approximately 6% of the average overall cost of hospital ownership. The initial costs of construction are a small portion when compared to the future costs that occur in the hospital. The fuel and utility expenses for a hospital are on average 6% of the overall costs as well. The energy costs are a small portion when compared to the personnel costs in a hospital.

1.1.1 Demand Trends

The health trends of the nation are impacting the healthcare facility management and construction market. According to Bridgers et al. (2005), some of the major trends affecting healthcare facility planning are the: Aging population; financial constraints of hospitals; and; the aging healthcare facilities. According to Ulrich et al. (2008), this convergence of multiple factors has created an opportunity for dramatic positive change within the healthcare system.

The U.S. baby boomer population has been an impetus of change throughout their lifetimes because of the large population segment. The aging population utilizes inpatient services at a much higher rate than those younger, and 50% of the U.S. healthcare expenditures are spent on the current senior population (Bridgers et al. 2005). The proportion of senior (over 65 years old) demographic will increase drastically as compared to the other demographics. The expectation is that the increasing requirement for inpatient capacity for the aging will drive the need for additional hospital construction in the future.

The MHS patient population consists of military, family members, and retirees. In Figure 2: MHS enrollment trends (Adapted from MHS 2010), the patient population steadily increases. The active-duty service members and their families segment of the population receive treatment in Military Treatment Facilities (MTF), while the purchased care segment are military reservists, retirees, and their families either located away from a MTF, or after exceeding the capability of the MTF.

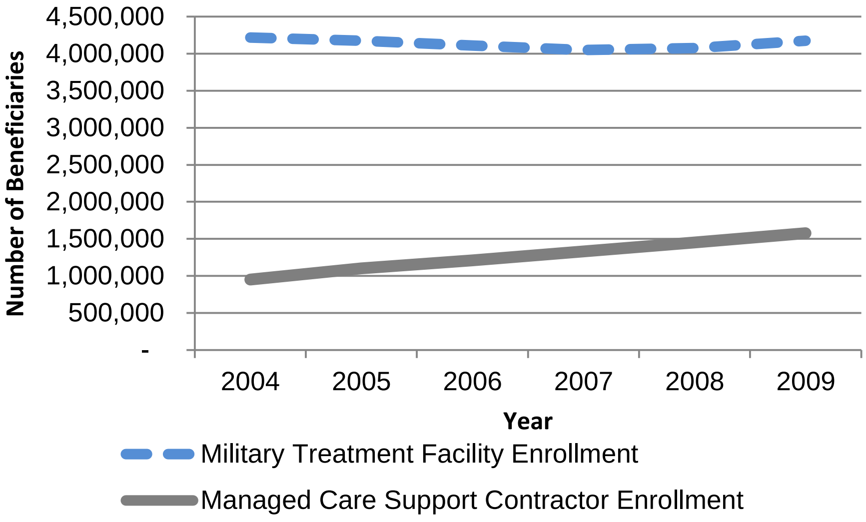


Figure 2: MHS enrollment trends (Adapted from MHS 2010)

In Figure 3: Total MHS inpatient workload (Adapted from MHS 2010), the MHS has maintained a steady growth in the amount of inpatient days provided by the system. The segment of the population that shows the increases are those away from the MTF locations or exceeding the MTF capability. The rate of increase is not comparative to the historical ratios of beneficiary to inpatient hours. The MHS data supports the projected patterns by Bridgers et al. (2005) and Ulrich et al. (2008) that as the average age of the population increases, or as the number of retiree veterans increase, the number of inpatient services required by the system increases at a greater rate than younger groups of the population.

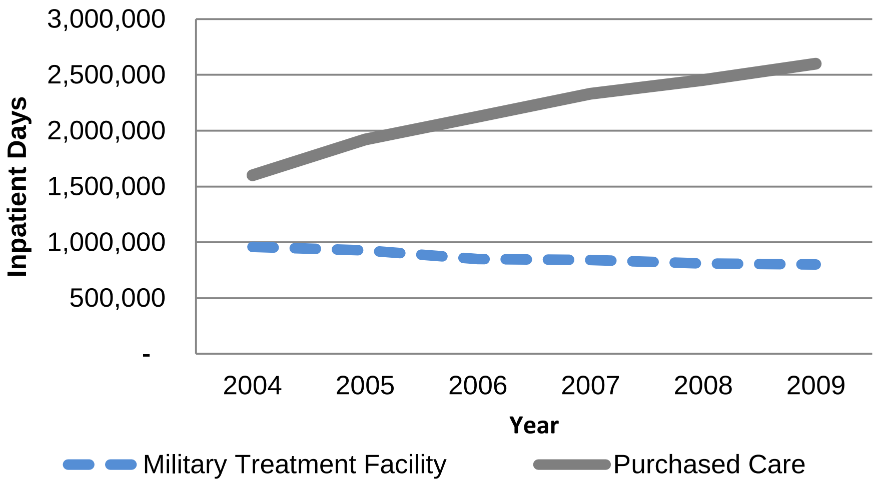


Figure 3: Total MHS inpatient workload (Adapted from MHS 2010)

The average age of U.S. hospitals is increasing, despite the amount of healthcare construction; it has not been enough replace the large amount of infrastructure within the nation. According to Bridgers et al. (2005) citing a Hospital & Health Networks survey, 60% of U.S. hospitals need to replace their facilities. The MHS currently has 59 hospitals, which consists of the Army, Navy, and Air Force facilities (MHS 2010). The U.S. Army Medical Command has 34 medical centers and hospitals in its portfolio of facilities, 29 of which are located within the continental United States. In Figure 4: Distribution by age of U.S. Army medical facilities, the in-patient facilities of the Army

Medical Department (AMEDD) are categorized by their age of construction. The average age of the 29 facilities is 34 years old. The information shows the majority of facilities as over 20 years old, with only 5 facilities being built within the last two decades.

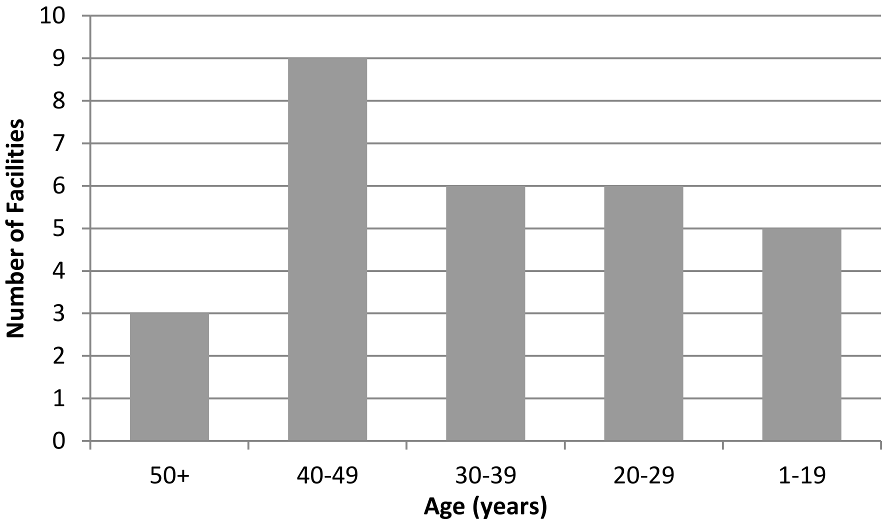


Figure 4: Distribution by age of U.S. Army medical facilities

1.1.2 Response to the Demand

Evidence-based design (EBD) is a research-based method of design wherein the most current information available is used to achieve desired results from a built space. (Hamilton and Watkins 2009). According to Hamilton (2003), EBD approaches link desired metrics or benchmarks in the final structure with key design features; much like a research experiment structure is linked to its hypothesis. Specific to healthcare, "evidence-based healthcare designs are used to create environments that are therapeutic, supportive of family involvement, efficient for staff performance, and restorative for workers under stress" (Hamilton 2003).

The Military Health System (MHS) is a large health system within the U.S. Department of Defense, which supports the military population. Civilian medical leadership, such as former Assistant Secretaries of Defense for Health Affairs, Dr. W. Winkenwerder and Dr. S. W. Casscells, have made it a priority to include both EBD and sustainable practices in the MHS. In 2007, Winkenwerder stated that the incorporation of evidence-based principles into MHS healthcare facilities is necessary and required (Malone et al. 2007). According to Casscells (2008), the MHS as a governmental entity should make the responsible use of taxpayer funds a priority in the management of the health system, emphasizing the importance of sustainable and evidence-based solutions. The efficient management of facilities and use of public funds requires analysis of the entire lifecycle costs of the healthcare system from design and construction to business operating costs and health outcomes (Malone et al. 2007).

1.2 Problem Statement

Literature search indicates that there are no existing studies on designs combining EBD, sustainable practices, and facility management (FM) concepts; therefore, their benefits and shortcomings on healthcare buildings' operations are unknown.

1.3 Research Objective

The main research objective is to investigate the impact that factors such as EBD design interventions, ASHRAE guidelines, and energy code compliance may have on the building envelope, and their consequence on the energy consumption of MHS facilities. This overall objective can be achieved by the following goals: (1) Collecting the EBD features that are supported by research findings, and identifying critical EBD features that directly impact the construction of the building envelope; (2) Assessment of current military hospitals and selection of case-study facilities; (3) Conducting simplified incremental analysis of simulations of the selected EBD features to determine their effects on the energy usage of the building envelope; and (4) Simulating energy usage of the selected facilities.

2. LITERATURE REVIEW

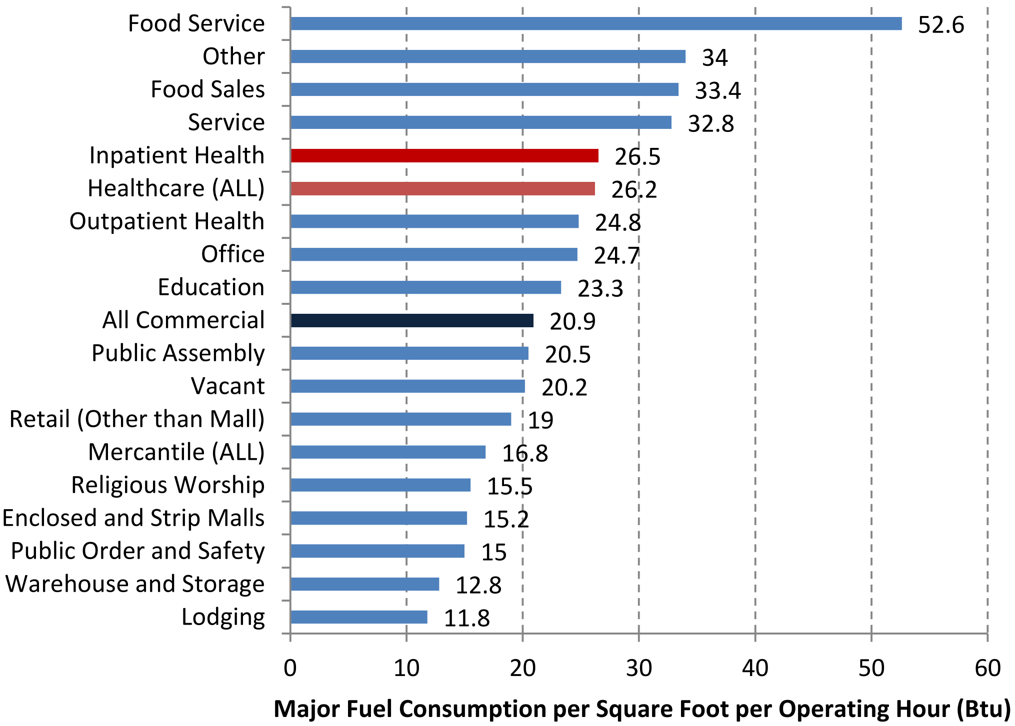
2.1 Energy Use in Hospitals

In the U.S., building energy usage accounts for 41 percent of the overall energy consumption of the national end-use by sector (EIA 2009a). The U.S. building group includes the residential and commercial sectors as compared to transportation and industrial sectors (EIA 2009a). The EIA also shows that building group energy usage is greater than either the transportation or industrial sectors usage. From the EIA we also can deduct that within the commercial sector, healthcare buildings are a leader in energy usage intensity. In 2003, according to the U.S. Energy Information Administration (EIA), the U.S. “healthcare buildings…consume 9 percent of total energy, but account for just 3 percent of buildings and 4 percent of total floor space” (EIA 2004a).Healthcare and food service are the only building types that substantially exceed an equal ratio of quantity of buildings to energy consumption. From EIA (2004b) we can also deduct that healthcare more than doubles its consumption ratio as compared to the number of facilities.

The healthcare building type is a small fraction of the overall nation’s built inventory, however it substantially contributes to the overall total consumption of energy and resources (EIA 2001). Healthcare leads commercial building types in the site and primary energy intensities per building by principal building activity according to the most recent Commercial Buildings Energy Consumption Survey (CBECS) **(**EIA 2004b), as shown in Figure 5: Major fuel consumption per square foot per hour by building type (Adapted from EIA 2009b, CBECS 1999).

Brown and Moore (1988) completed a study of the energy consumption of existing Georgia schools and hospitals. The report contained recommendations and projections for returns on investment. According to Brown and Moore (1988), hospitals had the highest energy consumption of any building category; however they also had the least potential for improvement in energy savings. The majority of the energy consumed was to maintain stringent interior environmental conditions, and as compared to educational facilities, hospitals already contained significant investments in their building envelopes, mechanical and lighting systems, and facility management.

Dunn (1998) conducted a study of the energy use and costs of 35 Texas hospitals. The hospitals' data portrayed a wide variation in the overall use and costs of energy, more specifically the use of electrical energy. According to Dunn (1998), the documentation of energy usage by hospital facilities is essential to manage improvements and to benchmark against other facilities as a performance measure.



Note: "Mercantile (ALL)" includes both "Retail (Other than Mall)" and "Enclosed and Strip Malls", "Health Care (ALL)" includes both "Inpatient Health" and "Outpatient Health".

Figure 5: Major fuel consumption per square foot per hour by building type (Adapted from EIA 2009b, CBECS 1999)

The U.S. General Services Administration (GSA)is the largest owner of buildings in the U.S.; hence it is viewed as a leader in facility management and the built environment (Colker 2008). The Energy Independence and Security Act of 2007 (EISA) was recently enacted, which prescribed the future milestones for reduction of fossil fuel energy consumption of new and existing buildings (FEMP 2010). According to Colker (2008), the EISA has requirements for existing buildings to begin to reduce their energy use by 2% in 2006 and escalating to 30% by 2015. New and renovated buildings must demonstrate a reduction of 55% in 2010 (below their CBECS 2003 baseline) and eventually reduce to zero consumption of fossil fuels by 2030. In 2008, ASHRAE reported the concerns that many federal and commercial entities had regarding the feasibility of attaining the milestones established by the EISA. A public/private group was formed by the Federal Facilities Council along with numerous private firms to propose solutions and direction in response to concerns.

According to ASHRAE (2008), the report published by the Federal Facilities Council public/private partnership defined the recommended direction for future efforts to renew the federal portfolio's performance. The report summarized recommendations in the following areas: Finance and acquisitions; Technical and design guidance; Technology solutions; and Education and training (Federal Facilities Council 2008).The financial and acquisitions recommendations focused on revising federal procedures for funding, which currently have separation between capital and operating budgets. Improvements in this area will assist in realizing life cycle planning and assessment of projects. One key technical and design guidance recommendation that was central to achieving the ambitious energy reduction goals was integrated design delivery, wherein professionals from all phases of a project are involved from the earliest aspects of the project. Technology solutions recommendations were sub-categorized by: Energy management &controls; Mechanical systems; Lighting & daylighting; and Building Envelope. Concepts, such as building massing and orientation, while simple in technical aspects are elegant solutions that address multiple challenges at once.

2.2 Impact of Evidence-based Design in Hospital Planning

According to Hamilton and Watkins (2009), “Evidence-based design is a process for the conscientious, explicit, and judicious use of current best evidence from research and practice in making critical decisions, together with an informed client, about the design of each individual and unique project.” The definition and concept of EBD have been developed over several years with references to evidence-based medicine. The concept of EBD is the object of some debate, mainly over the thought that EBD would regulate architecture to a degree where flexibility or creativity would not be allowed (Hamilton and Watkins 2009).

According to Zimring et al. (2008), the field of healthcare architecture and healthcare administration is embracing the EBD methodology as a way to improve overall health outcomes and business costs. The EBD decisions are made based off of existing quantitative and qualitative studies that support the overall goals and objectives of a project. If the existing body of research for a feature shows measurable improvements in health outcomes and costs, it may have a higher initial construction cost. Using EBD principles and looking at the overall healthcare business model, a decision can be made to incorporate features to take advantage of their long-term business savings in terms of positive healthcare outcomes, such as shorter length of patient stay, decreased pain medication, or improved quality of sleep. This analysis requires a comparative study of benchmarked alternatives to EBD that is available at the earliest phases of the project (Zimring et al. 2008).

Ulrich et al. (2008) conducted an extension to a previous literature review on available research relating to EBD and the connections between architectural designs, and patient outcomes and staff efficiency. The report categorized their findings in three separate categories: (1) Patient safety issues, such as infection, medical errors and falls; (2) Patient outcomes, such as pain, stress, length of stay, and satisfaction; and (3) Staff outcomes, such as injuries, stress, effectiveness, and satisfaction. According to Ulrich et al. (2008), the conclusions and design recommendations within this report are based off of “credible” research findings, as well as patterns of findings that have shown a correlation between specific design features and positive healthcare outcomes.

Malone et al. (2007) conducted a research study funded by the TRICARE Management Activity (TMA) Portfolio Planning and Management Directorate (PPMD) to collect the existing literature and references and provide MHS personnel with the background to implement EBD into military healthcare - design, construction, and facility management. According to Malone et al. (2007), the MHS has classified the desired outcomes from EBD into five categories: (1) Create a patient- and family-centered environment; (2) Improve the quality and safety of healthcare; (3) Enhance care of the whole person by providing contact with nature and positive distractions; (4) Create a positive work environment; and (5) Design for maximum standardization, future flexibility and growth.

The National Capital Region (NCR) Base Realignment and Closure Health Systems Advisory Sub-committee of the Defense Health Board was formed to provide recommendations to the Department of Defense (DOD) regarding the planned facilities in the NCR as well as if these facilities were meeting the criteria of “world class medical facilities” (Kizer et al. 2009). This report, while focused on the MHS facilities within the NCR, had implications that have affected all of the future healthcare design and construction within the MHS. According to Kizer et al. (2009), a key recommendation is for a life cycle cost analysis (LCCA) as well as healthcare outcome assessments of EBD features and other investments to become the normal part of the design and construction process.

2.3 Sustainability Efforts in Healthcare

According to Hodges (2005), the importance of sustainability to achieving business objectives is evidenced by the more common use of the “triple bottom line”. The operations costs of commercial buildings are typically the largest cumulative expense of the service life of a building, personnel costs as the majority (Hodges 2005; Dell’Isola and Kirk 2003). Projections of the overall cumulative life cycle cost (LCC) of a building show that the initial construction costs are dwarfed over time by the investment in personnel. There is mounting evidence that supports overall improvements in building occupant satisfaction, as measured by employee productivity and absenteeism. Design and construction features that positively impact the building occupants even minimally can have an overall benefit when viewed from a life cycle perspective of a building (Hodges 2005).

The sustainable construction and renovation of the inventory of health facilities may come with a cost premium to otherwise traditional construction alternatives (Houghton et al. 2009). Categories of first cost premiums are: features that take advantage of a financial incentive, either governmental or commercial; components that exceed the typical "baseline" practice; and measures that carry first-cost premiums but have incremental savings over their service life (Houghton et al. 2009).

The business case for savings over the life cycle of a structure to offset an increased first-cost is addressed by a lifecycle cost analysis (LCCA). "Lifecycle cost analysis is an economic method of project evaluation in which all costs arising from owning, operating, maintaining, and disposing of a project are considered important to the decision" (Fuller and Petersen 1995). According to Dell'Isola and Kirk (2003), LCCA"…is an economic assessment…that considers all the significant costs of ownership over its economic life…" The focus of any assessment should be on the inclusion of all significant costs to the owner. Construction costs are considered a fraction of the overall costs of the operation of a healthcare facility (Dell'Isola and Kirk 2003).

According to Qualk and McCown (2008), the built environment consumes more resources than any other sector in the nations' economy. Despite this, most construction and design is focused on the first costs of construction. The cost of capital and the feasibility of projects are important facets of the overall development of a strategic investment for a business; however the emphasis that these aspects receive overwhelms the long term future worth of a facility. Qualk and McCown (2008) emphasize that sustainability is not the addition of features to a design; it is a change in design process that originates in the programming phase and resonates across the entire life cycle of the building.

Matthiessen and Morris (2007) conducted a study for Davis Langdon that surveyed the construction costs of various building types, such as academic, laboratory, library, community centers, and ambulatory care facilities, in the construction market. In Figure 6: Ambulatory care facilities, LEED certification levels and costs/square feet (Adapted from Matthiessen and Morris 2007) survey data is presented. The data from the buildings surveyed was adjusted for geographic location, and then the costs were compared on a cost per square footage basis as well as the LEED certification and levels achieved. The selection of 17 ambulatory care facilities was composed of 9 LEED and 8 non-certified buildings. The sample group had only one building rated as LEED Silver; the remaining 8 were rated as LEED Certified, the lowest rating level. The LEED Silver facility was located close to the median of the facilities ranked by construction cost per square foot. The majority of the LEED Certified buildings were at the lower end of the cost per square foot range, and the majority of the non-LEED buildings were at the upper end of the cost per square foot range. The number of buildings sampled is too few to state that LEED buildings cost less, however this sample has shown that LEED buildings are within the average range of construction costs (Matthiessen and Morris 2007).

According to the FEMP (2003), the GSA is striving to improve the value and overall performance of its portfolio of buildings. The business case for sustainability efforts is not just a commercial endeavor and the reasons why it makes business sense for industry are improvement opportunities for the government as well.

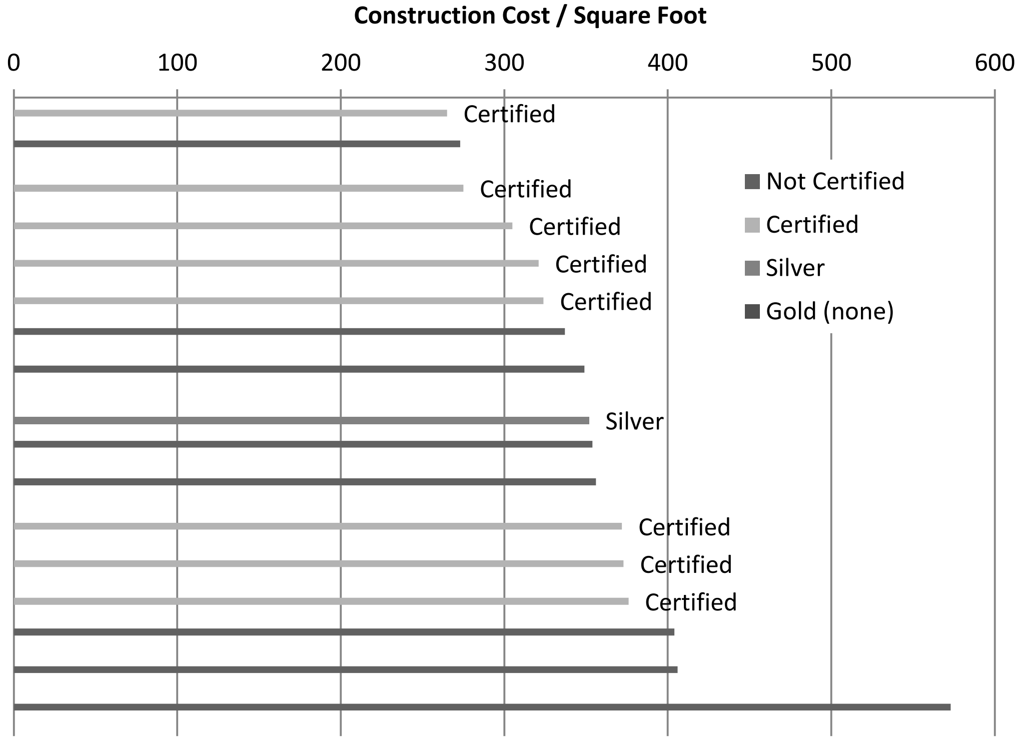


Figure 6: Ambulatory care facilities, LEED certification levels and costs/square feet (Adapted from Matthiessen and Morris 2007)

The Green Guide for Health Care (GGHC) is a best-practices document designed to educate and provide a framework for the sustainable health designs of the future. The GGHC seeks to protect health by the following measures: (1) Protecting the immediate health of building occupants; (2) Protecting the health of the surrounding community; and (3) Protecting the health of the global community and natural resources (GGHC 2007). The GGHC is based off of the LEED Sustainable Building Rating Systems, in accordance with a partnership between the two organizations. The familiar framework of scoring sustainable features of a design is adapted to meet the special conditions found in healthcare settings as opposed to other commercial settings. The LEED for Health Care (LEED-HC) Building Rating System was in development for many years and has recently been approved by the United States Green Building Council (USGBC) in 2010 (USGBC 2010b).The new LEED-HC Rating system identifies a new prerequisite to use an Integrated Project Planning process in order to receive credits in the Innovation in Design category. This addition exceeds the LEED for New Construction rating system's requirements, because of the increased size, complexity and cost of healthcare construction as compared to other commercial projects (USGBC 2010a).

According to Baker and Steemers (2002), the hospital building typology is an ideal occupancy type to take advantage of daylighting design features. The physiological benefits from daylight can have a large effect on building occupants when considering patients that might have a poor condition. The duration that patients stay in their rooms is dramatically longer than in other occupancies, with the exception of a residence.

2.4 Changes to the Hospital Building Envelope

The hospital building typology of today is distinct from other building typologies, such as office buildings, educational, retail or food service. According to Verderber (2010), the hospital typology has changed over time to what is currently being described as "The unsustainable mega-hospital." Hospitals have grown in size over time and have become enormous centers of infirmary.

Community planning, real estate values and the automobile have each led to the consolidation of many past community hospitals into larger facilities. According to Gormley (2010), the efficient use of real estate along with travel distances between buildings became a major consideration in multi-level hospital planning. In the early 1900's the advent of these social pressures as well as the use of technology in the medical profession shaped the use of large hospital block planning forms (Guenther and Vittori 2008).Advances in building construction technology have had a direct impact on hospital design trends. Steel frame structures and the use of heating, ventilation and air-conditioning (HVAC) systems have allowed healthcare designs that are dramatically different than earlier designs (Verderber 2010; Guenther and Vittori 2008). Previously, hospitals were limited by the efficient use of structural materials and the passive use of windows for ventilation.

2.4.1 Historical Background of the Hospital Typology

The hospital building typology has undergone many changes throughout its history. The earliest forms of hospitals as well as medicine were based on religion (Verderber 2010). The earliest practitioners would be responsible for not only the healing efforts for the patient, but also performing ceremonies and rituals as part of the treatment (Gormley 2010).

The earliest society to develop medical practices separate from their religious beliefs was the ancient Greeks (Verderber 2010). The covered portico was the most common building type of the time and it was adapted for use as a place of medicine. At the Asclepieion of Epidauros, in Greece was a long and narrow building oriented to the sunlight from the south. The building was enclosed on three sides by building into a hillside; however the south side was open to natural ventilation and daylight through the portico.

During the time of the Roman Empire, military hospitals, valetudinariums, were built to rehabilitate soldiers and return them to battle (Verderber 2010). These valetudinariums were built as rectilinear buildings with interior courtyards. Along the four sides ran a double-loaded corridor off of which were the inpatient rooms. According to Gormley (2010), these early hospitals used the “ward concept” to group and manage patients. The center of the corridor had a clerestory above that provided natural ventilation and daylighting.

In medieval times, the decline of the Roman Empire and the epidemics of disease, such as the bubonic plague, brought about changes in the way healthcare was delivered and in the built form of the hospital (Verderber 2010). The Catholic Church became the prominent provider of healthcare and using the form of the place of worship, most hospitals took on the cross as the shape of the hospital plan. The altar was centrally located at a vantage point from all the patient wards, much like the nurse’s station would be located in later designs (Gormley 2010). The building form was very similar to that of a cathedral with a hierarchy of windows that changes with the height of the space. The higher windows were fixed letting in daylight, and lower windows might have been operable, however all windows were positioned too high to be used for views.

In the Middle East, hospital designs were developed that would be significantly more advanced than those found in Europe at the time (Verderber 2010). The Islamic culture along with the desert landscape fostered designs that paid special attention to sunlight, views of the exterior and visual privacy. The designs featured courtyards and atriums that were connected to the interior both visually and physically by doors and openings overlooking the space.

The Renaissance brought a renewed interest in nature and therapeutic methods of treatment for the sick (Verderber 2010). The facades of the hospitals of the time were built to echo the style of the other period buildings, palaces and churches. The sick were separated by their social class, with the upper class residing in private patient rooms, the lower classes were subjected to dismal, crowded conditions. Fealy et al. (2010) indicated the political movements that occurred in the early 1800s were as a result of the poor conditions and the public view of hospitals as centers of disease. According to Gormley (2010), these crowded conditions would lead to improved designs that would seek to address the need to provide proper ventilation and lighting.

Florence Nightingale is notable due to an entire typology of hospital design named after her as “The Nightingale Ward” (Verderber 2010). According to Fealy et al. (2010), Nightingale promoted pavilion hospital planning which provided patients with access to fresh air and sunlight. A Nightingale Ward was arranged as a long open space, 30 by 128 feet, with tall operable windows that no more than 30 patients would occupy. These wards were connected at one end to a central corridor such that multiple wards could be planned and connected to the corridor. At the far end of the ward was an exterior sunroom that was accessible to patients.

The Kirkbride hospitals, in the mid-1800s, specifically addressed the architecture for the mentally ill. According to Verderber (2010), buildings for the insane up until this time were almost identical to a prison. Yanni (2003) stated the diagnosis of insanity shifted away from doctors' religious beliefs for their condition to a more scientific viewpoint. The moral treatment of the mentally ill became the goal of the medical field and consequently the design of asylums changed. The "Kirkbride System" of hospital design consisted of a stepped linear pavilion plan with a central double-loaded corridor (Verderber 2010). The stepping allowed large windows in the interior corridor when it extended to the exterior wall. The narrow building design emphasized natural ventilation and use of daylighting. According to Yanni (2003), doctors believed that the architecture of these asylums was part of, and essential to the treatment of insanity.

The development of treatments for and understanding of tuberculosis (TB), a highly communicable disease, occurred in the early 1900s (Verderber 2010). The TB sanitarium emerged as part of the treatment for the disease that was a leading cause of death at the time. The sanitariums were designed with natural daylighting and ventilation, exterior balconies and other access to outdoors were major components of the designs.

In the early 1900s, skyscraper hospitals were constructed as the rising costs of real estate in urban areas drove the usage of greater site densities (Verderber 2010). The recommendations of the Nightingale and other designs were incorporated in the earliest high-rise hospitals.   They were oriented for maximum daylight, and narrow building footprints were used to ensure proper ventilation. The steel structural systems allowed for greater building heights as well as longer spans with less material weight. The travel distances for staff and patients were long within the long pavilion planned hospitals. The stacking of hospital wards allowed for travel distance efficiencies that were not possible on a single floor plan (Guenther and Vittori 2008). The structure also changed the exterior wall systems going from thick masonry to thinner curtain wall systems.

According to Verderber (2010), the "unsustainable megahospital" typology was prevalent post WWII to the year 2000. The rising real estate costs within urban areas, combined with the scarcity of space for expansion drove the hospital planning sites outside of the city. The automobile was commonplace in most of America; this removed transportation factors which had kept hospitals in urban settings. HVAC systems became part of hospital designs as a way to increase and insure proper ventilation. However, as these systems were introduced the typology abandoned its reliance on windows as a source of outdoor air and light. As the height of hospital buildings increased, their connection with the ground was blurred, and as a result courtyards and other links to the exterior disappeared from designs (Guenther and Vittori 2008). The new technologies of medicine, diagnostic and treatment, took on a greater role within the hospital. The areas that housed this equipment became a deeper block plans which relied upon mechanical ventilation and artificial lighting.

2.4.2 Departure from the 'Megahospital' Typology

The hospital building typology has reached a point where it is recognizably unsustainable (Verderber 2010; Guenther and Vittori 2008). The healthcare building typology has consistently been listed as the third highest energy intensive of all commercial building types (EIA 2004a). If only the inpatient portion of the overall healthcare building type is assessed, then it becomes the second most energy intensive building type (EIA 2010). According to Pradinuk (2009), the hospital typology has become an inpatient tower on top of a block of diagnostic and treatment (D&T) spaces. The tower is designed with a racetrack corridor design that provides patient rooms with windows as required by code, and relegates the staff to the artificially sustained central core. The D&T block is designed as the most compact and consolidated section of the hospital producing a building with the least possible surface area and best use of real estate. According to Verderber (2010), the megahospital restricted the use of natural daylight and ventilation because of the deep plan building type.

According to Latimer et al. (2008), hospitals have incrementally increased in size over the past quarter of a century. In the study performed by Latimer et al. (2008), a sample of 76 hospitals designed over a 28-year period was analyzed including a range of sizes, from small community hospitals to large medical centers. The sizes of various room types, such as patient rooms, operating rooms, and diagnostic areas, were measured. The overall pattern was that the average size for each room type was increased, with average square footage for patient rooms increasing 77%, operating rooms increasing 53%, and radiography rooms increasing 28% all over a 20 year span. Gormley (2010) challenges the demand for wholly private patient rooms, as a requirement that is too extreme and will only continue to cause the cost of healthcare to increase.

While many agree that changes must be made to hospital planning, there is not complete agreement as to how to proceed. According to Fealy et al. (2010), the current healthcare problem of nosocomial infection, resistance to antibiotics, and the expected rise in infection rates are reminiscent of the abysmal conditions that preceded the massive reform in hospital planning in Nightingale’s time. Fealy et al. (2010) stated that in order to achieve safer healthcare conditions as well as a smaller economic and physical footprint, it will require comprehensive reform undertaken by cross-disciplinary teams of professionals.

According to Latimer et al. (2008), the overall factors that contributed to the continued growth of healthcare spaces are: changing patient care models, consumerism, and technology trends. These factors are not easily defined, and can be subjective to the opinions of the design team and each project situation. Karolides (2008) reminds us that in succeeding in our pursuit of the most cost prohibitive building, the result may no longer be ideal for the responsibility of patient care. So, the question that remains unanswered is whether this growth was warranted and how to further justify any additional gains.

According to Gesler et al. (2004), the future of hospital design will attempt to resolve the various competing functions of the space with the additional task of marketing to the healthcare consumer. The efficiency of the clinical procedures within the facility, as well as the attractiveness of the environment to the staff and patients will become the balancing act that designs should address in order to be competitive in tomorrow’s world of healthcare options. Healthcare consumers, when not in an emergency, are and will be choosing where they will receive their care.

Latimer et al. (2008) address this by defining growth in hospital space programming as “justified” when it adds value to service or space, however it is considered “unjustified” when it only contributes indirectly or will most likely not add value. When considering the spaces that add value, Karolides (2008) suggests that the entire hospital’s healthcare system be considered, so that efficiencies at the facility management level are not sacrifices for the environment of care for the patient and staff.

To break away from the megahospital typology, it has been recommended that the design process changes to leverage the expertise of various professional disciplines to achieve system level solutions. According to Karolides (2008), the design team and process should be integrated with building massing, orientation, and envelope selection as a primary focus. Pradinuk recommends that the programming of space includes requirements for daylighting levels by type of space and that “daylighting should be a major determinant of building form” (2009).

2.5 Tools Available for Energy Simulation of Hospitals

The selection of appropriate methods and systems to collect data on building energy usage is important to research outcomes. Capital investment and facility management decisions may be based on the measured performance of a building, therefore accurate measurement is important to decision making.

To achieve credits for energy optimization, the 2009 LEED for Health Care rating system (USGBC 2010a) requires that all LEED projects meet specified levels of energy savings over the baseline energy use of a comparable design. This requirement is usually documented by utilizing energy modeling to simulate the energy usage of a design. According to Qualk and McCown (2008), the design and construction industries are benefitting from the use of energy simulation software to weigh design alternatives.

According to Matthiessen and Morris (2007), the use of energy modeling software is a useful tool throughout the design process; the maximum benefits are achieved by its use in the earliest phases of design. According to Lehrer (2001), the early use of energy simulation during design is imperative prior to major design decisions that become difficult to retract. Simulation provides the ability to incrementally drive the design by weighing multiple alternatives in synch with the design process, before moving on to later phases of design (Lehrer 2001). Just as conceptual, schematic and design development phases require increasing levels of detail in the design, the levels of energy simulation, evaluation and validation of design decisions should be made in tandem with the design process (Lehrer 2001).

According to Crawley et al. (2008), there is an abundance of energy simulation programs available and the comparison of features and capabilities are difficult due to the lack of standard naming conventions. The range of applicability is overlapping for numerous software products, with no single product offering all features such as ease of use, modeling features and interoperability, daylighting, fenestration, and multi-zone airflow (Crawley et al. 2008). The energy simulation software, eQUEST, is user-friendly and provides detailed results without requiring a high degree of operator effort and time (Crawley et al. 2008).

Attia et al. (2009) conducted a survey of building performance simulation (BPS) tools that are currently in use by professionals. The survey concluded the most popular BPS software in use, as well as the characteristics that each tool offered as advantages or disadvantages. eQUEST was selected as one of the few tools that were considered “Architect Friendly”. eQUEST was considered by many respondents to be well suited for early design decisions, due to its usability. However, it was not an ideal selection for later detailed design phases, due to its limitations in representing more complex features (Attia et al. 2009).

According to the DOE, Building Energy Software Tools Directory, eQUEST has several drawbacks. The eQUEST software currently has California Title 24 energy code automatic compliance defaulting, however the ASHRAE 90.1 code compliance is not available within the software. Daylighting and complex spaces such as atria are examples of design features that eQUEST is limited in its ability to accurately represent (DOE 2010).

Milne et al. (2007) has developed the Climate Consultant software, which has the ability to process the weather file from any location and graphically present the local conditions that affect a design. The Climate Consultant software tool additionally has a menu of recommended design features that are pulled using algorithms from each weather file. The resulting list of design features is customized to the location of the weather file with proposed design goals for realizing the energy use and daylighting potential of that geographic area (Milne et al. 2007).

2.5.1 Passive Building Design in Varying Climates

The Rocky Mountain Institute (RMI), Green Development Services published a primer on sustainable building that discussed the recommended configurations of buildings in various climates. The rules of thumb for building in cold climates are to design compactly and orient the building east-west to take advantage of as much solar gain as possible while keeping the surface area as minimal as possible (Barnett and Browning 1995). In moderate climates, the building should be extended along the east-west orientation. In hot and humid climates, the building should be perpendicular to the prevailing wind direction and the building plan should be as shallow as practical (Barnett and Browning 1995). According to Barnett and Browning (1995), the surface area of the building envelope is a large factor in the overall energy performance of a building, which affects the performance differently by location and climate area of the site.

According to ASHRAE's 2009 Advanced Energy Design Guide (AEDG) for Small Hospitals and Healthcare Facilities, the majority of the solar heat gains in colder U.S. climate zones are on the southern sides of buildings. When planning and initially selecting sites; locations that allow orientation of the building to receive the most southern sunlight are preferred. The guidance is for elongation of the building along the east-west axis with glazing emphasized on the south façade. The overall window to wall ratio (WWR), or the amount of window surface area as compared to the remaining exterior envelope construction, is recommended to not exceed 40% for the entire building (ASHRAE 2009).

According to Lehrer (2001), the advances in the systems technology within buildings, allowed architects to cease designing for the climate of the area. Building designs that would create impossible interior environmental conditions were made possible by HVAC systems. Research for various building types has demonstrated that designs with the optimal massing and orientation can achieve 30 percent reduction in energy use as compared to building averages (Barnett and Browning 1995; Lehrer 2001).

The National Renewable Energy Laboratory (NREL) recently conducted a study of energy conservation measures as applied to large hospitals. The research methods of the study involved the development of a typical hospital based of averages of types of space, construction, systems specified and loads. The report used energy simulation tools to evaluate energy design measures (EDMs) and their effectiveness in reducing overall energy consumption of hospitals. According to Bonnema et al. (2010), EDMs for the study were chosen by simplicity of effort and capability of the software to evaluate. The EDMs included in the NREL study that were related to the building envelope were: Daylighting sensors; Increased envelope insulation factors; Overhangs on windows on southern facades; and Reduced infiltration with improved envelope.

According to Gilg and Valentine (2004), the “geometric ratio” of the area of exterior wall to the area of floor space is an indicator of the energy use intensity of a building. The variance in EUI of two buildings with different shapes and otherwise identical characteristics is correlated to this ratio. The practical use of this ratio in existing buildings is in determining the potential effect of energy saving measures when applied to the building envelope. Buildings with higher ratios have increased energy loads related to the envelope; therefore measures targeting the envelope have the most impact (Gilg and Valentine 2004).

2.6 Standards of Energy Performance

The requirements for buildings to perform at a certain level is not a new concept; however the ASHRAE 90.1-2010 Energy Standard for Buildings Except Low-Rise Residential Buildings underwent significant changes to address the rapidly changing energy economics as well as current legislative goals for building energy use (ASHRAE 2010). The goal of the revised standard is to achieve 30% energy savings in new construction over the past 2004 code. The ASHRAE standard describes the requirements for energy performance for new buildings as well as new systems in existing buildings. This standard is referenced by many local and state codes. The LEED building rating system uses the ASHRAE 90.1 standards to determine achievements within the USGBC rating system regarding energy performance (USGBC 2010a).

There are two paths to compliance with the standard for building envelope design, prescriptive building envelope options and the building envelope trade-off option (ASHRAE 2010). To be eligible for the prescriptive path of compliance a design must meet two requirements vertical fenestration must be less than 40% of the exterior wall area, and the skylight fenestration must be less than 5% of the roof area of conditioned spaces. The prescriptive path then specifies the minimum requirements for insulation values and assembly ratings for each climate zone in order to be in compliance with the code. The building trade-off option of compliance essentially allows designs to exceed the recommended amount of fenestration by providing a method to demonstrate design performance will exceed the requirements of a baseline building which meets the fenestration requirements. The trade-off option trades the additional window area for higher performance wall and glazing assemblies to comply with the code.

The DOE Energy Efficiency and Renewable Energy Standard Benchmark Energy Utilization Index was created by developing 16 separate, ASHRAE 90.1-2004 code compliant, building type models and calculating their performance in different cities across the United States (DOE 2009). These energy intensities are being utilized as benchmarking for future versions of the 90.1 standards to determine the additional savings with subsequent revisions to the reference. Within the ASHRAE 90.1-2010 standard the requirements are outlined for conducting energy simulations and calculating the percentage of savings achieved between baseline and proposed design solutions.

2.7 Assessment of Prior Work

The design of future healthcare buildings should reconcile the concepts of sustainability and evidence-based design. These concepts are not altogether mutually supporting and they do require a balance (Shepley et al. 2009). One of the most prominent instances where these concepts are at odds is in fulfilling a single patient room layout which requires more square footage per patient bed as well as an increase in energy usage (Zimmerman 2007). During the traditional design process, construction and lifecycle costs can be difficult to manage. The building industry is moving toward more integrated design practices, involving multiple professional disciplines early on in a project (Dell'Isola and Kirk 2003).

While including sustainable concepts with traditional energy saving approaches, the design outcomes could have negative effects in an evidence-based method of measurement. For example, decreasing air changes per hour (ACH) to minimum code requirements in a patient area which may benefit from increased air changes, or providing minimum window area to limit heat gains and losses and inadvertently providing a depressive space for a patient to heal. Conversely, the ACH of a space can be continually increased and use more energy to accomplish healing benefits but at some point the health advantage will either no longer be measureable or the cost will outweigh the benefit. Integration of EBD interventions using traditional construction techniques will likely create a facility which has energy needs much larger than an existing facility of comparable design. Dell'Isola and Kirk (2003) emphasizes the need for integrated design teams that can realize the best design solutions, and at the same time, develop the most effective lifecycle cost alternative. Collaboration and innovation is required to balance the two concepts of sustainability and evidence-based design in healthcare design.

The review of literature reveals that numerous studies have developed the theories of sustainability and EBD (Hamilton and Watkins 2009; Malone et al. 2007; Grumman 2003). Additionally, research exists that describes the overlap between the two areas and their complimentary and contrasting aspects relative to new construction

(Shepley et al. 2009; Zimmerman 2007). The application of the theories of sustainability and EBD to the modernization of existing healthcare facilities and the subsequent effects on facility management costs has not been investigated.

2.7.1 Major Conclusions

1. Continuous operations: According to the CBECS 2003 data (EIA 2004b), healthcare facilities, specifically those with in-patient services, have operating schedules that are continuous.
2. Energy consumption: The energy consumption of facilities that are only used during a typical week (five day business week) compared with those with continuous operations results in diluted energy usage intensity (EUI) due to the differences in occupancy schedules, and the EUI calculations based on energy use per area per operating hour. The equipment demands in healthcare have driven the energy consumption for this typology, although recent advances in technology have curtailed the consumption trend (EIA 2007).
3. Indoor Environmental Quality (IEQ): Factors that are special to healthcare buildings are the relatively strict indoor environmental quality (IEQ) conditions, operating and occupancy schedules, and the concentration of medical equipment demands. If buildings are to be considered well-designed and constructed, they therefore must also achieve good IEQ (Grumman 2003). To achieve a well-designed “sustainable” building, the criteria of energy efficiency and conservation must be achieved without sacrificing IEQ for its occupants.
4. Large number of facilities involved: According to the Military Health System (2010), the MHS is a worldwide healthcare network that is part of the U.S. Department of Defense (DOD). The MHS supports 9.6 million military service members, veterans and family members. The MHS has a fixed facility inventory of 59 hospitals, 364 health clinics and an annual budget of $50 billion. The MHS is one of the largest healthcare organizations in the world, and its approach to the future energy demands will be emulated by other smaller organizations (Ossmann et al. 2008).

5. Governmental mandate to modernize: In 2007, Dr. Winkenwerder, the Assistant Secretary of Defense (Health Affairs), issued a memorandum calling for the application of EBD into all future medical military construction (MILCON) projects. On February 28, 2008, the Honorable Dr. S. Ward Casscells, Assistant Secretary of Defense for Health Affairs, delivered "The Military Health System Overview Statement" before the House of Representatives, Subcommittee on Defense Appropriations. Key points pertinent to healthcare facilities were the focus on modernization, expansion and construction of healthcare facilities over the next five years.
6. Mandate to increase efficiency: The Asst. Secretary affirmed the MHS' intent to deliver excellence in healthcare by stating, "We can deliver this healing environment, and we can use evidence-based design and quantify the outcomes…In addition, we can and should build our new hospitals with the highest possible environmental ratings within our budget" (Casscells 2008).
7. Evidence-based design as a tool to increase efficiencies: EBD is a movement to utilizing research-based methods to provide the highest quality design. The traditional method of design is typically based on the designer's personal or firm's historical methods of accomplishing a project. Building types are designed and efficiency is attained by replication of the design decisions from past successful projects. The EBD design methodology is focused on including features that are proven, tested, and backed by evidence to contribute to the overall goals of the facility. EBD is not meant to supersede the designer's judgment, as each project is different and not all features are appropriate in every project (Hamilton and Watkins 2009). The application of EBD using supporting research that is not representative of the design situation at hand becomes subject to the designers' reasoning as to whether or not to utilize this data as rationale for a design choice.

2.7.2 Critical Appraisal of Literature

The requirement for healthcare infrastructure is growing proportionally faster than the rate of overall population increase. The rationale within the literature is that the average lifespan of Americans is getting longer, somewhat due to advances in medicine, but largely due to the aging of the baby boom population. Older patients utilize inpatient care more than younger patients, therefore it is expected that healthcare construction will stay consistently strong and possibly increase to meet the future needs.

The healthcare building typology is one of the most consumptive building types. Within healthcare, the inpatient hospital sub-type becomes the most consumptive of all building types. Healthcare costs are increasing for many reasons beyond just energy use, and healthcare management expends considerable effort in reducing costs. The topic of energy conservation in hospital planning, design and facility management is of primary interest to management because energy expenses are a significant portion of the overall budget. Reduction of energy costs reduces the costs of operations and therefore the overall costs of healthcare.

EBD concepts and methods are gaining momentum in healthcare planning and are based on ultimately improving the quality and lowering the cost of healthcare. Sustainability concepts as they relate to energy conservation can be supportive of EBD design measures when the improvement of healthcare is included in the assessment of sustainability. Instances wherein design measures result in a more energy intensive environment would normally not be considered sustainable design choices; however if the efficiency of the entire health system is improved the energy savings may be present. Metrics for measuring energy may ultimately shift from per floor space units to per patient costs.

Hospital design choices supporting EBD can affect the envelope, shape and orientation, of the facility. These choices likely involve the increase availability of exterior views as well as daylighting. The future of healthcare design will include these types of features because of the projected overall healthcare system savings, despite the potential lessened energy performance of these facilities. The careful planning of new hospitals with additional energy saving measures while still meeting the EBD goals of the project will result in larger overall facility life cycle savings.

The use of energy simulation software is useful throughout all phases of the facility life cycle. The EBD design process begins in the earliest phases of the planning and design process with setting goals. EBD is not the only concept that can benefit from early planning and professional collaboration in the design process. During the earliest planning and design phases the massing and exterior look of the building are designed. The use of simulation tools to set energy design goals and to provide feedback on design alternatives and their impact on the energy use of the facility is important. The development of the hospital building envelope and its EBD goals in tandem with energy targets is best practice for the future of healthcare planning.

The improved energy efficiency of hospitals is not only a business goal for most hospital administrations, but will also become a requirement with the adoption of the new ASHRAE 90.1-2010 Energy Standard for Buildings Except Low-Rise Residential Buildings by my local, state and federal government projects. The labeling of facilities as energy efficient is only appropriate if their energy use has been measured and benchmarked against a standard. The use of energy modeling techniques to forecast the performance of a building is also outlined in the new energy standard, to ensure the consistency and comparability of the results.

3. RESEARCH METHODS

3.1 Scope

The purpose of this section of the thesis is to explain the process and research methods that were used to reach the conclusions targeted by this study.

3.2 Statement of Research Aim

The purpose of conducting this research is to discuss the initiatives of EBD and energy sustainability and their effect on hospital design, specifically in building configuration. The consequences of incorporating the goals of each initiative are addressed.

3.3 Method of Analysis

3.3.1 Collection and Identification of EBD Features Affecting the Envelope

A literature review is done to identify the EBD principles and the features that are recommended as supporting those principles. The EBD interventions selected and used for the analysis are based on literature review of the most common and productive positive health outcome interventions, as discussed by Ulrich et al. (2008). The selected interventions relate directly to the utility costs of the facility as an imposed limitation on the study to focus specifically on energy costs of hospitals.

The initial phase of the research methodology consisted of a literature review to create a comprehensive list of EBD features. These features are categorized by the supporting MHS EBD principle of design (Malone et al. 2007). The MHS has developed a set of EBD principles that group the organization’s desired goals and metrics into five principles: (1) Create a patient and family-centered environment that respects privacy and dignity and relieves suffering; (2) Improve the quality and safety of healthcare delivery; (3) Support care of the whole person, enhanced by contact with nature and positive distractions; (4) Create a positive work environment through ergonomics, efficiencies, lighting, and adjacencies; and (5) Design for maximum standardization and future flexibility and growth (Malone et al. 2007, Casscells et al. 2009b).

The initial listing of features was adapted from the work of Malone et al. (2007) as part of a commissioned study for the MHS. The work was reviewed and each feature in the listing was linked by the narrative to the principles that are related. The Military Health System's EBD Design Review Checklist, of the Center for Health Design's (CHD) Evidence-Based Design Accreditation and Certification (EDAC) Study Guide 1 has a similar table linking the principles to features and responses (Malone et al. 2008). These works provided the basis of the matrix. Additional literature was reviewed for additional identified EBD features and noted on the matrix if in agreement with the listed features; newly identified features were added to the listing.

Literature search provides sustainability goals focused on energy efficiency of the building envelope. Matrices are used to delineate the relationships graphically between the principles, features, as well as the ability to affect the building envelope. This methodology is used to select EBD features that directly impact the construction of the building envelope. This satisfies the objective of collecting features in practice, and identifying EBD features that impact the building configuration.

3.3.2 Assessment of Military Hospitals and Selection of Case-study Facilities

The continental U.S. Army military hospitals were collected into a matrix with the following characteristics: Year of construction; Square footage; Hospital bed capacity; DOE Climate zone (ASHRAE 2009a); and Energy usage intensity (EUI). The age of construction was based off of the original year of construction, and not on any subsequent major renovations or additions. The hospital bed capacity is an important characteristic because every hospital serves differing populations and therefore each design may emphasize inpatient care or other high energy intensive activities more than another hospital. The Department of Energy determined climate zones are useful to correlate the zone specific design recommendations to a facility. The EUI is a benchmark that can be used as a comparison to hospital averages for each climate zone and facility size.

Existing typical floor plans of two military hospital facilities were selected for the modeling and comparative analysis. The number of case studies was limited by the expected amount of effort (time and resources) for each case study by the researcher, as well as the intent to provide insight from various climate zones, facility sizes, and ages of facilities.

The selected facilities are shown in Figure 7: Selected facilities - Bassett Army Community Hospital, Fairbanks, Alaska; and Brooke Army Medical Center, San Antonio, Texas .The following logic was used to select the case-study facilities: constructed within the last 20 years; located in the two most extreme climate zones; one facility was small and the other large. These selection criteria were expected to provide the most variation in observations as well as availability of research data.

Figure 7: Selected facilities - Bassett Army Community Hospital, Fairbanks, Alaska; and Brooke Army Medical Center, San Antonio, Texas

Energy Star web-based reporting system is used by the AMEDD for the energy management of the portfolio of buildings. The data is input by facility managers at each site location and much of the data is missing and/or reported incorrectly. The available data captured by the system was included in the matrix of facilities.

3.3.3 Conducting Simplified Incremental Analysis of Design Features and Simulation of Case-study Facilities

The testing of architectural features in a complex model of a large facility is difficult and demands a large amount of simulation time. The testing of basic concepts on smaller models and then applying these refined concepts to the larger models is the theory used in this step of the methodology. The comparison of these simulations to a benchmark of code compliance with ASHRAE 90.1-2010 was a significant part of the study.

In Figure 8: Diagram of modeling process the process that data was collected and applied to the simulation models is outlined. The development of a benchmark simulation using eQUEST was initially based off of the internal defaulting in accordance with California Title 24-2008 energy standards. A simple 100,000 square foot model was created that used the software's code compliance features to automatically size system and building construction settings. The ASHRAE 90.1-2010 standard was then utilized to further alter the model to be in compliance with this standard. The most notable changes to the benchmark model were the implementation of the daylighting controls feature; lower Watts per square foot levels, as well as weather files from the two locations that this study is using.

The third research objective of conducting incremental analysis of the design features and their effects on the building envelope was accomplished using simplified building forms that represent portions or simple rudimentary designs. These simple forms were based on a visual survey of actual military hospitals and recognizing the basic shapes that are repeated throughout designs.

The process of creating alternatives and then conducting analyses of energy performance and using it to drive the future design concepts was investigated. The major concepts and rules of thumb that are described in the literature search are applied to simple models to demonstrate the concepts in practical use. These heuristics have been developed into an outline and used as a basis for case-study analysis of an existing hospital design and energy performance by simulation.

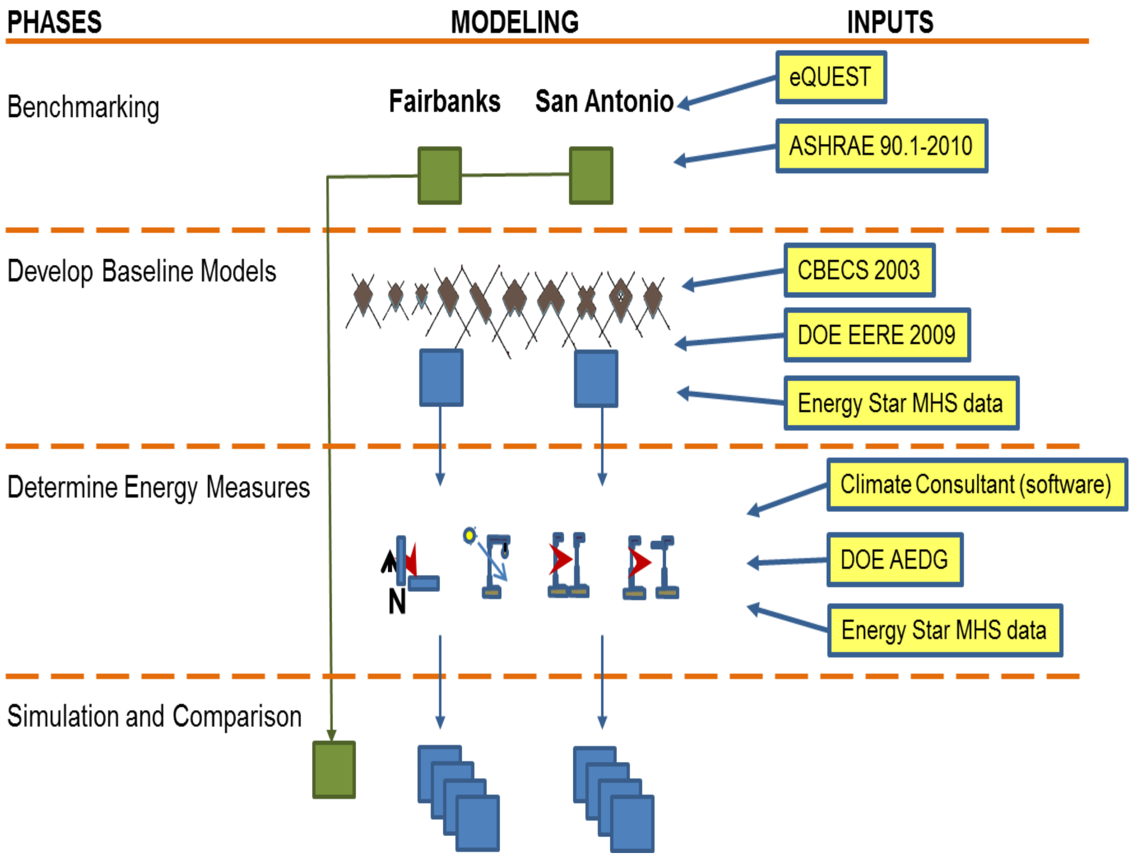


Figure 8: Diagram of modeling process

The simplified building forms were based off of a 100,000 square foot module. The simulation of a simple, single story, square shaped form was the basis of the initial simulation. The incremental alternatives to the simulation are based off of recommendations by Climate Consultant software, ASHRAE's Advanced Energy Design Guide for Small Hospitals, and NREL's report on Large Hospital energy savings.

The Department of Energy maintains a database of weather files for use in various energy simulation software programs. A weather files used by eQUEST software are derived from 30-year averages of weather data (Hirsch and Associates 2009). The files used by eQUEST are TMY2 and TMY3 file types. These weather files are not a single snapshot of a weather year, but instead are a composite year that is created using methods which produce a file which represents the average climatic conditions. According to Crawley (1998), the use of TMY2 datasets provides reasonable representation of the weather patterns and should be used to conduct energy simulations on commercial buildings. The weather files for Fairbanks, Alaska and San Antonio, Texas were used with eQUEST for both the incremental and the case-study simulations.

The use of Climate Consultant software for geographic location specific design recommendations was utilized. The weather files from the Department of Energy's database are utilized by the software which customizes design recommendations to the weather data provided (Milne et al. 2007). Sustainable approaches are supported by additional published authors and organizations, such as the ASHRAE's Advanced Energy Design Guide for Small Hospitals and Healthcare Facilities (ASHRAE 2009a). The ASHRAE IAQ design guide (ASHRAE 2009b) also recommends numerous design strategies to utilize in projects desiring energy savings.

An energy simulation of the simplified floor plans was performed using eQUEST software. The criterion for choosing this software was based on its frequency of use within the construction industry as well as its basis in research proven reliability (Neymark and Judkoff 2004). The software is a building energy simulation tool that uses DOE-2 (version 2.2) code with a graphic user interface (GUI,) which allows for user friendly access to DOE-2 software. The eQUEST software is qualified software for the calculation of commercial building tax deduction for energy use, as it meets standards set by the Department of Energy (DOE), the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE), and the Internal Revenue Service (IRS) (Hirsch and Associates 2009). eQUEST meets the ASHRAE standard for energy simulation software which is compliance with ASHRAE Standard 140.

The analysis is based on comparing baseline energy models utilizing software defaulting within the eQUEST software. The software tool was used to automatically size systems to meet current code requirements and mechanical equipment sizing. The purpose of the study is to evaluate the building envelope; therefore after setting the mechanical systems within the software, they remained unchanged for all alternatives, so that only impacts of the changes to the building envelope were assessed.

The simulations were conducted cumulatively with each EDM being added to the simulation model and features previously simulated. The intent of this study was not to compare the effectiveness of the various EDMs. The EDM are also interdependent, for example the daylighting EDM is more effective when the building is properly oriented for the climate area. Daylighting savings were simulated using the daylighting controls feature of the eQUEST software. The initial simulations of building shape and building orientation were simulated without daylighting controls. The following simulations included daylighting controls as part of the calculation; daylighting controls, window/wall ratio limitation to 40%, and exterior building overhangs. The daylighting controls measure was simulated within eQUEST using 15 feet from the perimeter zone as the area of potential daylighting. The simulation calculates the portion of the lighting loads that support the day lit area and estimates the savings in lighting that would be achieved if these spaces were equipped with daylighting controls that would dim or turn off the lighting systems in areas that have sufficient natural lighting levels.

The window/wall ratios (WWR) of the incremental buildings were established at 50% of the floor to ceiling wall area. The floor to ceiling height was set at 10 feet for all incremental simulations. The WWR limitation to 40% simulations changed the setting from 50% to 40% for all of the energy models. All of the facades had the same settings and the multi-story models had the same WWR for each floor. The simulations prior to the WWR 40% were simulated with 50% WWR which were an example of building designs which exceed the newly proposed ASHRAE 90.1 standard to limit window percentage to 40% of the exterior façade. Exceptions to this limitation must be equivalent or better the model meeting the 40% standard, by exceeding the standard in other ways such as high performance glazing.

The fourth objective simulated the energy performance of two selected facilities' building forms as baselines and assessed the validity of the design recommendations on their energy performance. The incremental simulations from each climate zone were considered in the development of each hospital simulation.

The rules of thumb that were learned in extreme cold and hot climates were applied to the building envelopes of the hospitals in climate zones 8 and 2. The hospital design was modified to show alternatives to the design product that would have enhanced building performance. The hospitals were modified to demonstrate the potential savings of the various EDMs.

3.3.4 Role of the Researcher (including qualifications and assumptions)

The researcher is an Army Medical Service Corps Officer. The researcher's educational and experience consists of a professional degree in Architecture as well as 10 years of experience in the United States Army, most recently the last 6 years within the Army Medical Department, with duties as a Health Facility Planner and Medical Logistician.

3.4 Limitations and Assumptions

The purpose of this study was not to undermine previous design decisions; it is meant to outline a methodology to test potential design improvements. The designs utilized likely have assessed factors beyond the scope of this study, such as construction cost, site limitations, and weather conditions not addressed. It is apparent that new construction and renovations will occur based off of age of facilities, changing views of EBD concepts, and other criteria. The purpose of this study was to validate the methods to provide solutions to the design decisions, and improve operating costs of facilities while improving the environment of care.

Existing building designs were selected based off of selection criteria discussed within the methodology, which may not represent the entire portfolio of military health facilities. The intent of this research was to isolate the energy impacts relative to the building envelope. It is understood by the researcher that the HVAC systems are a significant part of the overall energy efficiency of a building; however the mechanical systems are not the focus of this study. HVAC systems will be modeled utilizing software defaults and auto-sizing features.

The overall purpose of this study is to investigate the impacts of the building envelope and the energy consumption of hospitals. Building envelopes should be designed in response to the building loads. The mechanical systems are designed in response to internal loads. The comparison of the contribution of the building envelope shapes to the EUI with existing internal building loads is not comparable to the 90.1-2010 benchmark. This is due to the difference in existing internal loads and the loads established in the standard. The comparison of the overall disparity in EUI between the two was apparent; however the comparison of the individual contributions was a limitation of this study.

This study did not include any simulations of current advances in technology, such as combined cooling heat and power (CCHP) as part of the simulation. Simulations of various types of mechanical systems or variants of equipment were not the purpose of this study and were not simulated. The uses of various mechanical systems are too complex to assume one system would be ideal in every situation; however this assumption was made to limit the comparison between the envelope elements.

The simulations of the daylighting controls within this study are limited by the capability of eQUEST to simulate the ray tracing studies of daylighting in more appropriate software programs. The simulations in this study are an approximation and not a complete representation of all of the daylighting potential that might be achieved in a more comprehensive study of these elements.

The accuracy of the energy simulation depends on the quality of the data utilized, the precision of the tools used to measure it, as well as the skill of the operator of the software. The analysis of the energy usage of each variation of the renovation scheme is limited by the imperfect ability of the software operator and model to replicate reality (EPA 2000).

3.5 Validations

The Army Medical Department's portfolios of building data as well as the data available via the Department of Energy's CBECS surveys are the majority of the data input in this study. The use of building designs, plans and specifications of existing facilities as a foundation for simulations should increase the validity of the results.

3.6 Resources

Construction drawings from multiple existing hospitals throughout the country are required to complete this study. The drawings for all modifications to existing U.S. Army medical facilities are archived at Fort Sam Houston, Texas in the office of the Assistant Chief of Staff for Installation, Environment and Facility Management (ACSIEFM) of the U.S. Army Medical Command (MEDCOM).

4. FINDINGS

4.1 EBD Features Affecting the Building Envelope

The EBD features are arranged in a matrix that relates each EBD feature with the MHS EBD principles, as shown in Table 1: Matrix of EBD principles/features and effect on the building envelope. These relationships demonstrate the design intentions that can be derived by the successful use of each feature. EBD features can be related to multiple principles, depending on the systems influenced by the feature.

Casscells et al. (2009a) reported the findings from a Tricare Management Agency (TMA) Healthcare Facility Evidence-Based Design Survey. The TMA survey was designed to collect the opinions of recent military patients regarding desirable design features. The survey sampled 4,000 military members that were inpatients after return from operations in the Global War on Terrorism (GWOT). The researchers constricted the survey to ten features based off of literature review and professional experience to the features most likely to be utilized in MHS facilities. These ten features are annotated on the matrix as possible EBD features.

The Center for Health Design (CHD) has designed a hypothetical hospital that includes key EBD features as part of the design. The purpose of designing this “Fable Hospital” was for projecting potential costs of construction, operation, revenue and savings of a hospital with EBD features. The CHD released the results of its financial return on investment (ROI) projections in a 2010 article along with the 14 key EBD features that were included in its design model (CHD 2010).

Table 1: Matrix of EBD principles/features and effect on the building envelope

Features Principle	1: Create a Patient- & Family-Centered Environment	2: Improve the Quality and Safety of Healthcare	3: Enhance Care of the Whole Person (Contact with Nature & Positive Distractions)	4: Create a Positive Work Environment	5: Design for Maximum Standardization, Future Flexibility and Growth	Affects the Building Envelope	References:
Use Sound-Absorbing Materials, Especially High-Performance Sound-Absorbing Ceiling Tiles	X	X		X			A, C, D, E, F, G
Design Walled Rooms for Admitting, Examination and Treatment Spaces	X	X		X			A, G
Reduce or Eliminate Loud Noises	X	X		X			A, C, D, E, G
Isolation of construction and renovation areas from patient-care areas	X	X		X			A
Large Single-bed Rooms w/Family Zones	X	X				X	A, B, C, D, E, G
Maximize Natural Light throughout the Building	X		X	X		X	A, D, E, G
Access to a group activity room (additional family & social spaces)	X		X		X		B, C, E
"Residential-feeling" waiting areas and patient rooms	X		X				A, G
Convenient food facilities for patients and families (private kitchenette for family meals)	X		X				A, B, E
Operable windows in patient rooms with operable sashes	X		X			X	D, E
Patient wellness center with swimming and therapeutic pools	X		X				E
Windows in staff break rooms	X			X		X	A, E
Improved wayfinding	X			X			E, G
Patient controls for light, glare and temperature	X					X	A, B, G
Use of materials and furnishings that do not emit toxins	X						A
Health information centers (patient and family access to medical information)	X						C, F
Variety of room types for choice and variety	X						E
Install Ceiling-Mounted Patient Lifts		X		X			A, E, G
Acuity-adaptable rooms for a combined ICU/CCU		X		X			A, D, E, F
Improved lighting levels in medication preparation, dispensary and procedure areas (multi-functional lighting systems)		X		X			A, D, F
Decentralized inpatient nursing support (alcoves near beds)		X		X		X	A, C, D, E, F, G
Large and/or double-doors in patient rooms/bathrooms		X		X			C, D
Bathroom (in patient room) on headwall with handrail		X		X			D
Like-handed rooms (standardized layout)		X		X			D
Specially designed bariatric care rooms		X		X			E
Provide HEPA Filtration; Air-flow segregation		X					A, C, E, F, G
Regular maintenance, cleaning and inspection of water systems		X					A
Proper water treatment practices		X					A

Table 1: (continued)

Features / **Principle**	**1: Create a Patient- & Family-Centered Environment**	**2: Improve the Quality and Safety of Healthcare**	**3: Enhance Care of the Whole Person (Contact with Nature & Positive Distractions)**	**4: Create a Positive Work Environment**	**5: Design for Maximum Standardization, Future Flexibility and Growth**	**Affects the Building Envelope**	**References:**
Avoidance of decorative water fountains in high-risk patient care areas		X					A
Frequent cleaning of high contact surfaces		X					A
Providing well-located and highly visible sinks and hand-washing dispensers		X					A, C, D, E, F
Ensuring that HVAC systems are well maintained and operated		X					A, E, F
Providing secure access to nature and views (larger windows, gardens, roof gardens, internal courtyards)			X	X		X	A, B, C, D, E, G
Water feature in lobby			X	X			D
Providing positive distractions (music, appropriate art, etc.)			X				A, B, C, D, E, G
Providing multiple spiritual spaces and haven areas (meditation rooms for family and staff)			X				A, C
Access to multimedia entertainment (i.e. Internet, email, movies, video games, long-distance phone, etc.)			X				B, F, G
Ability to personalize room décor (digital personal photos or artwork)			X				B
Interaction with nature (greenhouse, planting beds, animal farm)			X				E
Use of softer floor materials like carpet and rubber as appropriate				X			A
Ergonomic evaluation of work areas				X			A
Decentralized staff support spaces (e.g. supplies and charting areas)				X		X	A, E, G
Providing flexible spaces for interactive team work				X			A
Staff gym (exercise equipment, locker rooms)				X			C
Optimizing unit adjacencies with Care Centers (e.g., Cancer, Musculoskeletal Care)					X		A, G
Modular Planning					X		G

References:

A	Evidence-Based Design: Application in the MHS (Malone et al. 2007)
B	(Casscells et al. 2009a)
C	Fable Hospital (CHD2010)
D	Dublin Methodist Hospital (Kent et al. 2009)
E	Royal Jubilee Hospital Patient Care Center, Victoria, British Columbia, Canada (Zensius and Keller 2009; Ulrich 2010)
F	Health Facility Management, 2010 Hospital Building Report (Carpenter and Hoppszallern 2010)
G	Fort Belvior Community Hospital, Virginia (DeWitt Health Care Network 2008; Repeta 2009; Repeta 2010)

The CHD has championed the work of “Pebble” project research, which is a partnership with healthcare organizations to provide examples of EBD designed hospitals for the entire industry’s benefit. In the EDAC Study Guide 3, a matrix of EBD features and target outcomes from the Dublin Methodist Hospital Pebble project is shown as an applied example (Kent et al. 2009). The fifteen features listed are useful illustrations of features that have been realistically included in healthcare construction.

The Royal Jubilee Hospital Patient Care Center (RJHPCC) is a hospital replacement project in Victoria, British Columbia, Canada that has received publicity and attention for its participation in the CHD “Pebble” research. The RJHPCC is a 500-bed elder-friendly facility that is expected to be open to patients in 2011 (Zensius and Keller 2009). The design research team that developed the listing of EBD features that are part of the design collaborated with other successfully completed project teams to determine the appropriate features for their goals.

The American Society of Healthcare Engineering (ASHE) conducted a survey of hospital executives regarding current trends in healthcare construction. According to Carpenter and Hoppszallern (2010), one of the talking points of the survey was regarding the recent downturn in hospital new construction projects and renovations. The economy and subsequent conservative budgeting in addition to uncertainty with the impact of health care reform legislation were listed as contributing factors. In spite of these circumstances, hospitals have included EBD features in their projects. There were eight features determined by the survey with the highest frequency of use in current projects.

The DeWitt Army Community Hospital in Fort Belvoir, Virginia has been designed with the MHS to include EBD features and goals as part of this new hospital. These features align with the commissioned studies and reports that have been performed as part of the government’s directives to include EBD in future healthcare projects (Malone et al. 2007; DeWitt Health Care Network 2008, Repeta 2009, 2010).

The features were then evaluated on whether they affect the building envelope. The building envelope effects are categorized in two ways: (1) The feature affects the construction or function of the building envelope, i.e. larger windows, window/wall ratio, and operable windows; and (2) The features change internal layout by function or adjacencies that changes the exterior shape and perimeter area of the building.

The features that affect the construction or function of the building envelope are related to the size and type of windows. The design and placement of windows can provide patients, staff and family members with views of nature and increased access to daylight. The features that alter the internal layout of the typical patient ward for reasons of staff efficiency have subsequent effect on the exterior of building. The amount of floor space remains similar, but the perimeter is longer and the surface area of building envelope is increased.

4.2 Characteristics of U.S. Army Medical Facilities

The set of total potential case studies consists of: 59 healthcare facilities worldwide are maintained by the DOD MHS, 34 of which are U.S. Army facilities. The U.S. Army Medical Department (AMEDD) has 30 in-patient facilities within the United States to which access to drawings was granted to the researcher. In Table 2: Matrix of U.S. Army military hospitals, within the United States, the listing of current medical facilities is shown. The facilities in this listing are located in 7 of the 8 climate zones of the United States, as determined by the DOE (ASHRAE 2009a). The facilities were originally constructed between 1957 and 2007, with an average facility age of 36 years. The floor area of each of the facilities ranges from approximately 63,818 square feet to 2,584,363 square feet, with an average facility size of 486,569 square feet.

Table 2: Matrix of U.S. Army military hospitals, within the United States

Facility Identification	Gross Area (square feet)	Year Built	Climate Zone (DOE, 1-8)	Hospital Bed Capacity (AHA)[2]	Patient Density (square feet per bed)	Energy Usage Intensity (Energy Star)[3]	Perimeter (linear feet)	# of floors	Type of shape	wall area to floor area ratio
A	2,364	1966	3	27	2,364	N/R	1,550	1	Rect	0.36
B	85,397	1991	6	0	N/A	155.40	1,900	2	Rect	0.33
C	115,020	1966	3	0	N/A	N/R	2,175	3	Rect	0.28
D	117,444	1961	4	0	N/A	N/R	3,600	4	L-shaped	0.46
E	126,986	1978	3	0	N/A	148.90	2,900	2	Rect	0.34
F	132,429	1962	4	30	4,414	N/R	3,257	3	Rect	0.37
G	134,140	1977	5	31	4,327	N/R	3,268	4	Rect	0.37
H	146,412	1962	4	0	N/A	N/R	4,100	3	L-shaped	0.42
I	168,694	1961	4	0	N/A	N/R	5,000	4	L-shaped	0.44
J	248,684	1966	3	0	N/A	133.50	4,000	2	Rect	0.24
K	260,245	1957	4	46	5,658	170.80	7,000	5	L-shaped	0.40
L	269,000	2007	8	24	11,208	N/R	5,600	3	Round/L	0.31
M	323,280	1972	3	60	5,388	N/R	9,500	11	Rect w/fins	0.44
N	340,000	1983	2	60	5,667	N/R	7,560	4	Rect	0.33
O	367,793	1983	3	44	8,359	132.40	5,950	7	Rect	0.24
P	380,736	1957	4	44	8,653	314.20	10,000	7	L-shaped	0.39
Q	392,765	1958	3	57	6,891	N/R	11,950	11	L-shaped	0.46
R	439,834	1965	4	56	7,854	190.80	10,033	7	Rect	0.34
S	462,410	1957	4	76	6,084	N/R	10,825	9	L-shaped	0.35
T	494,420	1982	4	66	7,491	249.00	7,508	5	Rect	0.23
U	504,198	1966	2	109	4,626	105.90	9,035	5	Rect	0.27
V	513,000	1994	3	44	11,659	N/R	9,248	3	Rect	0.27
W	515,600	1986	5	57	9,046	244.60	7,704	5	Rect	0.22
X	520,017	1985	1	180	2,889	N/R	24,000	10	L-shaped	0.69
Y	622,682	1974	3	105	5,930	N/R	12,632	13	Rect	0.30
Z	664,382	1972	3	209	3,179	218.40	12,478	12	Rect	0.28
AA	1,020,359	1998	3	138	7,394	139.20	15,004	7	Rect	0.22
AB	1,233,136	1990	4	205	6,015	N/R	19,837	9	Rect	0.24
AC	1,349,815	1996	2	226	5,973	N/R	21,000	7	Rect	0.23
AD	2,584,363	1977	4	236	10,951	N/R	40,000	6	Rect w/atrium	0.23

Average	Area	Age		Capacity	Patient Density	EUI	Perimeter	# of Floors		WWR[1]
Overall	486,569	36		71	6,610	184	9,620	6		0.34

Notes:

1. WWR assuming a floor to floor height of 15 feet for all buildings
2. American Hospital Association data on numbers of patient beds

3. U.S. Army MHS Energy Star data; N/R is not reported

The hospital bed capacities were determined by using the American Hospital Association (AHA) ratings available on-line at U.S. News Best Hospitals (2010). The numbers of in-patient beds is the number of beds that the facility is certified to have in accordance with the AHA's criteria. The patient density is the amount of facility square footage per the number of inpatient beds in the hospital.

The floor plans for most of the facilities were available to the researcher to be able to measure the perimeter wall lengths, categorize building shape and note the number of building levels above grade. To measure the facility plans that were not current or available, Google Earth software and photographs of the facilities were used to view the buildings and calculate the perimeter lengths. In Figure 9: Survey of military hospital shapes, the building shapes were surveyed and the design features that recurred were noted. Many of the military hospitals surveyed had deep rectilinear plans, which were typically lower. The patient towers were shallow in depth as compared to the diagnostic and treatment areas and were L-shaped. The majority of facilities were multileveled buildings. Some facilities had atria spaces.

The facilities displayed in the figure below are: Darnall Army Medical Center, Fort Hood, Texas; Walter Reed Army Medical Center, Washington, D.C.; Bassett Army Medical Center, Fort Bragg, North Carolina; and Martin Army Community Hospital, Fort Benning, Georgia. Additional pictures of facilities surveyed are located in APPENDIX E.

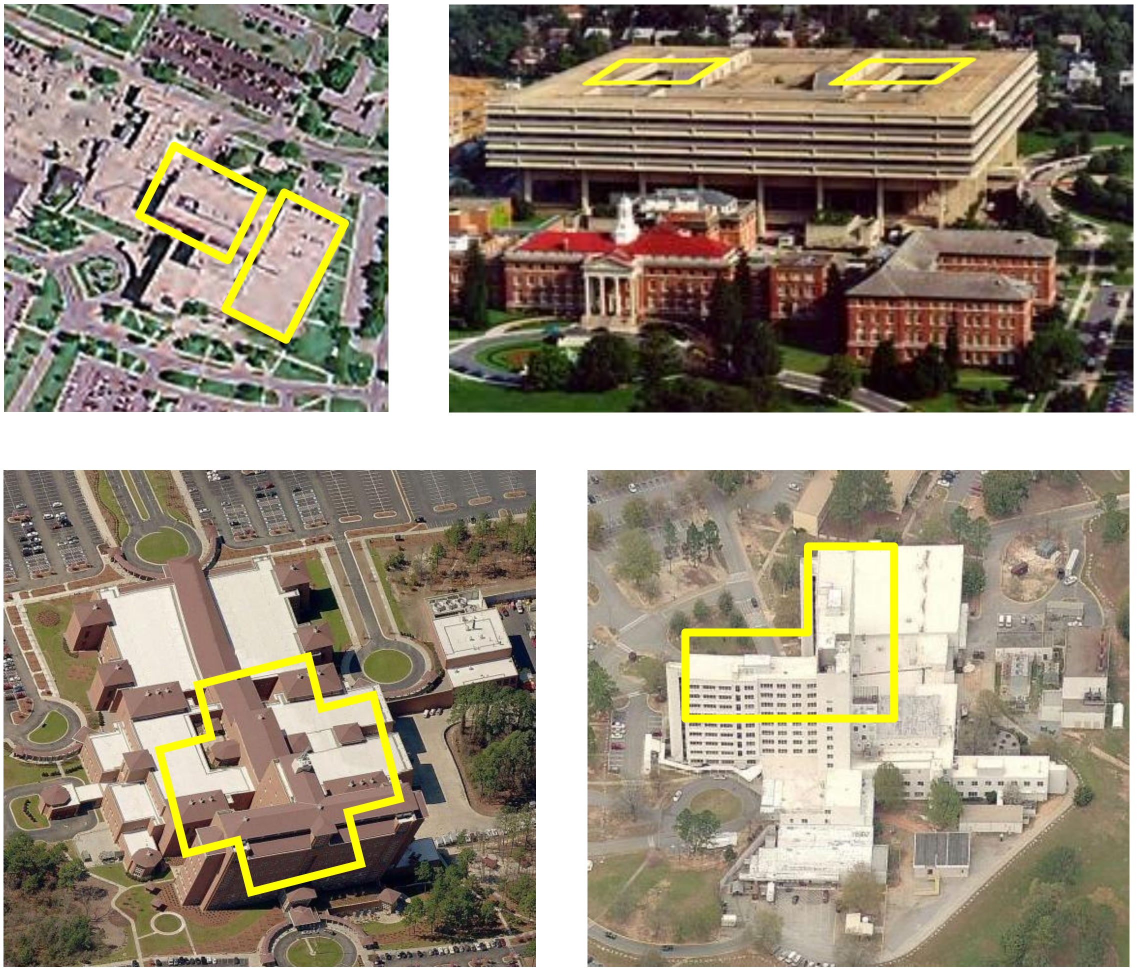
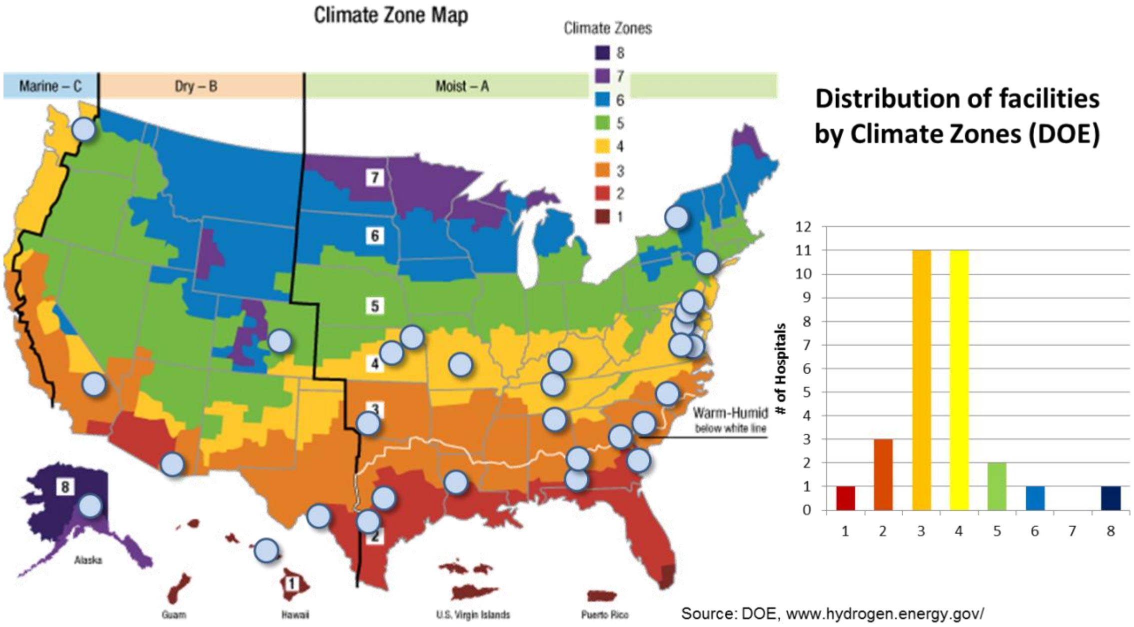


Figure 9: Survey of military hospital shapes

The amount of perimeter length was multiplied by an assumed factor of 15 foot floor to floor height. The factor was calculated as the average floor to floor height in the hospital plans. The exterior wall surface areas of all the military hospitals were calculated by multiplying the floor to floor height by the perimeter wall lengths. The wall area to floor area ratios were then determined by dividing the wall area by the floor area of each hospital.

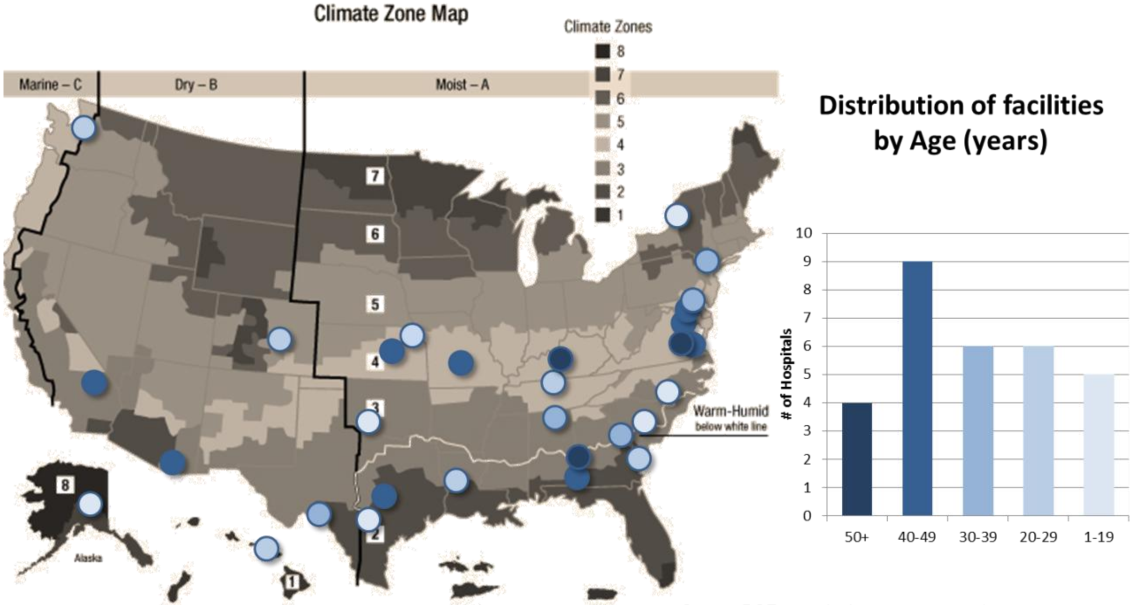
The distribution of the Army hospitals by climate zone is shown in Figure 10: Distribution of facilities by climate zones (DOE). The distribution shows the various climatic conditions that the overall portfolio of hospitals is spread across. The majority of the facilities (72.4%) fall into climate zones 3 and 4; however there is representation in all but one zone (climate zone 7).



Source: DOE, www.hydrogen.energy.gov/

Figure 10: Distribution of facilities by climate zones (DOE)

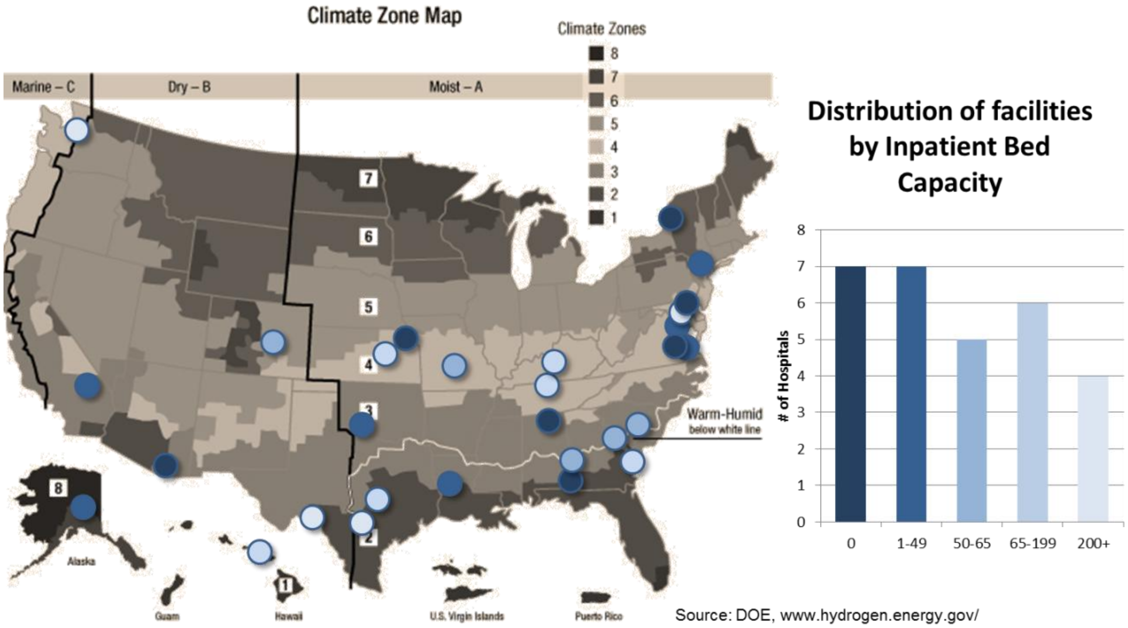
The age of AMEDD hospitals is across a wide range. Over half of military hospitals are over 30 years old (62.0%). The general locations and categories of facility age are shown in Figure 11: Distribution of facilities by age (years). The original age of construction was used, and this does not take into account numerous renovations and renewals that facilities have undergone during their service lives.



Source: DOE, www.hydrogen.energy.gov/

Figure 11: Distribution of facilities by age (years)

The range of inpatient bed capacity of AMEDD hospitals ranges and depends on various factors, such as supported beneficiary population, demographics, and the capacity of the civilian network of facilities. The military hospitals contained in the listing include both community hospitals medical centers. The differences in overall mission, services provided and capability are too broad to be included in this analysis. The inpatient bed capacities were determined by data reported by the American Hospital Association (AHA) (U.S. News 2010). The geographic location and capacity is shown in Figure 12: Distribution of facilities by inpatient bed capacity.

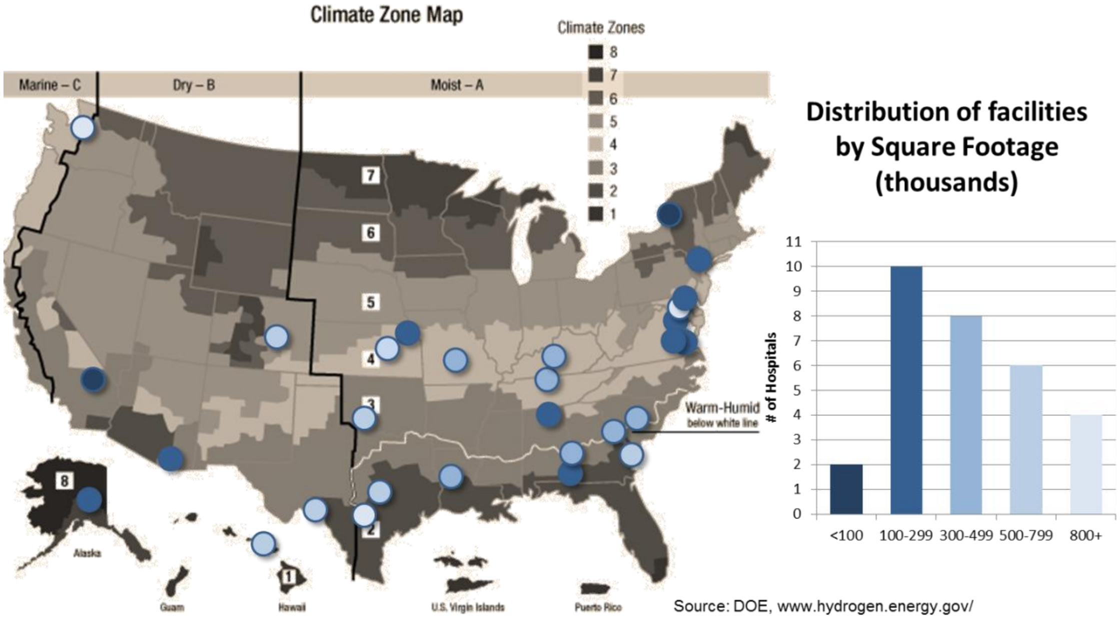


Source: DOE, www.hydrogen.energy.gov/

Figure 12: Distribution of facilities by inpatient bed capacity

The number of smaller facilities in the AMEDD, or less than 500 thousand square feet is well over half of the overall number of hospitals. The large, over 800 thousand square feet, hospitals are the 4 medical centers located across the country. The geographic locations and size of facility are shown in Figure 13: Distribution of facilities by square footage (thousands).

The Energy Star web-based energy use system is used by the U.S. Army Medical Department (AMEDD) for energy management. The reported EUI are based off of the overall annual energy use of the facility, electric and gas, converted to kBtu and then divided by the square footage of the building. This provides the unit of measure of kBtu per square foot per year for the EUI. The facilities are arranged from smallest to largest square footage, A to AC.



Source: DOE, www.hydrogen.energy.gov/

Figure 13: Distribution of facilities by square footage (thousands)

The CBECS database provides average EUI data for facilities and climate zones within the U.S. The assessment of the data provided by the Energy Star program points to some extremely low EUIs for some facilities, such as J, O, and U. The assumption is that this data is possibly due to some particular events occurring at the hospital which would lower the patient populations. The data is shown in Figure 14: U.S. Army hospital energy intensities (as reported by Energy Star, 2002-2009). Additionally, the data that has been collected has not been updated annually; therefore facility data can range from 2002 to 2009 usage data.

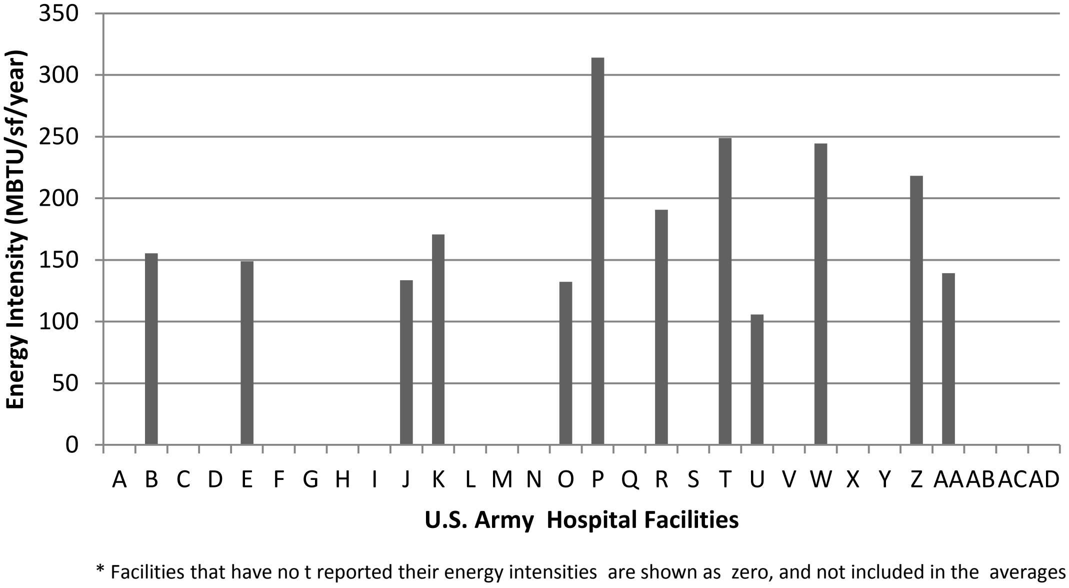


Figure 14: U.S. Army hospital energy intensities (as reported by Energy Star, 2002-2009)

4.3 Incremental Simulation of Features

The incremental simulation of simple models of hospital floor plans were conducted to illustrate the concepts described in the literature review, 2.4 Changes to the Hospital Building Envelope. The initial step of the research was to select two facilities for case study from the listing of military hospitals. The facilities ‘L’ and ‘AC’ are located in DOE Climate Zones 8 and 2, respectively, were selected. They were selected because of their recent construction, within the last 20 years, and their locations placed them in the most wide ranging weather zones which are expected to yield the most informative and interesting results.

The DOE, Buildings Energy Data Book is an online database of the CBECS 2003 data. Commercial buildings data were queried for hospital buildings located in climate zone 8. CBECS energy use data was also queried for hospitals in South Central United States. The average data was revealed regarding the energy usage of a sample of buildings meeting these criteria. The energy use intensity (EUI) is a metric used to compare the energy usage of buildings by measuring the amount of energy in kBtu per square foot of built space per year. The average EUI for hospitals in climate zone 8 with a size of 200,000 to 500,000 square feet is 279.85 kBtu per sf per year (EIA 2004b). The average EUI for hospitals in climate zone 2 was 242.45 kBtu per sf per year (EIA 2004b). The sample size of the CBECS surveys were very small; however upon review of average EUIs of other types of facilities in the same region and climate zone, they are shown to be reliable benchmarks.

The development of a baseline model and architectural form of a hospital was completed using eQUEST energy simulation software. The baseline model was a simple single floor, square floor plate, with system settings and using eQUEST's defaults for inpatient hospitals. The 100,000 square foot baseline model of a hospital was simulated using the parameters shown in Appendix A, Baseline Model parameters. Adjustments were made to the eQUEST default settings to bring the baseline model's EUI in line with the average EUI of climate zone 8.

Modifications to the basic plan were developed with the intention of demonstrating several concepts that were learned during the literature review in Section2.5 Tools Available for Energy Simulation of Hospitals. The modified building shapes all maintained the same amount of floor space as the baseline model. The intention of the alternates is to evaluate the impact of the building's shape on its energy usage, with all other variables the same. The baseline model and nine variations developed were: (1) Baseline model, square plan, single floor; (2) Rectangular plan, single floor, 2:1 length:width ratio; (3) Rectangular plan, single floor, 3:1 length:width ratio; (4) L-shaped plan, single floor, 2:1 length:width ratio; (5) L-shaped plan, single floor, 3:1 length:width ratio; (6) X-shaped plan, single floor; (7) Square plan with square atrium; (8) Square plan, single floor, with an interstitial floor; and two multi-story shapes (9) Square plan, two floors; and (10) Square plan, three floors. The additional geometric characteristics of the models are shown in Appendix B.

The location of facility L was input into the Climate Consultant software, described in Section 2.5 Tools Available for Energy Simulation of Hospitals. The software provided design recommendations for buildings in that location, specific to the weather data from that area. Additionally, the ASHRAE Advanced Energy Design Guide (2009), and the National Renewable Energy Lab (NREL), Large Hospital 50% Energy Savings (Bonnema et al. 2010) were referenced and used to determine energy design measures (EDMs) that would target the building envelope's impact on energy use (Bonnema et al. 2010).

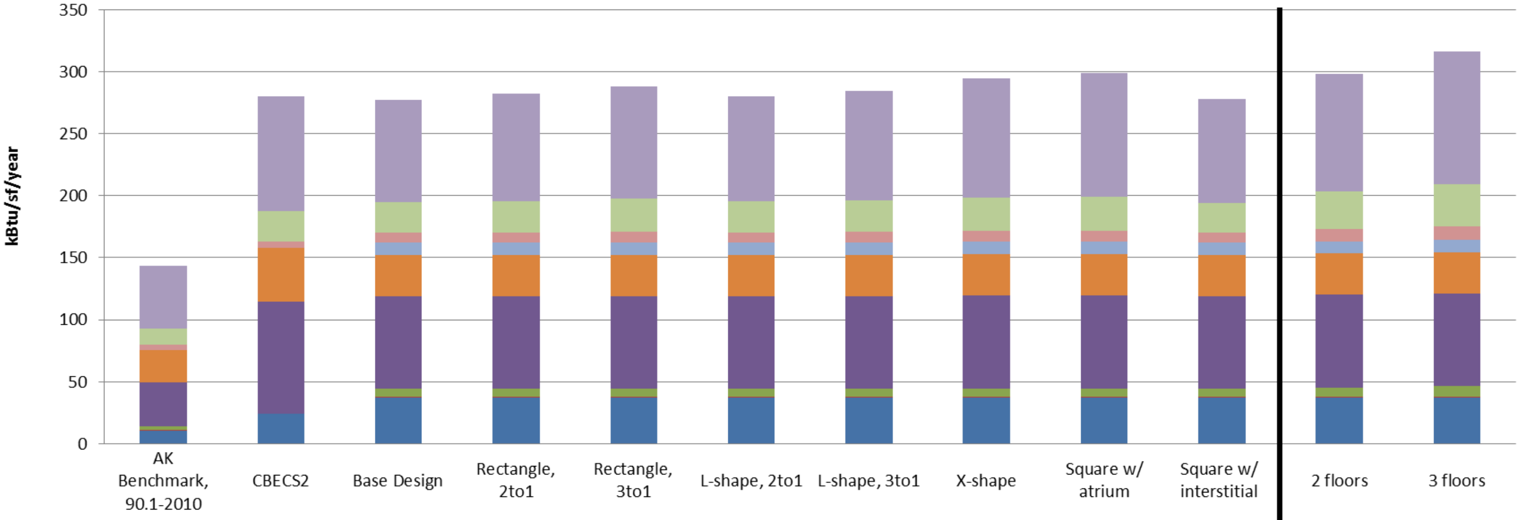
The simulation results of the incremental simulations and case study facility of Climate Zone-8 are found in Appendix C. The simulation results of the incremental simulations and case study facility of Climate Zone-2 are found in Appendix D. The eQUEST output files of the simulations conducted are located in Appendix E.

The simulation results are the overall kBtu, electric and gas, consumed by the facilities using site energy metrics. Site energy is the measurement of the energy consumed at the facility, excluding the production and transportation consumption. The tables used in the body of this study have used the simulation results and the floor space of the simulations to calculate the energy intensity of the models. The energy use intensity (EUI) is a metric of energy units per amount of floor space per period of time. The EUI is used to compare buildings with dissimilar amounts of floor space. The EUI units used in this research are thousand British thermal units per square foot per year (kBtu/sf/year).

4.3.1 Simulation of Building Forms in Extreme Cold Climates

The results of the simulations of the 10 models are shown in Figure 15: Climate Zone 8, Simulations of hospital building forms (kBtu/sf/year).

The EDMs that were recommended and utilized in this study were: (1) Orientation of buildings along an East-West axis with the majority of glazing facing South; (2) Daylighting controls (using eQUEST daylighting controls features); (3) Limiting window to wall ratio (WWR) to <40% of overall building; and (4) External shading devices or window overhangs.



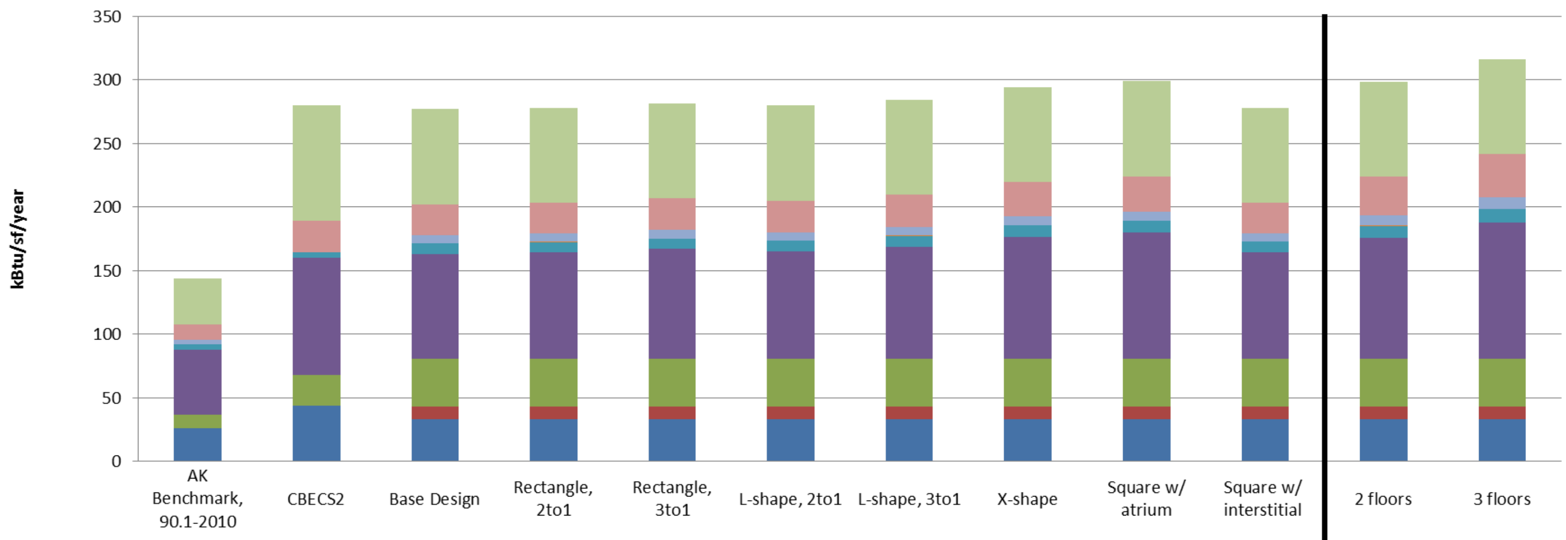
	AK Benchmark, 90.1-2010	CBECS2	Base Design	Rectangle, 2to1	Rectangle, 3to1	L-shape, 2to1	L-shape, 3to1	X-shape	Square w/ atrium	Square w/ interstitial	2 floors	3 floors
■ Space Heating	50.94	92.06	82.42	86.31	91.07	84.67	88.19	95.86	99.70	83.84	94.87	106.99
■ Vent Fans	12.75	24.99	24.34	25.37	26.49	24.77	25.49	26.99	27.50	24.19	30.54	34.14
■ Space Cooling	4.19	4.54	8.09	8.18	8.49	8.21	8.40	8.81	8.93	8.09	9.75	10.81
■ Task Lights	0.00	0.00	10.09	10.09	10.09	10.09	10.09	10.09	10.08	10.09	10.09	10.09
■ Ambient Lights	26.13	43.51	33.23	33.22	33.22	33.24	33.23	33.22	33.20	33.23	33.22	33.21
■ Exterior Usage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Dom Ht Wtr	35.71	90.27	74.79	74.77	74.78	74.81	74.79	74.77	74.74	74.81	74.64	74.62
■ Pumps & Aux	3.20	0.00	6.39	6.45	6.69	6.49	6.65	6.98	7.10	6.39	7.75	8.56
■ Heat Reject	0.13	0.00	0.23	0.24	0.25	0.23	0.24	0.25	0.26	0.23	0.28	0.30
■ Misc Equip	10.65	24.47	37.40	37.39	37.39	37.41	37.40	37.39	37.36	37.40	37.39	37.38

Figure 15: Climate Zone 8, Simulations of hospital building forms (kBtu/sf/year)

The EDMs that were simulated on the baseline model and variations were done sequentially and cumulatively. Each EDM simulated was left in place in the simulation model and subsequent EDMs were layered onto the model. This method illustrates an incremental process of improvement of the energy design of a facility. The first EDM was orientation of buildings along an East-West axis with the majority of glazing facing south. The results of these simulations are shown in Figure 16: Climate Zone 8, Simulations of east-west orientation (kBtu/sf/year).

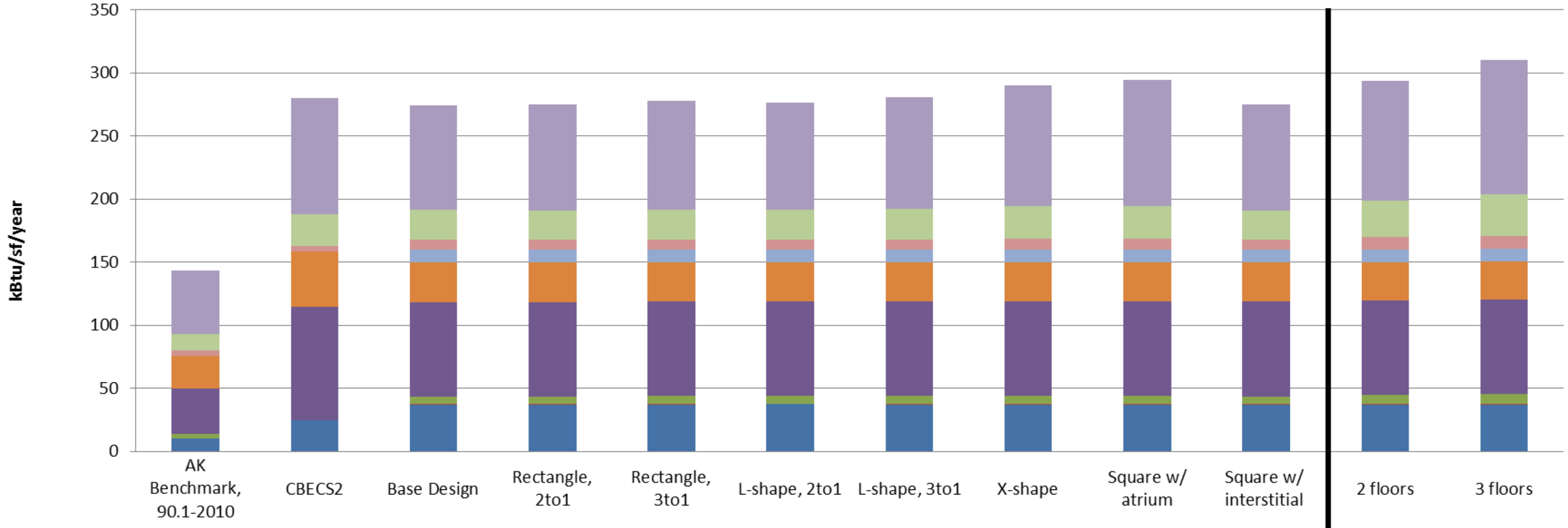
The simulations of building envelope shapes that are equivalent on all sides, such as the squares, and X-shapes did not have a response to the change in orientation.

The next EDM was the use of daylighting controls. The results of these simulations are shown in Figure 17: Climate Zone 8, Energy simulations of hospital building forms with daylighting controls (kBtu/sf/year). These simulations show the cumulative effects of orienting the buildings along an East-West axis as well as the daylighting controls. The building shapes which responded with the largest amounts of savings were the buildings that were the most elongated. The rectangle shapes benefited from the daylighting controls more than the simple square shapes. The 3:1 (length:width) rectangle realized more savings than the 2:1 rectangle. The multi-story had increasing benefits with each additional storied space.



	AK Benchmark, 90.1-2010	CBECS2	Base Design	Rectangle, 2to1	Rectangle, 3to1	L-shape, 2to1	L-shape, 3to1	X-shape	Square w/ atrium	Square w/ interstitial	2 floors	3 floors
Exterior Usage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dom Ht Wtr	35.71	90.27	74.79	74.77	74.78	74.81	74.79	74.77	74.74	74.81	74.64	74.62
Vent Fans	12.75	24.99	24.34	24.37	24.74	24.77	25.49	26.99	27.50	24.19	30.54	34.14
Pumps & Aux	3.20	0.00	6.39	6.41	6.49	6.49	6.65	6.98	7.10	6.39	7.75	8.56
Heat Reject	0.13	0.00	0.23	0.23	0.23	0.23	0.24	0.25	0.26	0.23	0.28	0.30
Space Cooling	4.19	4.54	8.09	8.10	8.19	8.21	8.40	8.81	8.93	8.09	9.75	10.81
Space Heating	50.94	92.06	82.42	83.62	86.26	84.67	88.19	95.86	99.70	83.84	94.87	106.99
Misc Equip	10.65	24.47	37.40	37.39	37.39	37.41	37.40	37.39	37.36	37.40	37.39	37.38
Task Lights	0.00	0.00	10.09	10.09	10.09	10.09	10.09	10.09	10.08	10.09	10.09	10.09
Ambient Lights	26.13	43.51	33.23	33.22	33.22	33.24	33.23	33.22	33.20	33.23	33.22	33.21

Figure 16: Climate Zone 8, Simulations of east-west orientation (kBtu/sf/year)

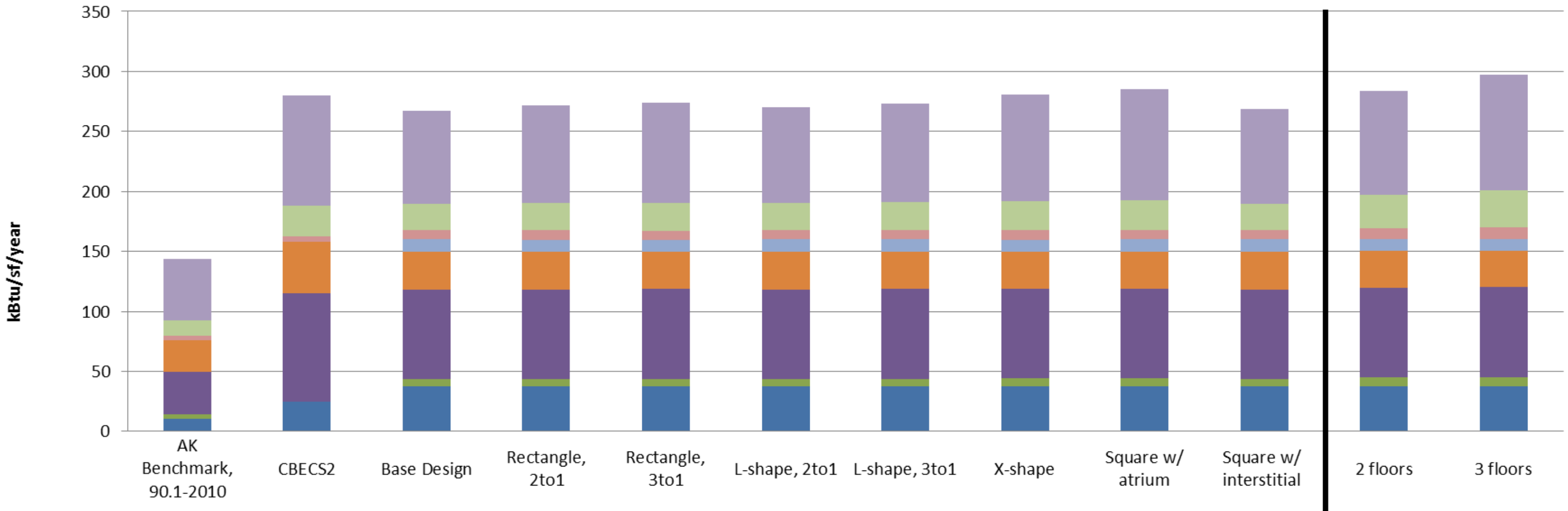


	AK Benchmark, 90.1-2010	CBECS2	Base Design	Rectangle, 2to1	Rectangle, 3to1	L-shape, 2to1	L-shape, 3to1	X-shape	Square w/ atrium	Square w/ interstitial	2 floors	3 floors
■ Space Heating	50.94	92.06	82.71	83.94	86.57	84.96	88.44	96.00	99.85	84.14	94.61	106.55
■ Vent Fans	12.75	24.99	23.49	23.46	23.75	23.87	24.51	25.88	26.30	23.35	29.37	32.76
■ Space Cooling	4.19	4.54	7.86	7.85	7.93	7.97	8.14	8.51	8.61	7.86	9.43	10.33
■ Task Lights	0.00	0.00	10.09	10.09	10.09	10.09	10.09	10.09	10.08	10.09	10.09	10.09
■ Ambient Lights	26.13	43.51	31.24	31.11	30.93	31.15	30.95	30.64	30.41	31.24	30.46	29.88
■ Exterior Usage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Dom Ht Wtr	35.71	90.27	74.79	74.78	74.78	74.81	74.79	74.77	74.74	74.81	74.64	74.62
■ Pumps & Aux	3.20	0.00	6.23	6.24	6.29	6.31	6.45	6.75	6.85	6.23	7.50	8.20
■ Heat Reject	0.13	0.00	0.22	0.22	0.23	0.23	0.23	0.24	0.25	0.22	0.27	0.29
■ Misc Equip	10.65	24.47	37.40	37.39	37.39	37.41	37.40	37.39	37.36	37.40	37.39	37.38

Figure 17: Climate Zone 8, Energy simulations of hospital building forms with daylighting controls (kBtu/sf/year)

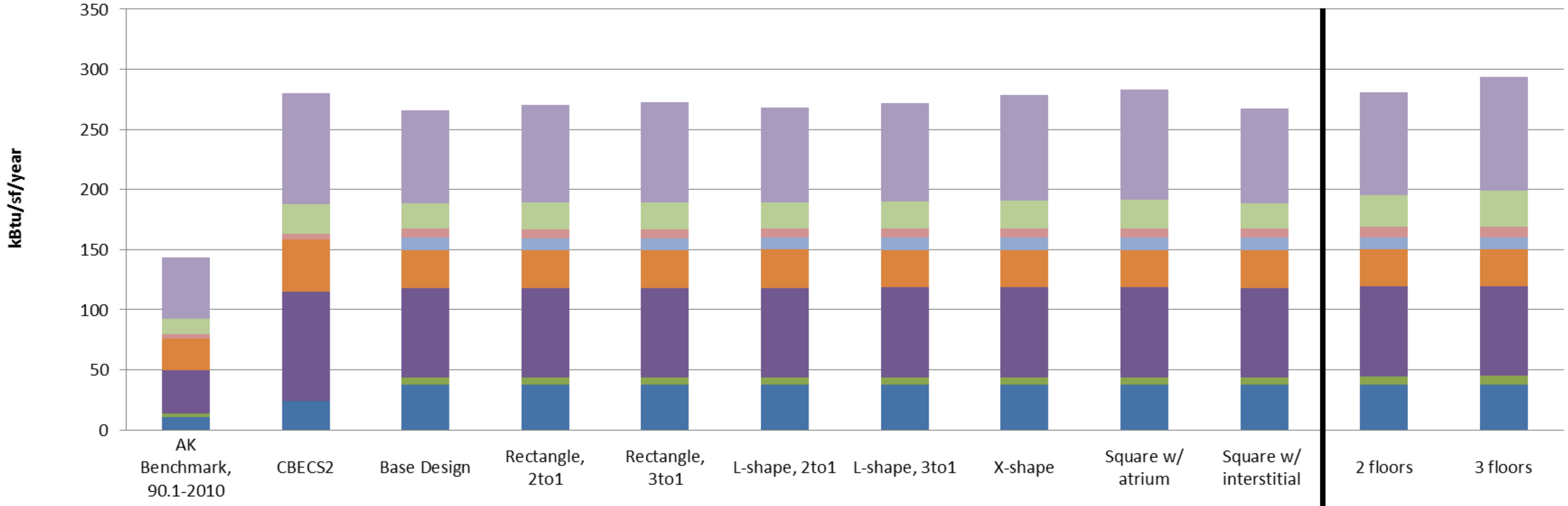
The next EDM is the window to wall ratio (WWR) limitation to 40% of the overall building's glazing. The results of these simulations are shown in Figure 18: Climate Zone 8, Simulations of hospital building forms with window/wall area percentage limited to <40% (kBtu/sf/year). The limitation of WWR percentage benefited those shapes which had the largest amounts of perimeter space. Of all the EDMs, the limitation of the WWR to 40% had the largest impact on the performance of the envelope.

The last EDM performed on the simple models was the exterior shading devices or window overhangs. The overhangs were simulated cumulatively with the previous EDMs to result in an overall energy use. The overhangs extend two feet from the window face and are located only on the window on the South facades. The results of these simulations are shown in Figure 19: Climate Zone 8, Simulations of hospital building forms with exterior shading devices (2 foot overhangs on southern windows) (kBtu/sf/year).



	AK Benchmark, 90.1-2010	CBECS2	Base Design	Rectangle, 2to1	Rectangle, 3to1	L-shape, 2to1	L-shape, 3to1	X-shape	Square w/ atrium	Square w/ interstitial	2 floors	3 floors
Space Heating	50.94	92.06	77.65	81.21	83.65	79.58	82.63	89.02	92.61	79.10	86.64	96.49
Vent Fans	12.75	24.99	22.23	22.69	22.92	22.57	23.10	24.19	24.70	22.10	27.62	30.64
Space Cooling	4.19	4.54	7.47	7.62	7.67	7.56	7.70	7.99	8.10	7.47	8.88	9.66
Task Lights	0.00	0.00	10.09	10.09	10.09	10.09	10.09	10.09	10.08	10.09	10.09	10.09
Ambient Lights	26.13	43.51	31.62	31.30	31.14	31.58	31.36	31.03	31.16	31.62	30.92	30.38
Exterior Usage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dom Ht Wtr	35.71	90.27	74.79	74.78	74.79	74.81	74.80	74.78	74.75	74.81	74.64	74.63
Pumps & Aux	3.20	0.00	5.96	6.06	6.11	6.01	6.13	6.35	6.47	5.96	7.08	7.71
Heat Reject	0.13	0.00	0.21	0.22	0.22	0.22	0.22	0.23	0.23	0.21	0.25	0.27
Misc Equip	10.65	24.47	37.40	37.39	37.39	37.41	37.40	37.39	37.36	37.40	37.39	37.38

Figure 18: Climate Zone 8, Simulations of hospital building forms with window/wall area percentage limited to <40% (kBtu/sf/year)



	AK Benchmark, 90.1-2010	CBECS2	Base Design	Rectangle, 2to1	Rectangle, 3to1	L-shape, 2to1	L-shape, 3to1	X-shape	Square w/ atrium	Square w/ interstitial	2 floors	3 floors
Space Heating	50.94	92.06	76.93	80.83	83.33	78.79	81.75	87.95	91.49	78.40	85.11	94.50
Vent Fans	12.75	24.99	21.67	22.43	22.70	21.98	22.44	23.43	23.90	21.54	26.77	29.60
Space Cooling	4.19	4.54	7.31	7.36	7.42	7.40	7.52	7.78	7.88	7.31	8.66	9.24
Task Lights	0.00	0.00	10.09	10.09	10.09	10.09	10.09	10.09	10.08	10.09	10.09	10.09
Ambient Lights	26.13	43.51	31.63	31.31	31.15	31.59	31.38	31.05	31.18	31.63	30.94	30.40
Exterior Usage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dom Ht Wtr	35.71	90.27	74.79	74.78	74.79	74.81	74.80	74.78	74.75	74.81	74.64	74.63
Pumps & Aux	3.20	0.00	5.85	5.84	5.90	5.92	6.02	6.20	6.30	5.85	6.91	7.33
Heat Reject	0.13	0.00	0.21	0.21	0.22	0.21	0.21	0.22	0.22	0.21	0.24	0.27
Misc Equip	10.65	24.47	37.40	37.39	37.39	37.41	37.40	37.39	37.36	37.40	37.39	37.38

Figure 19: Climate Zone 8, Simulations of hospital building forms with exterior shading devices (2 foot overhangs on southern windows) (kBtu/sf/year)

4.3.2 Simulation of Building Forms in Hot Climates

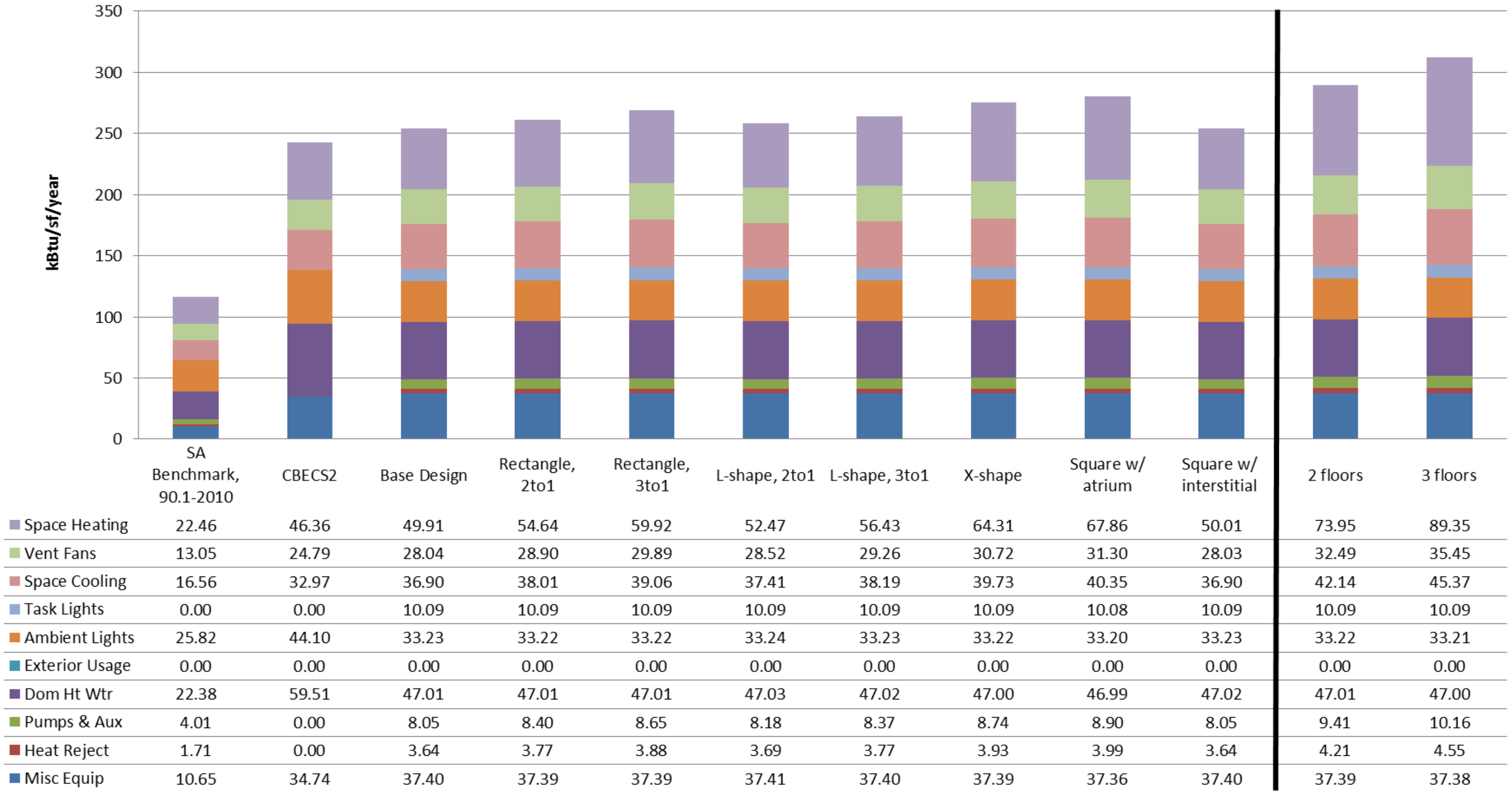
The same methodology, as it was used in the simulations in extreme cold climates, applies for this section with the exception that the model was calibrated to the average CBECS EUI for climate zone 2. The results of the simulations of the 10 models are shown in Figure 20: Climate Zone 2, Simulations of hospital building forms (kBtu/sf/year). The weather file data utilized for the hot climate simulations was the San Antonio, Texas data.

The EDMs that were simulated on the baseline model and variations were done sequentially and cumulatively. Each EDM simulated was left in place in the simulation model and subsequent EDMs were layered onto the model. This method illustrates an incremental process of improvement of the energy design of a facility. The first EDM was orientation of buildings along an East-West axis with the majority of glazing facing south. The results of these simulations are shown in Figure 21: Climate Zone 2, Simulations of hospital building forms east-west orientation (kBtu/sf/year).

The next EDM was the use of daylighting controls. The results of these simulations are shown in Figure 22: Climate Zone 2, Simulations of hospital building forms with daylighting controls (kBtu/sf/year). These simulations show the cumulative effects of orienting the buildings along an East-West axis as well as the daylighting controls.

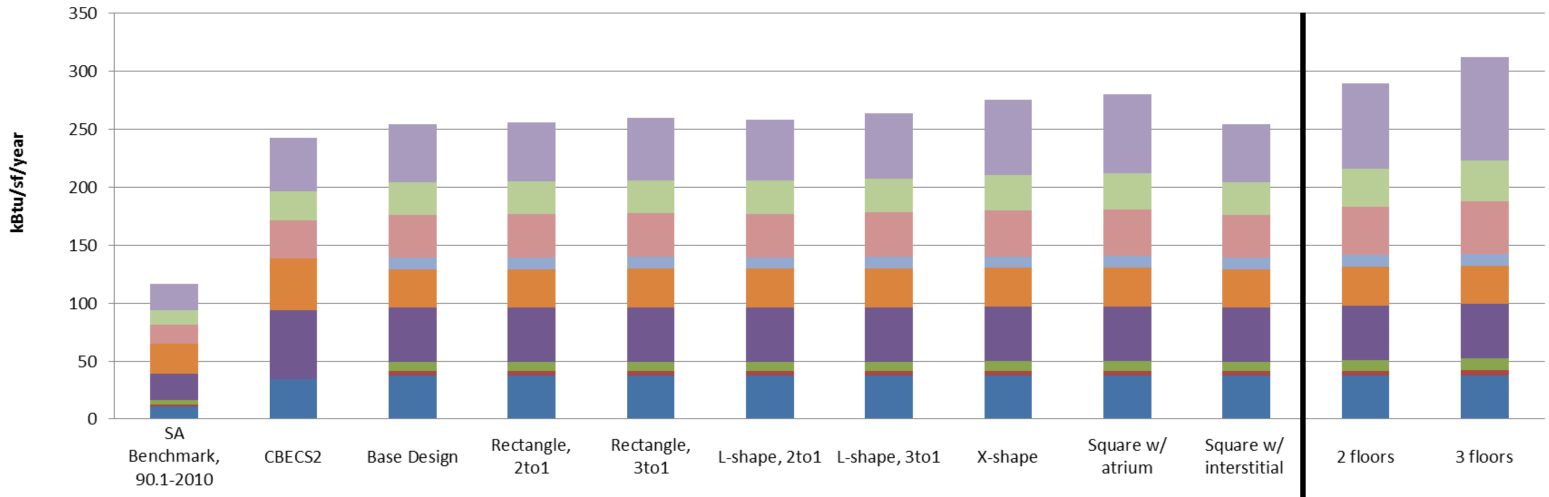
The next EDM is the window to wall ratio (WWR) limitation to 40% of the overall building’s glazing. The results of these simulations are shown in Figure 23: Climate Zone 2, Simulations of hospital building forms with window/wall area limited to 40% (kBtu/sf/year).

The last EDM performed on the simple models was the exterior shading devices or window overhangs. The overhangs were simulated cumulatively with the previous EDMs to result in an overall energy use. The overhangs extend two feet from the window face and are located only on the window on the South facades. The results of these simulations are shown in Figure 24: Climate Zone 2, Simulations of hospital building forms with exterior shading devices (2 feet overhangs) (kBtu/sf/year).



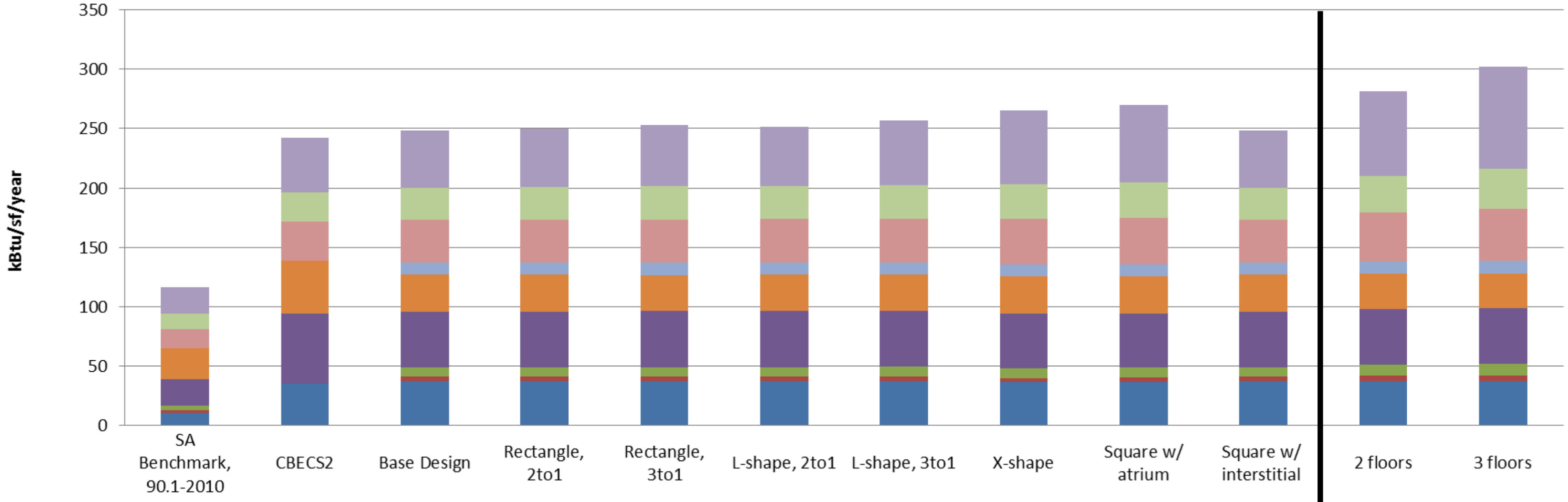
	SA Benchmark, 90.1-2010	CBECS2	Base Design	Rectangle, 2to1	Rectangle, 3to1	L-shape, 2to1	L-shape, 3to1	X-shape	Square w/ atrium	Square w/ interstitial	2 floors	3 floors
Space Heating	22.46	46.36	49.91	54.64	59.92	52.47	56.43	64.31	67.86	50.01	73.95	89.35
Vent Fans	13.05	24.79	28.04	28.90	29.89	28.52	29.26	30.72	31.30	28.03	32.49	35.45
Space Cooling	16.56	32.97	36.90	38.01	39.06	37.41	38.19	39.73	40.35	36.90	42.14	45.37
Task Lights	0.00	0.00	10.09	10.09	10.09	10.09	10.09	10.09	10.08	10.09	10.09	10.09
Ambient Lights	25.82	44.10	33.23	33.22	33.22	33.24	33.23	33.22	33.20	33.23	33.22	33.21
Exterior Usage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dom Ht Wtr	22.38	59.51	47.01	47.01	47.01	47.03	47.02	47.00	46.99	47.02	47.01	47.00
Pumps & Aux	4.01	0.00	8.05	8.40	8.65	8.18	8.37	8.74	8.90	8.05	9.41	10.16
Heat Reject	1.71	0.00	3.64	3.77	3.88	3.69	3.77	3.93	3.99	3.64	4.21	4.55
Misc Equip	10.65	34.74	37.40	37.39	37.39	37.41	37.40	37.39	37.36	37.40	37.39	37.38

Figure 20: Climate Zone 2, Simulations of hospital building forms (kBtu/sf/year)



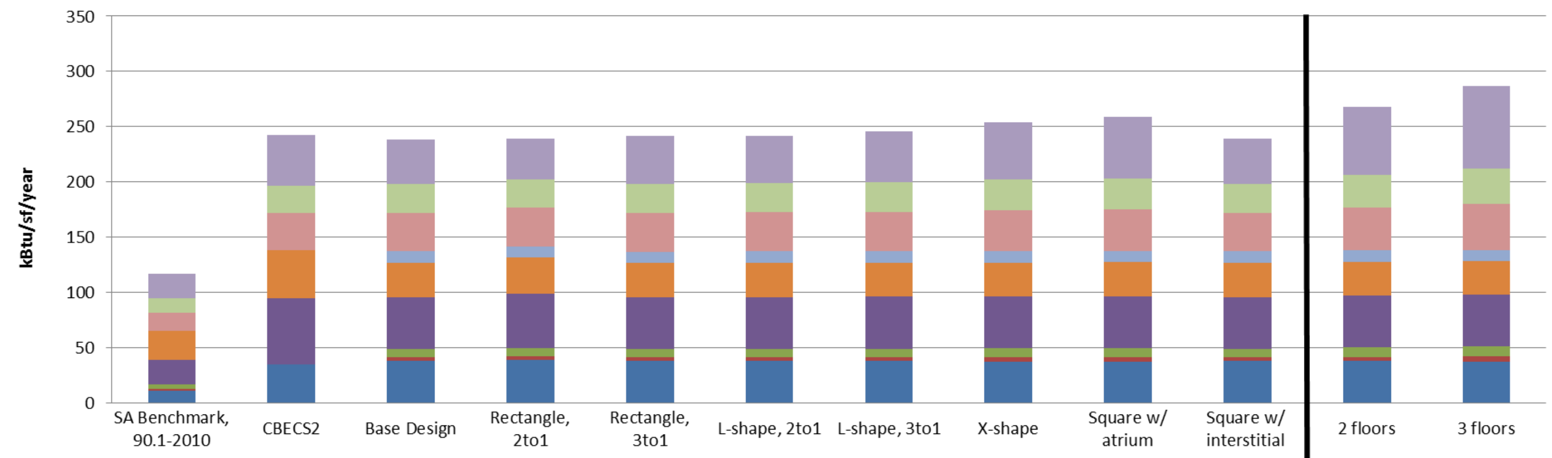
	SA Benchmark, 90.1-2010	CBECS2	Base Design	Rectangle, 2to1	Rectangle, 3to1	L-shape, 2to1	L-shape, 3to1	X-shape	Square w/ atrium	Square w/ interstitial	2 floors	3 floors
■ Space Heating	22.46	46.36	49.91	51.28	53.79	52.47	56.43	64.31	67.86	50.01	73.95	89.35
■ Vent Fans	13.05	24.79	28.04	28.29	28.75	28.52	29.26	30.72	31.30	28.03	32.49	35.45
■ Space Cooling	16.56	32.97	36.90	37.16	37.65	37.41	38.19	39.73	40.35	36.90	42.14	45.37
■ Task Lights	0.00	0.00	10.09	10.09	10.09	10.09	10.09	10.09	10.08	10.09	10.09	10.09
■ Ambient Lights	25.82	44.10	33.23	33.22	33.22	33.24	33.23	33.22	33.20	33.23	33.22	33.21
■ Exterior Usage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Dom Ht Wtr	22.38	59.51	47.01	47.01	47.01	47.03	47.02	47.00	46.99	47.02	47.01	47.00
■ Pumps & Aux	4.01	0.00	8.05	8.12	8.24	8.18	8.37	8.74	8.90	8.05	9.41	10.16
■ Heat Reject	1.71	0.00	3.64	3.67	3.72	3.69	3.77	3.93	3.99	3.64	4.21	4.55
■ Misc Equip	10.65	34.74	37.40	37.39	37.39	37.41	37.40	37.39	37.36	37.40	37.39	37.38

Figure 21: Climate Zone 2, Simulations of hospital building forms east-west orientation (kBtu/sf/year)



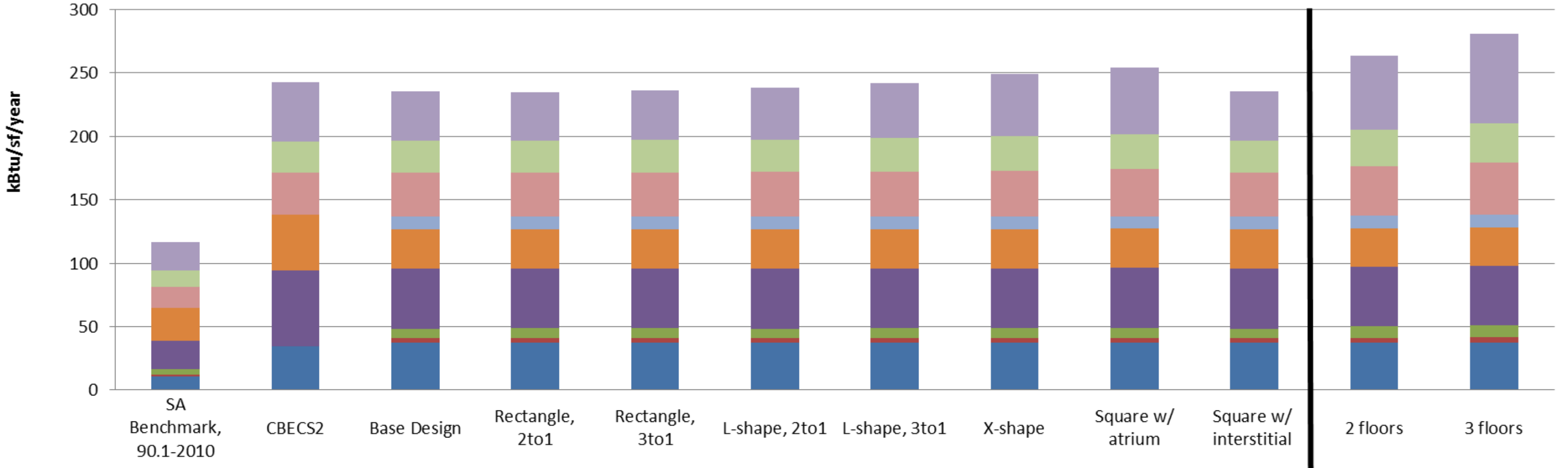
	SA Benchmark, 90.1-2010	CBECS2	Base Design	Rectangle, 2to1	Rectangle, 3to1	L-shape, 2to1	L-shape, 3to1	X-shape	Square w/ atrium	Square w/ interstitial	2 floors	3 floors
Space Heating	22.46	46.36	47.92	49.19	51.51	50.37	54.14	62.06	65.48	48.02	71.24	86.13
Vent Fans	13.05	24.79	27.28	27.48	27.87	27.71	28.38	29.64	30.21	27.27	31.43	34.18
Space Cooling	16.56	32.97	36.10	36.32	36.73	36.57	37.27	38.34	38.94	36.10	41.04	44.05
Task Lights	0.00	0.00	10.09	10.09	10.09	10.09	10.09	9.73	9.73	10.09	10.09	10.09
Ambient Lights	25.82	44.10	30.99	30.83	30.62	30.88	30.66	32.06	32.04	30.99	30.11	29.46
Exterior Usage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dom Ht Wtr	22.38	59.51	47.01	47.01	47.01	47.03	47.02	45.36	45.34	47.02	47.01	47.00
Pumps & Aux	4.01	0.00	7.88	7.92	8.02	7.98	8.15	8.43	8.59	7.88	9.18	9.85
Heat Reject	1.71	0.00	3.55	3.58	3.62	3.60	3.68	3.79	3.85	3.55	4.10	4.41
Misc Equip	10.65	34.74	37.40	37.39	37.39	37.41	37.40	36.08	36.05	37.40	37.39	37.38

Figure 22: Climate Zone 2, Simulations of hospital building forms with daylighting controls (kBtu/sf/year)



	SA Benchmark, 90.1-2010	CBECS2	Base Design	Rectangle, 2to1	Rectangle, 3to1	L-shape, 2to1	L-shape, 3to1	X-shape	Square w/ atrium	Square w/ interstitial	2 floors	3 floors
■ Space Heating	22.46	46.36	40.99	36.87	43.25	43.08	46.15	52.39	55.61	41.09	61.67	74.55
■ Vent Fans	13.05	24.79	26.00	25.87	26.37	26.38	26.91	27.99	28.55	25.99	29.64	31.98
■ Space Cooling	16.56	32.97	34.74	34.83	35.13	35.15	35.71	36.87	37.45	34.74	39.15	41.74
■ Task Lights	0.00	0.00	10.09	10.44	10.09	10.09	10.09	10.09	10.08	10.09	10.09	10.09
■ Ambient Lights	25.82	44.10	31.40	32.70	31.12	31.36	31.11	30.72	30.89	31.40	30.61	30.01
■ Exterior Usage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
■ Dom Ht Wtr	22.38	59.51	47.01	48.65	47.01	47.03	47.02	47.00	46.98	47.02	47.01	47.00
■ Pumps & Aux	4.01	0.00	7.56	7.57	7.65	7.66	7.78	8.06	8.22	7.56	8.73	9.39
■ Heat Reject	1.71	0.00	3.41	3.42	3.45	3.46	3.51	3.63	3.69	3.41	3.90	4.17
■ Misc Equip	10.65	34.74	37.40	38.70	37.39	37.41	37.40	37.39	37.36	37.40	37.39	37.38

Figure 23: Climate Zone 2, Simulations of hospital building forms with window/wall area limited to 40% (kBtu/sf/year)



	SA Benchmark, 90.1-2010	CBECS2	Base Design	Rectangle, 2to1	Rectangle, 3to1	L-shape, 2to1	L-shape, 3to1	X-shape	Square w/ atrium	Square w/ interstitial	2 floors	3 floors
Space Heating	22.46	46.36	38.57	38.06	39.41	40.51	43.34	49.10	52.15	38.67	58.52	70.76
Vent Fans	13.05	24.79	25.44	25.20	25.40	25.79	26.27	27.24	27.76	25.43	28.88	31.07
Space Cooling	16.56	32.97	34.38	34.62	34.83	34.75	35.26	36.31	36.86	34.38	38.75	41.20
Task Lights	0.00	0.00	10.09	10.09	10.09	10.09	10.09	10.09	10.08	10.09	10.09	10.09
Ambient Lights	25.82	44.10	31.40	31.30	31.12	31.36	31.11	30.73	30.90	31.40	30.62	30.02
Exterior Usage	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Dom Ht Wtr	22.38	59.51	47.01	47.01	47.01	47.03	47.02	47.00	46.98	47.02	47.01	47.00
Pumps & Aux	4.01	0.00	7.56	7.74	7.79	7.65	7.78	8.02	8.16	7.56	8.78	9.40
Heat Reject	1.71	0.00	3.40	3.45	3.47	3.43	3.49	3.59	3.65	3.40	3.89	4.15
Misc Equip	10.65	34.74	37.40	37.39	37.39	37.41	37.40	37.39	37.36	37.40	37.39	37.38

Figure 24: Climate Zone 2, Simulations of hospital building forms with exterior shading devices (2 feet overhangs) (kBtu/sf/year)

4.3.3 Analysis of Simulations

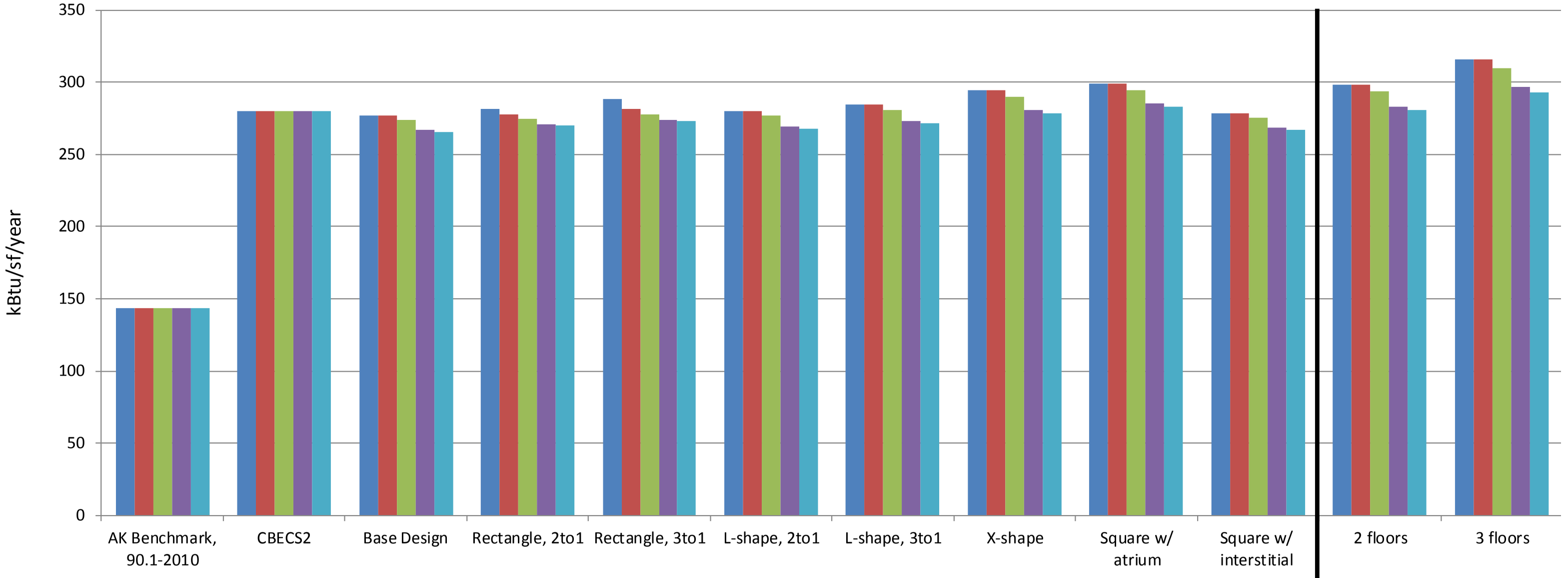
4.3.3.1 Analysis of Extreme Cold Climate Incremental Simulations

The summary of the hospital building forms simulated in climate zone 8 are shown in Figure 25: Climate Zone 8, EUI of building forms with energy design measures and percent difference from base design (kBtu/sf/year). The overall pattern of the data demonstrates that the baseline form of a square floor plan is the most energy efficient. The deviations from this ideal, result in higher energy consumption, given all other factors are the same.

The multiple floor plans while leading in the highest energy intensities are sharply decreased by using EDMs. The most effective reduction measure for the multiple storied plans was the limitation of the window area to 40% of the façade.

The literature is validated by the sharply increasing energy intensities of plans with multiple floors, as compared to rectilinear plans with similar depth of plan (Gilg and Valentine 2004). The two and three floor plans compared to the rectangle 2:1 and 3:1 plans are similar in that the single story plans are the equivalent of the multi-story floors laid out side by side.

The L-shaped plans compared to the rectilinear plans with the same depth of plan are decreased in energy intensity in the baseline simulations of massing within a north to south orientation. Once the plans are oriented in an east to west position the L-shaped plans receive no change due to their shape being similar to a square and no more or less is exposed to the southern façade. The rectangles however sharply decrease in energy consumption and actually become lower than the L-shaped plans, yet they are still higher than the base design. Further simulations of the daylighting controls keep the rectangles in the lower intensity comparison, after the base design. The limitation of window to wall ratio to 40 percent reduce the L-shaped plans sharply and lower the L-shape plans below the rectilinear. The window overhangs benefit both types of plans slightly.



	AK Benchmark, 90.1-2010		CBECS2		Base Design		Rectangle, 2to1		Rectangle, 3to1		L-shape, 2to1		L-shape, 3to1		X-shape		Square w/ atrium		Square w/ interstitial		2 floors		3 floors	
Massing	143.71	-48.1%	279.84	1.0%	276.97	0.0%	282.03	1.8%	288.47	4.2%	279.91	1.1%	284.48	2.7%	294.35	6.3%	298.87	7.9%	278.27	0.5%	298.53	7.8%	316.11	14.1%
Orientation	143.71	-48.1%	279.84	1.0%	276.97	0.0%	278.20	0.4%	281.41	1.6%	279.91	1.1%	284.48	2.7%	294.35	6.3%	298.87	7.9%	278.27	0.5%	298.53	7.8%	316.11	14.1%
Daylighting	143.71	-48.1%	279.84	1.0%	274.03	-1.1%	275.08	-0.7%	277.95	0.4%	276.80	-0.1%	281.02	1.5%	290.27	4.8%	294.46	6.3%	275.35	-0.6%	293.76	6.1%	310.10	12.0%
Window / Wall Ratio	143.71	-48.1%	279.84	1.0%	267.42	-3.4%	271.35	-2.0%	273.96	-1.1%	269.83	-2.6%	273.42	-1.3%	281.05	1.5%	285.46	3.1%	268.76	-3.0%	283.52	2.4%	297.25	7.3%
Overhangs	143.71	-48.1%	279.84	1.0%	265.87	-4.0%	270.23	-2.4%	272.98	-1.4%	268.19	-3.2%	271.61	-1.9%	278.87	0.7%	283.15	2.2%	267.24	-3.5%	280.75	1.4%	293.43	5.9%

Note: Units in chart are kBtu/sf/year, and percentages are calculated from performance greater than or less than the Base Design EUI of 276.97 kBtu/sf/year.

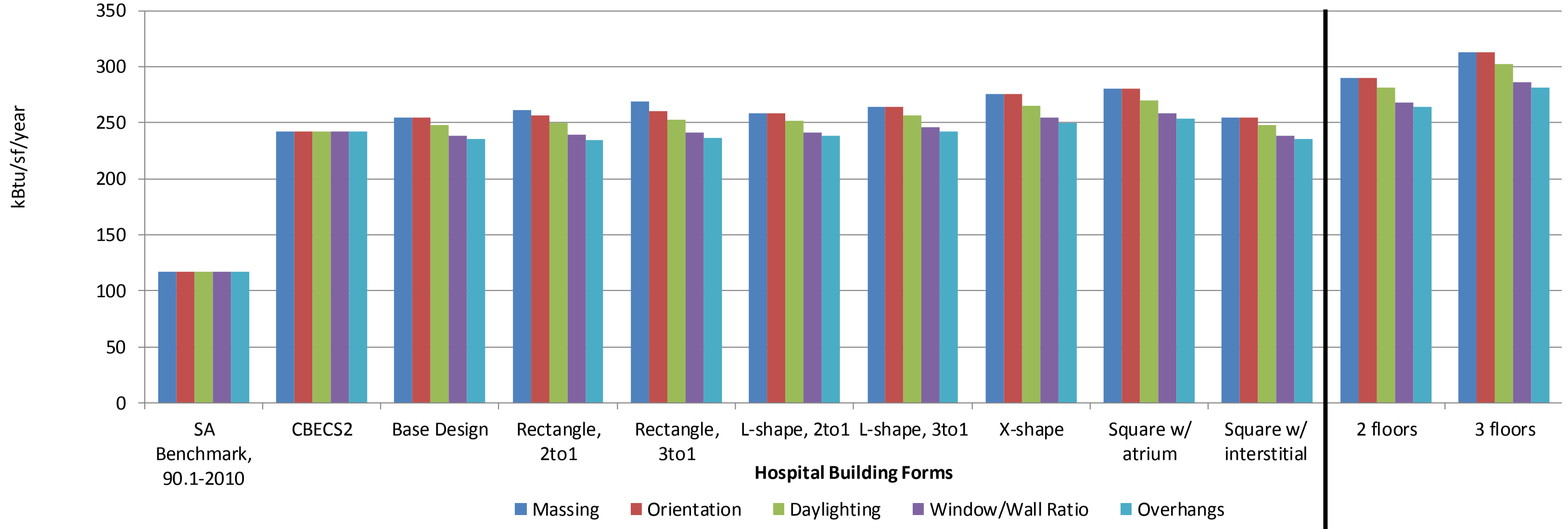
Figure 25: Climate Zone 8, EUI of building forms with energy design measures and percent difference from base design (kBtu/sf/year)

Future designs with the use of rectilinear plans will benefit from an east to west orientation. If the selection of L-shaped plans is more suited to a design, then the limitation of the amount of window area in the exterior walls is of the greatest benefit to the overall energy consumption.

The X-shaped plan has energy consumption higher than that of the rectilinear and L-shaped plans, but still lower than the multiple storied plans and the square plan with atrium space. The square plan with atrium space was roughly equivalent to the two story square plan. The square plan with an interstitial floor was only slightly above that of the baseline square plan. The lack of any substantial interstitial is related to the unconditioned and lack of windows in the interstitial space.

4.3.3.2 Analysis of Hot Climate Incremental Simulations

The summary of the hospital building forms simulated in climate zone 2 are shown in Figure 26: Climate Zone 2, EUI of building forms with energy design measures (kBtu/sf/year). The overall pattern of the data is similar to that of the extreme cold climate data in that the baseline form of a square floor plan is the most energy efficient. The other building forms seem to relate to each other in the same way as in a cold climate, only the differences seem to be greater. For instance the X-shaped plan is clearly higher than the rectilinear and L-shaped plans. The difference between the two story plans to the square plan with atrium is now much broader. The energy reductions in the east to west configuration with majority of glazing facing south as well as the daylighting controls have a much greater impact in this climate.



Massing	116.64	-54.1%	242.47	-4.6%	254.28	0.0%	261.42	2.8%	269.11	5.8%	258.03	1.5%	263.75	3.7%	275.12	8.2%	280.02	10.1%	254.37	0.0%	289.91	14.0%	312.57	22.9%
Orientation	116.64	-54.1%	242.47	-4.6%	254.28	0.0%	256.23	0.8%	259.86	2.2%	258.03	1.5%	263.75	3.7%	275.12	8.2%	280.02	10.1%	254.37	0.0%	289.91	14.0%	312.57	22.9%
Daylighting	116.64	-54.1%	242.47	-4.6%	248.22	-2.4%	249.80	-1.8%	252.86	-0.6%	251.64	-1.0%	256.78	1.0%	265.49	4.4%	270.22	6.3%	248.32	-2.3%	281.59	10.7%	302.55	19.0%
Window / Wall Ratio	116.64	-54.1%	242.47	-4.6%	238.61	-6.2%	239.05	-6.0%	241.46	-5.0%	241.61	-5.0%	245.67	-3.4%	254.14	-0.1%	258.83	1.8%	238.71	-6.1%	268.19	5.5%	286.32	12.6%
Overhangs	116.64	-54.1%	242.47	-4.6%	235.25	-7.5%	234.85	-7.6%	236.51	-7.0%	238.02	-6.4%	241.75	-4.9%	249.48	-1.9%	253.91	-0.1%	235.35	-7.4%	263.92	3.8%	281.07	10.5%

Note: Units in chart are kBTU/sf/year, and percentages are calculated from performance greater than or less than the Base Design EUI of 254.28 kBTU/sf/year.

Figure 26: Climate Zone 2, EUI of building forms with energy design measures (kBtu/sf/year)

4.3.3.3 Analysis of Simulation Model Characteristics

The characteristics recommended by the Climate Consultant for saving energy in climate zone 8 were to maintain a compact building type as well as to build upward to minimize building surface area (Milne et al. 2007). The surface area of the various building forms that were simulated is shown in Figure 27: Ratio of exterior surface area of simulations to overall floor area (wall & roof area). The decrease in surface area in the multiple story plans results in a much higher energy intensity as compared to the baseline single story square. The other models such as the rectilinear, L-, and X-shaped plans show small increases in area that resemble their modest increases in energy intensity. The interstitial model's increases in exterior wall area were large; however they did not correlate to the slight increase in energy consumption that was reported.

The window to wall area ratio as discussed by Gilg and Valentine (2004) correlates much closer to the hospital simulation data. The ratio of the exterior wall area to the interior floor area for each of the simulation building forms is shown in Figure 28: Wall area to floor area ratio of building forms. The window to wall area ratio is an indicator of levels of intensity when comparing otherwise similar buildings. The interstitial space is the only outlier that does not follow the relationship of window to wall area ratio compared to energy intensity.

Pearson's correlation was used to compare the EUI of the simulations to the wall to floor area ratio. The EUI data in Figure 23: Climate Zone 8, EUI of Building Forms with Energy Design Measures was compared to the wall to floor area ratios of the ten building forms. Correlation of the comparison of these two sets of characteristics show a very strong positive correlation. The correlations are listed Table 3: Climate Zone 8, EUI correlation to wall to floor area ratio, as well as the correlation of the data excluding the interstitial form and comparing only the remaining nine building shapes.

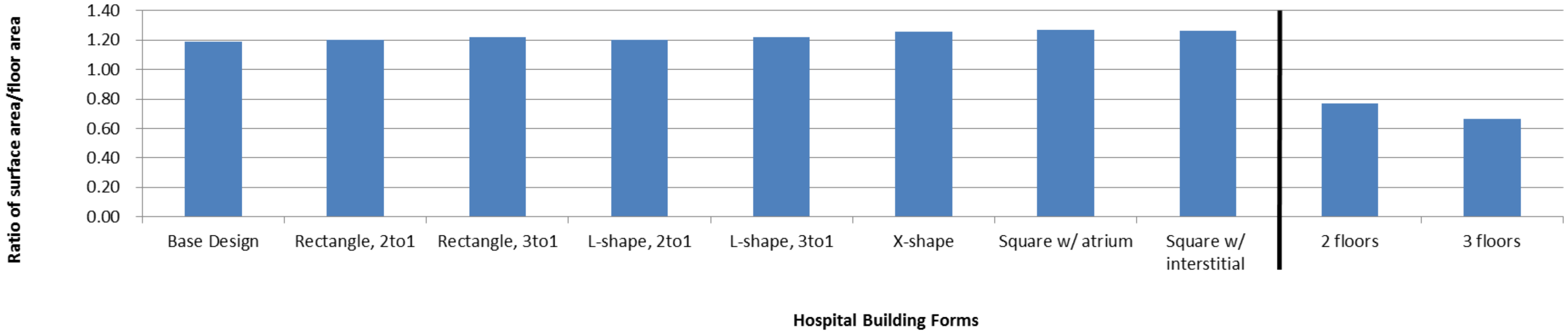


Figure 27: Ratio of exterior surface area of simulations to overall floor area (wall & roof area)

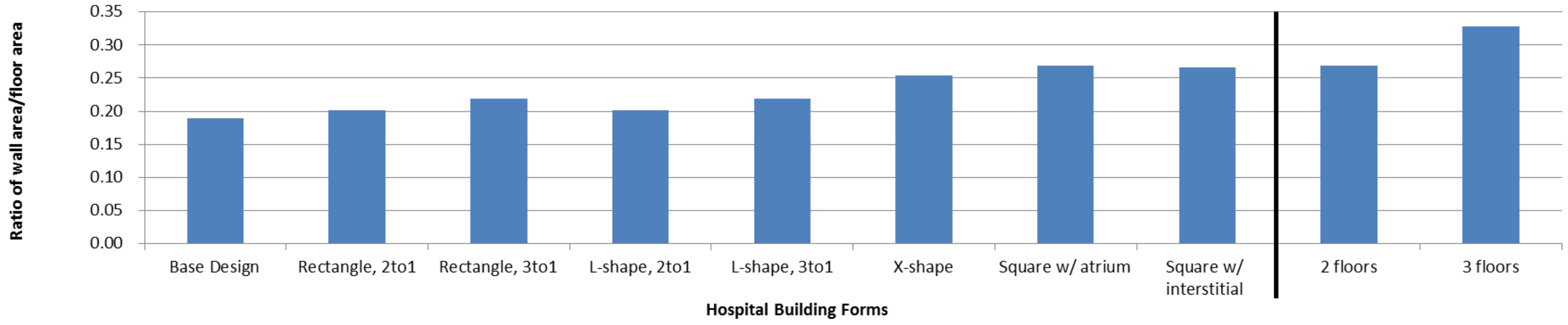


Figure 28: Wall area to floor area ratio of building forms

Table 3: Climate Zone 8, EUI correlation to wall to floor area ratio

Energy Design Measure	Pearson's Correlation	Pearson's Correlation without interstitial
Massing	0.8557	0.9943
Orientation	0.8800	0.9959
Daylighting	0.8810	0.9953
Window/Wall Ratio 40%	0.8670	0.9972
Overhangs	0.8595	0.9943

The multiple story plans greatly increase in the amount of floor space within 15 feet of the perimeter and potential for daylighting spaces. According to the GGHC, the potential day lit floor space is within 15 feet of the perimeter (2007). The amount of floor space for each model is shown in Figure 29: Ratio of day lit floor space to overall floor area (within 15 feet of perimeter of building).

The day lit floor areas shown in Figure 27 appear to more closely follow the EUI pattern. A correlation of the day lit floor area to the EUI results for all of the building forms were conducted, as listed in Table 4: Climate Zone 8, EUI correlation to day lit floor area (within 15 feet of perimeter). The correlation between the day lit floor area and EUI is shown to be stronger than the correlation between the exterior wall area and the EUI. This demonstrates that day lit floor area is a better indicator of energy intensity when comparing buildings with similar floor to floor heights. When comparing buildings of varying floor to floor heights it is apparent that the exterior wall area is still the appropriate indicator.

Table 4: Climate Zone 8, EUI correlation to day lit floor area (within 15 feet of perimeter)

Energy Design Measure	Pearson's Correlation
Massing	0.9835
Orientation	0.9816
Daylighting	0.9819
Window/Wall Ratio 40%	0.9907
Overhangs	0.9918

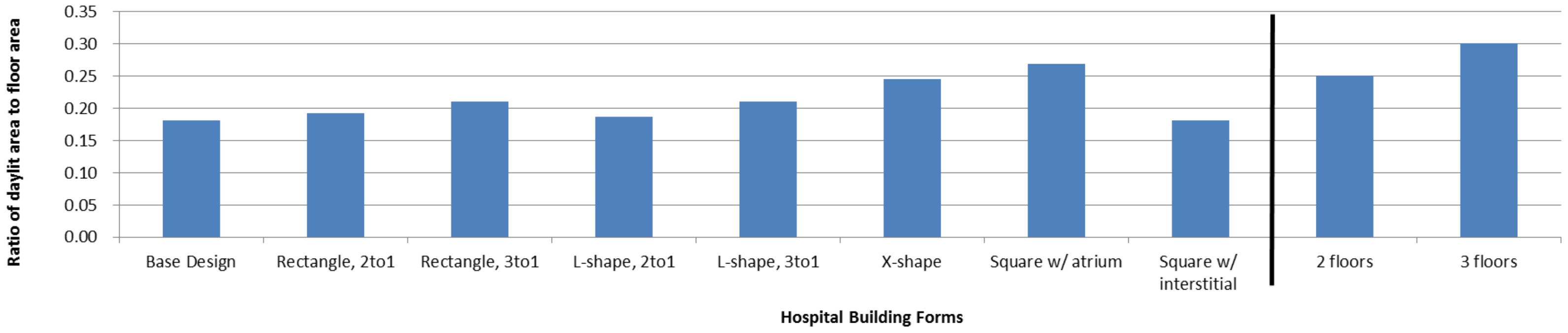


Figure 29: Ratio of day lit floor space to overall floor area (within 15 feet of perimeter of building)

4.4 Simulation of Hospitals

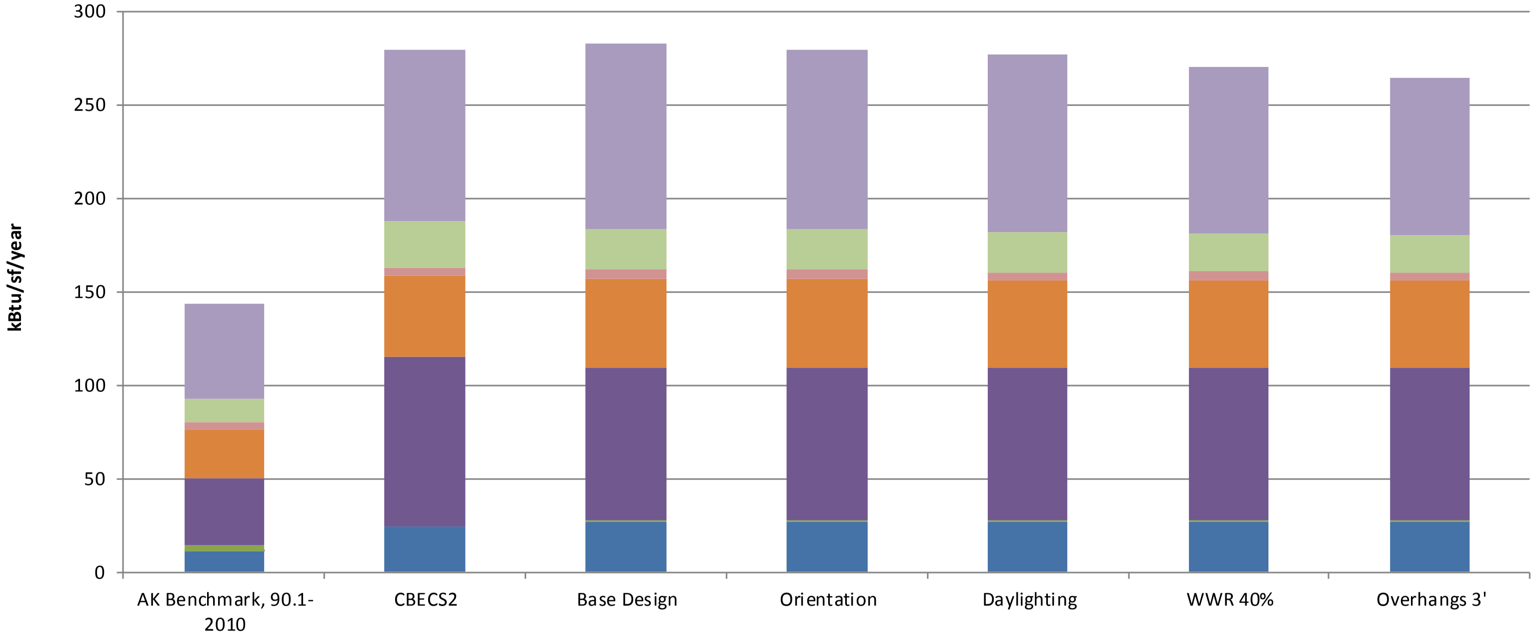
4.4.1 Simulation of Hospital in Extreme Cold Climate

The hospital located in climate zone 8, facility L in Table 2, was simulated in eQUEST using basic floor plans and the simulation model parameters that are listed in Appendix C. The hospital shape and approximate amounts of windows were simulated with pictures and use of the plans. The mechanical systems and other settings were default settings within the eQUEST software. The EUI used during the incremental simulations phase based on the CBECS 2003 data was used during this simulation as well. The hospital simulation model was calibrated to this EUI to set up the hospital baseline model.

The EDMs implemented in the hospital simulation were: Orientation to east to west with south facing windows; Daylighting controls; Limitation of window to wall area to 40%; and Window overhangs of 3 feet. The results of the simulation runs are shown in Figure 30: Simulations of hospital in extreme cold climate with energy design measures (kBtu/sf/year) and percent difference from base design (kBtu/sf/year**)**.

The overall simulation categories of energy consumption were ordered to display those that are impacted by the building envelope factors on the top of the stacked bar graphs. The space heating, ventilation fan, and space cooling loads are essentially the only categories of energy consumption that are impacted by building envelope changes, with all other systems and variables the same. The CBECS existing data shows that these three building envelope contributing categories amount to 43% of the overall energy consumption, in Climate Zone-8.

The overall energy savings from the EDMs as compared to the baseline design model was a 6% savings in energy consumption. This comparison is somewhat misleading because none of the internal loads have changed and they are heavily weighting the impact to the EUI. When only the three categories impacted by the envelope changes are assessed the savings gained amount to 13.6% of the three categories.



Space	Heating	50.9	-48%	92.1	-7%	98.7	0%	96.1	-3%	94.9	-4%	89.0	-10%	84.1	-15%
Vent	Fans	12.7	-42%	25.0	14%	21.9	0%	21.5	-2%	21.2	-3%	20.6	-6%	19.8	-10%
Space	Cooling	4.2	-17%	4.5	-10%	5.0	0%	4.9	-2%	4.9	-3%	4.7	-6%	4.6	-9%
Task	Lights	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Ambient	Lights	26.1	-45%	43.5	-8%	47.2	0%	47.2	0%	46.1	-2%	46.2	-2%	46.3	-2%
Exterior	Usage	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Dom	Ht Wtr	35.7	-56%	90.3	10%	81.9	0%	81.9	0%	81.9	0%	81.9	0%	81.9	0%
Pumps	& Aux	3.2	204%	0.0	-100%	1.1	0%	1.0	-1%	1.0	-3%	1.0	-5%	1.0	-8%
Heat	Reject	0.1	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Misc	Equip	10.7	-60%	24.5	-8%	26.7	0%	26.7	0%	26.7	0%	26.7	0%	26.7	0%
	Total	143.7	-49%	279.8	-1%	282.6	0%	279.4	-1%	276.6	-2%	270.1	-4%	264.3	-6%

Figure 30: Simulations of hospital in extreme cold climate with energy design measures (kBtu/sf/year) and percent difference from base design (kBtu/sf/year)

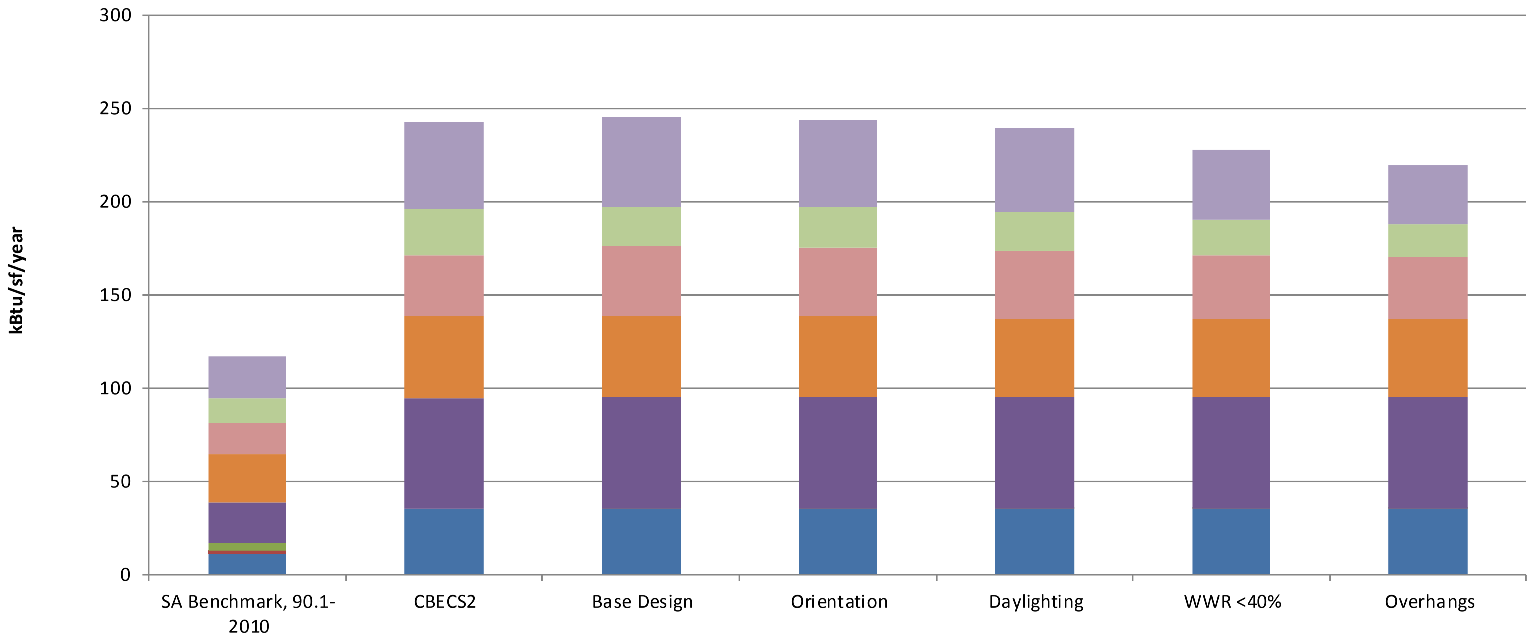
The energy consumption of the hospital in an extreme cold climate was near the highest energy intensities for hospitals. The extreme cold climate zone requires a large portion of energy for space heating. The existing design was oriented to the northeast to increase the amount of windows that are facing the south. The use of daylighting controls were implemented as the second EDM. The two largest reductions were the use of limiting window to wall 40% and the window overhangs.

4.4.2 Simulation of Hospital in Hot Climate

The facility, AC in Table 2, simulated in climate zone 2 was a medical center of approximately 1,349,815 square feet. It was constructed within the last 20 years and has a bed capacity of 226 in-patient beds. The hospital was simulated in the same manner as the facility in climate zone 8, except for using the floor plans and weather files for the southern location. The overall energy consumption of each measure is compared to the ASHRAE 90.1 benchmark in Figure 31: Simulations of hospital in hot climate with energy design measures and percent difference from base design (kBtu/sf/year).

The only categories of energy consumption that are impacted by building envelope changes are space heating, ventilation fan, and space cooling loads. The CBECS existing data shows that these three building envelope contributing categories amount to 42.9% of the overall energy consumption, in Climate Zone-2, with the categories more heavily weighted cooling loads.

The overall energy savings from the EDMs as compared to the baseline design model was an 11% savings in energy consumption. When only the three categories impacted by the envelope changes are assessed the savings gained amount to 21.3% of the three categories.



Misc	Equip	10.7	-70%	34.7	-1%	35.1	0%	35.1	0%	35.1	0%	35.1	0%	35.1	0%
Heat	Reject	1.7	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Pumps	& Aux	4.0	2258%	0.0	-100%	0.2	0%	0.2	0%	0.2	-2%	0.2	-12%	0.1	-17%
Dom	Ht Wtr	22.4	-62%	59.5	0%	59.6	0%	59.6	0%	59.6	0%	59.6	0%	59.6	0%
Exterior	Usage	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Ambient	Lights	25.8	-41%	44.1	1%	43.5	0%	43.5	0%	41.9	-4%	42.2	-3%	42.2	-3%
Task	Lights	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%	0.0	0%
Space	Cooling	16.6	-56%	33.0	-12%	37.4	0%	36.9	-1%	36.3	-3%	34.3	-8%	32.7	-13%
Vent	Fans	13.1	-39%	24.8	16%	21.4	0%	21.4	0%	20.9	-2%	19.2	-10%	18.1	-16%
Space	Heating	22.5	-53%	46.4	-4%	48.3	0%	47.2	-2%	45.8	-5%	36.9	-24%	31.2	-35%
	Total	116.6	-53%	242.5	-1%	245.6	0%	243.9	-1%	239.8	-2%	227.4	-7%	219.1	-11%

Figure 31: Simulations of hospital in hot climate with energy design measures and percent difference from base design (kBtu/sf/year)

4.5 Critical Analysis of Hospital Energy Performance

The analysis of various energy saving measures and their impact on the consumption of energy for the facility appears to be in conflict with some of the goals of EBD, such as the increased use of views and daylighting. The more window area that is created by changing the building's shape, the more energy is consumed. The simulations show that while some design choices may be made, such as multiple story high-rise building to increase functionality of the space; the choice of shape of the patient tower can be elongated and oriented to make use of some of the energy reductions in this way.

The purpose behind EBD is to increase the quality of healthcare and thereby decrease the length of stay and remittance of patients. The short term view of the facility's energy use with EBD designs is that they will have less than optimal energy performance. When viewed as the performance of the hospital as a system the EBD objectives are to provide treatment and allow shorter recovery periods, therefore saving energy on a per patient basis. The function of a space will be the primary design driver over the energy goals of a design. The gains in treatment capacity of the hospital are an energy savings strategy in of itself.

The increase in amount of floors or the height of the inhabited space is a large factor in the extreme cold climates, while in hot climates it was found to be very significant. Based on this study, the overall height of facilities is recommended to be kept as low as possible. The requirements for daylighting access and perimeter wall make multiple story plans preferable because of the increase in perimeter wall when arranging vertically. The types of space, such as patient towers, that require higher levels of daylight and views should make use of vertical spaces as the most efficient method of achieving the required amounts of perimeter wall. Types of space that can make use of open plans or are only occupied during business hours are recommended to be designed with as low a building form as feasible. If site conditions allow for a larger footprint for these types of space, it is recommended to have low-rise buildings with larger footprints.

The ideal and most compact shape of a building floor plan is the square plan, which consistently delivered the lowest energy intensities of all the models compared. The rectilinear plans and L-shaped plans behaved somewhat similarly as compared to the base square plan. In the hot climate zone, the rectilinear and L-shaped plans performed poorer than the square plans when oriented in north to south orientations, however when correctly oriented their energy consumption fell below that of the square plan. Only when the rectangle became very shallow did the advantage of the shape lessen. The 2:1 aspect ratio of rectangle performed better than the square plan.

In extreme cold climates, both the rectilinear and L-shaped plans performed well; however the gains in orientation and daylighting were not enough to bring their levels below that of the square plans ideal shape for heating. The use of properly oriented rectilinear plans in hot climates is strongly recommended. In extreme cold climates, the rectilinear plan is also recommended, as long as attention is paid to the aspect ratio as too narrow a plan will begin to sharply increase the energy use.

The L-shaped plans had the advantage of performing exactly the same regardless of north to south or east to west orientations. The L-shaped plans did not perform as well as the rectilinear plans; however they were only a small increase in energy usage. The use of L-shaped plans instead of rectilinear in the case of a confined site location is recommended.

The X-shaped plan is a variation of the plan that provided a substantial increase in the amount of perimeter wall, while still keeping all of the floor space on one level. The increase in perimeter wall was comparable to the increase seen with multiple levels, however the energy intensity of the plan was not on the same level as multi-story plans in either climate zone simulated. The design recommendation is that the complexity of angles in a building footprint will yield a higher amount of perimeter wall and will still be more advantageous from an energy conservation perspective than a multi-storied space.

The extreme cold climate simulations showed that a square plan with a large atrium is a more energy consumptive shape than a two story space with greater daylighting potential. The weather considerations in extreme cold areas, such as snow loads and removal, would likely preclude such as space to begin with, however it seems that they are less advantageous from an energy perspective as well.

Interstitial space did not significantly raise the energy use of facilities in either climate zone. The use of interstitial floors for future adaptability of spaces and maintenance accessibility is an obvious increase in construction cost; however it is not a significant factor in the overall future energy performance of the facility.

The building massing was overall the most influential of all the factors of the building envelope simulated. The choice of building shape may be determined mainly by the function of the interior space; however when options are available, the shape of the building can have a large impact on the future energy performance of the building.

The energy impacts of orientation of the hospitals east to west and the use of daylighting controls both are amplified by the other. The form of a hospital can determine the success of orientation and daylighting, and the most elongated forms benefit the most from these design measures.

The limitation of window percentage of wall area to 40% was a large factor in both extreme cold and hot climates. The generous use of glazing in many designs creates very attractive spaces; however the impacts of excessive windows had a large impact on energy consumption. The design recommendation would be to make use of southern facades for larger expanses of glazing, but to attempt to limit windows to the ASHRAE recommendation in other facades as the interior space requirements allow (ASHRAE 2009a).

The exterior shading devices used on the southern facing windows had an impact on all building forms in both climates. The quality of daylighting was not addressed by this study; however the value of shading devices to prevent direct sunlight and glare in many spaces would be an improvement to both the quality of care and energy savings aspects of a design.

5. CONCLUSIONS

5.1 Significance of the Study

The research aim was to discuss the concepts and initiatives of EBD and energy sustainability and how they each impacted the design of the hospital envelope. The most lasting feature of a building is its form, as compared to building systems which can change over time, the shape and design of the envelope continues for the life of the building (Baker et al. 2010). The hospital building type is a long lasting typology, wherein it is not uncommon for hospital buildings to remain in use for 50 to 100 years. The aim of this study was to determine the impacts of EBD related features in healthcare design that will impact the design of hospital building envelopes and overall energy use.

The first objective of this study was the analysis of EBD features that affect the overall layout of the interior or increase the requirements for spaces requiring perimeter access. These features that affect the design of hospitals are numerous, although many of the features are already part of the industry and AIA design standards, such as single-patient rooms. There are still other features, such as staff break rooms with exterior views that are not part of the current standards. It is concluded that for the overall improvement in the quality of care and work environment that there will be an increase in the amount of requirements for daylight and exterior views. The growing requirements will ultimately change the form of hospital building envelopes.

The second objective was to assess the inventory of MHS hospital facilities. It was not unexpected to realize the relatively old portfolio of facilities within the military. The high average age of facilities demonstrates the additional challenges to maintain compliance with newer standards and goals, such as EBD and ASHRAE Standard 90.1-2010. The dispersion of facilities throughout the United States is obvious due to the purpose of the MHS to support our military installations. This geographic dispersion and consequently varied site conditions for each hospital facility made it difficult to draw conclusions on energy use while comparing a range of facility sizes, capacities, ages, and climate zones.

The third objective of incremental analysis of various factors which contribute to EBD goals, such as increased daylighting and views, was accomplished by changing the shape of the building envelope. The multiple simplistic building forms were meant to mimic the modules that combine to make a contemporary hospital. Energy saving design measures selected from the ASHRAE Advanced Energy Design Guides were also used to weigh the impact of mitigating features to the overall building energy use. The degree of impact of building shape as compared to orientation to the sun, daylighting controls, limitations on window/wall amounts, and exterior shading devices was much larger. Each of the energy saving features made an impact, however it was apparent that the building form determined the range of successful use of each of the subsequent measures.

The fourth objective was conducted by simulating two military facilities and assessing the impact of the energy saving measures used in the incremental simulations. The amount that the EDMs impacted that overall energy use of the facilities was very modest. The building plans for these simulations were not altered in building form only in orientation, daylighting controls, window/wall percentage, and exterior shading devices. The measures implemented replicated modifications to an existing facility and it made apparent that the modifications did not have a large effect on the facilities' energy uses.

The large gap between the ASHRAE 90.1-2010 benchmark that was simulated and the average EUI of hospital facilities from the CBECS survey was over 50% disparity. The range of impact of the building form combinations and energy design measures would likely be limited to 5 to 10 percent of savings toward meeting the 90.1-2010 goals. The additional recommendations made by the NREL in their Large Hospital 50% Energy Savings (Bonnema et al. 2010) are what will allow designs to achieve the remaining 40 to 45 percent savings over building form. The recommendations consisted of: tighter and more insulated envelope; multi-zone variable air volume (VAV) dedicated outdoor air systems (DOAS) with zone-level water to air heat pumps; high efficiency systems equipment, such as chillers, boilers, and water heaters; and demand controlled ventilation.

The analysis of energy consumption with building forms with larger perimeter ratios concluded that the increases in EUI were moderate when compared to the overall energy consumption. The percent difference between base designs and 3-floor multi-story without any EDMs the energy consumption was 14.1%, in Figure 23: Climate Zone 8, EUI of Building Forms with Energy Design Measures. If the same comparison were made between the two with all EDMs, the difference was only 9.9%. These comparisons are between the simulation models with the lowest and highest amounts of perimeter day lit area in the extreme cold climate zone. In Figure 24: Climate Zone 2, EUI of Building Forms with Energy Design Measures, the difference in energy consumption between the base design and the 3-floor multi-story without EDMs was 22.9%. The comparison between the two models with EDMs was a difference of 18%. The comparison of the models with the widest range of building perimeter area resulted in the largest differences in energy consumption. Of the building envelope factors assessed, the building shape had the largest impact.

The multi-zone VAV systems are more advantageous because of their ability to accomplish the last recommendation, demand controlled ventilation. Multiple zones provide the ability to condition the air in the space that requires it, without conditioning spaces that do not require it. The increased capability to control what systems are doing is ultimately what is going to save energy. The use of dedicated outside air systems are recommended by Murphy in the April 2010 ASHRAE Journal, to separately condition outside air allows the humidification and appropriate outside air requirements are met as well as ensuring that excess is minimized to conserve energy. The building commissioning process is critical for the successful operation of systems to meet their design performance. According to Hatton et al. (2010), the optimization of systems controls is “the leading opportunity for reducing energy expenditures.”

The analysis of the EUIs of the multiple building forms made it apparent that multi-storied buildings were more energy intense than lower buildings of similar floor area, when assuming the same percent of window to wall area. The case can be made that multi-storied hospitals have shorter travel distances, because of use of elevators, and are therefore more efficient in other ways. The study of the amount of day lit perimeter area shows that multi-storied forms have the highest percentage of day lit area. The design recommendation would be to decrease the amount window area of multi-story buildings, and/or emphasize the importance of high-performing glazing in the building design. When designing multi-story spaces the amount of potentially day lit area increases quickly when vertically arranging spaces as opposed to low-rise designs. This is supported by the window to wall area ratio recommendations within the ASHRAE 90.1 Standard limiting WWR to 40%. Judicious design of windows is needed to accomplish the exterior viewing and daylighting requirements as efficiently as possible. Recommendations for future designs are that individual rooms with continuous use exterior view/daylighting requirements should be placed in multi-story spaces and business occupancy spaces placed in separate lower-level space with open space planning to make the best use of the perimeter glazing.

The overall trend in energy consumption is that the more window area that a facility has the more heat transfer occurs and therefore the heating/cooling loads are increased. The overall trend in EBD is that the more windowed areas the better the patient outcomes, staff satisfaction, which consequently makes for a better facility. The conclusion is that future hospitals will have more windows and therefore the windows need to perform better to meet the requirements of the space.

The general finding of this study is that the design features of EBD will result in hospital buildings that are shaped less efficiently from an energy sustainability standpoint. Hospitals designed using EBD features will have shapes that are more energy intensive than existing facilities. The building shape however has been shown to have a somewhat minimal impact on the overall energy intensity of the building when compared to the mechanical systems and internal loads of a hospital. Additionally, the costs targeted by EBD are personnel related costs, which are typically many times larger than the construction and energy costs of a facility. When comparing lifecycle costs, the overall personnel costs of a typical hospital are 64%, as compared to the 6% capital construction and 6% energy costs (Dell’Isola and Kirk 2003). A savings of 5% of the personnel costs would amount to over 50% of the costs of energy in a typical facility. The recommendation of this study is to give priority to the goals of EBD, which address the healthcare system at large and result in smaller in comparison inefficiencies at the facility management level. When considering the life cycle costs of a hospital, the savings in personnel costs can justify the additional expenses in capital and energy, as long as the EBD features are effective.

The energy sustainability goals of the GSA are to reduce energy requirements incrementally in accordance with the EISA of 2007. Within this study, the impact of the shape of the building envelope was shown to increase in energy intensity when comparing an ideal, deep square plan with the shallow, three-floor, multi-story plan. The increase in energy intensity from the baseline to the mid-rise plan was 14.1% in Climate Zone-8 and 22.9% in Climate Zone-2. When utilizing the energy saving measures recommended for building envelope design (ASHRAE 2009a; Bonnema et al. 2010; Milne et al. 2007), the increase was mitigated to an increase of 5.9% in Climate Zone-8 and 10.5% in Climate Zone-2. When comparing these losses in energy savings to the ASHRAE Standard 90.1-2010 benchmark, there is still an additional 48.1% in Climate Zone-8 and 54.1% in Climate Zone-2, which must be achieved to meet the goals, set by the standard.

The mechanical systems of a hospital are the largest portion of the energy consumption within the facility. The CBECS data used for the benchmark in Climate Zone-8 has 44% of the energy consumed with mechanical systems, such as heating, cooling, and ventilation fans. Lighting systems, both ambient and task lighting amounted to 15%. Miscellaneous equipment totaled 9%. Domestic hot water was 32% of the overall consumption, and is the second highest category the first of which is heating. The large domestic hot water consumption is unchanged by the modifications to the building envelope, unlike the heating, cooling and lighting components of energy use. The recommendation is to target the efficiency of the domestic hot water system, but improving the equipment efficiency (Mukhopadhyay et al. 2009) or by improving distribution and control strategies to decrease energy loss (Chen et al. 2004).

According to Zhu et al. (2000), the optimization of the mechanical systems and equipment of a facility can be achieved through building system commissioning. Systems within large buildings are complicated and are not permanently optimized after the initial commissioning process. Continuous Commissioning (CC) is a continual commissioning process whose objective is to lower the energy consumption of the facility as well as improve the IEQ. Procedures such as CC are recommended for existing buildings to achieve the savings called for in the 90.1-2010 benchmark.

The energy simulations conducted within this study utilized site energy as opposed to source energy as a metric. Site energy is the amount of energy consumed at a facility, and source energy is the amount consumed in the production and distribution to, and consumption at the facility. According to ASHRAE (2009a), the use of site energy metrics ignores the tremendous amount of waste involved in receiving large amounts of electricity from off site; wherein it takes approximately 3kWh to provide 1kWh of electricity to a typical building. This presents another real opportunity for energy savings by locating power sources close to hospitals and other large energy consumers.

The use of combined heat and power (CHP) technology provides on-site power production and makes use of the heat generated to fulfill heating needs. According to Herweck (2007), a building without CHP will consume 100 energy units for every 57 energy units that a building with CHP will consume. The savings in electrical energy losses in distribution to the hospital as well as greater power reliability and energy security are all features of CHP that would be desirable for governmental hospital facilities. According to Risner (2009), an example of successful CHP implementation within a hospital design is the Dell Children’s Hospital in Austin, TX. Additionally, the waste energy that still occurs in a typical CHP facility can be further optimized by networking with nearby facilities to make full use of waste heat. The concept of CHP with cooling and heating networks as proposed by Fu et al. (2006) is particularly useful for campuses of buildings or military installations.

Strategies used by other industries, such as cleanrooms, to maintain high IAQ can be utilized by the healthcare industry to achieve improvements. According to Kircher et al. (2010), demand controlled filtration has demonstrated significant savings for cleanroom facilities. The IAQ of hospitals is an important part of the environment of care and ensuring a high air quality often involves wasting energy in order to ensure the quality conditions are met. One aspect of IAQ is preventing contaminants from entering the HVAC system and causing odors or spreading mold or germs via the air handling system. According to Taylor (2000), mold and fungus can also have negative effects on the energy efficiency of the mechanical system as well, by slowing airflows and limiting heat transfer. The use of ultraviolet technology as a part of the HVAC system is recommended to provide savings in the form of IAQ benefits to building occupants as well as increased energy efficiency of the mechanical components.

The construction of the building envelope is first step in designing an energy efficient facility. This study has shown that impact that windows have on the energy intensity of a facility. It has also been discussed that increased daylighting and views are a prominent part of EBD, which achieves system-level savings by increasing these sources of heat transfer. The design recommendation is to shift the focus to increased building envelope performance. Better glazing and high performance wall systems are necessary to address both the goals of EBD and sustainability. This is supported by the findings of Torcellini et al. (2006), which recommend that future low-energy designs should emphasize the envelope construction and size mechanical systems for remaining requirements.

Architects designing future hospitals should partner early with other professionals to achieve EBD and sustainability goals. Collaboration with other professionals that are not typically involved early on or not at all in the design process will generate new designs to the challenges presented. This is supported by Skaggs et al. (2009), who discussed the challenges with designing in extreme climates and specifically the innovation required in the design of the building envelope. The Bassett Army Community Hospital designed and constructed in Fairbanks, Alaska was an example of atypical exterior envelope design that brings in natural light and retains energy efficiency.

The exposure to nature and daylighting concepts of EBD is more of a challenge to incorporate sustainably in extreme climates. One recommendation of this study is to develop new hospital building types with enclosed atria that bring a nature setting indoors. The extreme climatic conditions of cold and heat are not conducive to many types of vegetation and native plants are dormant for large portions of the year. Patients in a vulnerable state should not be outside in extreme temperatures or exposed to intense direct sunlight. Enclosed atrium features in hospitals can be a source of valuable daylighting and access to nature for patients. According to Atif et al. (1992), well designed atria spaces can reduce interior lighting and cooling loads. According to Molinelli and Kim (1986), the quality of the daylighting can be more easily controlled within enclosed atria. An example of large-scale indoor atriums with nature is the Opryland Hotel in Nashville, Tennessee. The successful business return on investment of the internal atrium at the Opryland Hotel is supported by Relf (1995), whom discusses the positive human effects of access to nature as well as the positive business aspects.

5.1.1 Original Contribution

The determination of the energy efficiency impacts of EBD strategies in MHS facilities will assist in planning of future healthcare facilities. The successful identification of EBD features that can counter sustainability efforts in a facility will bring to light future critical areas of collaboration among construction professionals. The implementation of EBD in MHS facilities is not a measure of success on its own. An assessment of what changes are occurring in facility management costs will assist in the future direction of research and capital improvements in the MHS.

The use of indicators to identify existing facilities which would most benefit from capital investment is an important contribution. The perspective that the investments in the mechanical systems will have larger effects on the energy use than those in the envelope is also valuable.

5.1.2 Further Research

The results of this study could be implemented within the MHS. The active management of the energy use of hospitals at the portfolio level could be augmented by using the indicators discussed in this study, such as wall to floor area ratios. These indicators can assist in determining which facilities would most benefit from modifications to the building envelope, as opposed to funding based on other unrelated factors. A metric of potential energy efficiency to determine future capital investments would assist in appropriate utilization of funds.

This study discussed the impacts of the building envelope on the energy use of hospitals. It is noted that the building envelope is a smaller contributor to the overall energy use than the efficient planning and use of mechanical systems. Additional research is needed to delineate mechanical systems that are recommended and determine the alternatives and their overall contribution to the energy demand.

The increases in energy use, due to building forms that are less than optimal, is understandably for the benefit of improved indoor environmental quality. The assumption with EBD is that energy is saved with the higher energy intense building because the numbers of patients supported is increased. The patients in the improved environment have shorter inpatient durations; therefore more patients can be treated over time. Additional research is needed to calculate these savings using a similar methodology as this study to calculate the additional energy costs attributed to EBD features and compare these to the additional patient healthcare savings.

As long as there is an overall goal to lower the energy intensity in military hospitals, the continued research into the more efficient equipment and distribution systems for hospitals should be pursued. Collaboration with equipment manufacturers and suppliers is recommended to target the greatest categories of energy consumption in MEDCOM facilities.

According to Brand (2009), the planet has been affected unlike any other time in its history by resource intensity of civilization. The homeostasis of natural ecosystems has remained quite stable and resilient to outside intervention. Normally, changes to the ecology are recovered from naturally due to the natural redundancy of the planet's systems. Our efforts to design in the future should be directed toward systems which mimic, interact positively, and enhance or facilitate natural systems. The incorporation of long-term planning at a global scale with these concepts in mind is necessary to make lasting and widespread improvements.

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APPENDIX A

Baseline Model Parameters, Climate Zone 8

Location:	Fairbanks, Alaska
Climate zone:	8
Building shape:	square
Floor space:	100000 square feet
Number of floors:	1
Floor to floor height:	15 feet
Floor to ceiling height:	10 feet
Cooling System:	chilled water coils
Heating System:	hot water boiler (natural draft); natural gas
Hot water system:	hot water loop; 25 gallons/person/day
HVAC system type:	Dual duct air handler with HW baseboard, return ducted
System fans:	Supply dual fan, VAV; Return, VAV
Thermal setpoints:	
Cooling:	76.0 F
Heating:	70.0 F
Schedules	simplified
Zoning Pattern	Perimeter/Core
Construction:	
Roofing-	Metal frame, 24 in. o.c.; flat, built-up; R-35
Walls-	Metal frame, 2x6, 24 in.o.c.; stucco; R-21 ext board; R-13 batt
Windows:	
Type 1:	Double clear 1/4in., 1/2in. Air; 50% floor to ceiling, North facade
Type 2:	Double Bronze 1/4in., 1/2in. Air; 50% floor to ceiling, South, East, and West facades
Activity Areas:	
Medical Care:	60% overall area; 150sf/person; 30 CFM/person
Laboratory:	15% overall area; 150sf/person; 25 CFM/person
Corridor:	10% overall area; 150sf/person; 7.5 CFM/person
Laundry:	5% overall area; 150sf/person; 25 CFM/person
Mechanical:	5% overall area; 450/person; 22.5 CFM/person
Restrooms:	15% overall area; 52.5/person; 50 CFM/person

Baseline Model Parameters, Climate Zone 2

Location:	San Antonio, Texas
Climate zone:	2
Building shape:	square
Floor space:	100000 square feet
Number of floors:	1
Floor to floor height:	15 feet
Floor to ceiling height:	10 feet
Cooling System:	chilled water coils
Heating System:	hot water boiler (natural draft); natural gas
Hot water system:	hot water loop; 25 gallons/person/day
HVAC system type:	Dual duct air handler with HW baseboard, return ducted
System fans:	Supply dual fan, VAV; Return, VAV
Thermal setpoints:	
Cooling:	76.0 F
Heating:	70.0 F
Schedules	simplified
Zoning Pattern	Perimeter/Core
Construction:	
Roofing-	Metal frame, 24 in. o.c.; flat, built-up; R-35
Walls-	Metal frame, 2x6, 24 in.o.c.; stucco; R-21 ext board; R-13 batt
Windows:	
Type 1:	Double clear 1/4in., 1/2in. Air; 50% floor to ceiling, North facade
Type 2:	Double Bronze 1/4in., 1/2in. Air; 50% floor to ceiling, South, East, and West facades
Activity Areas:	
Medical Care:	60% overall area; 150sf/person; 30 CFM/person
Laboratory:	15% overall area; 150sf/person; 25 CFM/person
Corridor:	10% overall area; 150sf/person; 7.5 CFM/person
Laundry:	5% overall area; 150sf/person; 25 CFM/person
Mechanical:	5% overall area; 450/person; 22.5 CFM/person
Restrooms:	15% overall area; 52.5/person; 50 CFM/person

APPENDIX B

Table 5: Specifications of simulation models

	AK Benchmark, 90.1-2010	CBECS2	Base Design	2 floors	3 floors	Rectangle, 2to1	Rectangle, 3to1	L-shape, 2to1	L-shape, 3to1	X-shape	Square w/ atrium	Square w/ interstitial
Orientation (North-South, East-West)			-	-	-	N-S	E-W		N-S		N-S	
Floor space (square feet)	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000	100,000
Levels	1	1	1	2	3	1	1	1	1	1	1	1
Dimensions: length (ft)	316	316	316	224	183	224	183	336	365	424	335	316
Dimensions: width (ft)	316	316	316	224	183	447	548	336	365	424	335	316
Dimensions: leg A	0	0	0	0	0	0	0	112	183	283	112	0
Dimensions: leg B	0	0	0	0	0	0	0	112	183	283	112	0
Perimeter of footprint (feet)	1,264	1,264	1,265	894	730	1,342	1,461	1,342	1,461	1,697	1,789	1,265
Daylit floor area (w/in 15 ft of perimeter)	9,030	9,030	9,037	12,516	15,082	9,612	10,505	9,615	10,506	12,277	9,612	9,037
% above 'square-root base' daylit area [1]	-0.08%	-0.08%	0.00%	38.50%	66.89%	6.37%	16.24%	6.40%	16.26%	35.86%	6.37%	0.00%
Floor to floor height (feet)	15	15	15	15	15	15	15	15	15	15	15	21
Ext wall surface area (square feet)	18,960	18,960	18,974	26,833	32,863	20,125	21,909	20,130	21,912	25,454	26,833	26,563
Exterior Surface Area of Simulations (wall & roof area)	118,816	118,816	118,974	76,833	66,197	120,125	121,909	120,169	121,929	125,454	126,833	126,563
wall area to floor area ratio	0.19	0.19	0.19	0.27	0.33	0.20	0.22	0.20	0.22	0.25	0.27	0.27

APPENDIX C

Table 6: Climate Zone 8, Simulations of hospital models, massing study

		AK Benchmark, 90.1-2010	**CBECS^2**	**Base Design**	**2 floors**	**3 floors**	**Rectangle, 2to1**	**Rectangle, 3to1**	**L-shape, 2to1**	**L-shape, 3to1**	**X-shape**	**Square w/ atrium**	**Square w/ interstitial**
Ambient	**Lights**	**2613**	**4351**	**3323**	**3322**	**3321**	**3322**	**3322**	**3324**	**3323**	**3322**	**3320**	**3323**
Task	**Lights**	**0**	**0**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1008**	**1009**
Misc	**Equip**	**1065**	**2447**	**3740**	**3739**	**3738**	**3739**	**3739**	**3741**	**3740**	**3739**	**3736**	**3740**
Space	**Heating**	**5094**	**9206**	**8242**	**9487**	**10699**	**8631**	**9107**	**8467**	**8819**	**9586**	**9970**	**8384**
Space	**Cooling**	**419**	**454**	**809**	**975**	**1081**	**818**	**849**	**821**	**840**	**881**	**893**	**809**
Heat	**Reject**	**13**	**0**	**23**	**28**	**30**	**24**	**25**	**23**	**24**	**25**	**26**	**23**
Pumps	**& Aux**	**320**	**0**	**639**	**775**	**856**	**645**	**669**	**649**	**665**	**698**	**710**	**639**
Vent	**Fans**	**1275**	**2499**	**2434**	**3054**	**3414**	**2537**	**2649**	**2477**	**2549**	**2699**	**2750**	**2419**
Dom	**Ht Wtr**	**3571**	**9027**	**7479**	**7464**	**7462**	**7477**	**7478**	**7481**	**7479**	**7477**	**7474**	**7481**
Exterior	**Usage**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Total	**14371**	**27984**	**27697**	**29853**	**31611**	**28203**	**28847**	**27991**	**28448**	**29435**	**29887**	**27827**
Energy Usage Intensity (kBTU/sf/year)		**144**	**280**	**277**	**299**	**316**	**282**	**288**	**280**	**284**	**294**	**299**	**278**

Table 7: Climate Zone 8, Simulations of hospital models, orientation along east-west axis and with windows facing south

		AK Benchmark, 90.1-2010	**CBECS^2**	**Base Design**	**2 floors**	**3 floors**	**Rectangle, 2to1**	**Rectangle, 3to1**	**L-shape, 2to1**	**L-shape, 3to1**	**X-shape**	**Square w/ atrium**	**Square w/ interstitial**
Ambient	**Lights**	**2613**	**4351**	**3323**	**3322**	**3321**	**3322**	**3322**	**3324**	**3323**	**3322**	**3320**	**3323**
Task	**Lights**	**0**	**0**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1008**	**1009**
Misc	**Equip**	**1065**	**2447**	**3740**	**3739**	**3738**	**3739**	**3739**	**3741**	**3740**	**3739**	**3736**	**3740**
Space	**Heating**	**5094**	**9206**	**8242**	**9487**	**10699**	**8362**	**8626**	**8467**	**8819**	**9586**	**9970**	**8384**
Space	**Cooling**	**419**	**454**	**809**	**975**	**1081**	**810**	**819**	**821**	**840**	**881**	**893**	**809**
Heat	**Reject**	**13**	**0**	**23**	**28**	**30**	**23**	**23**	**23**	**24**	**25**	**26**	**23**
Pumps	**& Aux**	**320**	**0**	**639**	**775**	**856**	**641**	**649**	**649**	**665**	**698**	**710**	**639**
Vent	**Fans**	**1275**	**2499**	**2434**	**3054**	**3414**	**2437**	**2474**	**2477**	**2549**	**2699**	**2750**	**2419**
Dom	**Ht Wtr**	**3571**	**9027**	**7479**	**7464**	**7462**	**7477**	**7478**	**7481**	**7479**	**7477**	**7474**	**7481**
Exterior	**Usage**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Total	**14371**	**27984**	**27697**	**29853**	**31611**	**27820**	**28141**	**27991**	**28448**	**29435**	**29887**	**27827**
Energy Usage Intensity (kBTU/sf/year)		**144**	**280**	**277**	**299**	**316**	**278**	**281**	**280**	**284**	**294**	**299**	**278**

Table 8: Climate Zone 8, Simulations of hospital models, daylighting controls

		AK Benchmark, 90.1-2010	**CBECS[2]**	**Base Design**	**2 floors**	**3 floors**	**Rectangle, 2to1**	**Rectangle, 3to1**	**L-shape, 2to1**	**L-shape, 3to1**	**X-shape**	**Square w/ atrium**	**Square w/ interstitial**
Ambient	**Lights**	**2613**	**4351**	**3124**	**3046**	**2988**	**3111**	**3093**	**3115**	**3095**	**3064**	**3041**	**3124**
Task	**Lights**	**0**	**0**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1008**	**1009**
Misc	**Equip**	**1065**	**2447**	**3740**	**3739**	**3738**	**3739**	**3739**	**3741**	**3740**	**3739**	**3736**	**3740**
Space	**Heating**	**5094**	**9206**	**8271**	**9461**	**10655**	**8394**	**8657**	**8496**	**8844**	**9600**	**9985**	**8414**
Space	**Cooling**	**419**	**454**	**786**	**943**	**1033**	**785**	**793**	**797**	**814**	**851**	**861**	**786**
Heat	**Reject**	**13**	**0**	**22**	**27**	**29**	**22**	**23**	**23**	**23**	**24**	**25**	**22**
Pumps	**& Aux**	**320**	**0**	**623**	**750**	**820**	**624**	**629**	**631**	**645**	**675**	**685**	**623**
Vent	**Fans**	**1275**	**2499**	**2349**	**2937**	**3276**	**2346**	**2375**	**2387**	**2451**	**2588**	**2630**	**2335**
Dom	**Ht Wtr**	**3571**	**9027**	**7479**	**7464**	**7462**	**7478**	**7478**	**7481**	**7479**	**7477**	**7474**	**7481**
Exterior	**Usage**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Total	**14371**	**27984**	**27403**	**29376**	**31010**	**27508**	**27795**	**27680**	**28102**	**29027**	**29446**	**27535**
Energy Usage Intensity (kBTU/sf/year)		**144**	**280**	**274**	**294**	**310**	**275**	**278**	**277**	**281**	**290**	**294**	**275**

Table 9: Climate Zone 8, Simulations of hospital models, window to wall ratio limited to <40%

		AK Benchmark, 90.1-2010	**CBECS[2]**	**Base Design**	**2 floors**	**3 floors**	**Rectangle, 2to1**	**Rectangle, 3to1**	**L-shape, 2to1**	**L-shape, 3to1**	**X-shape**	**Square w/ atrium**	**Square w/ interstitial**
Ambient	**Lights**	**2613**	**4351**	**3162**	**3092**	**3038**	**3130**	**3114**	**3158**	**3136**	**3103**	**3116**	**3162**
Task	**Lights**	**0**	**0**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1008**	**1009**
Misc	**Equip**	**1065**	**2447**	**3740**	**3739**	**3738**	**3739**	**3739**	**3741**	**3740**	**3739**	**3736**	**3740**
Space	**Heating**	**5094**	**9206**	**7765**	**8664**	**9649**	**8121**	**8365**	**7958**	**8263**	**8902**	**9261**	**7910**
Space	**Cooling**	**419**	**454**	**747**	**888**	**966**	**762**	**767**	**756**	**770**	**799**	**810**	**747**
Heat	**Reject**	**13**	**0**	**21**	**25**	**27**	**22**	**22**	**22**	**22**	**23**	**23**	**21**
Pumps	**& Aux**	**320**	**0**	**596**	**708**	**771**	**606**	**611**	**601**	**613**	**635**	**647**	**596**
Vent	**Fans**	**1275**	**2499**	**2223**	**2762**	**3064**	**2269**	**2292**	**2257**	**2310**	**2419**	**2470**	**2210**
Dom	**Ht Wtr**	**3571**	**9027**	**7479**	**7464**	**7463**	**7478**	**7479**	**7481**	**7480**	**7478**	**7475**	**7481**
Exterior	**Usage**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Total	**14371**	**27984**	**26742**	**28352**	**29725**	**27135**	**27396**	**26983**	**27342**	**28105**	**28546**	**26876**
Energy Usage Intensity (kBTU/sf/year)		**144**	**280**	**267**	**284**	**297**	**271**	**274**	**270**	**273**	**281**	**285**	**269**

Table 10: Climate Zone 8, Simulations of hospital models, exterior shading devices (2' overhangs)

		AK Benchmark, 90.1-2010	CBECS^2	Base Design	2 floors	3 floors	Rectangle, 2to1	Rectangle, 3to1	L-shape, 2to1	L-shape, 3to1	X-shape	Square w/ atrium	Square w/ interstitial
Ambient	**Lights**	**2613**	**4351**	**3163**	**3094**	**3040**	**3131**	**3115**	**3159**	**3138**	**3105**	**3118**	**3163**
Task	**Lights**	**0**	**0**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1008**	**1009**
Misc	**Equip**	**1065**	**2447**	**3740**	**3739**	**3738**	**3739**	**3739**	**3741**	**3740**	**3739**	**3736**	**3740**
Space	**Heating**	**5094**	**9206**	**7693**	**8511**	**9450**	**8083**	**8333**	**7879**	**8175**	**8795**	**9149**	**7840**
Space	**Cooling**	**419**	**454**	**731**	**866**	**924**	**736**	**742**	**740**	**752**	**778**	**788**	**731**
Heat	**Reject**	**13**	**0**	**21**	**24**	**27**	**21**	**22**	**21**	**21**	**22**	**22**	**21**
Pumps	**& Aux**	**320**	**0**	**585**	**691**	**733**	**584**	**590**	**592**	**602**	**620**	**630**	**585**
Vent	**Fans**	**1275**	**2499**	**2167**	**2677**	**2960**	**2243**	**2270**	**2198**	**2244**	**2343**	**2390**	**2154**
Dom	**Ht Wtr**	**3571**	**9027**	**7479**	**7464**	**7463**	**7478**	**7479**	**7481**	**7480**	**7478**	**7475**	**7481**
Exterior	**Usage**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Total	**14371**	**27984**	**26587**	**28075**	**29343**	**27023**	**27298**	**26819**	**27161**	**27887**	**28315**	**26724**
Energy Usage Intensity (kBTU/sf/year)		**144**	**280**	**266**	**281**	**293**	**270**	**273**	**268**	**272**	**279**	**283**	**267**

Table 11: Climate Zone 8, Simulations of community hospital with energy design measures

		AK Benchmark, 90.1-2010	CBECS^2	Base Design	Orientation	Daylighting	WWR 40%	Overhangs 3'
Ambient	**Lights**	**6820**	**11356**	**12324**	**12324**	**12024**	**12066**	**12080**
Task	**Lights**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Misc	**Equip**	**2780**	**6387**	**6979**	**6979**	**6979**	**6979**	**6979**
Space	**Heating**	**13294**	**24028**	**25768**	**25078**	**24759**	**23227**	**21961**
Space	**Cooling**	**1094**	**1185**	**1313**	**1291**	**1270**	**1237**	**1192**
Heat	**Reject**	**35**	**0**	**0**	**0**	**0**	**0**	**0**
Pumps	**& Aux**	**835**	**0**	**275**	**271**	**267**	**261**	**252**
Vent	**Fans**	**3328**	**6522**	**5721**	**5622**	**5526**	**5371**	**5163**
Dom	**Ht Wtr**	**9321**	**23560**	**21369**	**21369**	**21369**	**21369**	**21369**
Exterior	**Usage**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Total	**37508**	**73038**	**73748**	**72933**	**72193**	**70509**	**68995**
Energy Usage Intensity (kBTU/sf/year)		**144**	**280**	**283**	**279**	**277**	**270**	**264**

APPENDIX D

Table 12: Climate Zone 2, Simulations of hospital models, massing study

		SA Benchmark, 90.1-2010	CBECS^2	Base Design	2 floors	3 floors	Rectangle, 2to1	Rectangle, 3to1	L-shape, 2to1	L-shape, 3to1	X-shape	Square w/ atrium	Square w/ interstitial
Ambient	**Lights**	**2582**	**4410**	**3323**	**3322**	**3321**	**3322**	**3322**	**3324**	**3323**	**3322**	**3320**	**3323**
Task	**Lights**	**0**	**0**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1008**	**1009**
Misc	**Equip**	**1065**	**3474**	**3740**	**3739**	**3738**	**3739**	**3739**	**3741**	**3740**	**3739**	**3736**	**3740**
Space	**Heating**	**2246**	**4636**	**4991**	**7395**	**8935**	**5464**	**5992**	**5247**	**5643**	**6431**	**6786**	**5001**
Space	**Cooling**	**1656**	**3297**	**3690**	**4214**	**4537**	**3801**	**3906**	**3741**	**3819**	**3973**	**4035**	**3690**
Heat	**Reject**	**171**	**0**	**364**	**421**	**455**	**377**	**388**	**369**	**377**	**393**	**399**	**364**
Pumps	**& Aux**	**401**	**0**	**805**	**941**	**1016**	**840**	**865**	**818**	**837**	**874**	**890**	**805**
Vent	**Fans**	**1305**	**2479**	**2804**	**3249**	**3545**	**2890**	**2989**	**2852**	**2926**	**3072**	**3130**	**2803**
Dom	**Ht Wtr**	**2238**	**5951**	**4701**	**4701**	**4700**	**4701**	**4701**	**4703**	**4702**	**4700**	**4699**	**4702**
Exterior	**Usage**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Total	**11664**	**24247**	**25428**	**28991**	**31257**	**26142**	**26911**	**25803**	**26375**	**27512**	**28002**	**25437**
Energy Usage Intensity (kBTU/sf/year)		**117**	**242**	**254**	**290**	**313**	**261**	**269**	**258**	**264**	**275**	**280**	**254**

Table 13: Climate Zone 2, Simulations of hospital models, orientation along east-west axis and with windows facing south

		SA Benchmark, 90.1-2010	CBECS^2	Base Design		3 floors	Rectangle, 2to1	Rectangle, 3to1	L-shape, 2to1	L-shape, 3to1	X-shape	Square w/ atrium	Square w/ interstitial
Ambient	**Lights**	**2582**	**4410**	**3323**	**3322**	**3321**	**3322**	**3322**	**3324**	**3323**	**3322**	**3320**	**3323**
Task	**Lights**	**0**	**0**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1008**	**1009**
Misc	**Equip**	**1065**	**3474**	**3740**	**3739**	**3738**	**3739**	**3739**	**3741**	**3740**	**3739**	**3736**	**3740**
Space	**Heating**	**2246**	**4636**	**4991**	**7395**	**8935**	**5128**	**5379**	**5247**	**5643**	**6431**	**6786**	**5001**
Space	**Cooling**	**1656**	**3297**	**3690**	**4214**	**4537**	**3716**	**3765**	**3741**	**3819**	**3973**	**4035**	**3690**
Heat	**Reject**	**171**	**0**	**364**	**421**	**455**	**367**	**372**	**369**	**377**	**393**	**399**	**364**
Pumps	**& Aux**	**401**	**0**	**805**	**941**	**1016**	**812**	**824**	**818**	**837**	**874**	**890**	**805**
Vent	**Fans**	**1305**	**2479**	**2804**	**3249**	**3545**	**2829**	**2875**	**2852**	**2926**	**3072**	**3130**	**2803**
Dom	**Ht Wtr**	**2238**	**5951**	**4701**	**4701**	**4700**	**4701**	**4701**	**4703**	**4702**	**4700**	**4699**	**4702**
Exterior	**Usage**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Total	**11664**	**24247**	**25428**	**28991**	**31257**	**25623**	**25986**	**25803**	**26375**	**27512**	**28002**	**25437**
Energy Usage Intensity (kBTU/sf/year)		**117**	**242**	**254**	**290**	**313**	**256**	**260**	**258**	**264**	**275**	**280**	**254**

Table 14: Climate Zone 2, Simulations of hospital models, daylighting controls

		SA Benchmark, 90.1-2010	CBECS^2	Base Design	2 floors	3 floors	Rectangle, 2to1	Rectangle, 3to1	L-shape, 2to1	L-shape, 3to1	X-shape	Square w/ atrium	Square w/ interstitial
Ambient	Lights	2582	4410	3099	3011	2946	3083	3062	3088	3066	3206	3204	3099
Task	Lights	0	0	1009	1009	1009	1009	1009	1009	1009	973	973	1009
Misc	Equip	1065	3474	3740	3739	3738	3739	3739	3741	3740	3608	3605	3740
Space	Heating	2246	4636	4792	7124	8613	4919	5151	5037	5414	6206	6548	4802
Space	Cooling	1656	3297	3610	4104	4405	3632	3673	3657	3727	3834	3894	3610
Heat	Reject	171	0	355	410	441	358	362	360	368	379	385	355
Pumps	& Aux	401	0	788	918	985	792	802	798	815	843	859	788
Vent	Fans	1305	2479	2728	3143	3418	2748	2787	2771	2838	2964	3021	2727
Dom	Ht Wtr	2238	5951	4701	4701	4700	4701	4701	4703	4702	4536	4534	4702
Exterior	Usage	0	0	0	0	0	0	0	0	0	0	0	0
	Total	11664	24247	24822	28159	30255	24980	25286	25164	25678	26549	27022	24832
Energy Usage Intensity (kBTU/sf/year)		116.6	242.5	248.2	281.6	302.5	249.8	252.9	251.6	256.8	265.5	270.2	248.3

Table 15: Climate Zone 2, Simulations of hospital models, window to wall ratio limited to 40%

		SA Benchmark, 90.1-2010	CBECS^2	Base Design	2 floors	3 floors	Rectangle, 2to1	Rectangle, 3to1	L-shape, 2to1	L-shape, 3to1	X-shape	Square w/ atrium	Square w/ interstitial
Ambient	Lights	2582	4410	3140	3061	3001	3270	3112	3136	3111	3072	3089	3140
Task	Lights	0	0	1009	1009	1009	1044	1009	1009	1009	1009	1008	1009
Misc	Equip	1065	3474	3740	3739	3738	3870	3739	3741	3740	3739	3736	3740
Space	Heating	2246	4636	4099	6167	7455	3687	4325	4308	4615	5239	5561	4109
Space	Cooling	1656	3297	3474	3915	4174	3483	3513	3515	3571	3687	3745	3474
Heat	Reject	171	0	341	390	417	342	345	346	351	363	369	341
Pumps	& Aux	401	0	756	873	939	757	765	766	778	806	822	756
Vent	Fans	1305	2479	2600	2964	3198	2587	2637	2638	2691	2799	2855	2599
Dom	Ht Wtr	2238	5951	4701	4701	4700	4865	4701	4703	4702	4700	4698	4702
Exterior	Usage	0	0	0	0	0	0	0	0	0	0	0	0
	Total	11664	24247	23861	26819	28632	23905	24146	24161	24567	25414	25883	23871
Energy Usage Intensity (kBTU/sf/year)		117	242	239	268	286	239	241	242	246	254	259	239

Table 16: Climate Zone 2, Simulations of hospital models, exterior shading devices (2' overhangs)

		SA Benchmark, 90.1-2010	**CBECS^2**	**Base Design**	**2 floors**	**3 floors**	**Rectangle, 2to1**	**Rectangle, 3to1**	**L-shape, 2to1**	**L-shape, 3to1**	**X-shape**	**Square w/ atrium**	**Square w/ interstitial**
Ambient	**Lights**	**2582**	**4410**	**3140**	**3062**	**3002**	**3130**	**3112**	**3136**	**3111**	**3073**	**3090**	**3140**
Task	**Lights**	**0**	**0**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1009**	**1008**	**1009**
Misc	**Equip**	**1065**	**3474**	**3740**	**3739**	**3738**	**3739**	**3739**	**3741**	**3740**	**3739**	**3736**	**3740**
Space	**Heating**	**2246**	**4636**	**3857**	**5852**	**7076**	**3806**	**3941**	**4051**	**4334**	**4910**	**5215**	**3867**
Space	**Cooling**	**1656**	**3297**	**3438**	**3875**	**4120**	**3462**	**3483**	**3475**	**3526**	**3631**	**3686**	**3438**
Heat	**Reject**	**171**	**0**	**340**	**389**	**415**	**345**	**347**	**343**	**349**	**359**	**365**	**340**
Pumps	**& Aux**	**401**	**0**	**756**	**878**	**940**	**774**	**779**	**765**	**778**	**802**	**816**	**756**
Vent	**Fans**	**1305**	**2479**	**2544**	**2888**	**3107**	**2520**	**2540**	**2579**	**2627**	**2724**	**2776**	**2543**
Dom	**Ht Wtr**	**2238**	**5951**	**4701**	**4701**	**4700**	**4701**	**4701**	**4703**	**4702**	**4700**	**4698**	**4702**
Exterior	**Usage**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Total	**11664**	**24247**	**23525**	**26392**	**28107**	**23485**	**23651**	**23802**	**24175**	**24948**	**25391**	**23535**
Energy Usage Intensity (kBTU/sf/year)		**117**	**242**	**235**	**264**	**281**	**235**	**237**	**238**	**242**	**249**	**254**	**235**

Table 17: Climate Zone 2, Simulations of medical center with energy design measures

		SA Benchmark, 90.1-2010	**CBECS^2**	**Base Design**	**Orientation**	**Daylighting**	**WWR 40%**	**Overhangs**
Ambient	**Lights**	**37437**	**63945**	**63074**	**60810**	**61188**	**61248**	**37437**
Task	**Lights**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
Misc	**Equip**	**15446**	**50373**	**50886**	**50886**	**50886**	**50886**	**15446**
Space	**Heating**	**32568**	**67222**	**70031**	**66421**	**53491**	**45284**	**32568**
Space	**Cooling**	**24009**	**47807**	**54285**	**52580**	**49706**	**47457**	**24009**
Heat	**Reject**	**2482**	**0**	**0**	**0**	**0**	**0**	**2482**
Pumps	**& Aux**	**5814**	**0**	**247**	**240**	**218**	**205**	**5814**
Vent	**Fans**	**18927**	**35946**	**31061**	**30313**	**27804**	**26197**	**18927**
Dom	**Ht Wtr**	**32444**	**86290**	**86475**	**86475**	**86475**	**86475**	**32444**
Exterior	**Usage**	**0**	**0**	**0**	**0**	**0**	**0**	**0**
	Total	**169127**	**351582**	**356060**	**347725**	**329768**	**317751**	**169127**
Energy Usage Intensity (kBTU/sf/year)		**117**	**242**	**246**	**244**	**240**	**227**	**219**

APPENDIX E

Additional pictures of the visual survey that was performed on military medical hospital building forms. The facilities below are: Tripler Army Medical Center, Hawaii; Keller Army Community Hospital, West Point, New York; and Reynolds Army Community Hospital, Fort Sill, Oklahoma.

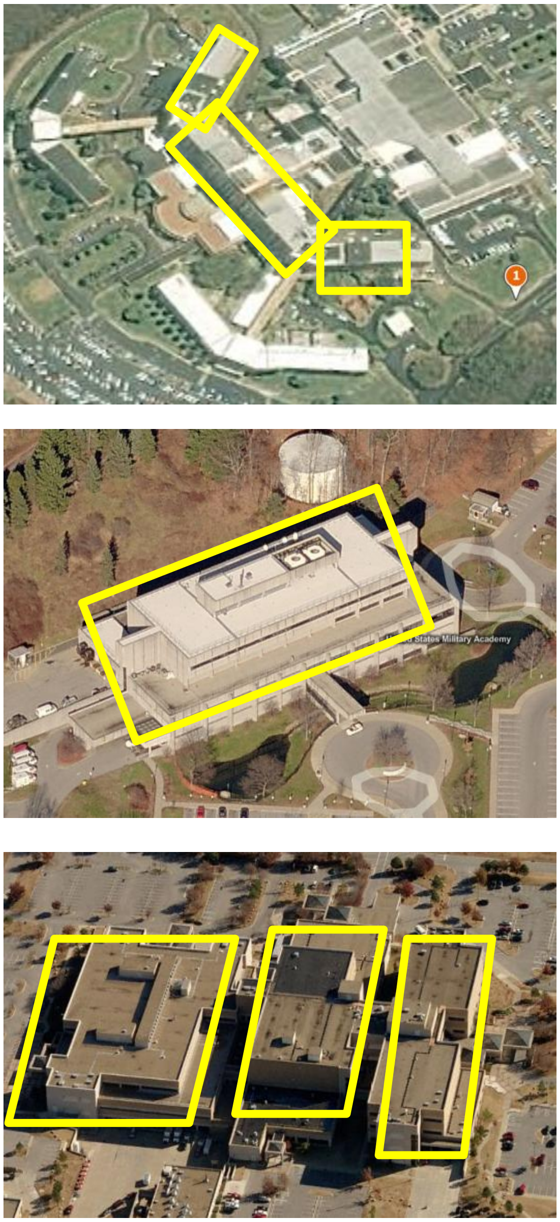

Figure 32: Additional surveyed facility building forms

APPENDIX F

The eQUEST output files for the simulations are included as part of this thesis. The files are of the Climate Zone-8 and Climate Zone-2 overall incremental simulations, and the overall simulations of the two hospital facilities. The simulation output files are in .txt file format.

VITA

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