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Healthcare Facilities: Planning for Increasing Extreme Heat Events

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Abstract

Hospitals and healthcare buildings are energy intensive units due to the specific requirements to maintain patient comfort, meet standards for a bacteria and virus free environment, and deliver patient services. Besides being a cost factor for the hospitals, this energy use contributes to the amount of greenhouse gas emitted into the atmosphere and hence impacts public health. There are many factors that contribute to the amount of energy consumed in a healthcare facility. Energy consumed by HVAC is a significant factor, and is strongly related to outdoor temperature. The relationship between energy consumed and air temperature is difficult to quantify in light of the large number of building specific variables (type of insulation, number of MRI machines, etc.), energy efficiency projects, and the increased weather variability from climate change. With the current increase in prolonged heat events, it is important for a given healthcare facility to understand and plan for energy consumed in the coming decades.

In this paper the energy consumption of a major healthcare facility in Wichita, KS is examined to understand the relationship between energy use and ambient air temperature, energy efficiency programs, and extreme temperatures. The results are used to estimate consumption in the next 3 decades.

Keywords
Hospital energy consumption; Air temperature; Climate change; Weather variability; Healthcare sustainability

1. Introduction
Hospitals are significant consumers of energy. A large portion of that energy is used for heating ventilation and air conditioning (HVAC) systems in order to maintain a healthy indoor air quality through adequate ventilation with filtration and to provide thermal comfort [1]. The U.S. Energy Information Administration estimates that HVAC accounts for 21% to 44% of a hospital's total energy [2]. Other end uses include medical equipment, computers and lighting. Besides being extremely costly for hospitals, this energy use contributes to the amount of greenhouse gasses emitted into the atmosphere. Forecasting energy use and planning for energy efficiency projects are confounded by the number of impact variables and the small number of meters installed for monitoring. The picture has become even more complicated due to increasing variability in weather and the frequency of extreme temperatures. The Great Plains and Southwestern regions of the U.S. are predicted to experience the greatest increases in numbers and durations of heat waves [3]. Kansas a state in the Great Plains, in 2011 and 2012 experienced record high temperatures. In a forthcoming paper by the authors, outdoor temperature is shown to have

the greatest impact on energy consumption by HVAC in a hospital and therefore is the focus of the work presented here.

The goal of this paper is to understand how a hospital's energy consumption will change due to increased weather variability and extreme temperatures. The preliminary results of a case study of a large hospital in Wichita, Kansas is given to demonstrate how extreme temperatures impact the amount of electricity consumed during the summer months (May through September) of years 2007 through 2012. That information is then used to provide rough estimates of electricity consumed as the number of extreme heat events increases. This paper begins with the context and boundaries for the case study data collection.

2. Boundaries for Data Collection

Data on energy consumption came from a major healthcare provider in Wichita, Kansas. The healthcare provider has been serving Kansas and northern Oklahoma for over a century. The hospital is 1.27 million ft^2, has 400-staffed beds, employs 4457 people (2007), and is a Level 1 Trauma Center. The totals for monthly energy consumption over a six-year period (2007-2012) were obtained. The monthly ambient air temperatures were derived from average daily temperatures in Wichita over the same time period [4]. While this paper is limited to summer months (May through September), the entire years' worth of electricity use and temperature is given to demonstrate fluctuations by months. Figure 1 plots total monthly electricity consumption by year and Figure 2 provides a plot of outdoor average monthly temperatures for the period of study.

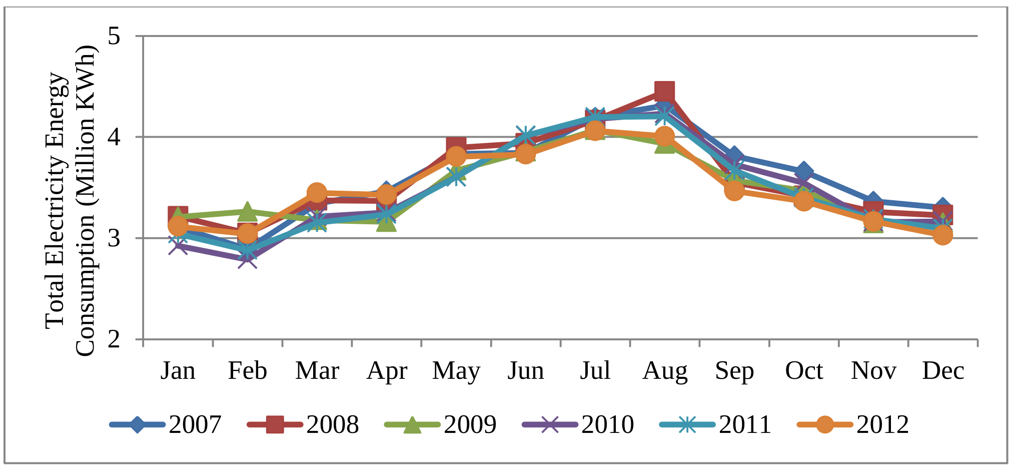

Figure 1: Monthly total electricity energy consumption by year

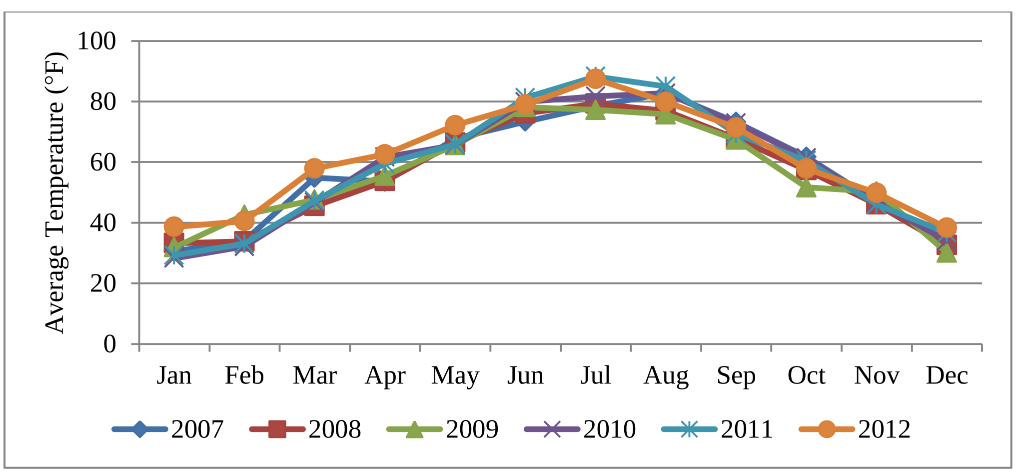

Figure 2: Wichita average monthly temperatures by year

When considering temperature in Figure 2, July exhibits the highest average temperatures (~ 90 °F) for years 2011 and 2012. Counter to the expected, electricity consumption for 2011 and 2012 does not follow the same trend. Successful energy improvement projects will be shown in the following sections to account for the divergence. Energy improvement projects while positive, adds to the complexity in meeting the goal to understand and project future energy consumption with increases in extreme heat events. The next section provides the methodology developed for this work to remove the effects of energy improvements.

3. Methodology

As indicated earlier, a large portion of a hospital's total energy consumption is attributed to HVAC and therefore variations in outside air temperature. According to HVAC professionals, the standard approach for evaluating energy consumed by HVAC is to use cooling degree days (CDD) in place of outdoor temperatures. CDD are used in the analysis that follows.

3.1 Cooling degree days and the relationship to electricity consumption

"The degree day method is one of the well-known and the simplest methods used in the heating, ventilation, and air-conditioning industry to estimate heating and cooling energy requirements" [5]. 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 outside temperature [6]. When used to calculate CDD the baseline temperature refers to the maximum outside temperature at which HVAC does not need to operate [7]. The value of the baseline temperature depends on several factors such as thermal characteristics of the building, internal and external heat gains [7]. This means that the baseline temperature should be measured for each building separately. This issue is not addressed in this paper. Instead the standard baseline temperature, 65°F is used to calculate the monthly CDD values based on daily average temperature obtained from [4]. Equation 1 is used to calculate the number of CDD in an *N*-day given period using the difference between θ_i , the average temperature in day *i* and θ_b , the baseline temperature.

$$CDD = \sum_{i=1}^{N} (\theta_i - \theta_b)_{>0} \tag{1}$$

where *N* is the number of days in each month. Figure 3 provides the cumulative CDDs versus months for the years studied. The figure depicts the relative difference between the hot summer months (2011, 2012) and the cooler summers of 2007-2010.

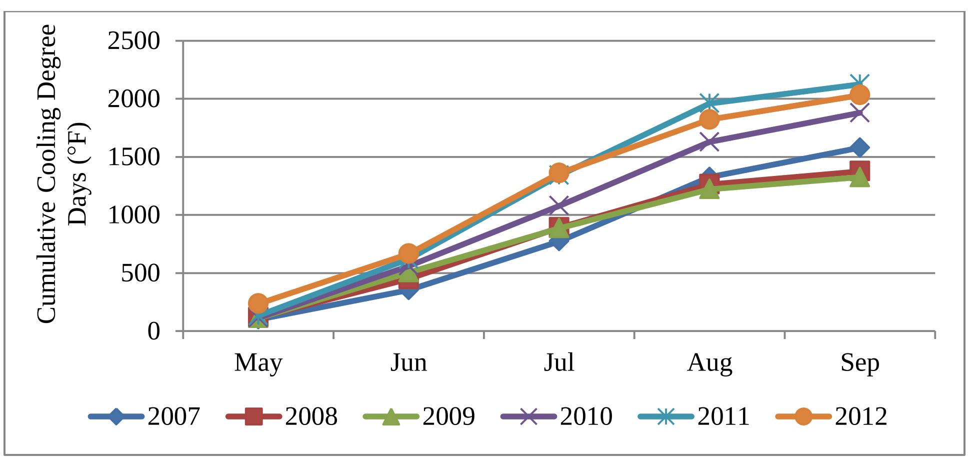

Figure 3: Cumulative summer monthly CDD for Wichita from 2007 to 2012

To gain insight into the relationship between monthly energy consumed and the number of cooling degree days the data are plotted in Figure 4. The relationship measured by $R^2 = 0.613$, is significant at a $p - value < 0.000$, however a greater R^2 (> 0.80) is preferred for projecting future energy use.

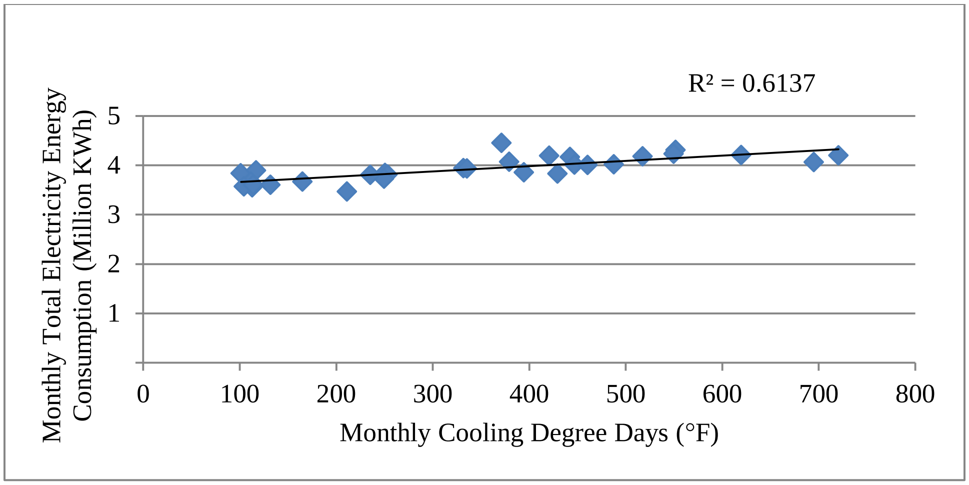

Figure 4: The relationship between monthly electricity energy consumption and CDDs during the summer months

In order to utilize CDD to estimate energy consumed in future decades, the data are aggregated to yearly values to be consistent with projections given by climate scientists. Total yearly energy use and total yearly CDD is shown in Figure 5. For aggregated data no relationship exists. This information supports previous statement regarding the success of the hospital's energy improvement program. The next section uses this information to remove the effects of improvement projects.

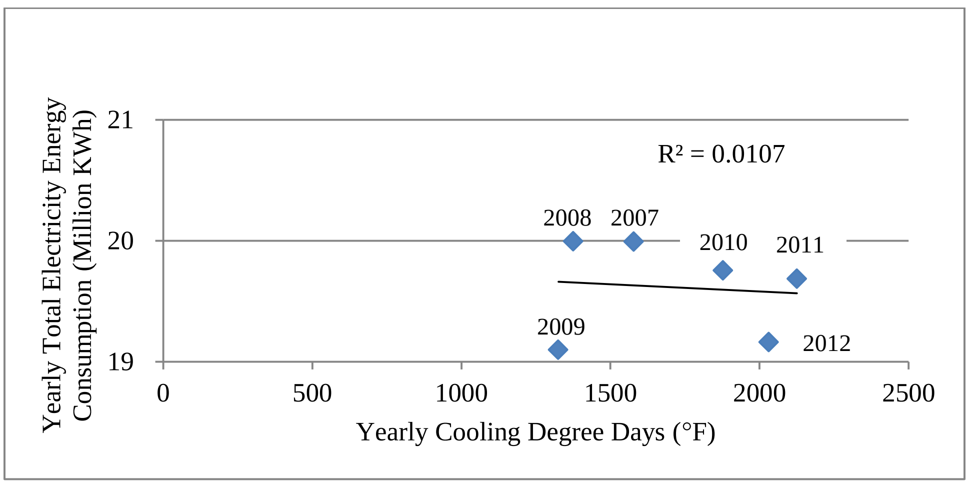

Figure 5: Relationship between yearly total electricity energy consumption and CDD

3.2 A method to assess energy efficiency programs within the hospital

The hospital's energy professionals in an effort to reduce its energy consumption invested in a number of projects targeting HVAC to reduce its energy use over the years studied. A method to assess the amount of improvement was developed and used in this work to project future energy use. The methodology is described here.

To assess the levels of energy improvement by year, monthly electricity consumption values were made comparable by applying a linear transform using the CDDs of the base year 2012. Percent improvement is then found using transformed values. Equation 2 gives the linear transformation.

$$EEC_n^{xy} = \left(CDD^{xy} . EEC_m^{xz}\right) \Big/ CDD^{xz} \tag{2}$$

where

EEC_n^{xy} is the transformed (normalized) value of electricity energy consumption for month x and year y,

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

EEC_m^{xz} is the actual (measured) value of electricity energy consumption in the month x of the baseline year z,

m is the indicator for the measured value

n is the indicator for transformed (normalized) value

Using z = 2012 as the year by which years 2007 through 2011 are transformed Equation (2) indicates that, if CDD in the month x of the year y were equal to month x of 2012, then the correction factor is 1. It is noteworthy that Equation (2) is not applicable when the CDD value month equals zero.

To demonstrate the value of annual improvements to reduce consumption, the total transformed energy of each year is compared to the total transformed energy of the baseline year. The results are given in Table 1. Overall there was a 34% reduction is energy consumed by HVAC. In 2008 and 2009 no reduction in energy use were seen (-8.3%, -9.6%). This cannot be interpreted as a failure for energy projects in those years. Most likely high energy consuming additions to operations (such as new installation of MRI machines) overwhelmed the effects of improvements made to HVAC. The relationship between transformed energy consumption and CDD is significant since $R^2 = 0.895$ was significant at $p-value < 0.000$ (Figure 6). The transformed data and regression results are used in Section 4 to estimate future consumption.

Table 1: Outcome of energy improvement projects

	2007	2008	2009	2010	2011	2012
Transformed Electric Energy (KWh) Consumption	29,189,294	31,607,939	32,002,958	23,600,462	21,827,521	19,163,061
Cumulative % improvement over year 2007		-8.3	-9.6	19.1	25.2	34.3

4. Energy Consumption Projections

In this section long-term energy consumption estimates are made based upon the climate change work of two University of Kansas climate scientists [8]. Projections for average yearly CDD by decade in south central Kansas (location of Wichita) were used here. To estimate long-term energy consumption, the relationship between the hospital's transformed yearly energy use and CDD was found using linear regression ($R^2 = 0.895$, $p-value < 0.000$). The relationship is given by Equation 3.

$$\text{Transformed energy consumed } (\text{KWh}) = 12{,}161.94 * CDD - 1{,}148{,}685.33 \quad (3)$$

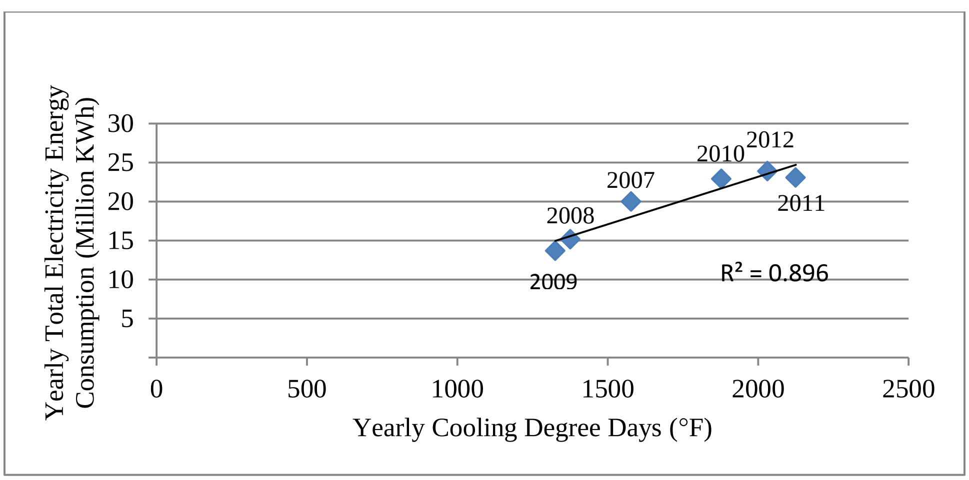

Figure 6: Relationship between yearly CDD and energy use transformed by energy improvements

Yearly energy estimates for decades 2010 through 2040 are made by climate model projections of CDD and extending Equation 3. The projections are shown in Figure 7.

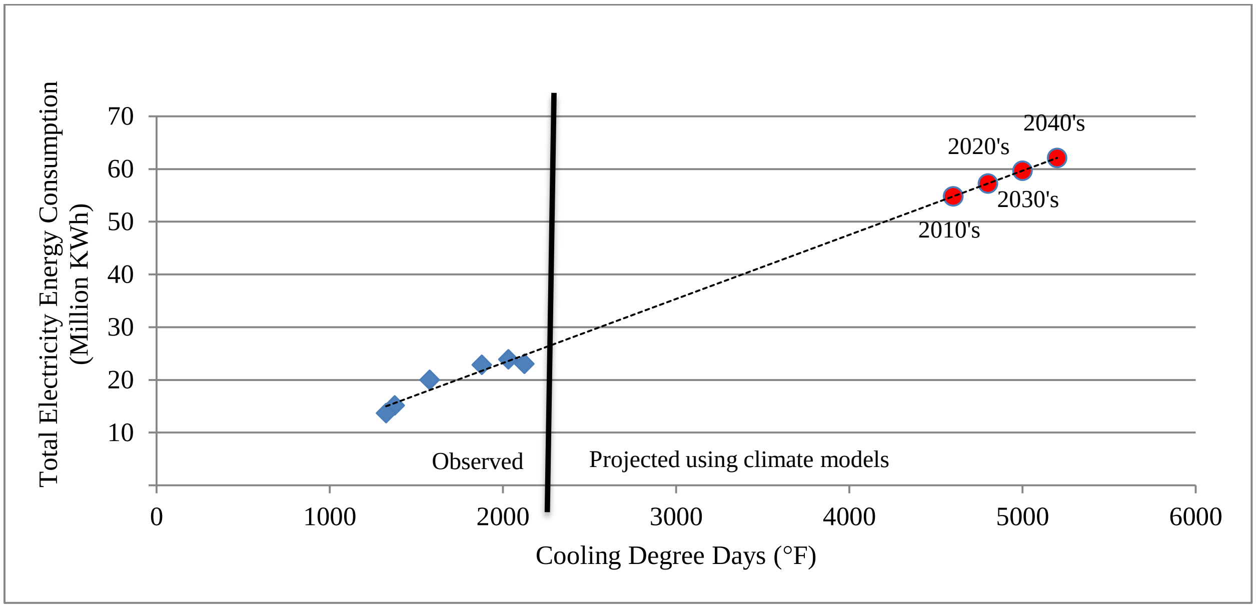

Figure 7: Projected yearly electricity energy consumption for 2010 through 2040

The average number of CDD using observed data in 2010, 2011, and 2012 is approximately 2200 days. By the end of this decade (2010's) the projected average number of CDD will double, 4200 days (~ 3 times the CDD is the base year of 2007). Estimated energy consumption for the 2010's will therefore be approximately 2 times the amount (55 Million KWh) consumed in 2007 (20 Million KWh). With these estimates the hospital will have to achieve greater efficiencies (200% reductions) to maintain 2012 energy consumed.

5. Conclusion

This paper reports a preliminary analysis of a hospital's electricity consumption, where the goal is to understand and predict energy consumption under increasingly variable weather and major heat events. Data on electricity consumption was obtained for a major healthcare facility located in Wichita, KS. Other work conducted by the authors found that HVAC was a major consumer of energy and that HVAC was sensitive to outdoor temperatures. The study was limited to the summers of 2007 through 2012; where 2011 and 2012 were reportedly among the hottest summers in Kansas. A transformation of electricity use was developed so that the relationship between energy consumed and outdoor temperatures could be determined and used to forecast energy consumed over the next four decades. The transformation removed the effects of the hospitals energy improvement projects. CDD projections by decade reported by Kansas climate scientists were used to forecast future energy consumption. The outcome of the analysis projects the hospital's energy consumption to double in the next decades using 2007 as a reference year.

The forecasts in energy use over the next 3 decades are based on climate models. The amount of error at the local level (south central Kansas) and over short time spans is most likely large. The next step will be to estimate the error associate with projected energy use.

This study is part of a larger body of work in the area of energy use and healthcare by the authors. The quantification of energy consumed corresponding to the 13 major processes with in a hospital is a goal.

Acknowledgements

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