SIMULATIONS OF DESIGN MODIFICATIONS IN MILITARY HEALTH FACILITIES

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The United States Military Health System (MHS) facility inventory is aging and requires extensive facility management, renovations and replacement to maintain the environment of a high quality of care. Recent developments in sustainability and evidence-based design (EBD) have created additional requirements for the design and construction of facilities. Existing facilities in the MHS have been directed to undergo restoration and modernization by the U.S. Department of Defense (DoD). Hospital buildings are recognized as one of the highest energy intensity facilities out of all commercial building types, mainly due to the evolution of the deep-plan hospital. Within this scope, the design of the building envelope is the most lasting feature affecting the energy use of a hospital, as its service-life typically equaling the life of the facility. This study aims to quantify the impact of changes in building form to the building's energy consumption in two extreme climate zones—extreme hot and extreme cold weather conditions. For this purpose, four major EBD features were selected based on literature recommendations, and energy simulations were conducted for each of these four features. The study demonstrates the relationship between incorporating positive building occupant features, such as increased daylighting and views of nature, and efficient energy design choices.

Keywords: energy, facility management, green buildings, health, modelling

INTRODUCTION

Sustainability of energy resources is an important topic of global discussion. The United States consumes more energy per capita than any other nation. Within the U.S., the built environment consumes more energy resources than either the transportation or industrial sectors (U.S. EIA 2009a). Within the built environment are the commercial and residential sectors, where healthcare is a building typology within the commercial sector which although only occupying 4% of commercial built space, it accounts for 9% of commercial building energy consumption (U.S. EIA 2004). Sustainability efforts at state and national levels are targeting this large consumer with rigorous building codes and elevated standards of energy efficiency. The U.S. military health system (MHS) is undergoing significant capital investment in its healthcare facilities, as the MHS inventory is aging and in need of modernization.

The hospital building type consumes more energy per unit area than most any other type of commercial building type (U.S. EIA 2004). The hospital building typology is expected to undergo a growth trend. The national inventory of healthcare facilities is not sufficient to support the growing needs of the baby boom generation. 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). This need is only exaggerated by the advances in medicine which are lengthening the average lifespan of an American. The over-65 demographic is becoming a larger portion of the population, which is also the main portion of the population which utilizes the most inpatient and other healthcare services.

There is a movement in architectural design called evidence-based design (EBD) which focuses on applying research methods to the implementation of design features (Hamilton and Watkins, 2009). The design features which are shown to enhance the function of a space are quantitatively measured. The purpose of this movement is to provide additional rigor to the design process in disciplines other than the traditional engineering and business areas of influence. The intent is to achieve the best patient outcomes while using the most current research data in order to identify design features which directly support excellence in healthcare. EBD measures of performance within the healthcare realm focus on patient outcomes as well as hospital staff efficiency (Zimring et al. 2008). The MHS has embraced the concepts of EBD and is incorporating the principles into their design process.

Daylighting design and hospital staff efficiencies are reversing some of the trends of hospital design. With the development of

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technologies such as heating, ventilation and air-conditioning (HVAC) and lighting systems, hospitals have progressively become deep-plan buildings (Guenther and Vittori 2008), evolution which is mainly due to the lessened reliance on exterior windows for ventilation and lighting. The reintroduced concepts of patient and staff benefits from additional access to daylighting and other features will lead to hospitals with shallow plans and more exterior wall area.

The change in design of hospitals does not wholly align with the goal of energy sustainability in future designs. The elongation of building forms has the potential to increase heating/cooling loads on buildings which will be designed to more stringent energy codes (ASHRAE 2009a). The gains from the superior provision of healthcare are expected to lead to a higher throughput of patients and therefore energy efficiency gains in a "per patient" as opposed to a "per unit" area basis. Exactly how the introduction of these design features will impact the operation and energy consumption of hospitals has not been discussed in literature to date.

The EBD design measures being implemented in design are targeting the large portion of healthcare costs that can be categorized as patient and personnel. Whereby, energy consumption is a very small portion, only 6%, of the entire model of healthcare operation costs (Dell'Isola and Kirk 2003). Sustainability in the field of architecture is a movement that transcends the advances that can be made during the design and construction phases of a building. Buildings, such as hospitals, exist and remain in operation for many times longer than the short duration of initial construction. Hospitals can remain in service for as long as one hundred years. The costs of operating a facility during its service life can be mitigated by smarter investments during its design and construction. The most identifiable opportunity for savings is energy usage in the built environment. Sustainable buildings are designed to use less energy to support the same space as in a previous structure, by improving building systems and looking at a design holistically.

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) have authored the most widely used standard energy code. The ASHRAE 90.1-2010 Energy Standard for Buildings Except Low-Rise Residential Buildings, underwent large changes to address the new federal legislation requiring improvements in energy performance in buildings. A major objective of the ASHRAE 90.1-2010 Standard is to achieve a 30% improvement in energy consumption over the 2004 energy standard. This standard has been referenced in numerous state and local governmental regulations and will become a major characteristic of federal construction projects.

RESEARCH METHODS

The research methods conducted in this study included the following:

1. Selection of EBD features that are supported by research findings and impact the building envelope construction. This was conducted by reviewing the existing literature on EBD, and categorizing it into the following five MHS categories: (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. 2009)
2. Assessment of current United States Army hospital characteristics. The continental U.S. Army military hospitals were collected into a matrix with their characteristics, including: year of construction; square footage; hospital bed capacity; Department of Energy (DoE) climate zone (ASHRAE 2009b); and Energy usage intensity (EUI).
3. Simplified energy simulations of selected EBD features. This 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.
4. Simulation of energy consumption of selected case-study facilities. Existing typical floor plans of two military hospital facilities were selected for the modelling 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 two hospitals selected for the case-studies are located in Alaska and in Texas, and therefore, represent extreme weather conditions.

FINDINGS

EBD FEATURES WHICH AFFECT BUILDING ENVELOPE CONSTRUCTION

The selection of design features to study was accomplished by a review of available literature and research in the field of hospital design. The current literature describes numerous design features related to improving healthcare performance measures. Using the framework established by Malone et al. (2007), design features can be categorized by their improvements to the environment in the following areas: patient and family-centered healthcare; quality and safety of healthcare; holistic individual care, including access to nature; staff work environment; and standardization and flexibility.

The existing literature discusses the multitude of design aspects which can affect these areas in a positive manner; however not all of these features would be expected to actually alter the structure and/or layout of the building. The many features discussed affect finish materials, furniture and equipment selection (FF&E), and otherwise the operational aspects of healthcare. The focus of this research is those features which will alter the shape and exterior characteristics of hospital construction.

There were 46 design features identified, of which 8 were assessed to affect the construction of the building envelope. These 8 features were: (1) Large single-bed rooms with family zones; (2) Maximize natural light throughout the building; (3) Operable windows in patient rooms; (4) Windows in staff break rooms; (5) Patient controls for light, glare and temperature; (6) Decentralized inpatient nursing support (alcoves near beds); (7) Providing secure access to nature and views (larger windows, gardens, roof gardens, internal courtyards); and (8) Decentralized staff support spaces (e.g. supplies and charting areas).

ASSESSMENT OF CURRENT U.S. ARMY HOSPITAL CHARACTERISTICS

The United States Army currently has 30 hospitals located within the continental United States. The following characteristics of these healthcare facilities were assessed: gross floor area; year of construction; climate zone location; hospital bed capacity; patient density (area per bed); energy usage intensity (EUI); perimeter; number of floors; building shape; and ratio of wall area to floor area.

The hospitals assessed range in size from approximately 64,000 to 2.6 million square feet (6,000 to 240,000 square meters) with the average area at 487,000 square feet (45,200 square meters). The facilities range in age from 54 years to 4 years (built between 1957 and 2007), with an average age of 36 years old. The hospitals' locations were plotted in the Department of Energy (DoE) eight climate zones of the United States. Almost three quarters of the hospitals fell within climate zone 3 and 4, with representation in all but climate zone 7.

The hospitals ranged in capacity from as little as 0 to as many as 236 patient beds, with an average capacity of 71 patient beds. Their energy usage intensity was not determined for all of the facilities due to a lack of data; however for the 12 facilities that had historical data it showed an average EUI of 184,000 BTU per square foot per year (equivalent to almost 2 million BTU per square meter per year).

The perimeter distances and the number of floors were recorded for each facility and used to calculate approximate exterior wall areas. The ratio of the exterior wall area of a facility to its gross floor area was determined using these factors. The facility exterior wall to floor area ratios range from 0.22 to 0.69 with an average ratio of 0.34. The hospitals were categorized in broad categories of shapes based off of visual assessment as rectilinear, L-shaped, and cross-shaped. The majority of the hospitals were grouped as deep-plan rectilinear buildings.

SIMPLIFIED ENERGY SIMULATIONS OF SELECTED EBD FEATURES

The simulation modelling process can become extremely long when using complex building designs. A series of energy simulations was performed using simplified design shapes to demonstrate the iterative changes in energy consumption for each modification of the design. Two baseline models were made of a square floor plan of 100,000 square foot sample space (9,300 square meters). The two models were simulated using location and weather data from two climate zones.

Figure 1 describes the overview of the phases of the simulation methodology. The benchmarking phase set the foundation for the rest of the simulations by creating benchmark models to compare subsequent modified designs to. The simple simulations were composed using the quick energy simulation tool (software) (eQUEST) energy simulation software and compliance with the guidance within recent ASHRAE 90.1-2010.

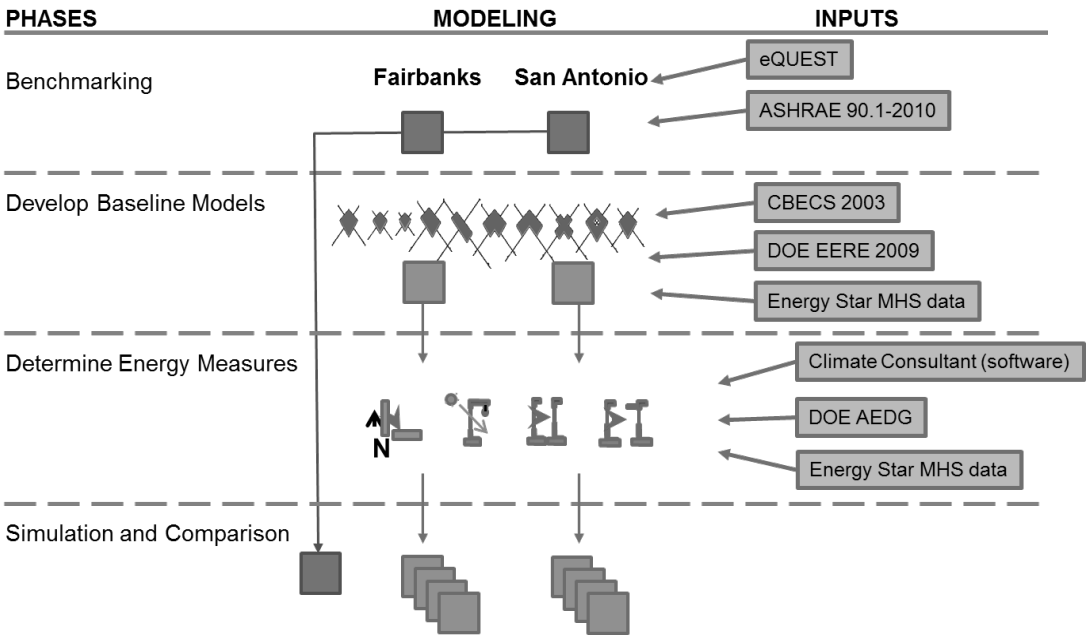


Figure 1: Diagram of the simulation modelling process

In the develop baseline models phase, simple simulations were composed using eQUEST energy simulation software and data and code inputs from Department of Energy (DoE) commercial building energy consumption surveys (CBECS) (U.S. EIA 2004). The baseline square model and 9 variations of shapes were simulated for each climate zone.

The determine energy measures phase, utilized existing research based design recommendations into the simulations. Energy design measures (EDMs) used in the research were: Orientation and elongation of plans according to their climatic location; Daylighting control systems; Limitations on ratio of window area to exterior wall area; and Exterior window overhanging shading devices. These design measures were selected from previous research in Climate Consultant software (Milne et al. 2007) and the ASHRAE Advanced Energy Design Guides for hospitals (ASHRAE 2009a).

The final modelling phase of simulation and comparison was the aggregation of the multiple simulations into tables in order to compare the results of each design modification. Figure 3 compares the energy intensity of the benchmark model against the baseline model and its 9 variations in floor plan. The shapes to the left of the solid bar are all single floor plans with rectilinear, L-shaped and X-shaped plans. The plans to the right of the solid bar are multi-floor plans, two and three storeys.

Figure 2 is an example of the many stacked bar graphs used which allowed the comparison of the types of energy consumption, such as lighting, heating, cooling or equipment. In the energy models, the only categories of energy consumption affected by the envelope changes were the space heating, ventilation fans, and space cooling. These categories in aggregate are 43% of the overall energy consumed in the baseline model. The "geometric ratio" as presented by Gilg and Valentine (2004) is validated by the increases in energy intensity in models with larger surface areas.

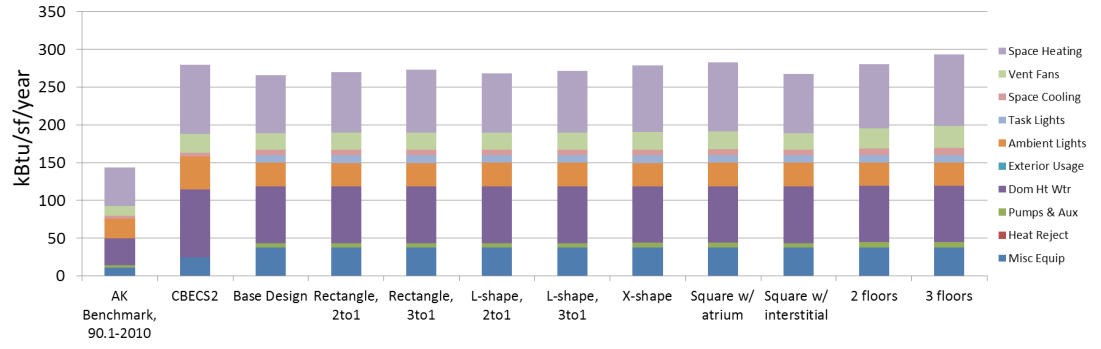


Figure 2: Comparison of Shapes w/all Energy Design Measures, Climate Zone-8

SIMULATION OF ENERGY CONSUMPTION OF SELECTED CASE-STUDY FACILITIES

The final study of two hospital facilities was conducted with the selection of two buildings in the U.S. Army inventory. The first facility was recently constructed in DoE climate zone 8, an extreme cold environment, and it is a relatively small facility with less than 270,000 square feet of space (25,000 square meters). The second facility, a medical center, was built within the last 20 years, in climate zone 2, a hot and humid environment, and is one of the largest in the inventory with more than 1.3 million square feet of space (over 120,000 square meters). It was expected that by selecting such different cases, the findings would offer a larger breadth of application.

The case study of these two selected facilities validated the design modifications tested in the simple models. The use of elongation and orientation to the sun, daylighting controls, limitation of window area to 40% or exterior wall area, and overhanging shade devices were all simulated. Each design measure was cumulatively added to the simulation to demonstrate the interaction of the modifications with each other.

Figure 3 shows the simulation results for the case-study facility in an extreme cold climate. The stacked bar graph shows the simulation results in energy intensity units, kBtu per square foot per year. The figure displays the graphic comparison of the following (from left to right): ASHRAE 90.1-2010 benchmark simulation model standard; the CBECS reported consumption of surveyed facilities of this type; baseline model consumption; and design modifications of orientation of the facility to the south, daylighting controls, limitation of window area to 40% of exterior wall, and overhanging shading devices.

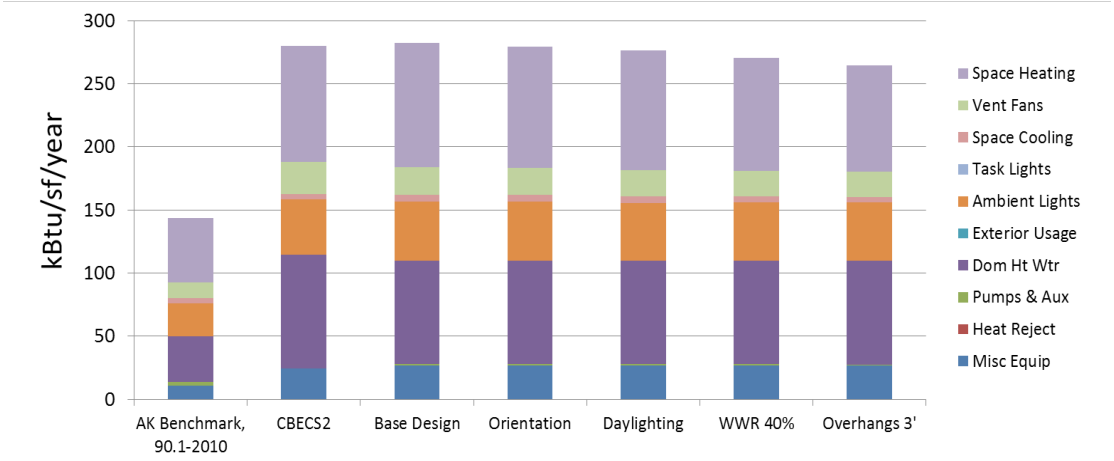


Figure 3: Energy Consumption of Hospital with EDMs, Climate Zone-8

CONCLUSIONS

Future design of healthcare facilities will take into account the potential operational savings in innovative layouts. Additionally, designers will incorporate design measures based on research findings that improve patient outcomes and ultimately the efficiency of the healthcare system. Some of these evidence-based design measures, such as daylighting and improvements in distributed logistics and administration, have the potential to increase other facility operations costs, such as energy. This research investigated the size of these increased facility operations resources, specifically the changes in energy consumption. The changes in energy consumption are minor as compared to the scale of the targeted savings in healthcare operations costs from implementing the measures.

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 authors anticipate increased window areas in future designs. The construction of window systems are constantly improving, and using state of the art systems in hospitals will be not only appropriate, but mandatory.

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. The simulations focused on the building envelope and therefore the heating, cooling and ventilation equipment consumption became the focus of this study; however these categories of consumption were only about 40% of the overall building's usage. This study while not directly addressing these other categories, illustrates the major opportunities for energy savings in the mechanical systems, the remaining 60%.

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 (Kiss 2011).

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