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Linking design and energy performance in U.S. military hospitals

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Hospital buildings have one of the highest energy intensities of all commercial building types. The design of the building envelope is the most lasting feature affecting the energy use of a hospital, due to its service-life typically equaling the life of the facility. Recent developments in sustainability and evidence-based design (EBD) have created additional requirements for the design and construction of facilities. This study investigates the impact that design interventions supported by EBD and energy code compliance may have on the building envelope, and their consequence for the energy consumption of Military Health System facilities. Energy simulations were conducted using eQUEST software on two case-study facilities. The analysis demonstrates that various EBD design measures, such as increased use of views and daylighting, appear to be in conflict with certain goals of energy design. Yet, their impact on energy consumption may be limited compared to the potential savings that can be achieved from proper design of the mechanical systems. The use of energy simulation software and early design collaboration between multiple professional disciplines is recognized as critical to achieve optimal design solutions.

Keywords: facility management; healthcare; energy consumption; computer simulation; design

Introduction

One of the most prominent topics within the built environment literature is sustainability. Heating/cooling, lighting, and communication power demands in facilities are driving up the energy requirements at increasing rates (U.S. Energy Information Administration [EIA], 2007). However, the costs of the initial design and construction are a fraction of the operations and maintenance when compared to the lifecycle costs of a facility (Lavy & Shohet, 2007). Operating costs are becoming more of a concern in the 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 industry, the business cost of healthcare is multiple times larger than the construction cost or the operating and maintenance costs combined (Sadler, DuBose, & Zimring, 2008).

The recently enacted Energy Independence and Security Act of 2007 (EISA) prescribes future milestones for reducing fossil fuel energy consumption of new and existing buildings (Federal Energy Management Program [FEMP], 2010). According to Colker (2008), the EISA requires that existing buildings reduce their energy use by 2% in 2006, increasing to 30% by 2015.

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New and renovated buildings must demonstrate a reduction of 55% in 2010 (below their Commercial Buildings Energy Consumption Survey [CBECS], 2003 baseline), and eventually, reduce it to zero consumption of fossil fuels by 2030. In 2008, the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) reported the concerns of numerous federal and commercial entities regarding the feasibility of attaining the milestones established by the EISA (ASHRAE, 2008).

One method to address this concern is through evidence-based design (EBD), a research-based method of design, which, according to Hamilton and Watkins (2009), links desired metrics or benchmarks with key design features. Specific to healthcare, EBD is “...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), a large health system within the U.S. Department of Defense, supports the military population consisting of military members, family members, and retirees. According to MHS (2011) data, the patient population has steadily increased, and the MHS has maintained a steady growth in the amount of inpatient days. Also, as the average age of hospital facilities increases, the need for replacement or major renovations becomes clear. According to Bridgers, Lawless, and Church (2005), citing a Hospital & Health Networks survey, 60% of U.S. hospital facilities need to be replaced.

Civilian MHS leadership, such as former Assistant Secretaries of Defense for Health Affairs, Dr William Winkenwerder Jr and Dr S. Ward Casscells, have made it a priority to include both EBD and energy design savings in the MHS. In 2007, Winkenwerder stated that the incorporation of evidence-based principles into MHS facilities is necessary (Malone, Mann-Dooks, & Strauss, 2007). According to Casscells (2008), the MHS as a governmental entity should responsibly use taxpayer funds in the management of the health system, emphasizing the importance of sustainable and evidence-based solutions. The efficient management of facilities and the use of public funds requires analyzing the entire lifecycle costs, from design and construction to business operating costs and health outcomes (Malone et al., 2007).

The main objective of this study is to investigate the impact that factors such as design interventions supported by EBD, guidelines set by ASHRAE and energy code compliance may have on the building envelope. Specifically, we investigate their effects on the energy consumption of MHS facilities.

Background

Energy use and sustainability efforts in healthcare facilities

In the U.S., building energy usage accounts for 41% of the overall national energy consumption by sector (EIA, 2009a). The healthcare building type is a small fraction of the overall nation’s built inventory; however, it contributes substantially to the overall total consumption of energy and resources (EIA, 2001). In 2003, U.S. healthcare buildings were found to consume 9% of total building energy, but account for just 3% of buildings and 4% of total floor space (EIA, 2004a). This means that the healthcare sector more than doubles its consumption ratio as compared to total floor area, and triples its consumption ratio as compared to the number of facilities.

According to Brown and Moore (1988), hospitals in their study had the highest energy consumption of any building category; however, they also had the least potential for improvement in energy savings, as the majority of the energy consumed maintained stringent interior environmental conditions. Dunn (1998) conducted a study of the energy use and costs of 35 Texas hospitals, and found that the hospitals’ data portrayed a wide variation in the overall use and costs of energy, more specifically the use of electrical energy.
In addition to rating systems developed by the United States Green Building Council (USGBC), the Green Guide for Health Care (GGHC) was developed as a best-practice document to educate and provide a framework for sustainable health designs of the future. The GGHC seeks to protect health through 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).

**Impact of evidence-based design in hospital planning**

The definition and concept of EBD have evolved over several years in reference 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 & Watkins, 2009). According to Zimring, Augenbroe, Malone, and Sadler (2008), the fields of healthcare architecture and healthcare administration are embracing EBD as a way to improve overall health outcomes and business costs. EBD decisions are based on existing quantitative and qualitative studies that support the overall goals and objectives of a project.

Ulrich et al. (2008) extended a previous literature review on available research related to EBD and the connections between architectural designs, patient outcomes, and staff efficiency. The report classified the findings into 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 are based on “credible” research findings, which are those that have shown a correlation between specific design features and positive healthcare outcomes.

Malone et al. (2007) collected the existing literature to 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. According to Kizer, McGowan, and Bowman (2009), in order for military hospitals to be known as “world class medical facilities,” a lifecycle cost analysis, as well as healthcare outcome assessments of EBD features and other investments, must become the norm for their design and construction processes. This report held implications that have affected future healthcare design and construction decisions within the MHS.

**Hospital typology and hospital building envelope**

According to Verderber (2010), hospital typology has changed over time to what is currently being described as “the unsustainable mega-hospital.” Community planning, real-estate values and the automobile have each led to the consolidation of 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 1900s, 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 & Vittori, 2008). Advances in building construction technology are among the factors that 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 for healthcare designs that are dramatically different from earlier designs (Guenther & Vittori, 2008; Verderber, 2010).
The hospital building typology has reached a point where it is recognizably unsustainable (Guenther & Vittori, 2008; Verderber, 2010), a fact reflected in its listing 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, 2009b). 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 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 mega-hospital design restricted the use of natural daylight and ventilation because of the deep plan building type.

In a study performed by Latimer, Gutknecht, and Hardesty (2008), it was found that the average size for various room types has increased, with the 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. Fealy, McNamara, and Geraghty (2010) state that in order to achieve safer healthcare conditions, as well as a smaller economic and physical footprint, comprehensive reform must be undertaken by cross-disciplinary teams of professionals. Karolides (2008) argues that in succeeding in our pursuit of the most cost-efficient building, the result may no longer be ideal for the responsibility of patient care. So, the questions that remain unanswered are whether this growth in scale was warranted and how to further justify additional gains.

According to Gesler, Bell, Curtis, Hubbard, and Francis (2004), the future of hospital design will attempt to resolve the various competing functions of space with the additional task of marketing to the healthcare consumer. The efficiency of 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. 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 “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 system be considered, so that efficiencies at the facility management level are not sacrificed for the environment of care for the patient and staff.

This literature shows recommendations that the design process should change to leverage the expertise of various professional disciplines to achieve system level solutions. According to Karolides (2008), the design team and processes should be integrated with building massing, orientation, and envelope selection as a primary focus. Pradinuk (2009) 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.”

**Energy simulations of hospitals**

Capital investment and facility management decisions may be based on the measured performance of a building’s energy usage; therefore, accurate measurement is important for decision making. The use of energy modeling software is a useful tool throughout the design process, with maximum benefits achieved in the earliest phases of design (Matthiessen & Morris, 2007). 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; Qualk & McCown, 2008).
According to Crawley, Hand, Kurnmert, and Griffith (2008), an abundance of energy simulation programs exist and the comparison of features and capabilities is difficult due to the lack of standard measurements. The range of applicability overlaps 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 measures (Crawley et al., 2008). Attia, Beltran, De Herde, and Hensen (2009) conducted a survey of building performance simulation (BPS) tools that are currently in use by professionals. The survey revealed 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,” and considered by most 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 Department of Energy’s (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 90.1-2010 code compliance (ASHRAE, 2010) is not available within the software. Daylighting and complex spaces (e.g. atria) are examples of design features for which eQUEST is limited in its ability to accurately represent (U.S. DoE, 2010).

In addition to those programs reviewed by Attia et al. (2009), Milne, Liggett, and Al-Shaali (2007) have developed the Climate Consultant software, which processes the weather file from any location and graphically presents local conditions that may affect a design. This tool offers a menu of recommended design features that use algorithms from each weather file. The resulting design features are customized to the weather file location with proposed goals for realizing the energy use and daylighting potential of that geographic area (Milne et al., 2007).

**The effect of building design on energy use**

Barnett and Browning (1995) state that the rules of thumb for building in cold climates are to design compactly and to orient the building East–West, thus taking advantage of as much solar gain as possible, while minimizing surface area. 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 & Browning, 1995). In addition, the surface area of the building envelope is a large factor in the overall energy performance of a building, which affects performance differently by location and climate (Barnett & Browning, 1995).

According to ASHRAE’s 2009 Advanced Energy Design Guide (AEDG) for Small Hospitals and Healthcare Facilities, the majority of solar heat gains in colder U.S. climate zones are on the southern exposure. Therefore, locations that allow the most southern sunlight are preferred. ASHRAE’s guidance is for elongating 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 compared to the remaining exterior envelope construction, is recommended to not exceed 40% for the entire building (ASHRAE, 2009a). Research on various building types has demonstrated that designs with optimal massing and orientation can achieve 30% reduction in energy use as compared to average consumption (Barnett & Browning, 1995; Lehrer, 2001).

The National Renewable Energy Laboratory (NREL) conducted a study of energy conservation measures for large hospitals. The study developed a “typical hospital” based on averages of the 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, Studer, Parker, Pless, and Torcelini (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 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 energy usage intensity (EUI) of two buildings with different shapes and otherwise identical characteristics is correlated to this ratio. The practical use of this ratio lies 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 & Valentine, 2004).

To conclude this section, the literature indicates that no existing studies on design combine EBD, sustainable practices, and facility management concepts; therefore, their benefits and shortcomings for healthcare building operations are unknown.

Research methods

Identification of EBD features affecting the building envelope

The literature review identified EBD principles and the features recommended to support those principles, based on the most common and productive positive health outcome interventions (Ulrich et al., 2008). The interventions selected for this study relate directly to a facility’s utility costs, as the study focuses specifically on energy costs of hospitals. The EBD features were categorized by the supporting MHS EBD principles of design that group the organization’s desired goals and metrics into five principles, as outlined by Malone et al. (2007) and Casscells, Kurmel, and Ponatoski (2009b).

Selection of case-study facilities

Demographic data for all 30 continental U.S. Army military hospital facilities were collected. The following assumptions were made:

1. The age of construction was based on the original year of construction and not on subsequent major renovations or additions.
2. Floor plans for most facilities were available to measure the perimeter wall lengths, categorize building shapes, and note the number of floors above grade. To measure facility plans that were not current or unavailable, Google Earth software and photographs of the facilities were used to view the buildings and calculate the perimeter lengths.
3. Perimeter length was multiplied by a factor of 4.57 m (15 feet) floor-to-floor height, which was calculated as average height in the hospital plans.
4. The exterior wall surface area was calculated by multiplying floor-to-floor height by perimeter wall lengths by the total number of floors.
5. The wall-to-floor area ratios were determined by dividing the exterior wall area by the floor area of each hospital.

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 for each case study, as well as the intention to provide insight from various climate zones and facility sizes. The selected facilities are one hospital in Fairbanks, Alaska, and one in San Antonio, Texas. These two hospitals were selected based on the following criteria: (1) relatively new construction (within the last 20 years); (2) location – two extreme climate zones; and
(3) size – one large and one small. These criteria were expected to provide the most variation in observations and results.

EnergyStar® web-based reporting system was used for the energy management of the portfolio of buildings in both locations. The data are typically input by facility managers; however, there is no way to verify the accuracy of the data reported.

**Simplified incremental analysis of design features and simulation of case-study facilities**

Testing architectural features in a complex model of a large facility is difficult and it demands extensive simulation time. Testing basic concepts on smaller models and then applying these refined concepts to larger models is the idea behind this step of the methodology. Comparing these simulations to a benchmark of code compliance with ASHRAE 90.1-2010 (ASHRAE, 2010) was a significant part of the study.

The benchmark simulation using eQUEST was initially based on the internal defaulting in accordance with California Title 24-2008 energy standards. A 9300 m² (100,000 square-foot) model was created that used the software’s code compliance features to automatically size system and building settings. The ASHRAE 90.1-2010 standard (ASHRAE, 2010) was then utilized to further alter the model.

An incremental analysis of ten selected design features (described below) and their effects on the building envelope was accomplished using simplified building forms that represent simple rudimentary designs. These forms were based on a visual survey of actual military hospitals, recognizing that basic shapes were repeated throughout the designs. The basic plan was modified based on the findings from the literature review. 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 remaining 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;
9. Square plan, two floors; and
10. Square plan, three floors.

The process of creating alternatives and then conducting analyses of energy performance and using it to drive the future design concepts was investigated. Major concepts described in the literature were 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.

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 on recommendations by Climate Consultant software, ASHRAE’s AEDG for Small Hospitals, and NREL’s report on Large Hospital energy saving.

The DoE maintains a database of weather files for use in various energy simulation software programs. Weather files used by eQUEST software are derived from 30-year averages of weather
data (Hirsch, 2009). According to Crawley (1998), the use of these datasets provides a reasonable representation of the weather patterns and should be used to conduct energy simulations on commercial buildings. The eQUEST weather files for Fairbanks, Alaska, and San Antonio, Texas, were used for both the incremental and the case-study simulations.

Climate Consultant software for geographic location-specific design recommendations was also utilized. DoE’s weather files were used to customize design recommendations (Milne et al., 2007). Additional sustainable approaches considered in this study were ASHRAE (2009a, 2009b) design guides that recommend design strategies for projects desiring energy saving.

An energy simulation of the simplified floor plans was performed using eQUEST software. The criteria for choosing this software were based on its frequency of use within the construction industry, as well as its basis in research-proven reliability (Neymark & Judkoff, 2004). The software is a building energy simulation tool that uses DOE-2 (version 2.2) code with a graphic user interface, which allows for user-friendly access to DOE-2 software. eQUEST software is qualified software for the calculation of the commercial building tax deduction for energy use, as it meets standards set by the DoE, the ASHRAE, and the Internal Revenue Service (Hirsch, 2009).

The eQUEST software tool automatically sizes systems to meet current code requirements and mechanical equipment needs. The purpose of this study was 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 following simulations were considered: building orientation, daylighting controls, WWR limitation to 40%, and exterior building overhangs, as they all affect the exterior envelope of the building. 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 design measures are also interdependent; for example, the daylighting EDM is more effective when the building is properly oriented for the climate area. The initial simulations of building shape and building orientation were accomplished without daylighting controls. The daylighting controls measure was simulated within eQUEST using 4.57 m (15 feet) from the perimeter zone as the area of potential daylighting. The simulation calculates the portion of lighting loads that support the daylit area and estimates the saving that would be achieved if these spaces were equipped with daylighting controls that would dim or turn off the lighting systems in areas with sufficient natural lighting.

The WWRs of the incremental buildings were established at 50% of the floor to ceiling wall area. The floor to ceiling height was set at 3.05 m (10 feet) for all incremental simulations. Limiting the WWR to 40% changed the setting from 50% to 40% for all of the models. All facades had the same settings and the multi-story models had the same WWR for each floor.

Lastly, the energy performance of the two selected facilities was simulated to assess the validity of the design recommendations. Incremental simulations from each climate zone were considered, and the lessons learned in extreme cold and hot climates were then applied to the building envelopes of the hospitals in these extreme climate zones. The hospital design was modified to show alternatives to the design product that would have enhanced the building performance.

**Findings**

**EBD features affecting the building envelope**

Table 1 presents a matrix of EBD design features categorized by the five MHS EBD principles of design according to Malone et al. (2007), as presented earlier.

It should be emphasized that Table 1 presents the design features found to be directly related to the building envelope; thus, only 8 of 46 features are presented. The building envelope effects
are classified into two types: (1) features affecting the construction or function of the building envelope, i.e. larger windows, window/wall ratio, and operable windows; or (2) features that change the internal layout by function or adjacencies, which eventually change the exterior shape and perimeter area of the building.

Features affecting 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. Features that alter the internal layout of the typical patient ward for reasons of staff efficiency have a subsequent effect on the exterior of buildings. The amount of floor space remains similar, but the perimeter is longer and the surface area of the building envelope is increased.

### Characteristics of the U.S. Army Medical facilities

The MHS currently has 59 hospitals, which consists of Army, Navy, and Air Force facilities (MHS, 2011). The U.S. Army Medical Command has 34 medical centers and hospitals in its portfolio of facilities, 30 of which are within the continental United States. According to Table 2, the average age of these facilities is 36 years, with the majority of facilities (86.7%) over 20 years old.

Table 3 provides a summary of the profile of the 30 U.S. Army military hospitals included in this study.

Hospital bed capacity is a unique characteristic for each hospital; therefore, one design may emphasize inpatient care or other high-energy intensive activities more than another. In terms of the facility’s shape, 21 of the 30 hospitals (70%) had a rectangular shape, eight (26.7%) had an L-shape, and one (3.3%) had a round shape. Several facilities had atria spaces.

The range of inpatient bed capacity of U.S. military hospitals depends on various factors, such as supported beneficiary population, demographics, and the capacity of the civilian network of facilities. Differences in overall mission, services provided, and capability are too broad to be included in this analysis. The inpatient bed capacities were drawn from American Hospital Association data (U.S. News, 2010).

### Table 1. Evidence-based design features affecting the building envelope, by MHS EBD design principles.

<table>
<thead>
<tr>
<th>Feature</th>
<th>Principle</th>
<th>Reference</th>
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<tbody>
<tr>
<td>Large single bedrooms with family zones</td>
<td>X X</td>
<td>A,B,C,D,E,G</td>
</tr>
<tr>
<td>Maximize natural light throughout the building</td>
<td>X X</td>
<td>A,D,E,G</td>
</tr>
<tr>
<td>Operable windows in patient-rooms with operable sashes</td>
<td>X X</td>
<td>D,E</td>
</tr>
<tr>
<td>Windows in staff break-rooms</td>
<td>X X</td>
<td>A,E</td>
</tr>
<tr>
<td>Patient controls for light, glare, and temperature</td>
<td>X</td>
<td>A,B,G</td>
</tr>
<tr>
<td>Decentralized inpatient nursing support (alcoves near beds)</td>
<td>X X</td>
<td>A,C,D,E,F,G</td>
</tr>
<tr>
<td>Providing secure access to nature and views (larger windows, gardens, courtyard)</td>
<td>X X</td>
<td>A,B,C,D,E,G</td>
</tr>
<tr>
<td>Decentralizing staff support spaces (e.g. supplies areas)</td>
<td>X</td>
<td>A,E,G</td>
</tr>
</tbody>
</table>

References:
- A, Malone et al. (2007);
- B, Casscells et al. (2009a);
- C, CHD (2010);
- D, Dublin Methodist Hospital (Kent et al., 2009);
- E, Royal Jubilee Hospital Patient Care Center, Victoria, British Columbia, Canada (Ulrich, 2010; Zensius & Keller, 2009);
- F, Health Facility Management, 2010 Hospital Building Report (Carpenter & Hoppszallem, 2010);
- G, Fort Belvoir Community Hospital, Virginia (Boenecke & Repeta, 2010).
The CBECS database provides average EUI data for facilities and climate zones, assuming that particular events that might lower the patient population were not considered. Additionally, the data have not been updated annually; therefore, facility data range from 2002 to 2009 usage data.

The distribution of the Army hospitals by climate zone (Figure 1) shows the various climatic conditions across which the hospitals are spread. The majority of facilities (73.3%) fall into climate zones 3 or 4; however, there is representation in all but one climate zone (7).

### Incremental simulation of features

Incremental simulations of simple models of hospital floor plans were conducted to illustrate the concepts described in the literature review. As noted earlier, two facilities, located in DoE climate zones 8 and 2, were selected for the case studies. Data regarding average energy usage were obtained from the CBECS 2003 database (EIA, 2004a, 2004b). The average EUI for hospitals in climate zone 8 (cold weather) with a floor size ranging from 18,600 to 46,500 m$^2$ (200,000–500,000 square feet) was 3012.2 kBtu/m$^2$/year (EIA, 2004a). The average EUI for the same floor area hospitals in climate zone 2 (hot weather) was 2609.7 kBtu/m$^2$/year (EIA, 2004a). Although the sample sizes of the CBECS surveys are very small, a review of average EUIs of other types of facilities in the same climate zones showed them to be reliable benchmarks.

The simulation results are the overall kBtu, electric and gas, consumed by the facilities using site energy metrics, which is the measurement of energy consumed at the facility, excluding production and transportation consumption. The EUI units used are thousand British thermal units per square-meter per year (kBtu/m$^2$/year).

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<thead>
<tr>
<th>Parameter (units)</th>
<th>N</th>
<th>Average</th>
<th>S.D.</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Gross area (m$^2$)</td>
<td>30</td>
<td>45,204</td>
<td>47,218</td>
<td>5929</td>
<td>240,095</td>
</tr>
<tr>
<td>Age of construction (years)</td>
<td>30</td>
<td>36.0</td>
<td>14.0</td>
<td>4</td>
<td>54</td>
</tr>
<tr>
<td>Number of floors</td>
<td>30</td>
<td>5.8</td>
<td>3.3</td>
<td>1</td>
<td>13</td>
</tr>
<tr>
<td>Perimeter (m)</td>
<td>30</td>
<td>2932</td>
<td>2462</td>
<td>472</td>
<td>12,192</td>
</tr>
<tr>
<td>Wall-to-floor area ratio$^a$</td>
<td>30</td>
<td>0.335</td>
<td>0.102</td>
<td>0.22</td>
<td>0.69</td>
</tr>
<tr>
<td>Bed capacity, per AHA$^b$</td>
<td>30</td>
<td>71.0</td>
<td>72.8</td>
<td>0</td>
<td>236</td>
</tr>
<tr>
<td>Patient density (m$^2$/bed)</td>
<td>23</td>
<td>614</td>
<td>238</td>
<td>220</td>
<td>1083</td>
</tr>
<tr>
<td>Energy usage intensity (EUI)$^c$[kBtu/m$^2$/year]</td>
<td>12</td>
<td>1976</td>
<td>662</td>
<td>1140</td>
<td>3382</td>
</tr>
</tbody>
</table>

$^a$Assuming a floor-to-floor height of 4.57 m (=15 feet) for all buildings.

$^b$Based on the American Hospital Association data.

$^c$Based on the U.S. Army Military Health Services EnergyStar data.
Simulation of building forms in an extreme cold climate

The simulation results of the 10 models for an extreme cold climate are shown in Table 4. The next step included applying EDMs on each of the 10 models, as shown in Table 4. The measures applied 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 WWR to <40% of overall building; and (4) adding external shading devices or window overhangs, which extend 61 cm (2 feet) from the window face and are located only on the windows on the South facades. For the purpose of this article, only the top two ranked models (i.e. “square, 1 floor” and “square with interstitial”) and the bottom two ranked models (i.e. “square with atrium” and “square, 3 floors”) are presented in Table 5.

The measures were simulated on the baseline model (referred to as “Level 0” in Table 5), with the above-mentioned variations (referred to as “Level 1” through “Level 4”, respectively) applied sequentially and cumulatively. Each measure simulated was left in place in the simulation model, with subsequent measures layered onto the model. This method illustrates an incremental process of improvement of the energy design of a facility.

The overall pattern of the hospital simulation data in climate zone 8 demonstrates that the baseline form of a square floor plan is the most energy efficient. Deviations from this result in higher energy consumption, given that all other factors remain 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-story plans was the limitation of the window area to 40% of the façade.

The simulations show that energy consumption for lights, domestic hot water, heat reject, and miscellaneous equipment deviates vary little from one building form to another. Energy consumed for space heating and vent fans was found to show the most significant differences between the maximum and the minimum values, with variations of 264.5 and 107.1 kBtu/m²/year, respectively. These represent an addition of 29.8% and 41.1% energy consumption for space heating and vent fans, respectively.
Table 4. EUI based on simulations of hospital building forms in climate zone 8 (kBtu/m²/year).

<table>
<thead>
<tr>
<th>Type of design</th>
<th>Space heating</th>
<th>Vent fans</th>
<th>Space cooling</th>
<th>Lights</th>
<th>Domestic hot water</th>
<th>Pumps and auxiliary</th>
<th>Heat reject</th>
<th>Misc. equipment</th>
<th>Total (rank)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASHRAE&lt;sup&gt;a&lt;/sup&gt;</td>
<td>548.3</td>
<td>137.2</td>
<td>45.1</td>
<td>281.3</td>
<td>384.4</td>
<td>34.4</td>
<td>1.4</td>
<td>114.6</td>
<td>1546.8</td>
</tr>
<tr>
<td>CBECS</td>
<td>990.9</td>
<td>269.0</td>
<td>48.9</td>
<td>468.3</td>
<td>971.7</td>
<td>0.0</td>
<td>0.0</td>
<td>263.4</td>
<td>3012.2</td>
</tr>
<tr>
<td>Square, 1 floor&lt;sup&gt;b&lt;/sup&gt;</td>
<td>887.2</td>
<td>262.0</td>
<td>87.1</td>
<td>466.3</td>
<td>805.0</td>
<td>68.8</td>
<td>2.5</td>
<td>402.6</td>
<td>2981.4 (1)</td>
</tr>
<tr>
<td>Rectangle, 2:1</td>
<td>929.0</td>
<td>273.1</td>
<td>88.0</td>
<td>466.2</td>
<td>804.8</td>
<td>69.4</td>
<td>2.6</td>
<td>402.5</td>
<td>3035.6 (4)</td>
</tr>
<tr>
<td>Rectangle, 3:1</td>
<td>980.3</td>
<td>285.1</td>
<td>91.4</td>
<td>466.2</td>
<td>804.9</td>
<td>72.0</td>
<td>2.7</td>
<td>402.5</td>
<td>3105.1 (6)</td>
</tr>
<tr>
<td>L-shape, 2:1</td>
<td>911.4</td>
<td>266.6</td>
<td>88.4</td>
<td>466.4</td>
<td>805.2</td>
<td>69.9</td>
<td>2.5</td>
<td>402.7</td>
<td>3013.0 (3)</td>
</tr>
<tr>
<td>L-shape, 3:1</td>
<td>949.3</td>
<td>274.4</td>
<td>90.4</td>
<td>466.3</td>
<td>805.0</td>
<td>71.6</td>
<td>2.6</td>
<td>402.6</td>
<td>3062.1 (5)</td>
</tr>
<tr>
<td>X-shape</td>
<td>1031.8</td>
<td>290.5</td>
<td>94.8</td>
<td>466.2</td>
<td>804.8</td>
<td>75.1</td>
<td>2.7</td>
<td>402.5</td>
<td>3168.5 (7)</td>
</tr>
<tr>
<td>Square with atrium</td>
<td>1073.2</td>
<td>296.0</td>
<td>96.1</td>
<td>465.9</td>
<td>804.5</td>
<td>76.4</td>
<td>2.8</td>
<td>402.1</td>
<td>3217.0 (9)</td>
</tr>
<tr>
<td>Square with interstitial</td>
<td>902.4</td>
<td>260.4</td>
<td>87.1</td>
<td>466.3</td>
<td>805.2</td>
<td>68.8</td>
<td>2.5</td>
<td>402.6</td>
<td>2995.3 (2)</td>
</tr>
<tr>
<td>Square, 2 floors</td>
<td>1021.2</td>
<td>328.7</td>
<td>104.9</td>
<td>466.2</td>
<td>803.4</td>
<td>83.4</td>
<td>3.0</td>
<td>402.5</td>
<td>3213.4 (8)</td>
</tr>
<tr>
<td>Square, 3 floors</td>
<td>1151.6</td>
<td>367.5</td>
<td>116.4</td>
<td>466.1</td>
<td>803.2</td>
<td>92.1</td>
<td>3.2</td>
<td>402.4</td>
<td>3402.5 (10)</td>
</tr>
</tbody>
</table>

<sup>a</sup>Based on ASHRAE 90.1-2010.

<sup>b</sup>Considered as the baseline model.
The literature is validated by the sharply increasing energy intensities of plans with multiple floors, as compared to rectilinear plans with a similar depth of plan (Gilg & Valentine, 2004). The two and three floor plans were found to have significantly higher energy intensities compared to the rectangle 2:1 and 3:1 plans.

Simulation of building forms in a hot climate

A similar methodology to the simulations in extreme cold climates applied for this section, with the exception that the model was calibrated to the average CBECS EUI for climate zone 2. The results of these simulations of the same 10 models are shown in Table 6.

The next step included applying the same four EDMs on each of the ten models in the same order described above. For the purpose of this article, only the top two ranked models (i.e. “square, 1 floor” and “square with interstitial”) and the bottom two ranked models (i.e. “square, 2 floors” and “square, 3 floors”) are presented in Table 7.

The overall pattern of the data is similar to that found for the extreme cold climate in that the baseline form of a square floor plan is the most energy efficient. The other building forms relate to each other in the same way as in a cold climate. However, the energy reductions in the East–West configuration with the majority of glazing facing South, as well as the daylighting controls, have a much greater impact in this climate.

Analysis of simulation model characteristics

The characteristics recommended by the literature 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 energy simulations showed that decreasing the surface area in the multiple story plans results in a much higher energy intensity as compared to the baseline single story square. 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 WWR, as discussed by Gilg and Valentine (2004), correlates much closer to the hospital simulation data. The WWR is an indicator of levels of energy intensity when comparing otherwise similar buildings. The interstitial space is the only outlier that does not follow the relationship of WWR compared to energy intensity.
Table 6. EUI based on simulations of hospital building forms in climate zone 2 (kBtu/m²/year).

<table>
<thead>
<tr>
<th>Type of design</th>
<th>Space heating</th>
<th>Vent fans</th>
<th>Space cooling</th>
<th>Lights</th>
<th>Domestic hot water</th>
<th>Pumps and auxiliary</th>
<th>Heat reject</th>
<th>Misc. equipment</th>
<th>Total (rank)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ASHRAE&lt;sup&gt;a&lt;/sup&gt;</td>
<td>241.8</td>
<td>140.5</td>
<td>178.3</td>
<td>277.9</td>
<td>240.9</td>
<td>43.2</td>
<td>18.4</td>
<td>114.6</td>
<td>1255.5</td>
</tr>
<tr>
<td>CBECS</td>
<td>499.0</td>
<td>266.8</td>
<td>354.9</td>
<td>474.7</td>
<td>640.6</td>
<td>0.0</td>
<td>0.0</td>
<td>373.9</td>
<td>2609.9</td>
</tr>
<tr>
<td>Square, 1 floor&lt;sup&gt;b&lt;/sup&gt;</td>
<td>537.2</td>
<td>301.8</td>
<td>397.2</td>
<td>466.3</td>
<td>506.0</td>
<td>86.6</td>
<td>39.2</td>
<td>402.6</td>
<td>2736.9 (1)</td>
</tr>
<tr>
<td>Rectangle, 2:1</td>
<td>588.1</td>
<td>311.1</td>
<td>409.1</td>
<td>466.2</td>
<td>506.0</td>
<td>90.4</td>
<td>40.6</td>
<td>402.5</td>
<td>2814.0 (4)</td>
</tr>
<tr>
<td>Rectangle, 3:1</td>
<td>645.0</td>
<td>321.7</td>
<td>420.4</td>
<td>466.2</td>
<td>506.0</td>
<td>93.1</td>
<td>41.8</td>
<td>402.5</td>
<td>2896.7 (6)</td>
</tr>
<tr>
<td>L-shape, 2:1</td>
<td>564.8</td>
<td>307.0</td>
<td>402.7</td>
<td>466.4</td>
<td>506.2</td>
<td>88.0</td>
<td>39.7</td>
<td>402.7</td>
<td>2777.5 (3)</td>
</tr>
<tr>
<td>L-shape, 3:1</td>
<td>607.4</td>
<td>315.0</td>
<td>411.1</td>
<td>466.3</td>
<td>506.1</td>
<td>90.1</td>
<td>40.6</td>
<td>402.6</td>
<td>2839.1 (5)</td>
</tr>
<tr>
<td>X-shape</td>
<td>692.2</td>
<td>330.7</td>
<td>427.7</td>
<td>466.2</td>
<td>505.9</td>
<td>94.1</td>
<td>42.3</td>
<td>402.5</td>
<td>2961.5 (7)</td>
</tr>
<tr>
<td>Square with atrium</td>
<td>730.4</td>
<td>336.9</td>
<td>434.3</td>
<td>465.9</td>
<td>505.8</td>
<td>95.8</td>
<td>42.9</td>
<td>402.1</td>
<td>3014.2 (8)</td>
</tr>
<tr>
<td>Square with interstitial</td>
<td>538.3</td>
<td>301.7</td>
<td>397.2</td>
<td>466.3</td>
<td>506.1</td>
<td>86.6</td>
<td>39.2</td>
<td>402.6</td>
<td>2738.0 (2)</td>
</tr>
<tr>
<td>Square, 2 floors</td>
<td>796.0</td>
<td>349.7</td>
<td>453.6</td>
<td>466.2</td>
<td>506.0</td>
<td>101.3</td>
<td>45.3</td>
<td>402.5</td>
<td>3120.6 (9)</td>
</tr>
<tr>
<td>Square, 3 floors</td>
<td>961.8</td>
<td>381.6</td>
<td>488.4</td>
<td>466.1</td>
<td>505.9</td>
<td>109.4</td>
<td>49.0</td>
<td>402.4</td>
<td>3364.4 (10)</td>
</tr>
</tbody>
</table>

<sup>a</sup>Based on ASHRAE 90.1-2010.

<sup>b</sup>Considered as the baseline model.
Pearson’s correlation was used to compare the EUI of the simulations to the wall-to-floor area ratio of various building forms in climate zone 8 for each EDM (levels 0–4). The analysis included a correlation of all 10 building forms first, followed by a correlation to only nine building forms, excluding the interstitial form. The results show a very strong positive correlation, as seen in Table 8.

The multi-story plans greatly increase the amount of floor space within 4.57 m (15 feet) of the perimeter and potential for daylighting spaces. According to the GGHC (2007), the potential daylit floor space is within 4.57 m of the perimeter. The daylit floor areas appear to more closely follow the EUI pattern, and correlations of the daylit floor area to the EUI results for all of the building forms were conducted, as seen in Table 9. The correlation between the daylit floor area and EUI is shown to be stronger than the correlation between the exterior wall area and the EUI. This indicates that the daylit floor area is a better indicator of energy intensity.

<table>
<thead>
<tr>
<th>Energy design measure</th>
<th>Square, one floor</th>
<th>Square with interstitial floors</th>
<th>Square, two floors</th>
<th>Square, three floors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>EUI</td>
<td>$\Delta_b$ (%)</td>
<td>EUI</td>
<td>$\Delta_c$ (%)</td>
</tr>
<tr>
<td>Level 0</td>
<td>2736.9</td>
<td>Base design</td>
<td>2738.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Level 1</td>
<td>2736.9</td>
<td>0.0%</td>
<td>2738.0</td>
<td>0.0</td>
</tr>
<tr>
<td>Level 2</td>
<td>2671.8</td>
<td>$-2.4%$</td>
<td>2672.9</td>
<td>$-2.3%$</td>
</tr>
<tr>
<td>Level 3</td>
<td>2568.4</td>
<td>$-6.2%$</td>
<td>2569.5</td>
<td>$-6.1%$</td>
</tr>
<tr>
<td>Level 4</td>
<td>2532.2</td>
<td>$-7.5%$</td>
<td>2533.3</td>
<td>$-7.4%$</td>
</tr>
<tr>
<td>$\Delta_a$</td>
<td>$-7.5%$</td>
<td>$-7.5%$</td>
<td>$-9.0%$</td>
<td>$-10.1%$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy design measure</th>
<th>Pearson’s correlation, all 10 building forms</th>
<th>Pearson’s correlation, nine building forms, excluding interstitial floor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massing (level 0)</td>
<td>0.8557</td>
<td>0.9943</td>
</tr>
<tr>
<td>Orientation (level 1)</td>
<td>0.8800</td>
<td>0.9959</td>
</tr>
<tr>
<td>Daylighting (level 2)</td>
<td>0.8810</td>
<td>0.9953</td>
</tr>
<tr>
<td>Window:wall ratio (level 3)</td>
<td>0.8670</td>
<td>0.9972</td>
</tr>
<tr>
<td>Overhangs (level 4)</td>
<td>0.8595</td>
<td>0.9943</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Energy design measure</th>
<th>Pearson’s correlation, all 10 building forms</th>
</tr>
</thead>
<tbody>
<tr>
<td>Massing (level 0)</td>
<td>0.9835</td>
</tr>
<tr>
<td>Orientation (level 1)</td>
<td>0.9816</td>
</tr>
<tr>
<td>Daylighting (level 2)</td>
<td>0.9819</td>
</tr>
<tr>
<td>Window:wall ratio (level 3)</td>
<td>0.9907</td>
</tr>
<tr>
<td>Overhangs (level 4)</td>
<td>0.9918</td>
</tr>
</tbody>
</table>

Pearson’s correlation was used to compare the EUI of the simulations to the wall-to-floor area ratio of various building forms in climate zone 8 for each EDM (levels 0–4). The analysis included a correlation of all 10 building forms first, followed by a correlation to only nine building forms, excluding the interstitial form. The results show a very strong positive correlation, as seen in Table 8.

The multi-story plans greatly increase the amount of floor space within 4.57 m (15 feet) of the perimeter and potential for daylighting spaces. According to the GGHC (2007), the potential daylit floor space is within 4.57 m of the perimeter. The daylit floor areas appear to more closely follow the EUI pattern, and correlations of the daylit floor area to the EUI results for all of the building forms were conducted, as seen in Table 9. The correlation between the daylit floor area and EUI is shown to be stronger than the correlation between the exterior wall area and the EUI. This indicates that the daylit floor area is a better indicator of energy intensity.
when comparing buildings with similar floor to floor heights; however, when comparing build-
ings of varying floor to floor heights, it is apparent that the exterior wall area is still the most
appropriate indicator.

**Simulation of hospitals**

*Simulation of a hospital in an extreme cold climate*

The hospital located in climate zone 8 was simulated in eQUEST using basic floor plans and its
simulation model parameters. The hospital shape and approximate amounts of windows were
simulated with pictures and use of the plans. The hospital has an L-shape with a total floor
area of approximately 25,000 m², and is 4 years old. The mechanical systems and other settings
were set as default settings within the software. The EUI obtained from CBECS 2003 data was
used during this simulation, where the hospital simulation model was calibrated to this EUI to
set up the hospital baseline model. The EDMs implemented in the hospital simulation were
similar to those mentioned above (levels 1 through 4). The results of the energy simulation are
shown in Table 10.

The extreme cold climate requires a large portion of energy to be used for space heating. The
existing design was oriented to the northeast to increase the amount of windows facing south.
Based on the simulations, the measures that accounted for the largest reductions in EUI were lim-
iting the window to wall to 40% and the use of window overhangs.

*Simulation of a hospital in a hot climate*

The largest hospital located in climate zone 2 was simulated in this case. The hospital has a rec-
tangular shape with a total floor area of approximately 125,400 m², and is 14 years old. The
overall results of each EDM are shown in Table 11.

<table>
<thead>
<tr>
<th>Simulation of EDMs</th>
<th>EUI (kBtu/m²/year)</th>
<th>Δ from base design (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBECS 2003</td>
<td>3012.2</td>
<td>−1.0</td>
</tr>
<tr>
<td>Base design</td>
<td>3041.9</td>
<td>0.0 (Benchmark)</td>
</tr>
<tr>
<td>Orientation (level 1)</td>
<td>3007.4</td>
<td>−1.1</td>
</tr>
<tr>
<td>Daylighting (level 2)</td>
<td>2977.3</td>
<td>−2.1</td>
</tr>
<tr>
<td>Window:wall ratio (level 3)</td>
<td>2907.3</td>
<td>−4.4</td>
</tr>
<tr>
<td>Overhangs (level 4)</td>
<td>2844.9</td>
<td>−6.5</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Simulation of EDMs</th>
<th>EUI (kBtu/m²/year)</th>
<th>Δ from base design (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>CBECS 2003</td>
<td>2609.9</td>
<td>−4.9</td>
</tr>
<tr>
<td>Base design</td>
<td>2744.8</td>
<td>0.0 (Benchmark)</td>
</tr>
<tr>
<td>Orientation (level 1)</td>
<td>2769.6</td>
<td>+0.9</td>
</tr>
<tr>
<td>Daylighting (level 2)</td>
<td>2815.8</td>
<td>+2.6</td>
</tr>
<tr>
<td>Window:wall ratio (level 3)</td>
<td>2792.2</td>
<td>+1.7</td>
</tr>
<tr>
<td>Overhangs (level 4)</td>
<td>2788.9</td>
<td>+1.6</td>
</tr>
</tbody>
</table>
Based on the energy simulations, all four proposed EDMs led to an increase in the hospital’s EUI. These findings mean that the four EDMs were already taken into account and considered thoroughly in the design of the hospital building. The factor affecting most negatively in this simulation was daylighting design measures, which means that in hot climate zones, increasing daylighting should be considered very carefully due to its additional radiation, and therefore, increased heat generation.

Discussion

The analysis of various energy saving measures and their impact on the consumption of energy for hospital facilities appears to be in conflict with certain goals of EBD, such as the increased use of views and daylighting. Energy simulations demonstrated that the more window area is created by changing the building’s shape, the more energy is consumed. The simulations also show that while some design choices may be made, such as multiple story high-rise building to increase the functionality of the space, the patient tower could be elongated and oriented to make use of some energy reduction measures.

The increase in amount of floors or height of the inhabited space is a large factor in extreme cold climates, while in hot climates it was found to be even more significant. Based on this study, the overall height of facilities is recommended to be as low as possible in both cold and hot climates. 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 the use of vertical spaces 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 square building floor plan was found in this study to deliver the lowest energy intensities of all the models. The rectilinear plans and L-shaped plans behaved somewhat similarly, 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–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 plan’s 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 sharply increase energy use.

The L-shaped plans had the advantage of performing exactly the same regardless of North–South or East–West orientations. The L-shaped plans did not perform as well as the rectilinear plans; however, they showed 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 floor space on one level. The increase in perimeter wall was comparable to the increase seen with multiple levels; however, the energy intensity was not on the same level as multi-story plans in either climate zone. The design recommendation is that the complexity of angles in a building footprint will yield a higher amount of perimeter wall, and is still more advantageous from an energy conservation perspective than is 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 a space to begin with; however, 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 energy performance of the facility.

The building massing was overall the most influential of all the factors of the building envelope. The choice of building shape may be determined mainly by the function of the interior space; however, when options are available, the shape of a building greatly affects its future energy performance.

The energy impacts of East–West orientation and the use of daylighting controls are amplified by each other. The form of a hospital can determine the success of orientation and daylighting, and the most elongated forms benefit the most from these EDMs.

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

Exterior shading devices on 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 would be an improvement to both the quality of care and energy savings aspects.

The analysis of the EUIs of multiple building forms made it apparent that multi-story buildings were more energy intense than lower buildings of similar floor area, assuming the same percentage of window to wall area. The case can be made that multi-storied hospitals have shorter travel distances, because of elevator use, and are therefore more efficient in other ways. The study of the amount of daylit perimeter area shows that multi-storied forms have the highest percentage of daylit area. The design recommendation would be to decrease the amount of window area in 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 daylit area increases quickly with vertically arranged spaces as opposed to low-rise designs. This is supported by the window to wall area ratio recommendations within the ASHRAE 90.1-2010 Standard (ASHRAE, 2010) limiting WWR to 40%. Judicious window design 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 spaces with open space planning to make the best use of perimeter glazing.

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, EBD objectives provide treatment and allow shorter recovery periods, therefore saving energy on a per patient basis. The function of a space is likely to be the primary design driver over the energy goals of a design. Gains in treatment capacity are an energy savings strategy in and of itself.
The overall trend in energy consumption is that greater window area correlates with greater heat transfer; therefore, the heating/cooling loads increase. The overall trend in EBD is that the more the windowed areas, the better the patient outcomes and staff satisfaction, which consequently makes for a better facility. Therefore, future hospitals may have more windows; hence, the windows must perform better to meet space requirements.

The general finding of this study is that the design features of EBD will result in hospital buildings shaped less efficiently from an energy sustainability standpoint. The building shape, however, has 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, costs targeted by EBD are personnel-related costs, which are typically much greater than construction and energy costs of a facility. When comparing lifecycle costs, the overall personnel costs of a typical hospital are 64%, as compared to 6% capital construction and 6% energy costs (Dell’Isola & Kirk, 2003). Saving 5% of 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, but result in inefficiencies at the facility management level. When considering the lifecycle costs of a hospital, savings in personnel costs can justify additional capital and energy expenses, as long as the EBD features are effective.

The large gap between the ASHRAE 90.1-2010 benchmark (ASHRAE, 2010) that was simulated and the average EUI of hospital facilities from the CBECS survey was over 50% disparity. The range of impact of building form combinations and EDMs would likely be limited to 5–10% of savings toward meeting the ASHRAE 90.1-2010 (ASHRAE, 2010) goals. Additional recommendations made by the NREL in their Large Hospital 50% Energy Savings (Bonnema et al., 2010) will help achieve the remaining 40–45% savings over building form. These recommendations consist of tighter and more insulated envelope, multi-zone variable air volume 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 mechanical systems of a hospital are the largest portion of energy consumption within the facility. The CBECS data used for the benchmark in climate zone 8 show 44% of the energy consumed by mechanical systems, such as heating, cooling, and ventilation fans. Domestic hot water constituted 32% of the overall consumption, the second highest category. Lighting systems amounted to 15%, while miscellaneous equipment totaled 9%. The large domestic hot water consumption is unchanged by modifications to the building envelope, unlike the heating, cooling, and lighting components. The recommendation is to target the efficiency of the domestic hot water system by improving equipment efficiency (Mukhopadhyay et al., 2009) or by improving distribution and control strategies (Chen, Bensouda, Claridge, & Bruner, 2004).

The energy simulations 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 waste involved in receiving large amounts of electricity from off site, wherein it takes approximately 3 kWh to provide 1 kWh of electricity to a typical building. This presents another real opportunity for energy saving by locating power sources close to hospitals and other large energy consumers.

The construction of the building envelope is the first step in designing an energy-efficient facility. This study has shown the impact that windows have on the energy intensity of a facility. 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
recommended that future low-energy designs should emphasize the envelope construction and the size of the mechanical systems.

The exposure to nature and daylighting concepts of EBD is more of a challenge to incorporate sustainability in extreme climates. One recommendation is to develop new hospital building types with enclosed atria that bring a nature setting indoors. Extreme climatic conditions of cold and heat are not conducive to certain 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 atria can be a source of valuable daylighting and access to nature for patients. According to Atif, Boyer, Degelman, and Claridge (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.

Conclusions
This paper studied the concepts and initiatives of EBD and energy sustainability and how they each impact the design of the hospital envelope. The most lasting feature of a building is its form: compared to building systems which change over time, the shape and design of the envelope continues for the life of the building (Baker, Vaidya, & D’Souza, 2010), perhaps as long as 50–100 years.

The high average age of facilities in the MHS inventory demonstrates additional challenges to maintain compliance with newer standards and goals, such as EBD and ASHRAE Standard 90.1-2010 (ASHRAE, 2010). The dispersion of facilities throughout the United States is obvious due to the MHS needing to support its military installations. This geographic dispersion and consequently varied site conditions make it difficult to draw conclusions on energy use, when comparing a range of facility sizes, capacities, ages, and climate zones.

When simulating two military facilities and assessing the impact of energy-saving measures used in the incremental simulations, it was found that EDMs impacted overall energy use very modestly. 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; the modifications did not have a large effect on the facilities’ energy use.

Determining the energy efficiency impacts of EBD strategies in MHS facilities may assist in planning 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, and assist in the future direction of research and capital improvements in the MHS.

The use of indicators, such as the wall-to-floor ratio, to identify existing facilities that would most benefit from capital investments is another contribution of this study. The perspective that investments in mechanical systems will have larger effects on energy use than will those in the envelope is also valuable.

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.

Existing building designs were selected based on selection criteria discussed within the research methods section, which may not represent the entire portfolio of military and/or civilian healthcare facilities. The intention of this study was to isolate energy impacts relative to the building envelope. It is understood that the HVAC systems are a significant part of the overall energy efficiency of a building; however, the mechanical systems were not the focus of this study.
Additional research is needed to delineate mechanical systems that are recommended and determine alternatives and their overall contribution to energy demand.

The Army Medical Department’s portfolios of building data as well as the data available via the Department of Energy’s CBECS surveys formed 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.

The increase 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 a higher energy-intense building because the number of patients supported increases. Patients in the improved environments have shorter inpatient durations; therefore, more patients can be treated over time. Additional research is needed to calculate these savings and the additional energy costs attributed to EBD features, and compare these to the healthcare savings.

Acknowledgments

Construction drawings from multiple existing hospitals throughout the country were 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 of the U.S. Army Medical Command (MEDCOM). The authors acknowledge this office whose help and cooperation enabled the completion of this study.

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