A Longitudinal Study of the

Post-Occupancy Energy Performance of

K-12 School Buildings in Arizona

by

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ABSTRACT

Energy performance and efficiency plays of major role in the operations of K-12 schools, as it is a significant expense and a source of budgetary pressure upon schools. Energy performance is tied to the physical infrastructure of schools, as well as the operational and behavioral patterns they accommodate. Little documentation exists within the existing literature on the measured post-occupancy performance of schools once they have begun measuring and tracking their energy performance. Further, little is known about the patterns of change over time in regard to energy performance and whether there is differentiation in these patterns between school districts.

This paper examines the annual Energy Use Intensity (EUI) of 28 different K-12 schools within the Phoenix Metropolitan Region of Arizona over the span of five years and presents an analysis of changes in energy performance resulting from the measurement of energy use in K-12 schools. This paper also analyzes the patterns of change in energy use over time and provides a comparison of these patterns by school district.

An analysis of the energy performance data for the selected schools revealed a significant positive impact on the ability for schools to improve their energy performance through ongoing performance measurement. However, while schools tend to be able to make energy improvements through the implementation of energy measurement and performance tracking, deviation may exist in their ability to maintain ongoing energy performance over time. The results suggest that implementation of ongoing measurement is likely to produce positive impacts on the energy performance of schools, however further research is recommended to enhance and refine these results.

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CHAPTER 1

INTRODUCTION

With an estimated national total of $7.5 billion being spent annually, energy expenditures are second only to salary and benefit expenses as the highest operating expense of K-12 school districts within the United States and have become a source of increasing budgetary pressure (Energy Star, 2006). Energy costs are one of the few expenses that can be decreased without adversely impacting the level of instruction that students receive, while also creating environmental and social benefits (Energy Efficiency Programs in K-12 Schools, 2011; Energy Star, 2006). Several studies have identified a divergence, frequently referred to as the Energy Efficiency Gap (EEG), between the ideal and actual implementation of energy efficiency measures that is pervasive across several sectors (Jafarzadeh & Bouwer Utne, 2014; Thollander & Palm, 2013; Jaffe & Stavins, 1994; Blumstein, Krieg, Schipper & York, 1980; Fleiter, Worrell & Eichhammer, 2011; Chai & Yeo, 2012). Conner suggests the existence of four market barriers to delivering energy efficiency: awareness, availability, accessibility and affordability (2009). For K-12 schools, many energy efficiency barriers may exist including a lack of expertise, funding and governmental support (Energy Efficiency Programs in K-12 Schools, 2011). Research on energy and facility management practices in K-12 schools is a key factor in evaluating the impact of measurement upon the energy performance of schools over time and the patterns of change over time.

The implementation of energy efficiency measures within schools is directly impacted by the operations and maintenance program that is implemented (which can be at a district-wide or school-wide scale) and by overall facility management practices

(U.S. Department of Energy, 2009). According to an Arizona school district employee, many schools struggle to develop a proactive approach to facility maintenance and operations. This reactive approach is largely characterized by allowing building systems to run until failure (Swanson, 2001). Evidence of social inequalities within the facility management practices and the resulting condition of school buildings within the U.S. has been a subject of increased concern over the past two decades, frequently resulting in litigation (Kowalski, 1995; Alexander & Lewis, 2014; Kozol, 1991; Lewis, Snow, Farris, Smerdon, Cronen, & Kaplan, 2000; Filardo, Vincent, Sung & Stein, 2006). A 2008 assessment estimated that the total national school infrastructure need was approximately $252.6 billion and at the state level the average funding need was $5.2 billion (Crampton & Thompson, 2008). With building systems within school facilities reaching the end of their expected or anticipated useful life and the increasing need for upgrades or complete replacements, significant opportunities exist in terms of planning and cost effectiveness to optimize the energy performance of school facilities through alignment of energy efficiency opportunities with system upgrades (Laustsen, 2008).

While extensive research has been conducted around methods for the measurement and simulation of energy performance in schools, and governmental agencies have made sizable efforts to address challenges schools face in making improvements to their facilities, little research currently exists regarding the measured post-occupancy performance of schools once they have begun measuring and tracking their energy performance. Further, little is known about the patterns of change over time in regard to energy performance and whether there is deviation in these patterns between school districts.

High energy performance and energy efficiency has been identified to provide many positive impacts such as “significant energy cost savings” and “environmental, economic, and educational benefits” (Energy Efficiency Programs in K-12 Schools, 2011). This study will serve to enhance the knowledge base relating to the longitudinal, measured energy performance of K-12 school facilities from which further study of the energy performance of K-12 schools can be performed. Facility managers are encouraged to embrace their role in the relationship between facility management practices and energy performance within schools in order to promote high performing schools while reducing energy consumption, expenditures and environmental impacts.

The purpose of this paper is to provide an analysis of the energy performance of twenty-eight schools within the Phoenix Metropolitan Region of Arizona over the span of five years as a means of identifying whether ongoing measurement and performance benchmarking in K-12 schools promotes change in energy performance over time. It further seeks to identify what the pattern of change in energy performance is over time and to compare the patterns of change by school district. Funding and budgetary information was unavailable to the author and has been omitted from this study.

CHAPTER 2

LITERATURE REVIEW

Energy Star defines the energy management process as a seven step cycle. The steps progress as follows: (1) make commitment, (2) assess performance, (3) set goals, (4) create action plan, (5) implement action plan, (6) evaluate progress and (7) recognize achievements (Energy Star, 2013a). The U.S. Green Building Council's (USGBC) Center for Green Schools defines the energy management process for schools as the following five step program: (1) create a team, (2) gather information and identify priorities, (3) create momentum, (4) celebrate success and (5) provide recognition and initiate special projects (Crosby & Baldwin Metzger, 2013). The International Organization for Standardization (ISO) standard for Energy Management is known as ISO 50001. This standard is based on a continual Plan-Do-Check-Act improvement model similar to models used in the development of other ISO standards (About ISO 50001 and DOE, n.d.; ISO 50001 - Energy management, n.d.). The ISO 50001 requirements for energy management include: policy development for energy efficiency, fix targets and objectives to meet the policy, use data for decision making about energy use, to measure results, to review the policy and to continually improve energy management (ISO 50001 - Energy management, n.d.).

Energy use is not visible and is often not very well understood by its users. This makes measurement and feedback critical in improving energy efficiency (Darby, 2006). Monitoring the energy use of buildings is an important step in understanding the energy performance of a building and creates the foundation upon which decisions regarding energy efficiency improvements can be formed (Wang, Yan, & Xiao, 2012; Energy Star, 2013a). Energy Star states that in order to identify energy efficiency and improvement opportunities, users should assess what their current use is through a comparison of past to current performance, and the change in energy performance over a specified period of time by benchmarking against the energy performance of a peer data set (Energy Star, 2013b). While there are varying approaches for the measurement of energy use, the precision and quantification of a performance-based approach is often preferable (Darby, 2006). As well as serving as an indicator, the quantification of energy performance also enhances the user's ability to effectively plan and communicate energy efficiency improvements (Energy Star, 2013a; Crosby, & Baldwin Metzger, 2013). Further, research has found that the establishment and ongoing tracking of quantifiable, performance-based measurements creates transparency, improves communications and helps create justifiable business cases from which accurate and effective budget planning can be built from (Willoughby & Melkers, 2005). Many state budgets have established links between performance reporting and financial decision-making (Melitski, & Manoharan, 2014).

Once energy efficiency measures have been identified and documented, a project scope and budget can be created and prioritized (Energy Star, 2013a). Studies from various sectors have found that during the prioritization of project opportunities, it is important not only to understand where the biggest opportunities for improvement are but also to create an approach that allows for the alignment of the funding mechanisms needed to implement energy efficiency measures (North Carolina Department of Transportation, 2015; Brenner, 1994). In practice, the alignment of energy planning and funding mechanisms is often a barrier in the implementation of energy efficiency measures, especially within the public sector due to funding mechanisms dependent primarily upon public funding and state legislation (Energy Efficiency Programs in K-12 Schools, 2011). The perceived value of facilities related expenditures are often misunderstood due to relatively high capital needs and other ongoing expenses (Kok, Mobach, & Omta, 2011). Operational and capital funding are fundamental barriers in performing the work necessary to improve or replace building systems within schools (Filardo et al., 2006, Lewis et al, 2000). Utilities costs have become an increasing concern in Arizona since Proposition 301 cut funding to the Excess Utilities provision in 2009 (Wiggall, 2004). An Arizona school district employee reported that, lean operations and maintenance budgets within K-12 schools in Arizona have put increasing pressure upon facilities budgets and have made the need for capital funding essential to successfully implement energy efficiency measures.

Most energy efficiency programs, until recently, focused on energy efficiency measures such as: rebates, energy audits, building system replacements and upgrades (Todd, Stuart, & Goldman, 2012; Frankel, Heck, & Tai, 2013). Behavior-based energy efficiency measures have started to become more and more popular within energy efficiency programs as budgetary demands have created the need to incorporate all cost-effective energy efficiency measures into energy efficiency programs (Todd, Stuart, & Goldman, 2012). Crosby and Baldwin define behavior-based energy efficiency measures as having a “focus is on raising awareness among faculty, staff and students about energy-saving opportunities” (2013). Case studies of behavior-based energy efficiency measures implemented in K-12 schools have shown that these types of strategies provide high value for relatively low monetary investment (Crosby, & Baldwin Metzger, 2013).

Further, behavioral scientists have found links between energy conservation behaviors and normative information. A study done by Nolan, Schultz, Cialdini, Goldstein and Griskevicius, found that when door hangers with energy conservation messages were left, the normative message of joining neighbors in energy conservation had a greater effect on actual energy conservation than other messages such as, saving money, protecting the environment and protecting the environment for future generations (2008).

CHAPTER 3

METHODOLOGY

Sample

Annual energy consumption data was collected from 28 different K-12 schools, throughout the Phoenix Metropolitan Region of Arizona. This data was collected over a five year period from 2009 to 2013. The sample for the study contained both elementary and secondary schools. These schools range in size from 49,460 Gross Square Feet (GSF) to 124,840 GSF. Schools were selected for this study based on the requirements that they had maintained energy performance measurement throughout this five year period and were public schools.

Instrument

The data collection instrument utilized for this research was the Energy Star Portfolio Manager, which was used to collect data such as building type, building size, number of computers used by the schools, number of walk-in refrigerators, weekend building use, energy use from cooking, classification of school as high school if applicable, location (which is further used to identify weather and climate information) and the percentage of the building that is heated or cooled. Energy Star is a voluntary program run by the United States Environmental Protection Agency (EPA) in partnership with the Department of Energy (DOE) and various industry entities. The Energy Star Portfolio Manager is a free, online energy measurement and benchmarking tool produced by Energy Star as a means of measuring and tracking ongoing energy use (the tool is also capable of measuring and tracking water use and greenhouse gas emissions).

The Energy Star Portfolio Manager is developed around objectives for energy performance ratings established by the EPA, which require that the tool meet the following criteria: the ability to evaluate energy performance for an entire building, reflect actual billed energy data, normalize for operation and provide a peer group comparison (Energy Star, 2014). As part of these requirements, the tool primarily relies on a statistically robust data set gathered by the U.S. DOE through the Commercial Building Energy Consumption Survey (CBECS). Although the intention of the DOE is to update this data every four years, as of the date of this study, benchmarks are still based on data updated in 2003. The Energy Star Portfolio Manager allows users to input energy consumption data from monthly energy bills into the tool, which then converts all energy sources into thousand British thermal units (kBtu). The tool also distinguishes between source and site energy to account not only for energy consumed on site but also energy consumption and loss that occurs during generation and transmission of energy to give an equal comparison of various energy types (ex. Electric grid, Steam, Solar). Once the total consumption is determined for both site and source energy use, this measurement is divided by the square footage of the building to calculate a common metric upon which energy performance can be determined. This common metric is referred to as energy use intensity (EUI) (Energy Star, 2014).

Procedure for Data Collection

All data was collected through a voluntary benchmarking campaign through the Building Owners and Managers Association's (BOMA) Kilowatt Krackdown program which challenges owners and managers of different types of buildings to reduce energy use over time. Building owners and managers voluntarily input their information into

Energy Star Portfolio Manager and track their progress over time (GBC Kilowatt Krackdown. n.d.). Educational support on the use of the Energy Star Portfolio Manager was developed and provided by an industry expert and is available on-demand through the BOMA Greater Phoenix website. Data collection was conducted and is maintained by the local BOMA Greater Phoenix chapter. The energy performance data collected for K-12 schools was then delivered to the researcher.

Due to the voluntary nature of the data collection, data analysis was conducted upon the source (energy consumption including factors that account for loss during the transmission and distribution of energy) EUI for each building rather than the calculated Energy Star Score. Although specific information about the characteristics used to develop the Energy Star Score for each school was unavailable to the researcher, it was assumed that an evaluation of the Source EUI provided a more accurate representation of energy performance than that of the Energy Star Score (due to the potential for data entry error while entering these characteristics). A lapse in data collection occurred from 2011 to 2012. For the purposes of this study the values from 2011 to 2012 were assumed to be unchanged from the 2010 to 2011 values (see Figure 1).

CHAPTER 4

RESULTS

The energy performance data from the 28 schools selected, were analyzed from the following perspectives:

- The change in the measured source EUI by year for all 28 schools.
- The change in the measured source EUI and the percent change over 5 years for all 28 schools.
- A cross-sectional analysis comparing the mean energy performance across School District A and School District B

The K-12 school energy performance data selected for this study met the following requirements:

1. Energy performance data must be available for 5 year time period
2. School must categorize as a public school
3. Schools must be located within the Greater Phoenix Metropolitan Region of Arizona

From the K-12 school data submitted and received, 28 buildings from 2 school districts totaling 2,336,942 Gross Square Feet (GSF) were identified for this research. The average GSF of all the buildings was 83,462. The performance data for these buildings ranged from 2009 to 2013. All data that could be used to identify research participants has been excluded for the purposes of this study. The majority (82%), of the sample buildings were from School District A and the minority (18%), were from District B (see Table 1).

Table 1 - Sample Characteristics

District	n	Percent
A	23	82%
B	5	18%

The analysis of the longitudinal outcomes of energy performance was conducted with 2009 as the start of schools measuring and tracking energy consumption and performance through the Energy Star Portfolio Manager tool. From 2009 to 2010, one school (from District A) did not see any change through energy consumption and performance measurement. Between these years, 22 (78%) of the 28 schools within the sample population saw a decrease in source EUI. Of the schools with a decrease in EUI, 17 were from District A (74% of the District A sample population) and 5 of these were from District B (100% of the District B sample population). The remaining 5 schools from District A (22% of the District A sample population) saw an increase in source EUI.

From 2010 to 2011, all schools saw changes in EUI measurements, with 23 schools (82%) of the 28 schools having decreased EUI measurements. Of the 23 schools, 19 (83% of the District A sample population) were from District A and 4 (80% of the District B sample population) were from District B. The count of schools with an increased EUI remained the same from 2009 to 2010 (5 schools), however none of the 5 schools with an increased EUI measurement from 2010 to 2011 were schools that had an increase in EUI in the previous year. Of the schools with increased EUI measurements from 2010 to 2011, 4 (17% of the District A sample population) schools were from District A and 1 (20% of the District B sample population) of the schools was from District B.

Upon resuming data collection from 2012 to 2013 (after the lapse in data collection from 2011 to 2012), one school (from District A) did not see a change in EUI measurements from the measured value collected from 2010 to 2011. From 2012 to 2013, 18 schools (64%) of the 28 schools had a decreased EUI measurement and 9 (32%) schools saw increased EUI measurements from the 2010 to 2011 values. Of the 18 schools that had a decrease in EUI, 17 schools (74% of the District A sample population) were from District A and 1 school (20% of the District B sample population) was from District B.

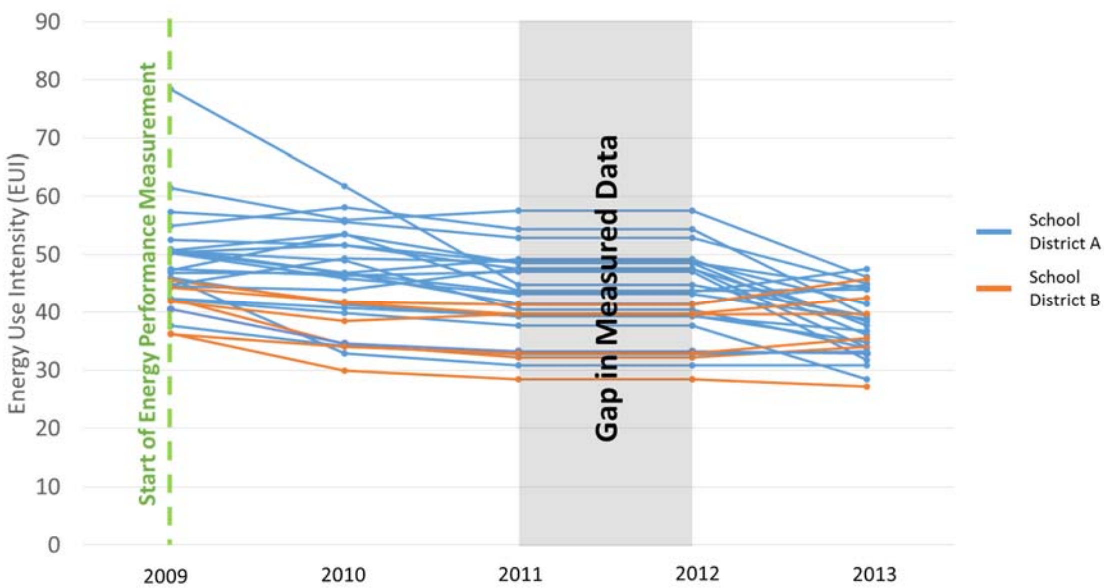

Figure 1 - Energy Use Intensity (EU) for All Schools (2009 – 2013)

The data for the 28 schools had an overall average source EUI of 47.9 kBtu/GSF in 2009 and 38.0 kBtu/GSF in 2013. This was an average decrease in EUI of -9.9 kBtu/GSF (see Figure 2). From 2009 to 2013, 26 of the 28 schools (93%) saw improvement, while 2 of the 28 schools (7%) had an increased EUI. Of the schools that saw improvement, 13 schools (50%) were above the average decrease in EUI of -9.9

kBtu/GSF. School number 24 had a markedly high change in EUI with a decrease of -39 kBtu/GSF (see Figure 2).

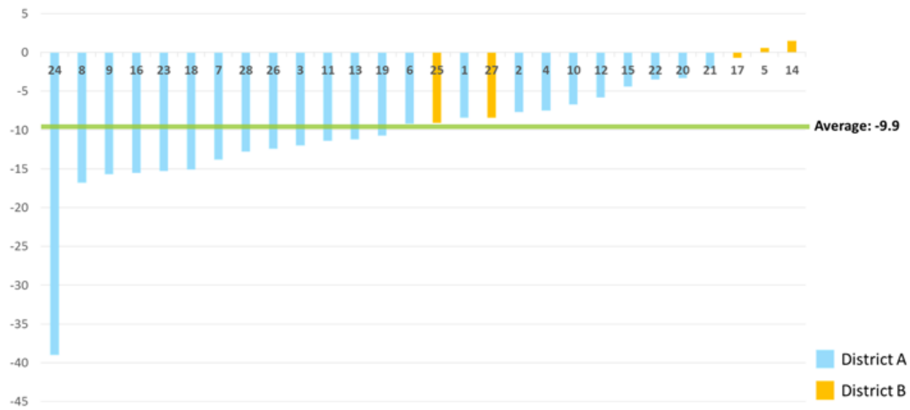

Figure 2- Change in EUI Over 5 Years (2009-2013)

The data for the 28 schools had an overall average percent change toward improvement in source EUI of 20%. Of the 28 schools 12 (43%) underperformed the average in their percent change and 16 (57%) performed equal to or above the average (see Table 2). Of the 26 schools that saw improvement from 2009 to 2013, there was an average percent improvement of 21%, while the 2 schools with an increased EUI had an average percent increase of 2%. School number 24 had a percent improvement significantly higher than other schools at 50% improvement from 2009 to 2013.

Table 2 - Performance vs. Average Percent Change

Below Average	**Above or Equal to Average**
12	**16**
43%	**57%**

When the percent change in source EUI over the 5 years was categorized by each school’s respective school district, District A had an average percent improvement of

22%. Of the 23 schools in the District A, 13 schools saw a percent improvement above the average percent improvement in EUI of 22%, with an average improvement of 29%. District B had an average percent improvement of 8%. Of the 3 schools in the District A that saw improvement from 2009 to 2013, the average percent change in EUI was 16% improvement. Of the 2 schools who had an increase in EUI, the average percent change was 2%. 2 of the 3 schools that had a percent improvement, saw a percent improvement above the average percent improvement in EUI of 16%, with an average improvement of 22%.

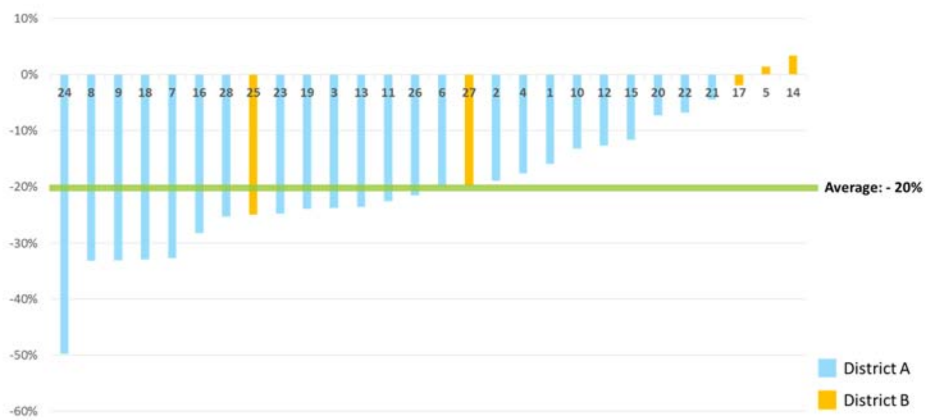

Figure 3- Percent Change in EUI Over 5 Years (2009-2013)

When a cross section of the source EUI over the 5 years for the schools was taken by school district, District A had an average source EUI of 49.6 kBtu/GSF in 2009 and 38.2 kBtu/GSF in 2013 and an average EUI improvement of 11.4 kBtu/GSF. From 2009 to 2013, 23 of the 23 schools (100%) in the District A saw improvement and 3 of the 5 schools (60%) in the District B saw improvement, while 2 of the 5 schools (40%) had an increased EUI. The average change in EUI for District A from 2009 to 2013 has a negative, linear pattern, while the average change in EUI for District B has an upward-facing, u-shaped pattern (see Figure 4).

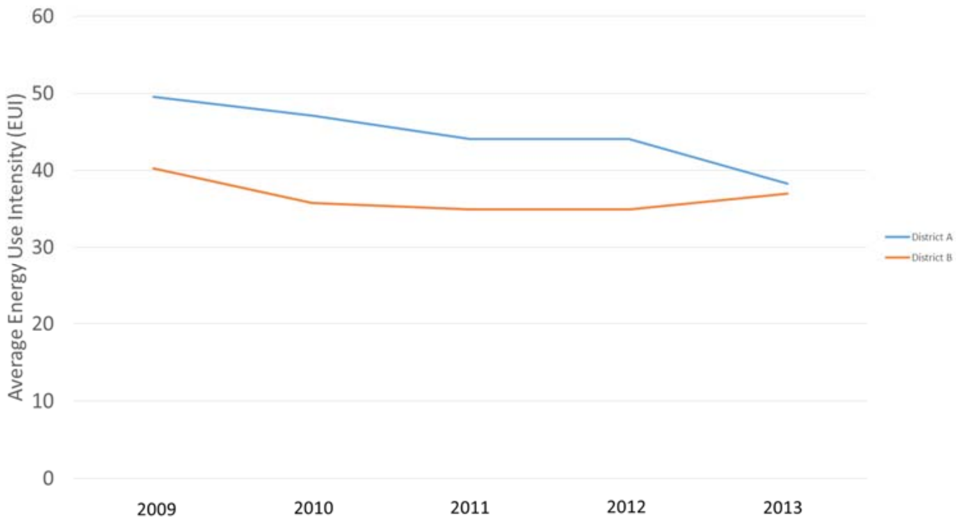

Figure 4 - Average Energy Use Intensity (EUI) Over 5 Years

CHAPTER 5

DISCUSSION & FURTHER RECOMMENDATIONS

Energy performance and efficiency play major roles in the operations of K-12 schools in Arizona, as it is a significant expense and a source of budgetary pressure upon schools. Energy performance is tied to the physical infrastructure of schools, as well as the operational and behavioral patterns, which they accommodate. The goal of this paper was to provide a longitudinal study of the measured energy performance of K-12 schools in the Phoenix Metropolitan Region of Arizona, as well as to provide a foundation upon which further understanding and development of energy performance for schools can be built.

The study documented that overall, ongoing measurement of energy performance had a positive impact on energy performance. Prior to this study, there was little documentation available regarding the impact of ongoing measurement on measured energy performance. This study documented that overall, most schools were able to improve energy performance over time, however it should be noted that a significant portion of schools underperformed the overall average of percent improvement from 2009 to 2013. A notable and unintended shift in the pattern of average EUI of District B following a lapse in data collection between 2011 and 2012 was identified, shifting from a negative, linear pattern to an positive, linear pattern, resulting in a u-shaped patterns that differed from the negative, linear pattern of District A's average EUI. This deviation in the pattern of the average EUI between school districts, seems to signify that organizational and management differences may impact how effectively schools are able to maintain ongoing energy performance over time.

Based on the results of this research, the following subjects are areas are recommended for future research:

- Determine whether a relationship exists between budgetary decision making and energy performance in schools.
- Determine whether a relationship exists between the energy management structure of school districts and energy performance.
- Determine whether geo-spatial relationships exist in connection to the energy performance of schools.
- Studies on the impact of education and expertise upon the ability of K-12 schools facilities departments to effectively manage energy.
- Studies upon the impacts of energy performance upon schools including:
    - Building occupants
    - Cost
    - Quality of education
- Determine the impact of behavioral-based energy improvements upon including:
    - Energy performance
    - Energy program cost
    - Building occupants
- Studies on the holistic, measured performance of K-12 school buildings.

CHAPTER 6

CONCLUSION

Ongoing measurement of energy performance has a significant positive impact upon the ability of schools to improve their energy performance. While schools tend to be able to make energy improvements through the implementation of energy measurement and performance tracking, deviation may exist in their ability to maintain ongoing energy performance over time. The implementation of ongoing energy measurement would likely produce positive impacts on the operations and maintenance of K-12 schools and is, therefore, recommended.

This paper is intended as a high-level evaluation of the annual, whole building energy performance of K-12 schools as a means of identifying whether the energy use of schools changes over time following the implementation of performance benchmarking and measurement. It serves as a means of identifying the patterns of change in the energy use of schools. Further study upon the impacts of characteristics, such as funding and school district, upon the energy performance of schools, is needed to enhance and refine this research. This work provides a foundation for further understanding and enhanced decision making in regard to energy management practices and strategies utilized in K-12 schools in Arizona and challenges schools across the state toward high performance.

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APPENDIX A

ENERGY USE INTENSITY (EUI) ANALYSIS

Energy Use Intensity Analysis

Number	School District	2009 Energy Use Intensity	2010 Energy Use Intensity	2011 Energy Use Intensity	2012 Energy Use Intensity	2013 Energy Use Intensity	Change in EUI Over 5 Years	Percent Change Over 5 Years
1	District A	52.6	51.7	48.7	48.7	44.2	-8.4	-16%
2	District A	40.6	34.6	33.2	33.2	32.9	-7.7	-19%
3	District A	50.4	51.6	47.5	47.5	38.4	-12	-24%
4	District A	42.4	40.8	39.4	39.4	34.9	-7.5	-18%
5	District B	41.9	38.5	39.8	39.8	42.5	0.6	1%
6	District A	46	41.4	39.3	39.3	36.8	-9.2	-20%
7	District A	42.3	39.9	37.7	37.7	28.5	-13.8	-33%
8	District A	50.6	49	40.5	40.5	33.8	-16.8	-33%
9	District A	47.5	46.4	47.1	47.1	31.8	-15.7	-33%
10	District A	50.7	53.6	43.8	43.8	44	-6.7	-13%
11	District A	50.3	45.9	43.2	43.2	38.9	-11.4	-23%
12	District A	45.6	41.7	39.7	39.7	39.8	-5.8	-13%
13	District A	47.3	53.5	48.6	48.6	36.1	-11.2	-24%
14	District B	44.3	41.8	41.4	41.4	45.8	1.5	3%
15	District A	37.7	34.2	32.8	32.8	33.3	-4.4	-12%
16	District A	55	58.2	54.4	54.4	39.5	-15.5	-28%
17	District B	36.2	34	32.9	32.9	35.5	-0.7	-2%
18	District A	45.9	32.9	30.8	30.8	30.8	-15.1	-33%
19	District A	44.6	43.9	47.7	47.7	33.9	-10.7	-24%
20	District A	44.8	49.4	48.8	48.8	41.5	-3.3	-7%
21	District A	46.9	46.9	41.5	41.5	44.8	-2.1	-4%
22	District A	51	46.9	43.5	43.5	47.5	-3.5	-7%
23	District A	61.5	56	57.6	57.6	46.2	-15.3	-25%
24	District A	78.4	61.8	44.8	44.8	39.4	-39	-50%
25	District B	36.3	29.9	28.4	28.4	27.2	-9.1	-25%
26	District A	57.4	55.7	52.9	52.9	45	-12.4	-22%
27	District B	42.4	34.5	32.2	32.2	34	-8.4	-20%
28	District A	50.5	46.9	49.2	49.2	37.7	-12.8	-25%
AVERAGE		**47.9**	**45.1**	**42.4**	**42.4**	**38.0**	**-9.9**	**-20%**