THE INTERSECTION OF ENERGY, HEALTHCARE AND CLIMATE

A Thesis by

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Submitted to the Department of Industrial and Manufacturing Engineering
and the faculty of the Graduate School of
Wichita State University
in partial fulfillment of
the requirements for the degree of
Master of Science

May 2015

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The following faculty members have examined the final copy of this thesis for form and content, and recommend that it be accepted in partial fulfillment of the requirement for the degree of Master of Science with a major in Industrial Engineering.

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DEDICATION

To my family and my adviser

ACKNOWLEGEMENTS

I would like to thank my adviser, Janet Twomey, for her three years of thoughtful, patient guidance and support. Thanks are also due to Michael Overcash. Together their friendship and selfless role modeling have contributed to my professional development. I would also like to extend my gratitude to members of my committee, Lawrence Whitman, and Vinod Namboodiri, for their valuable comments and suggestions.

ABSTRACT

The reduction of energy use in hospitals as energy intensive units is critical to the overall goals of lowering the cost of healthcare and emissions from those facilities. Hence, the assessment and identification of key end-use demand factors impacting energy consumption is essential. In this paper, end-use demand factors not previously examined are investigated. Instead of the usual engineering analysis and energy audits, the work presented here examines demand in terms of changing outdoor temperatures and levels of hospital activity measured by inpatient and outpatient census. An energy analysis of two major hospitals in Wichita, Kansas, using their monthly energy bills is presented. New insights into the major drivers of energy consumed within a hospital setting are reported. Those insights are used to assess heating, ventilation, and air conditioning (HVAC) energy-efficiency improvements through monthly hospital energy bills.

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CHAPTER 1

INTRODUCTION, BACKGROUND AND MOTIVATION

1.1 Introduction

The research presented in this master's thesis is part of a larger body of work conducted by Janet Twomey, PhD and Michael Overcash, PhD investigating the impacts of healthcare on the environment; the intersection between healthcare, energy and the environment [1,2,3,4,5,6,7,8,9]. The work of Twomey, Overcash and their student has examined the energy consumed in the delivery of imaging and hemodialysis services. The energy consumed is translated into CO_2 emitted so that contribution of healthcare to global climate change may be estimated. The research undertaken here expands that work to include healthcare facilities (Figure 1.1). An analysis of hospital energy end-use demand is performed. The analysis looks at end-use variables that were not previously examined by the literature.

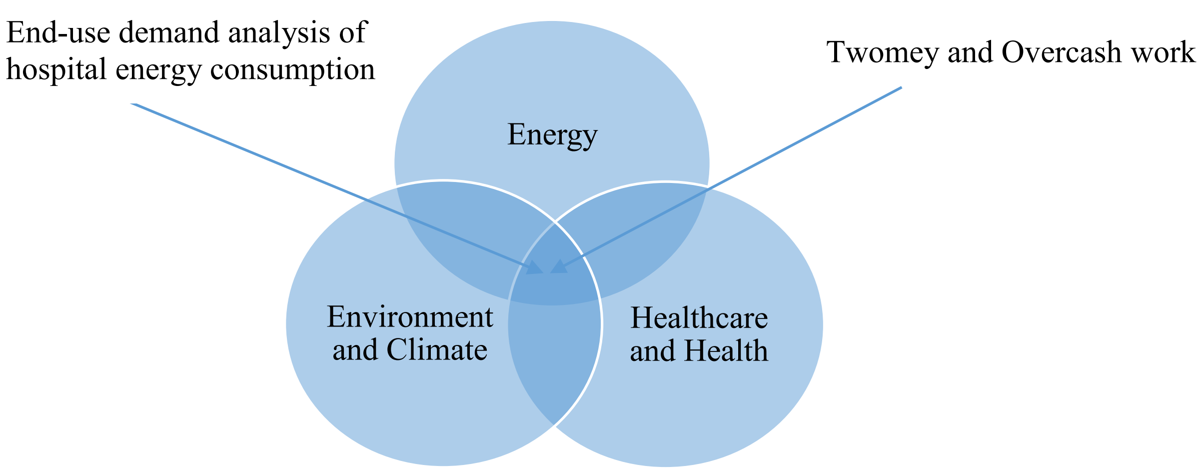

Figure 1.1**.** Energy, healthcare and environment research

1.2 Healthcare Facilities and Energy Use: Background and Motivation

Energy consumption of commercial sector in U.S. includes 19% of the total energy consumption. The Lodging, educational, healthcare, office and retail buildings account for more than 66% of the total energy use by commercial sector (http://www.aceee.org/portal/commercial). The energy usage has adverse effects on the environment and human health due to emissions. In 2012 commercial and residential buildings were responsible for 10 % of total greenhouse gas emitted into atmosphere in the United States, Figure 1.2.

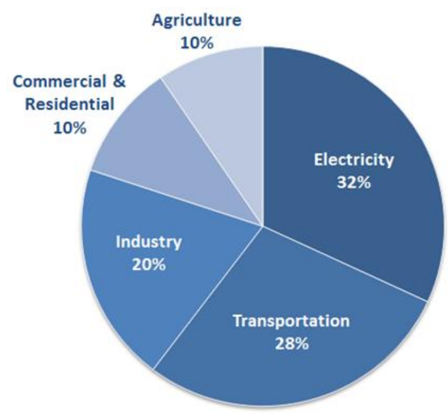

Figure 1.2. Total U.S. greenhouse gas emissions by economic sector in 2012 (Source: U.S. Environmental Protection Agency, http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html)

Hospitals are large consumers of energy due to their 24 hour service, specific requirements for health, large number of occupants, and complexity of HVAC systems (http://www.eia.gov/consumption/commercial/reports/2007/large-hospital.cfm). Figure 1.3 shows the contribution of each source in energy usage for hospitals in climate zone 3 (Kansas included). Obviously, HVAC system with 29% of total energy use is a major source of energy consumption in a hospital.

The problem of greenhouse gas emissions worsens with climate projections made for long term horizons. The climate change scenarios over long term exhibit hotter conditions for weather. This causes hospitals having to consume large amount of energy in order to control the costs of increasing emissions and to provide a comfortable and immune environment for their occupants. Thus hospitals design and implement energy efficiency programs to reduce the energy consumption. The objective of this research is to analyze the energy consumption of hospitals over time.

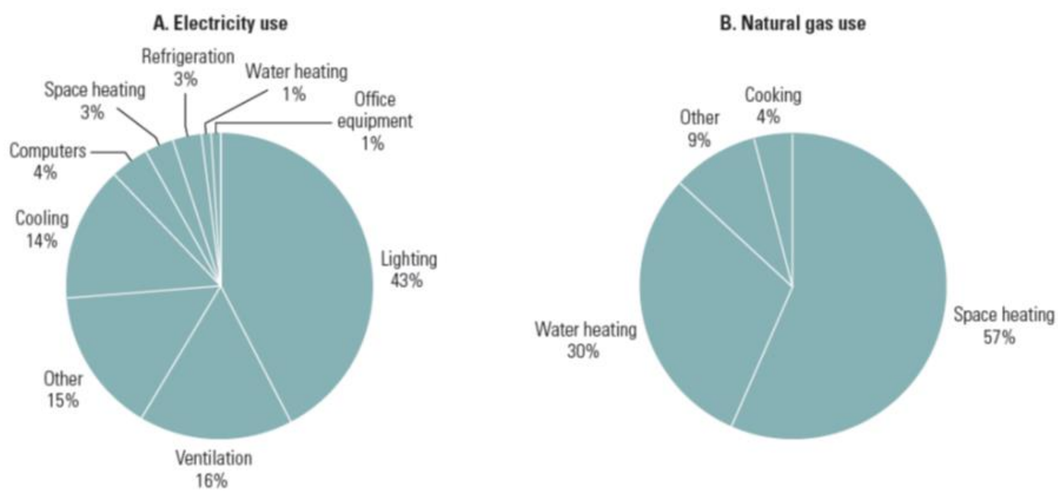

Figure 1.3**.** Energy consumption in hospitals by end use (Source: U.S. Energy Information Administration, http://www.nationalgridus.com/non_html/shared_energyeff_hospitals.pdf)

1.3 Research Scope and Objective

In this research energy consumption in two major healthcare facilities in Wichita, KS is addressed. The objective being followed includes evaluating the effectiveness of energy efficiency programs performed in the two hospitals in 2007-2012. The presence of different factors affecting energy usage level in hospitals complicates the task of evaluation. However, methodologies are applied to gain insight into factors affecting energy consumption and assessing the individual and overall impact of those factors. Those insights are used to evaluate the hospitals past and future long term energy consumption.

1.4 Thesis Proposal Organization

This thesis proposal is organized as follows: In chapter 2 the end-use demand of hospitals energy consumption is analyzed. Chapter 3 concludes the thesis and provides insights for future work.

CHAPTER 2

END-USE DEMAND ANALYSIS OF HOSPITAL ENERGY CONSUMPTION

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Abstract: The reduction of energy use in hospitals as energy intensive units is critical to the overall goals of lowering the cost of healthcare and emissions from those facilities. Hence, the assessment and identification of key end-use demand factors impacting energy consumption is essential. In this paper, end-use demand factors not previously examined are investigated. Instead of the usual engineering analysis and energy audits, the work presented here examines demand in terms of changing outdoor temperatures and levels of hospital activity measured by inpatient and outpatient census. An energy analysis of two major hospitals in Wichita, Kansas, using their monthly energy bills is presented. New insights into the major drivers of energy consumed within a hospital setting are reported. Those insights are used to assess heating, ventilation, and air conditioning (HVAC) energy-efficiency improvements through monthly hospital energy bills.

Keywords: Hospital energy consumption; Air temperature; HVAC; Hospital energy demand factors.

2.1 Introduction

Hospitals are significant consumers of energy due to specific requirements for maintaining patient comfort, meeting standards for a bacteria- and virus-free environment, and providing 24-7 delivery of patient services. Previous work has indicated that a large portion of that energy is used for heating, ventilation, and air conditioning (HVAC) systems in order to maintain healthy indoor air quality through adequate ventilation with filtration and to provide thermal comfort (http://www.epa.gov/iaq/schooldesign/hvac.html, accessed 2014; Ascione et al. 2013). Estimates of the amount of a hospital's total energy that can be attributed to HVAC vary widely by climate region and building characteristics. Other energy consumers within hospitals include medical equipment, meal services appliances, computers, and lighting. In addition to being costly for hospitals, energy use contributes to greenhouse gases and particulates emissions. Planning for energy-efficiency improvement requires information related to end-use consumption in order to target improvements. The most common approach used to assess end-use demand is through energy audits of machines and equipment. The work presented here seeks to add to the body of knowledge related to hospital energy consumption by using outdoor ambient temperature and a different set of factors hypothesized to significantly impact end-use demand: the utilization of hospital services. This paper also demonstrates a procedure for assessing energy-efficiency improvements using only the hospital's monthly energy bills.

Literature on the practice of energy demand analysis for commercial and industrial facilities is voluminous. Methods to audit and reduce a building's energy consumption are typically categorized by the size and type of the building envelope, energy-consuming devices, and systems used in the building's operations. The reader is referred to research by Harvey (2009) and Bawaneh et al. (2014) for reviews of facility energy analysis.

The literature related to energy demand of hospital facilities is comparatively limited but similar in approach. Čongradac et al. (2012) developed a tool to model and assess the energy consumed by a hospital HVAC system. This tool calculates energy demand from data such as building location, hourly weather, building envelope, internal heat load, room location and orientation, room usage and occupation, user input, and additional requirements. Martini et al. (2007) developed a methodology to minimize the environmental impacts of energy inefficiency in the healthcare sector of Argentina by identifying and assessing variables for efficient use of energy and emission reductions. In their analysis, they considered lighting, various types of equipment and the amount of cooling needed to provide patient comfort. Gordo et al. (2011) identified areas for improvement and installed upgrades for energy reduction in a Portuguese hospital. Upgrades included energy-efficient lift systems, and upgrades to chillers, lighting, and window frames. They concluded that it is possible to keep the comfort level fixed and reduce the use of energy. Ascione et al. (2013) studied the impact of different building envelope factors on an Italian hospital energy consumption. Their study included an analysis of environmental and economic factors of two different building envelopes and three different types of HVAC systems. Saidur et al. (2010) studied and identified electric motors as a significant source of consumption in a Malaysian hospital. Different upgrades for energy savings were examined, and variable speed drives were suggested for achieving an approximate 33% reduction in energy intensity.

Unlike the previous work on hospital energy analysis, the work presented here examines end-use demand in terms of factors other than building envelope, lighting, and mechanical and motor systems. Instead, hospital activity or service-level utilization, together with fluctuating outdoor temperatures, are considered the major drivers of energy use. Multiple linear regression models are constructed from information on two major hospitals. A best subset of independent variables is applied in order to identify and quantify the contributions of hypothesized variables to energy consumed: ambient outdoor temperature measured by cooling and heating degree days (CDD and HDD, respectively) and level of hospital activity as measured by four factors: number of patients admitted to and staying in the hospital, number of patients seen in the emergency room, number of patients receiving outpatient services and number of patients receiving diagnostic imaging services. Electricity and gas are considered separately and in total as the dependent variable.

2.2 Setting for Analysis and Data Sources

Data on electricity and gas consumption were collected from two hospitals belonging to a major healthcare provider in Wichita, Kansas. This healthcare provider has been serving Kansas and northern Oklahoma for more than a century. In this paper, these providers are referred to as Hospital A and Hospital B. Hospital A is 1.27 million ft^2, has 400 staffed beds, employs approximately 2,800 staff and physicians, and is a Level 1 Trauma Center. Hospital B is 0.464 million ft^2, employs approximately 1,000 staff and physicians, and has 300 staffed beds. The monthly electricity and gas consumption over a six-year period (2007–2012) for each hospital was obtained from energy bills. Billing cycle information was first adjusted to coincide with calendar months. Natural gas consumption typically reported in thermal units was transformed to kWh to be consistent with electricity consumed. Outpatient and inpatient census information was collected for the same time period. Wichita cooling and heating degree days were calculated using average daily temperatures taken from *The Old Farmer's Almanac* website (http://www.almanac.com, accessed 2013).

The seasonality of electricity and gas consumed by Hospitals A and B is shown in Figures 2.1 and 2.2. In both hospitals, annual gas consumption (kWh) is on average 49% higher than annual electricity consumption. Figure 2.3 plots energy intensity for each hospital by source of energy. The differences in energy intensity between hospitals indicate variations in building construction and age, and possibly the type and degree of services offered.

2.3 Research Hypotheses and Factors

Outdoor temperature and level of activity within a hospital are two elements hypothesized as have large impacts on hospital energy consumption. The rationale for choosing these factors follows.

HVAC has already been established as a major source of energy consumption in hospitals. These systems adjust variables such as temperature, humidity, and the quality of air inside a building by transferring heat and moisture into and out of the air. HVAC energy demand varies dramatically depending upon the climate zone in which a hospital is located. Additionally, as the climate warms and temperature variability increases, HVAC requirements will change (Christenson et al. 2006).

Hospital activity levels or service utilization has not been considered in previous studies on end-use demand for a hospital facility, with the exception of the work of Bacon (2014), who investigated energy demand profiles as a function of changing occupancy over a 24-hour period through simulation. The goal of that investigation was to demonstrate possible reductions in energy from the perspective of control systems. In this research, the relationship between hospital activity levels and energy demand are analyzed on a monthly basis using actual data from two hospitals. One basis for this investigation is previous research conducted by the authors in a production setting, which established a strong linear relationship between energy consumed and activity within a production facility (Bawaneh et al. 2014). The authors constructed regression models using actual data from several productions facilities. Similar to the work presented here, a relationship between monthly total energy use and monthly production levels over several years was found. As an example, one case considered by the authors was a laundry facility. The independent variable was monthly kilograms of laundered materials, and the dependent variable was gas in MJ/month. The resulting equation (equation 2.1) showed a significant positive relationship where $R^2 = 0.7948$:

$$\text{MJ/month} = 7.50 * \text{thousand kilograms laundered/month} + 28{,}779 \text{ MJ/month} \tag{2.1}$$

At a production level of zero laundry, 28,779 MJ/month was consumed. The authors identified this value to be the consumption of non-processes energy (lighting, computers, HVAC). The relationship between dependent and independent variables was tested in a hospital setting where the monthly hospital activity level and service utilization were analogous to the monthly production level. The goal here was to determine the sensitivity of monthly energy consumption to changes in levels of end-use demand.

2.3.1 Outdoor temperature, and cooling and heating degree days

According to building energy experts, the best measure for outdoor temperatures is not °F or °C, but rather heating and cooling degree days (HDD and CDD). “The degree day method is one of the most widely used and simplest methods in the heating, ventilation, and air-conditioning industry to estimate heating and cooling energy requirements” (Rong and Dequan 2011; Day et al. 2003). Degree day is defined as a measure that gauges the amount of heating or cooling needed for a building based on a specific baseline temperature and the varying outdoor temperature (http://www.nws.noaa.gov/climate/f6.php?wfo=mpx, accessed 2014). When used to calculate CDD (HDD) values, the baseline temperature refers to the maximum (minimum) outside temperature at which no cooling (heating) is required to maintain thermal comfort inside the building (http://www.nws.noaa.gov/climate/f6.php?wfo=mpx, accessed 2014). The value of the baseline temperature indicates the balance point of a building and depends on several building features, such as number of windows and doors, building layout, and building insulation. In this analysis, the standard baseline temperature θ_b = 65 °F is used to calculate monthly CDD and HDD values. The calculation of degree day uses the mean daily temperature. Taking θ_b as the baseline temperature and θ_i as the average temperature in day *i*, CDD over an *N*-day month is calculated as

$$\mathrm{CDD} = \sum_{i=1}^{N}(\theta_i - \theta_b) \quad \begin{cases} \text{if } (\theta_i - \theta_b) > 0 \\ 0 \quad \text{otherwise} \end{cases} \tag{2.2}$$

Using the same notation, HDD is found over a period of days and is calculated as

$$\mathrm{HDD} = \sum_{i=1}^{N}(\theta_b - \theta_i) \quad \begin{cases} \text{if } (\theta_b - \theta_i) > 0 \\ 0 \quad \text{otherwise} \end{cases} \tag{2.3}$$

The average daily temperature for Wichita, Kansas, for years 2007 to 2012 are used to find the number of CDD and HDD per month. The number of monthly CDD and HDD by year, plotted in Figure 2.4, indicate distinct differences in temperature during the years studied, where the summer months of 2011 and 2012 had the largest number of CDD, the winter of 2012 had the lowest number of HDD, and 2012 was one of the hottest years in Kansas recorded history.

2.3.2 Measures of hospital activity and utilization of high-energy-consuming equipment

Hospitals provide a variety of medical services to inpatients and outpatients. Thus, an increase in the number of patients admitted to and staying in the hospital, the number of patients seen in the emergency room, the number of patients receiving outpatient services and the number of patients receiving diagnostic imaging services are expected to correspond to an increase in energy consumed. These four variables are used to represent the monthly level of hospital activity.

Inpatient activity level is measured by the monthly inpatient census. "Inpatient" refers to a patient who is confined to the hospital with at least one overnight stay, and the daily count of inpatients is summed over the month. Monthly outpatients are the number of patients admitted to the hospital and discharged on the same day and summed over each month. Outpatient data are broken into three categories: patients who are admitted to the hospital for a series of radiological images (Series), patients who are admitted to the emergency room (ER), and patients who are seen for treatment and diagnostic tests (OP). Patients in the outpatient categories (Series, ER, and OP) are considered outpatient until they are admitted to the hospital for an overnight stay and become inpatients. Figure 2.5 plots monthly hospital activity levels by hospital. Series patients are plotted separately since x-ray, MRI, and CT scans, which are the dominant modes of imaging, are known as high-electricity consumers (Twomey et al. 2012). All plots demonstrate that activity levels are relatively stable by month. Hospital activity information was limited to 29 observations corresponding to the hospital activity within a month between May 2010 and September 2012.

2.4 Multiple Regression and Best Subset Results

Multiple linear regression models were built to identify end-use demand factors that are significant contributors to monthly gas, monthly electricity, and combined total energy consumption within hospital facilities (dependent variables) (equation 2.4). The six independent variables are monthly values of CDD, HDD, inpatient census, ER admissions, OP seen, and number of radiological series of images).

$$y_i = \beta_1 x_{i1} + \beta_2 x_{i2} + \beta_3 x_{i3} + \beta_4 x_{i4} + \beta_5 x_{i5} + \beta_6 x_{i6} + \varepsilon \qquad i = 1, \dots, 12 \qquad (2.4)$$

where

y_i is total energy consumption (either gas, electricity, or total energy) in month i

x_{i1} is CDD in month i

x_{i2} is HDD in month i

x_{i3} is number of ER patients in month i

x_{i4} is number of OP patients in month i

x_{i5} is number of Series patients in month i

x_{i6} is number of inpatient days in month i

Analyses were performed using SAS 9.2. An "all subset" of independent variables analysis was performed to identify the "best subset" of predictor variables, i.e., the model with the lowest value of Akaike information criterion (AIC). AIC is the common approach to assessing the quality of a model relative to other models. Results of the linear regression analyses and best subset analyses for both hospitals are summarized in Tables 2.1 and 2.2. Significant variables are indicated for $p \leq 0.05$ and $p \leq 0.10$. All regression models satisfied tests for normality, independence of errors, and homoscedasticity. An exanimation of the results of significant variables as contributors in the full simple regression models shown in Table 2.1 is consistent with the best subset results given in Table 2.2. Therefore, the discussions and conclusions in the next sections will focus on the best subset results (Table 2.2).

2.4.1 Total energy findings

An examination of significant contributors to the consumption of total energy reveals some similarities and differences between Hospitals A and B. For Hospital A, both CDD and HDD were found to be significant. The coefficient for HDD is positive and almost four times the size of CDD coefficients. This outcome is logical since the amount of energy consumed primarily in the winter months for heating is greater. The coefficient of CDD is negative because cooling occurs more on days where no or little heat is required. In Hospital B, CDD was not found to be significant and therefore not included in the model. While the monthly number of outpatients (OP) was included as a significant variable in both hospitals, only Hospital B included the number of monthly Series patients and inpatients. The inconsistency of results between hospitals makes it difficult to draw conclusions based upon total energy consumed. A clearer outcome for monthly energy consumption differentiated by source, electricity, and gas is provided in the next section.

2.4.2 Electricity and gas findings

For both Hospitals A and B, CDD, HDD and Series are included as the best subset of independent variables in the prediction of monthly electricity consumption. Also, CDD, HDD, Series, and outpatients are the best subset of variables in the prediction of monthly gas consumption.

Hospital A electricity consumption indicates an increase of 1,298 kWh in usage per month for every CDD. For every HDD, the amount of electricity consumed is 452 kWh lower per month, as indicated by a negative coefficient. There is a 150 kWh increase in electricity use for every series of diagnostic images given in a month. Significant variables are the same for Hospital B.

The number of CDD and HDD per month had the greatest impact on gas consumption. The signs of CDD and HDD coefficients are opposite those of electricity, as expected. Series was included, but has negative coefficients because it is powered by electricity. In both hospitals, gas consumption rises with an increase in the number of outpatients.

Splitting out electricity and gas as dependent variables provides more coherency to the outcome. It can be concluded that CDD, HDD, and Series in fact contribute significantly to the consumption of a hospital's energy. The number of outpatients (OP) seen in a hospital also makes a significant difference in gas consumption.

The different outcomes of electricity use by the ER of Hospital A and gas use relative to inpatients of Hospital B are most likely due to the differences between hospitals relative to the number of patients seen by the different services. The percentage of total patients seen by Hospital A in the ER is 25%, whereas the percentage of total patients seen by Hospital B in the

ER is 43%. The percentage of inpatients seen in both hospitals also differs: 44% in Hospital A and 29% in Hospital B. The main conclusion that can be drawn from these results is that electricity consumption is (significantly) sensitive to the number of ER patients in Hospital A, and that gas consumed in Hospital B is (significantly) sensitive to the number of inpatients.

2.5 Implementation of Regression Model for Energy Improvements

The outcome of the best subset regression analysis in section 3 is used in this section to evaluate the number of energy-efficiency improvements made in both hospitals since 2007. The method developed here is significant since it uses monthly energy bills and does not rely on metering each upgrade individually.

Examples of the more significant upgrades include the following: a three-way to two-way valve conversion, right sizing of a de-coupler, controls retrofitted chilled water loop, and boiler retrofits. An examination of monthly energy consumed by both (Figures 1 and 2) shows only modest reduction in consumption compared to the base year of 2007. This direct comparison between years is not completely clear because the number of CDD in year 2012 was 29% higher than in 2007. This section describes a method derived to provide a more precise assessment of energy reduction due to HVAC upgrades.

According to results of the regression analysis in section 3, monthly outdoor air temperature measured by CDD and HDD accounts for the greatest variation in monthly consumption of electricity and gas. This would imply the high significance of linear dependence between CDD and electricity consumption as well as HDD and gas consumption. Based on this linear relationship, the percent reduction in energy consumed due to HVAC upgrades is found by removing the effects of temperature differences between years, i.e., monthly energy consumed is transformed such that all years have equivalent outdoor temperature in terms of CDD or HDD to a base year. Equation 2.5 is used to transform electricity consumed.

$$\mathrm{TEC}^{xy} = (\mathrm{EC}^{xy}/\mathrm{CDD}^{xy}) * \mathrm{CDD}^{xz} \qquad (2.5)$$

where

TEC^{xy} is transformed energy consumed for month x of year y

CDD^{xy} are cooling degree days for month x and year y

EC^{xz} is the observed energy consumed for month x and year y

CDD^{xz} are cooling degree days for month x and base year z

Equation 5 is applied during those months where CDD is not zero. Equation 5 is applied to the gas consumed (TGC^{xy}) using HDD for the same baseline year. 2012 which is among the hottest years in Kansas history has been selected as the baseline year.

2.5.1 Transformed electricity consumption

Table 2.3 contains total transformed electricity values for the years studied. The cumulative impact of the energy upgrades is graphically depicted in Figure 2.6. The reduced amount of electricity use in years 2010 to 2012 demonstrates the effectiveness of hospital energy-efficiency projects, where reductions in electricity consumed are equal to 34% and 42% by Hospitals A and B, respectively.

2.5.2. Transformed gas consumption

Monthly gas consumption values are transformed using monthly HDD values. Transformed gas and the percent change in consumption since 2007 is provided in Table 2.4.

Unlike the results of electricity consumed, a cumulative reduction in gas consumption was not seen (see Figure 2.7). By 2012, both Hospitals A and B saw an increase in consumption over 2007 by 13% and 16%, respectively. However, it cannot be concluded that upgrades to the heating systems in Hospital A had no impact, since in years 2010 and 2011, the cumulative reduction in Hospitals A and B was 15% and 13%, respectively. Further investigation is needed to determine possible reasons for the increase.

2.6 Discussion and Conclusion

Hospitals are one of the large consumers of energy in the commercial sector (http://www.eia.gov/consumption/commercial/reports/2007/large-hospital.cfm, accessed 2015). Other than personnel, energy accounts for the greatest cost in the operation of a hospital. Thus, the reduction of energy is critical in the overall goal of reducing the cost of healthcare. Assessing and understanding energy consumption within a hospital for targeted solutions is difficult since facility managers typically have only monthly energy bills and a few energy meters for information. In this paper, a case study involving two major hospitals in Wichita, Kansas, illustrated a statistical approach for assessing and understanding different factors that account for energy use. The factors studied included hospital activity as measured by four variables, and ambient outdoor temperature measured by CDD and HDD. The best subset multiple linear regression was used to quantify the impact of inpatient census, the number of patients seen by the ER and outpatient services, the use of high-energy intensive services (imaging services), and outdoor temperature. Hospital utilization variables were not considered prior to this work.

The outcome from this work complements standard energy audits with new information that is important in developing a schedule for energy improvements. Since gas and electricity were shown to be largely tied to ambient outdoor temperature, the regression model coefficients may be employed for long-term energy planning. In light of climate change and global warming, such information is key to planning horizons over multiple decades (Christenson et al. 2006). The analysis also indicates that when compared to CDD and HDD, levels of hospital activity (the number of imaging services, inpatients, outpatients, and ER patients) accounted for relatively less variability in the consumption of electricity or gas. This explains why, when a wing of a hospital is closed for remodeling and HVAC continues to operate, the hospital energy consumption remains mostly unchanged. The results can be used to plan for changes in energy demand associated with changes in hospital services, such as an increase in electricity consumption for an expansion in imaging services.

A number of energy-efficiency upgrades were made to both Wichita hospitals HVAC systems during the years of this study. However, the analysis of observed direct monthly energy use has shown minor reductions in electricity and gas from 2007 and 2012. When corrected for CDD and HDD by year, electricity reductions were more substantial. The transformed values of electricity use yielded savings over the 2007 energy consumption of 34% to 42%. Similar savings were not found for gas consumption, thus highlighting a need for additional investigation.

Acknowledgements

The work presented in this paper is a part of a larger effort by Wichita State University faculty in healthcare sustainability. The goal of their work is to reduce the impact that healthcare has on the environmental while maintaining patient care quality.

The authors acknowledge support from the National Science Foundation No. EPS-0903806 and the state of Kansas. The authors also express their appreciation of assistance from hospital staff in obtaining data.

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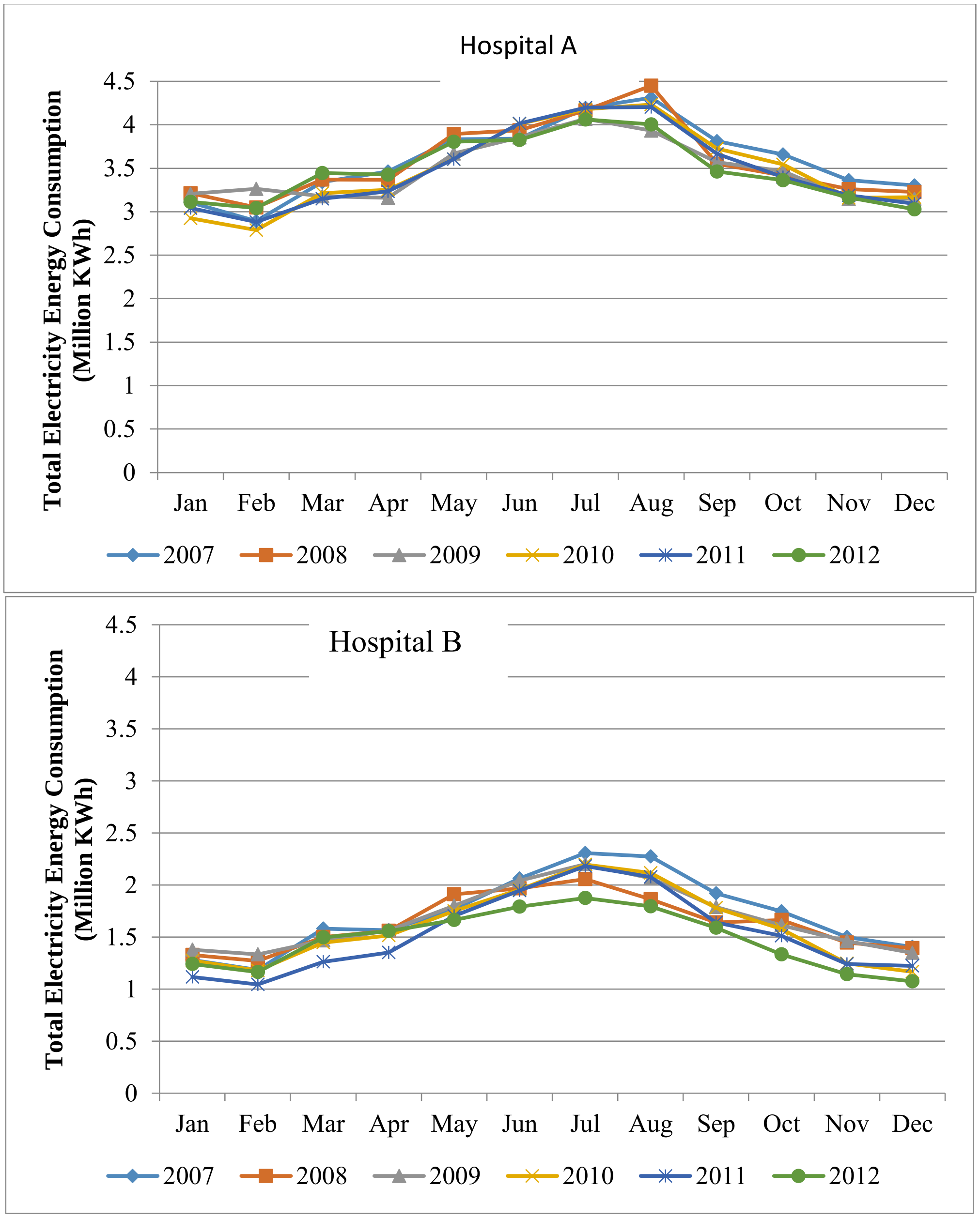


Figure 2.1. Monthly electricity consumption for Hospital A and Hospital B

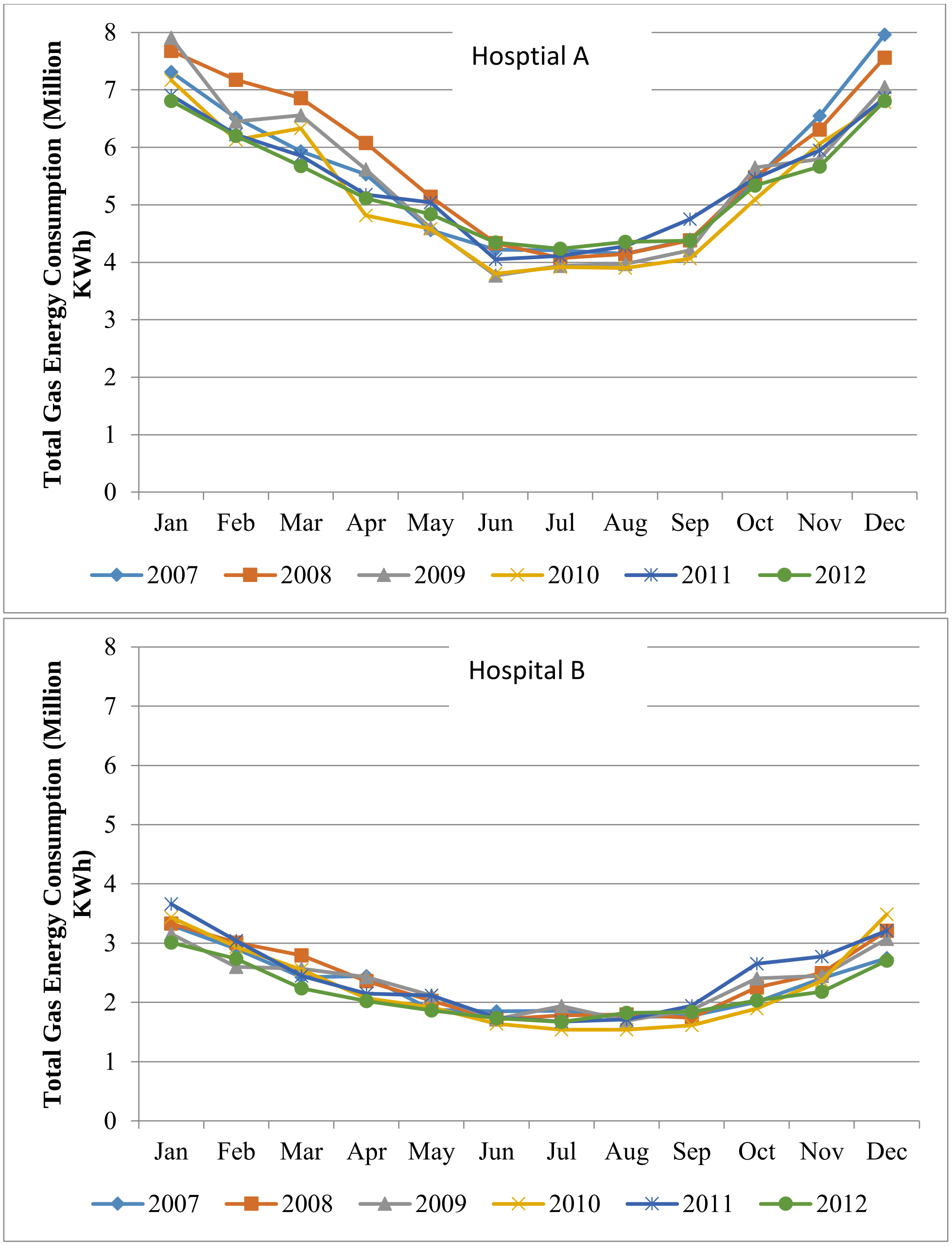


Figure 2.2. Monthly electricity consumption for Hospital A and Hospital B

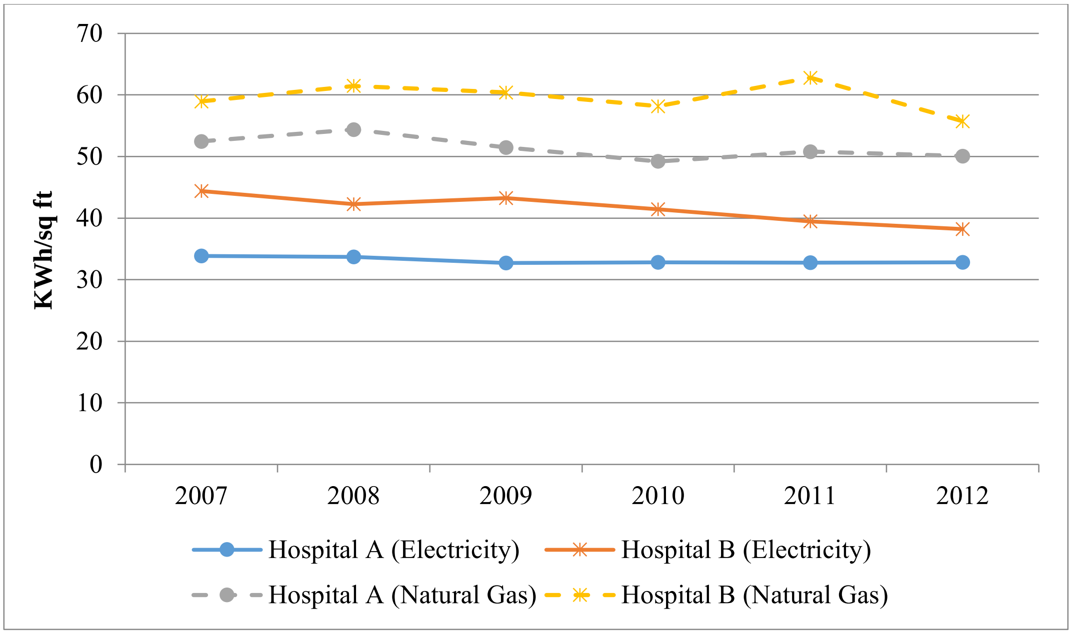
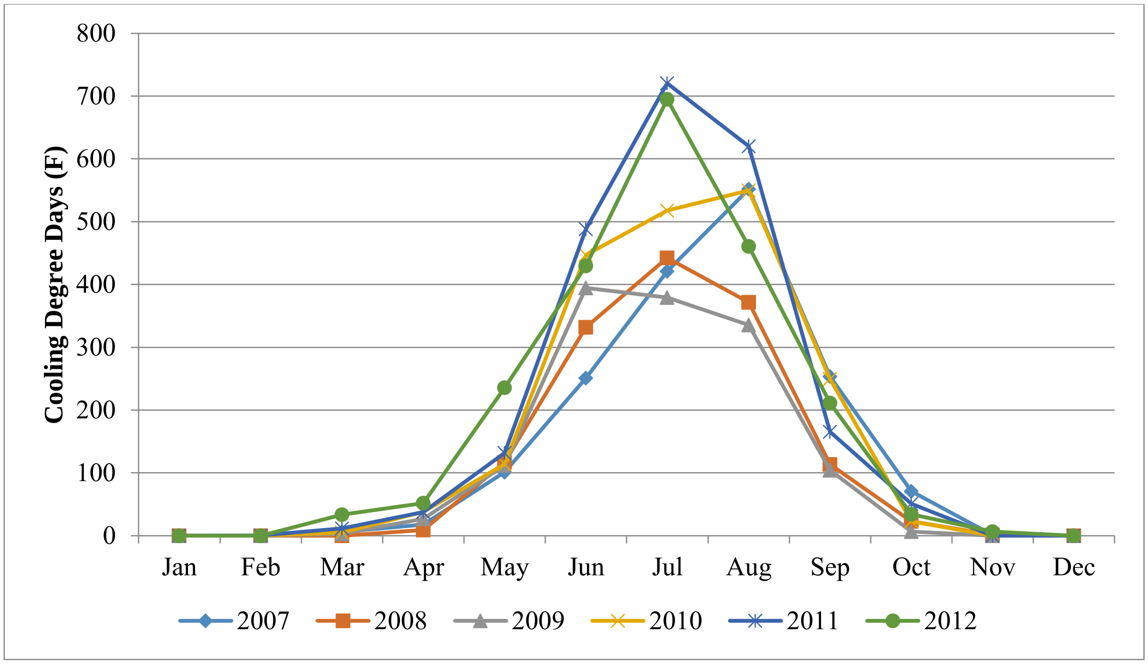


Figure 2.3. Annual gas and electricity intensity for Hospitals A and B



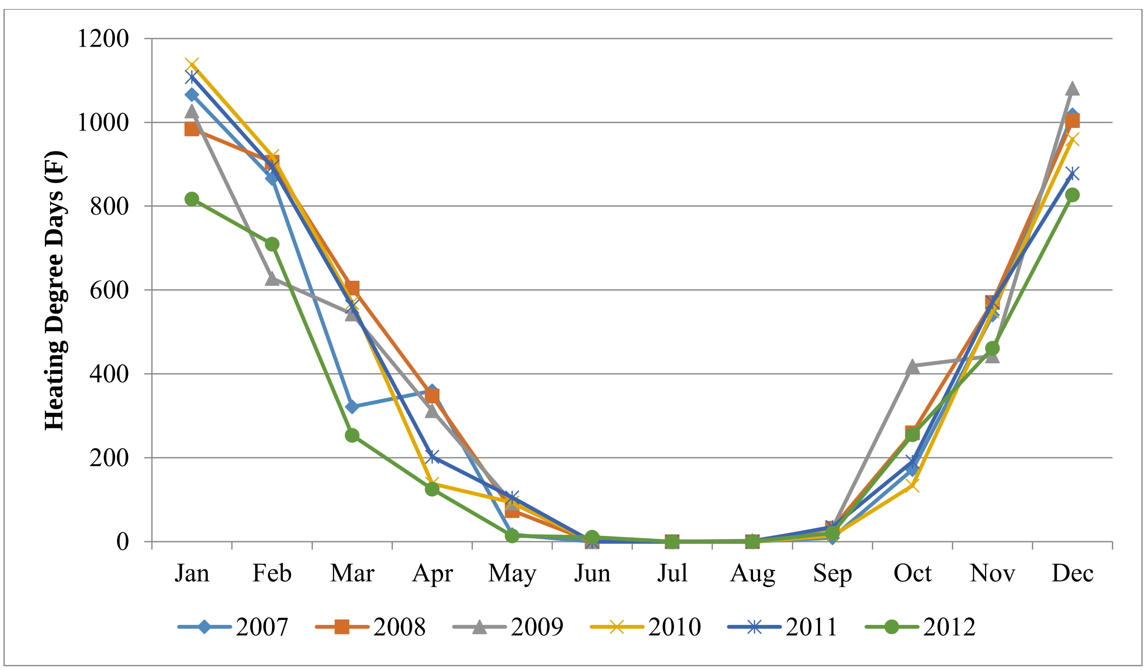


Figure 2.4. Monthly (a) CDD and (b) HDD, in Wichita from 2007 to 2012

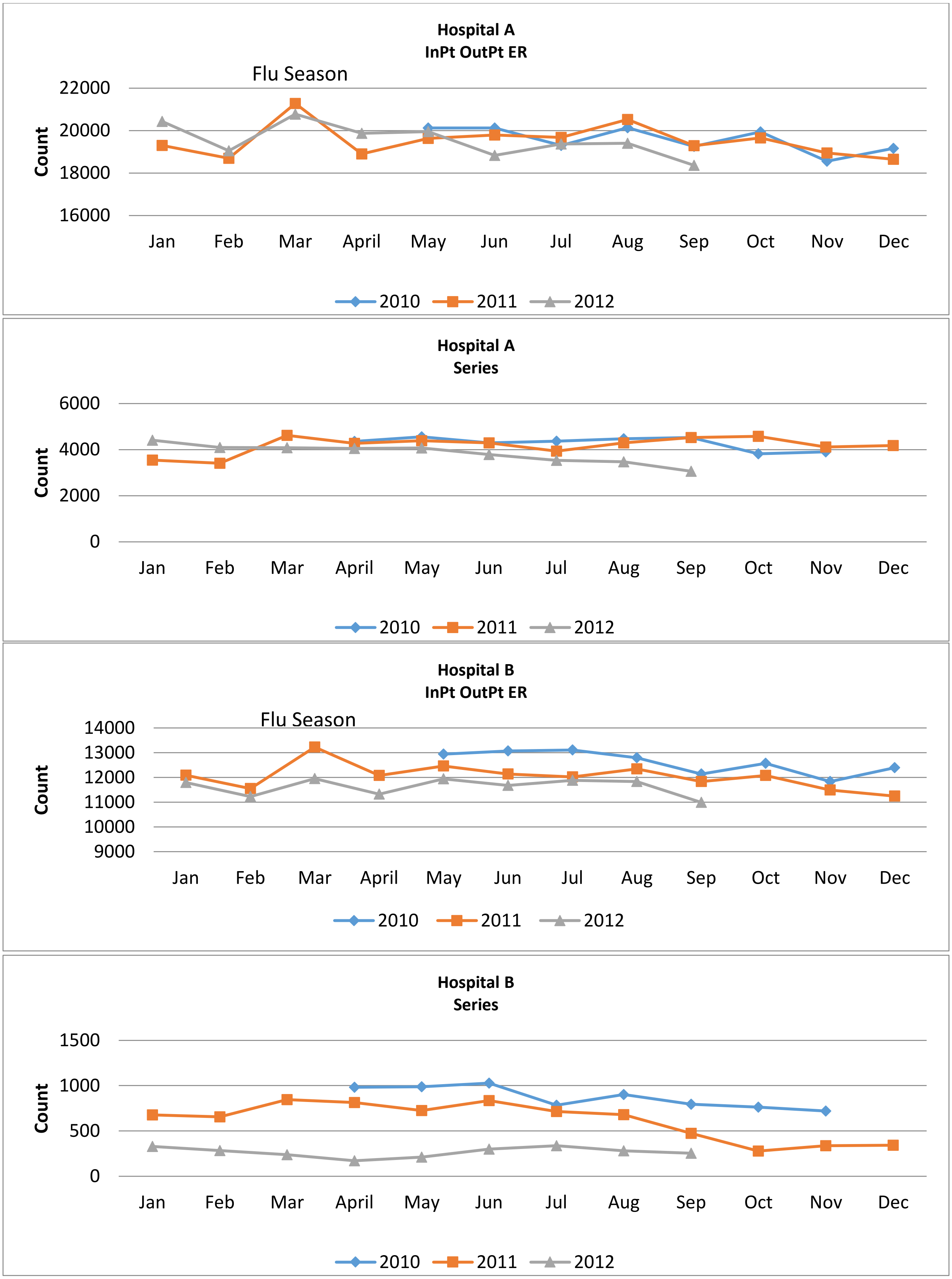


Figure 2.5. Hospitals monthly activity level

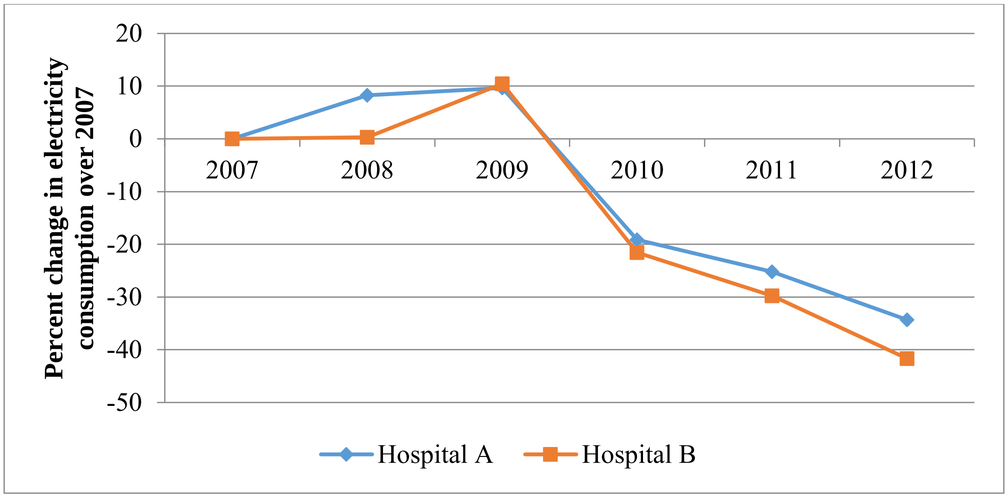


Figure 2.6. Annual percent change in total electricity energy consumption

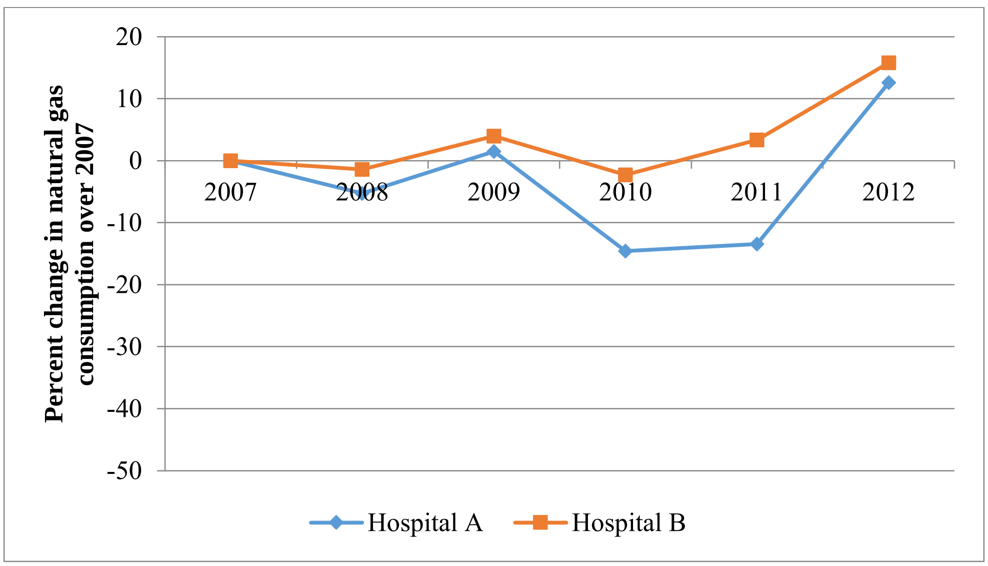


Figure 2.7. Annual percent change in total natural gas energy consumption

TABLE 2.1
RESULTS OF FULL MULTIPLE REGRESSION

	Hospital A Total Energy	Hospital A Electricity	Hospital A Gas	Hospital B Total Energy	Hospital B Electricity	Hospital B Gas
	R^2 =0.83	R^2=0.95	R^2=0.92	R^2=0.81	R^2=0.93	R^2=0.95
Intercept	* 5,595,763	1,743,708	3,852,055	~2,023,527	536,736	1,486,791
CDD	~ -633	*1288	*-1922	188	*911	*-723
HDD	*2,541	*-393	*2934	*1,709	*-663	*2,372
Series	-132	~143	-274	*-256	~145	*-401
OP	*1,471	28	~1,443	325	90	235
ER	-212	~264	-475	-140	85	-225
inpatient	170	-39	209	428	46	382

* indicates significant at $p<0.05$
~indicates significant at $p<0.10$

TABLE 2.2
RESULTS OF 'BEST SUBSET' MULTIPLE REGRESSION

	Hospital A Total Energy	Hospital A Electricity	Hospital A Gas	Hospital B Total Energy	Hospital B Electricity	Hospital B Gas
	R^2 =0.82	R^2=0.95	R^2=0.92	R^2=0.79	R^2=0.92	R^2=0.99
Intercept	5,794,545	1,692,683	2,858,688	1,573,906	1,370,244	
CDD	-615	1,298	-2,048		917	-733
HDD	2,846	-452	3,377	1,650	-712	2,471
Series		150	-342	-228	189	-441
OP	1,300		1,788	342		303
ER		213				
inpatient				344		424

TABLE 2.3
TRANSFORMED YEARLY TOTAL ELECTRICITY ENERGY CONSUMPTION IN HOSPITAL A AND HOSPITAL B

		2007	**2008**	**2009**	**2010**	**2011**	**2012**
Hospital A	KWh [a]	29,189,294	31,607,938	32,002,959	23,600,461	21,827,520	19,163,061
	% change [b]		8.3%	9.6%	-19.1%	-25.2%	-34.3%
Hospital B	KWh [a]	14,950,818	14,990,951	16,509,995	11,724,821	10,498,486	8,720,918
	% change [b]		0.3%	10.4%	-21.6%	-29.8%	-41.7%

[a] KWh of Electricity Energy Consumption (normalized by 2007)
[b] Percent change in Electricity Energy Consumption (2007 as the baseline year)

TABLE 2.4
TRANSFORMED YEARLY TOTAL GAS ENERGY CONSUMPTION TREND IN HOSPITAL A AND HOSPITAL B

Hospital		**2007**	**2008**	**2009**	**2010**	**2011**	**2012**
Hospital A	KWh a	27,668,072	26,205,316	28,078,955	23,633,857	23,945,124	31,160,524
	% change b		-5.3	1.5	-14.6	-13.5	12.6
Hospital B	KWh a	11,111,243	10,958,004	11,553,993	10,857,397	11,480,839	12,867,842
	% change b		-1.4	4.0	-2.3	3.3	15.8

[a] KWh of Gas Energy Consumption (normalized by 2012)
[b] Percent of decrease in Gas Energy Consumption (2007 as the baseline year)

CHAPTER 3

CONCLUSION AND FUTURE WORK

3.1 Conclusion

The research presented in this thesis is part of a larger effort by the Wichita State University faculty in healthcare sustainability. The goal of their work is to reduce the impacts that healthcare have on the environment while maintaining patient care quality. This study of two hospitals in Kansas has illustrated a statistical approach for assessing and understanding different factors that account for energy use. The outcomes indicate that ambient temperature is the most significate factor affecting energy consumption. This outcome is used as a means to linearly adjust energy consumption values based on weather variables to assess the effectiveness of energy efficiency programs performed in the hospitals over time.

3.2 Future Work

The aspect not considered in this proposal has been the potential tradeoff of electricity and gas energy consumption by 2050 due to projected Kansas climate conditions. Pertaining to a region such as Kansas, the climate change projections exhibit hotter summers versus less severe winters. This means the energy usage for cooling in summers is expected to increase while energy usage for heating in winters is expected to decrease. The climate change effects are non-linear because energy usage for heating versus cooling in hospitals is unequal. Hence, in future works, energy and cost trade-off analyses of increased summer cooling versus decreased winter heating over four decades ahead is attempted for the two major hospitals in Wichita, KS.

In addition, the area of research will be extended to include the impacts of climate variability on public health. Extreme heat has been a major weather-related factor leading to increased risks to public health. A service provided by most state health and environment departments is to forecast and post alerts impending extreme heat events. The long-term goal of this research will be to provide the Department of Health and Environment of Kansas with a system to forecast risk for illness due to extreme heat.

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REFERENCES

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