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Energy Dashboard for Evaluating Performance of Net Zero Energy Buildings

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EVALUATING PERFORMANCE OF ENERGY DASHBOARD FOR NET ZERO ENERGY BUILDINGS

by

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To my mother, who wanted nothing more than to watch her children grow. She without a doubt supported their every dream and ambition. You will never be forgotten.

"What a wonderful life I've had! I only wish I'd realized it sooner" --*My mother*

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF ABBREVIATIONS

AEL- Applied Energy Labortory

AHU- Air Handling Unit

ASHRAE- American Society of Heating, Refrigeration, and Air conditiong Engineers

BAS- Building Automation System

HVAC- Heating, Ventilation, and Air Conditioning

KPI- Key Performance Indicator

NZEB- Net Zero Energy Building

UX- User Interface

GLOSSARY

1. *Building Automation System (BAS)*: The control of a building is automated through a system that uses inputs-such as temperature and humidity--from building performance measurements. These measurements are used to control outputs-such as those related to fans and dampers. Automation systems vary from building to building, depending on level of control and the company used to create controls, which dictates the programming language.
2. *Energy Dashboard*: Building metrics are conveyed through a pictorial display using graphs, color changing pictures, or numbers to articulate building performance.
3. *Plug Load*: The total electrical load (kWh) that is consumed by modern amenities such as computers, washers, dryers, and coffee machines.
4. *Occupancy Level*: Displayed by a percentage to represent occupancy quantitatively in a building at a given time.
5. *Net Zero Energy Building (NZEB)*: A building where energy produced from a renewable source is equal to the amount of energy that the building consumes.
6. *User Experience (UX):* A field of research that focuses on human interaction with technology and attempts to find ways to make it more seamless
7. *Key Performance Indicator (KPI)*: a high-level performance metric that is used to simplify complex information and point to the general state of a phenomenon.
8. *Building Performance Metric*: A standard of measurement of a function or operation. Examples: Building Energy Use Intensity (BEUI), Net PV System Production, and Lighting Power Density
9. *Applied Energy Laboratory (AEL):* A research facility comprised at Purdue University of a variety of heating, ventilation, and air conditioning and renewable energy equipment that mimics what is found in a commercial building

ABSTRACT

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People spend the majority of their day inside a building but remain unaware of the complex inner workings shaping their indoor environment. Energy dashboards simplify thousands of building data points to allow users to improve and understand the performance of their buildings. Traditionally, energy dashboards have had a more limited role in facility management in terms of monitoring performance, detecting sensor malfunctions, and identifying broken equipment. Smart buildings are expected to become a 137-billion-dollar market within the next five years, energy dashboards are needed to interface with homes and offices. Increasingly, energy dashboards are developed to actively manage and optimize the performance of sophisticated net zero energy buildings (NZEBs).

The experiment prototyped and evaluated users' ability to navigate an energy dashboard built in a tradition building automation system (BAS) for a net zero Applied Energy Laboratory (AEL). The AEL is a research facility comprised of a variety of heating, ventilation, and air conditioning and renewable energy equipment that mimics a commercial building. The AEL energy dashboard was evaluated by users before and after edits were made to the existing energy dashboard in the BAS.

The results of the energy dashboard study validated methods to classify the users to optimize navigation of building performance metrics. Key performance indicators (KPI) were used to determine users' identity among a set of diverse energy dashboard users. The study found statistical significances that a purposefully designed an energy dashboard improves a user's ability to find building performance metrics. Understanding the user's knowledge level and role in the building is an essential aspect to proper energy dashboard design.

This study created an energy dashboard that was a rapid deployable prototype for net zero energy commercial buildings of the future. Current research has revealed that occupants want more control over their buildings, and energy dashboards can allow for this, thus helping reduce energy use. Coupled with the expansion of smart home technology, energy dashboards are increasing in prevalence; understanding proper design aims to increase positive user experience and forming more sustainable behaviors.

CHAPTER 1: INTRODUCTION

People spend the majority of their day inside a building but remain unaware the complex inner workings shaping their indoor environment. The scheduling of equipment and energy consumption pattern are not in the peripherals of an occupant. A monthly electrical bill does not provide the feedback needed for users to make instantaneous habit changes. A net zero energy building (NZEB) requires the users involvement in the operations process to meet energy goals. An energy dashboard is the interface between a building's operation and the occupants to aid a user in understanding of operations.

NZEB rely on occupants to understand energy consumption patterns and how to reduce them to meet the overarching goal. These changes can be as simple as finding lights that need to be turned off at night. Properly operating smart buildings require seamless interactions between buildings and humans to optimize building performance. New visualization tools are being developed in an attempt to gain a grasp on the best way to visualize intensive data sets of building information (Yarbrough *et al.*, 2014).

The evolving field of key performance indicators (KPIs) focuses on the best way to display energy data. Related research encompasses understanding the correct demographic for KPIs and characteristics of best design practices. Tracking and displaying the performance of net zero energy buildings (NZEBs) is an increasingly important application for energy dashboards.

1.1. Introduction: Net Zero Energy Building

While NZEB is a general term, by American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) standards, NZEB is defined as a building that produces as much renewable energy as it consumes on an annual basis ((Peterson, Torcellini, Grant, Taylor, Punjubi, & Diamon, 2015). This definition is accepted by American Institute of Architects, United States Green Building Council, and the Illuminating Engineering Society of North America.

A new approach to defining NZEBs is according to differing levels and scenarios, which can be based on climate and feasibility of onsite production (Deng, Wang, & Dai, 2014). Creating an aggregate sum of energy production allows for the lower solar power generation during the winter months to be outweighed by higher generation levels seen during summer months. If daily consumption is the basis, systems must be sized for worst possible scenarios such as an overcast or rainy day. For this study, the term net zero energy is based on an equal balance of consumption and production over a month-long timeframe.

In the United States, there is a push at the federal level to increase energy efficiency through NZEBs. A Presidential Executive Order (EO) was signed, mandating that all federal buildings be designed to net zero energy standards by 2020 (Obama, 2015). The state of California has expanded on this executive order and required that all residential construction be net zero energy by 2020. The United States is not the only country pushing NZEBs at the federal level. The entire European Union issued a statement declaring their goals to decrease carbon emissions through use of NZEBs (EPBD 2010).

1.2. Introduction: Energy Dashboard

The term dashboard is typically interpreted as the interface between driver and car, where the dashboard gives a basic overview of the car's performance, as well as warning lights to alert drivers in certain situations. An energy dashboard for a building closely resembles this, by giving an overview of a building's performance through energy data (Yarbrough, Sun, Reeves, Hackman, Bennett, & Henshel, 2014). Dashboards for buildings give a facility manager or building occupant perspective about the overall performance of equipment in building. Energy dashboards help put facility managers and occupants in control of issues needing attention in a building (Shadpour, 2015).

Buildings produce an enormous amount of data that is articulated through an energy dashboard. An energy dashboard is designed to focus on what the user needs to view. Different people in a building might need different granularity of data on a dashboard. Resulting in four different levels of energy dashboards based on the granularity of data for each dashboard level type. Lower level energy dashboards display real-time data and are the most frequently used for occupants (Shadpour, 2015). The upper level dashboards that show analytics and controls to control equipment are designed for facility managers or maintenance staff.

Dashboards can be used for an array of notifications, but finding the best fit is key to increasing effectiveness. Companies specialize in dashboards based on diagnostic and information capability to provide a turnkey solution. Energy dashboards and building controls are moving to smart phone applications. Products are available on the market to control outlets and trend energy consumption at the plug load level. As products continue to evolve at the consumer and industrial level, energy dashboards need optimize to encourage energy consumption changing habits.

1.3. Significance of the Problem

Roughly 20% of the energy used by buildings is due to unnoticed faults and underperformance (Want, Xu, Lu, & Yaun, 2015). There are also intangible benefits to energy efficiency measures, such as productivity and safety. Often these benefits outweigh the energy saved (Pye & McKane, 2000; Worrell, Laitner, Ruth, & Finman, 2003). A reason for overconsumption is the downtime between faults and detection (Wang *et al.*, 2015).

Public buildings have found performance issues and invested energy saving solutions based off processing metered building data. A combination of building controls and energy dashboards is a feasible way to combat wasted building energy. Many government entities are hard funded, meaning that an opportunity to save on unnecessary overhead means big gain for other areas in the facilities. Of all NZEBs, 49% of them are public projects (Eley, 2017). An energy dashboard can help the public and private sector decrease their energy costs, while decreasing carbon emissions at the same time.

At the federal level, an EO was signed, pledging the United States’ continued goals to decrease carbon emissions. Specifically, the EO states that all new construction of federal buildings greater than 5,000 gross feet are to be designed to NZEB standards, beginning in 2020 (Obama, 2015). The EO goes on to state other energy efficiency measures and even a plan to for buildings to become net zero waste.

California as a state has moreover pledged that all new residential and commercial construction be net zero energy by 2020 and 2030, respectively (Deng *et al.*, 2014). This means creating homes and workplaces that produce as much energy as they consume annually. Politics are now coming into play around creating a carbon-neutral world. An algorithm depicting important data in displaying energy usage can be a proof of concept and may be useful for the entire state of California and other states as they begin to adopt their own energy saving plans. More broadly, there are similar conversations about NZEBs popular for the European Union, Canada, and Japan (Berry *et al.*, 2014).

While most of the research is focused on how to create a building that is a NZEB in the long term, there is little discussion about how monitoring a NZEB is beneficial for the building's energy performance. A survey was done, asking why design companies must return to the building after its construction, and the number one reason found was incorrect installation (Eley, 2017). If building owners can monitor their own building's performance, they can help find such issues, so they do not persist longer than needed.

As the feasibility of NZEBs increases, people having little knowledge of mechanical systems are calling a NZEB their home. Energy dashboards are becoming the interface between the house and the occupants. A low-cost option that provides basic information about the building's energy performance is what is needed at the beginner level of dashboards.

1.4. Research Question

The research question for this study focuses on the functionality of an energy dashboard from the perspective of diverse users of a building:

How does an energy dashboard help different categories of users understand and interpret building performance (by simplifying large amounts of data)?

1.5. Statement of Purpose

As population and quality of life increases around the world, so does the demand for energy. China alone needs 3.7% more energy every year and has doubled its consumption within the last 20 years (Pérez-Lombard, Ortiz, & Pout, 2007). The growth of industries and amount of jobs to support an increasing population size continues to strain the electrical grid. NZEBs are thus becoming the focus of decreasing strain on the electrical grid (Deng *et al.*, 2014). In combating an overstrained electrical grid, it is easier to implement energy conservation methods than to build larger energy generation plants (Coltrane, Archer, & Aronson, 1986). There is also a disconnect between knowing real-time building energy consumption values and behaviors that can be altered to reduce demand.

Researchers are trying to find ways to increase a building's energy efficiency without decreasing the quality of living (Berry, Whaley, Davidson, & Saman, 2014). There are energy savings to be found through the various energy loads. Dashboards are used to enhance understanding of the different avenues of energy usage. Unfortunately, the best practices are underdeveloped and leaving people more confused than informed (L. Aelenei, D. Aelenei, Goncalves, Llllini, Musall, Scognamiglio, Cubi & Noguchi, 2013). A dashboard helps to make a quick observation as to whether the building is operating within design parameters. An effective NZEB design combines energy efficiency measures and renewable energy to power the building.

The graphics and interfacing technology themselves are inexpensive as the interface moves to cellphone based platforms. However, the data processing methods are cumbersome and expensive. An input from a temperature sensor has a software feature to historize data every 30 seconds, 1 minute, 5 minutes or 30 minutes. A basic fractional-horsepower Fan Coil Unit (FCU) supplying air to one room has roughly four temperature sensors. Buildings typically have one FCU for every room or several rooms combined. Assuming the readings are only done every minute and recorded, roughly 5,760 readings are stored daily for one FCU. The sheer amount of data stored and available to be processed for a single FCU is an enormous task. Sensors are used in energy analysis to know if a FCU is operating under correctly. Artificial intelligence is starting to be used in buildings to autodetect faults but these methods are cost prohibitive. Developing inexpensive algorithms that can be integrated into a Building Automation System (BAS) decreases overall costs for the development of an energy dashboards.

Research on available feature in a BAS is needed to increase availability to energy dashboards as a way to decreasing building energy costs. Companies such as Microsoft have tested different types of dashboards that can be used on campus and the energy savings that can be achieved by using the fault detection feature (Cook, Smith, & Meier, 2012). Graphical features in BAS software have been underrated because of companies like ICONICS can create turnkey solutions designed for high-resolution graphics that display performance trends. The majority of studies reviewed used third-party companies to only analyze the data, but not all businesses can afford these solutions (Cook *et al.*, 20126; Chen, Delmas, & Kaiser, 2013; Yarbrough *et al.*, 2014).

1.6. Assumptions

1. The Applied Energy Laboratory functions as its own net zero energy building.
2. Assumptions about space occupancy are be made to account for use of lights, computers, and other teaching- and research-related plug loads.
3. Users had the technical competence to navigate an energy dashboard
4. Users completed the survey independently and to the best of their knowledge.

1.7. Limitations

1. The study is only conducted during the beginning of the winter months, when solar power generation is at its lowest.

1.8. Delimitations

1. Only electrical loads are monitored, displayed, and analyzed. Natural gas, steam, chilled water, other utilities are not considered.

1.9. Chapter Summary

The strain on the electrical grid has become an international concern of the 21^{st} century. Building controls allow building occupants to monitor and control a building's energy consumption. The expansion of rooftop renewable energy and building controls has enabled NZEB to arise as a solution to the increase of electrical demands. The term NZEB is used to describe a building that produces onsite renewable energy to counteract the energy needed to operate the building. NZEB are an inventive way to decrease strain on the electrical grid by trying to neutralize the load.

For this research a proof of concept energy dashboard increases a user's ability to identify energy performance metrics, testing if a laboratory space achieves net zero energy. The research is focused on the best design practices and optimization of a user interface with a typical BAS energy dashboard. The energy dashboard study added perspective to an evolving field of net zero energy buildings, as well as continue research on rapidly constructing energy dashboards through a typical BAS.

CHAPTER 2: LITERATURE REVIEW

2.1. Net Zero Energy Buildings

Designing and building net zero energy buildings is difficult because the climate poses different environmental challenges. Across the country locations have differing heating and cooling loads and there are also variances in the availability of solar energy. Currently, research on net zero energy buildings is heavily focused on design and performance verification. The use of Building Information Modeling (BIM) allows for homes to be virtually tested. A building is designed using BIM to simulate building loads and the required amount of on-site renewable energy production to meet those demands. Current research is focused on creating more accurate models and designing homes for different climates.

Occupant behavior is highly variable and affects energy demand, causing buildings to underperform compared to the prediction models (Ascione, Bianco, Bottcher, Kaltenbrunner & Vanoli, 2016). A case study using one of Germany's first federal NZEBs found that occupancy behavior had a bigger impact on the building's performance than predicted. Research on NZEBs has also shown that the next step is putting occupants and building owners in charge of their own building. Achieving net zero energy in monitoring the performance of buildings is important to success. An ASHRAE interview with net zero energy professionals found that building owners want more control of their NZEBs (Torcellini, P. A., Eley, C., Gupta, S., McHugh, J., Lui, B., Higgins, C., & Rosenberg, M. , 2017). A study interviewing 25 NZEB homeowners found that homeowners wondered if their houses were operating as designed (Berry *et al.*, 2014). As more people begin to call a NZEB home or office, research needs to be developed to include the participation of the occupants of those buildings.

During 2014, the United States Department of Energy (DOE) established a common definition for net zero energy buildings. To meet the requirements to be considered a NZEB, the total of consumed energy and renewable energy generated over a year must equal zero (Peterson *et al*, 2015). A typical building produces more renewable energy in the summertime than it consumes. The opposite is also true for the winter; more energy is consumed than is produced by the renewable energy resource. Solar panels are the most popular renewable energy resource for NZEBs and are typically placed on the roof of the home. There are options for other sources of renewable energy, including geothermal and solar thermal to heat hot water.

During 2010, the European Union published a statement known as the Energy Performance of Buildings Directive. The initiative encouraged zero-energy building construction in the European countries. The directive states, “Member States shall draw up national plans for increasing the number of nearly zero-energy buildings. These national plans may include targets differentiated according to the category of building. (EPBD, 2010).” The directive includes details about all member states building net zero energy buildings by December 31st, 2020, as well as increasing energy efficiencies and the number of zero-energy buildings.

Domestic requirements for NZEBs have also been created at the state and federal government level. In the state of California, net zero energy is becoming a building requirement. All new residential construction is required to be net zero energy by 2020 and all new commercial buildings are required to be net zero energy by 2030. Under the Obama administration, the federal government committed to begin requiring all new construction of federal buildings to be NZEBs. There is support from international governments all the way down to the state level to decrease energy usage.

2.2. Building Performance Metrics

Buildings generate complex and unprocessed performance metrics that takes time and research to process. Research focused on processing data and visually displaying building performance is called KPIs. The term KPI was originally intended for business applications. Increased concern for the performance of buildings initiated KPI research for the building technologies sector (Alwaer & Clements-Croome, 2010). Another term, e-KPI, is specifically used to denote energy-related KPIs. A performance indicator is a metric that can be used to paint a picture of the data. For example, the time correlation between energy generation and energy use or reduction in carbon dioxide (CO_2) emissions depicts data that would otherwise be hard to visualize. The word ‘key’ in KPI is where the research is leading to improvements.

Knowing how to create graphics that are geared towards the audience and effectively depict the data is important. Current practices look at various methodologies for identifying the correct KPIs for buildings. Research is also focused on identifying specific graphics based on the demographic, such as different criteria for occupants versus facility managers. Current research is focused on how to create quality KPIs for the correct demographic with helpful data.

Eight characteristics, or criteria, have been identified to help create a suitable performance metric, focusing on creating KPIs that are useful at all stages of the building's lifecycle. Incorporating all these characteristics is challenging, but using them decreases the communication gap between clients and design engineers (O'Brien, Gaetani, Carlucci, Hoes & Hensen, 2017). Using the list of characteristics shown in Table 1 creates a clearly defined performance objective and is essential for designing KPIs.

Table 2.1. Criteria Identified in Developing Effective KPIs.

Criteria	Definition	Used for AEL
Fit-for-Purpose	Designed to quantify a goal and to optimize the building to reach the goal.	Yes
Reproducible	Reproducible results when measured under similar scenarios and conditions.	Yes
Easy to Obtain	Readily calculated by using building measurements, which in turn are simple to collect.	Yes
Comparable	Enables comparison of results to facilitate benchmarking.	Yes
Quantitative	A quantitative benchmark is the starting point to improve a building's performance.	Yes
Actionable	Presents information that allows the user to act.	Yes
Accessible	Straightforward and should not be based on complicated indexes that users do not know how to interpret.	No
Unbiased	A neutral indication of a building's performance and does not mislead the user	No

The criteria are used to evaluate each indicator during the design and re-evaluation phases, and are also used to evaluate existing indicators to determine corrections needed. Using the criteria helps the designer to keep focused on the desired outcome of the KPIs. The characteristics were used for AEL's net zero energy study to help the pretest and posttest evaluation of the energy dashboard, resulting in a hierarchy of KPIs to determine what was needed in creating an occupant-centric energy dashboard.

The AEL energy dashboard study used six out of eight characteristics, omitting "accessible" and "unbiased." The qualitative component of unbiased and accessible was not be measured for this study. O'Brien *et al.* expresses that not all eight of the characteristics need to be addressed, thus justifying adapting the characteristics for the net zero study.

The study done by O'Brien *et al.*, focused on how to incorporate KPIs for occupancy and lighting load and created a characteristic hierarchy for an occupant-centric building. The study found that designers need to integrate sensors to detect occupancy earlier in the design phase. As a common theme, the sensor-related data do not have a high enough granularity for the analysis desired. Creating an occupancy-centric building needs to be part of the design phase, and not an afterthought. One way to combat this is to think about what level of monitoring is desired after the construction phase. Another study depicted efforts in monitoring a manufacturing plant to decrease energy usage. The level of granularity for the energy data was not detailed enough to find machine-level energy usage. Developing KPIs needs to be thought about in the design stage of a building.

A three-step process can be used to help prioritize stakeholders for enhanced multi-level energy management (Li, O'Donnell, Garcia-Castro & Vega-Sanchez, 2017). The first step is to identify intervention points for energy performance at various levels. A building is broken up into three levels: district, building, and zone. For the purposes of the AEL's net zero study, the terms building, component, and sensor are used to indicate the various levels. Since the study only looks at one classroom, the district level does not hold value. However, designing a dashboard for a whole campus would require using the three levels of building, equipment, and zone.

The next step is to identify which KPIs would be important to the stakeholders. The last step requires having the stakeholders evaluate the KPIs that the designer has identified. The second step used for AEL's net zero study is adapted from Li *et al.*'s study. The analysis of categorizing the users was done to help future energy dashboard developments. Li *et al.* identified over 30 KPIs that could be used to define energy performance. Different stakeholders such as architects, building owners, and occupants were questioned to find out what KPI was important to whom.

Table 2 shows the indicators that were given to a cross-divisional group of people in Li *et al.*'s study. The significance is the ability to test Li *et al.*'s method to determine if the same KPIs of high value work for AEL's energy dashboard. The person evaluates each indicator on a scale of one to five, with five being of the highest importance. The study split engineers, occupants, and architects into separate groups to evaluate which group values which indicator. The evaluation is used to help designers define the target group and design KPIs tailored to their needs.

Table 2.2. Indicators Adapted from Li *et al.*'s Study, Used for the Users' Evaluation of KPIs.

Key Performance Indicator	**1 to 5**
Reduction in CO_2 emissions	
Energy cost savings (total energy cost savings caused by reducing purchased energy)	
Energy balance (net zero energy calculations)	
Overall energy use reduction (total energy use reduction due to energy efficiency improvements)	
Individual equipment energy balance (net zero energy for each piece of equipment)	
Time correlation between energy generation and use	

This systematic approach was used for AEL's net zero energy study to learn about what demographic the users associated with and to determine future work for graphics. The hierarchy is also used to see if a traditional BAS has the graphics needed to satisfy the most important KPIs. Awareness that stakeholders are important and how to incorporate them into the design of KPIs was looked at in the Li *et al.* study in an unbiased way. The study found a methodology to support multi-level energy performance analysis, and a systematic approach for determining key stakeholders, while defining clear performance goals to aid with the design of KPIs.

A limitation to KPIs is the amount of energy data that are available, which is dependent on granularity of data at the lower levels of energy use. For example, May *et al.* conducted a study, trying to show where energy savings could be realized in an industrial plant. May *et al.*'s study found that when producing a seven-step approach to creating e-KPIs for an industrial setting, a limitation was the machine-level data. Comparable to O'Brian *et al.*'s study where the data for the occupancy level was missing, data for machine performance was not thought about in the design phase. An analysis can only be done if the data exist, which was found true in the May *et al.* study and at the sensor level for AEL's net zero study. Designing KPIs is a task that should be thought about through the entire design process of a building. Limited granularity of data limits the feasibility of creating actionable e-KPIs in the future.

As the trend of building automation continues, occupants need to be considered as the owners responsible for building performance (O'Brien *et al.*, 2017). An evolution has taken place from quality and production efficacies to environmental performance (May, Barletta, Stahl & Taisch, 2017). Finding the best methods for designing net zero energy dashboards, as well as tailoring the KPIs to the stakeholders, needs to be researched. The recent movement of the owners now becoming the primary stakeholders responsible for building performance is increasing the need for KPI-related research.

2.3. Human Behavior for Energy Conservation

Energy conservation research took off during the 1970s energy crisis, when predictions were that fossil fuel resources were depleting. Researchers at the time wanted to understand how to encourage people to use less energy. Understanding what causes people to become concerned and change their behavior is important when designing an energy dashboard. The dashboard focuses on curtailment behaviors such as lowering the thermostat. Buying energy efficient appliances is not enough because if they are not used correctly, the building owner experiences no energy savings.

A study examined over 30 previous studies to summarize effective strategies for reducing household energy consumption (Abrahamse, W., Steg, L., Vlek, C., & Rothengatter, 2005). Providing homeowners with feedback about energy usage proved to the best method. Gaps in the research are frequency of feedback and methods to display the data. Providing specific feedback rather than generally nonactionable information changed the success of the improving conservation behaviors. A knowledge gap about how building perform and ways to decrease consumption is causing excess energy usage. The ability to understand how to convey and predict what will cause a person to change consumption behavior is a powerful tool.

The energy conservation gap in research laboratories is becoming apparent and a complex issue due to the wide variety of energy consumption loads. Laboratories need to decrease their energy consumption, because they use disproportionately more energy than most buildings on university campuses (Kaplowitz, Thorp, Coleman, & Yebaoh, 2012). One study found that there was a knowledge gap on how to save energy in laboratories and strategies focused on regular feedback would positively impact the participants' behaviors (Kaplowitz *et al.*, 2012). For building owners to decrease their energy usage, they must first be educated on types of behavior changes, and then also be provided real-time feedback.

Humans play a big role in increasing the energy efficiency of buildings. However, research connecting User Experience (UX) and User Centered Design (UDC) to the energy efficiency field is limited (Irizar-Arrieta & Casado-Mansilla, 2017). A guideline of 10 usability heuristics is the center of UDC and is used to find faults in an interface (Nielsen, 1995). One heuristic feature that was looked at in this study was flexibility and efficiency of use. Allowing users to find the information they need quickly positively increases their experience. Understanding UX in respect to energy dashboards has the potential to generate positive impact towards promoting sustainable behaviors (Irizar-Arrieta, 2017).

2.4. Energy Dashboards

There are various levels of energy dashboards, including different vendors for commercial and residential purposes. One method is to use a third-party web-based service. These are designed at the most basic level for people to understand the performance of the building. A web-based service allows occupants to access the energy dashboard frequently and make habit adjustments to decrease energy usage. Figure 2.1 is an example of a study that used a web-based service.

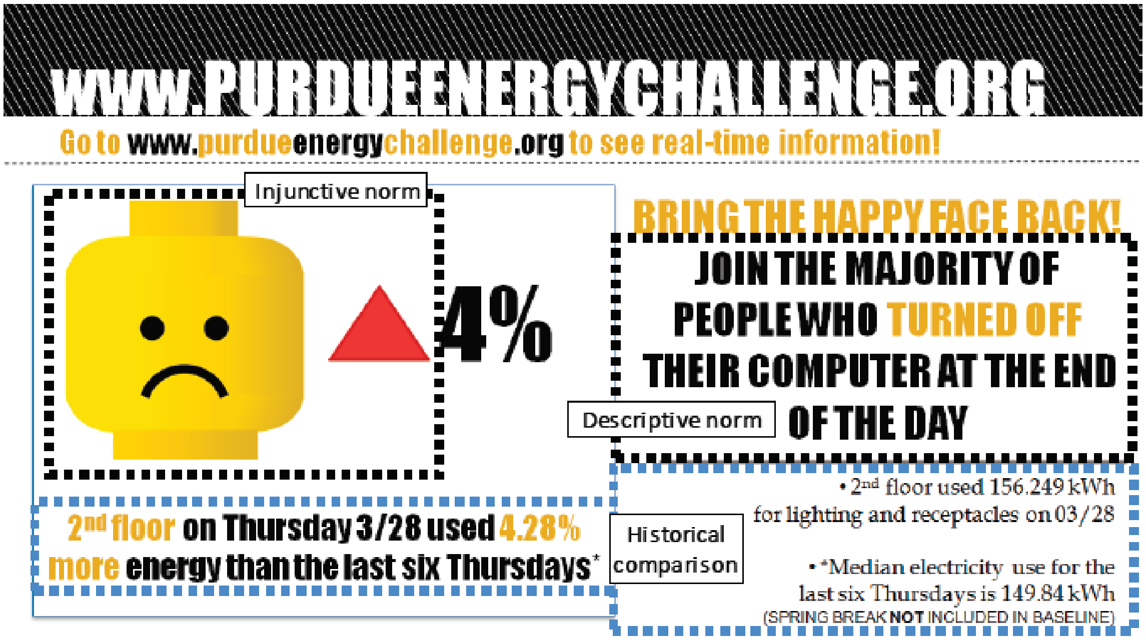

Figure 2.1. An example of a level zero energy dashboard (Cuadrado-Borbonés, 2013).

An energy dashboard was constructed to encourage occupants of a building to decrease energy and suggested habit changes. The energy dashboard in Figure 2.1 is an example of a level zero dashboard design. The energy dashboard in Figure 2.1 was in the lounge area of a building. This type of energy dashboard is the most basic design and used for quick glances to gain an understanding.

A hierarchy of four levels of energy dashboards that are recognized by ASHRAE (Shadpour, 2015). The first two levels focus on real-time factors such as how the building performs in relation to real-time weather conditions. These first two levels, like Figure 2.1, give a basic overview of the building and designed for online monitoring purposes.

The upper two levels of dashboards provide in-depth performance details of smart buildings, where the energy dashboard can be used to find faults in a building and report higher level-trends based on building performance as it relates to the price of energy. These levels are known more as actionable intelligence (Shadpour, 2015). Figure 2.2

shows an example of a level two energy dashboard. Real-time analytics and trended forecast allow for this dashboard to be used by a more skilled user.

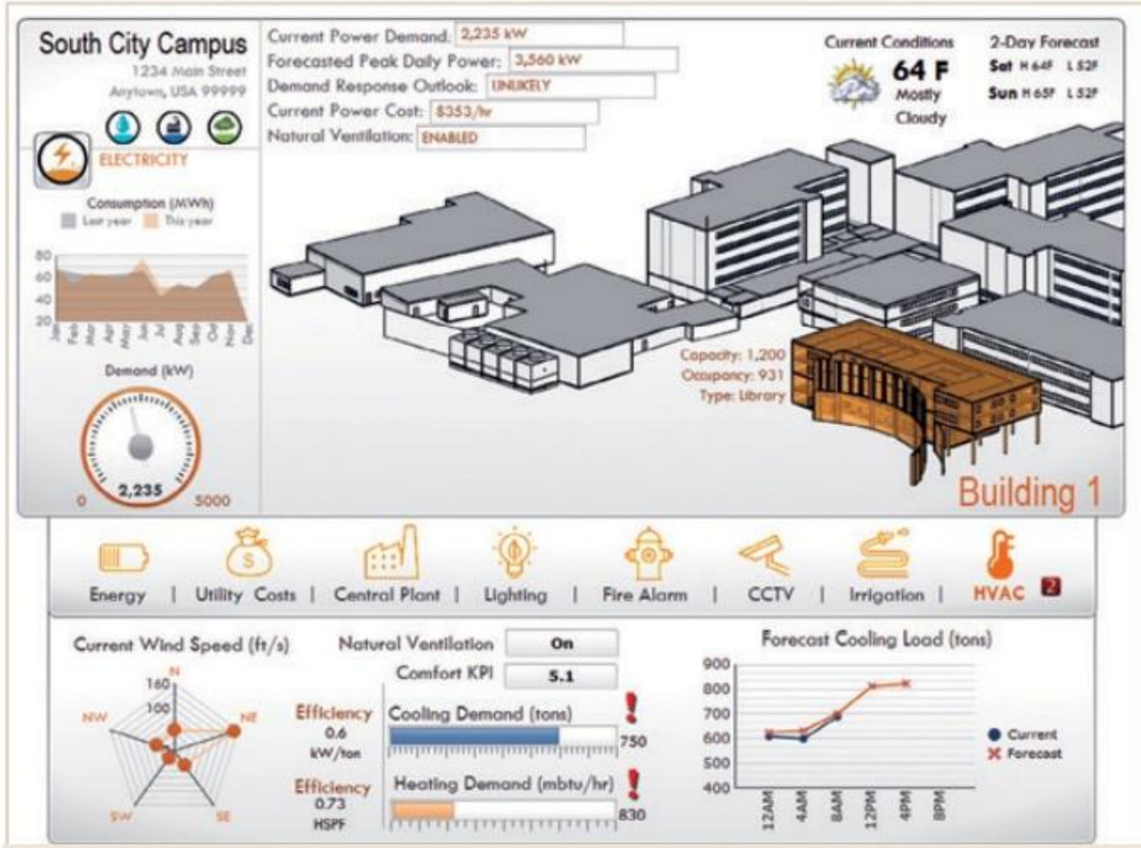

Figure 2.2. An example of a level two energy dashboard (Shadpour, 2015).

A first steps in the design phase of an energy dashboard is assessing the energy dashboard user and what level of detail is required. Energy dashboards can be built directly into the BAS to enhance understanding of performance. Higher-level designs are used for facility managers and engineers focused on operations of the building.

The energy dashboard research in this study had the user rank their understanding of energy dashboards to help gauge which level was best fit. The difference between the the levels of energy dashboards is rooted from answering the question, “What actions is the user expected to take based off the information provided?” The overarching goal of a dashboard is to display information effectively, so that actions can be taken to reduce energy either through habitual changes, or by detecting building faults. The dashboard serves as the connection between building data and humans.

Research conducted in dorm rooms and office settings has evaluated the effectiveness of dashboards in making building occupants aware of energy usage. One study made the correlation between a person's environmental awareness and their energy usage patterns. A correlation exists between those who have strong environmental ethics and those who have a drive to decrease energy consumption (Delmas & Lessem, 2014). Environmentally aware people are more drawn to the statistics of how their building is preforming and make energy-related corrective behavioral changes.

Energy dashboards are also used on the facilities side as a troubleshooting technique. A building manger can easily monitor multiple buildings using a pictorial display, rather than looking at raw building data continuously. The layout of a building can be displayed in colors that match the current room temperature, in order to more easily find rooms in failure mode. Energy dashboards can also display trends and gages that can be used to detect underperforming buildings. Deadbands can be displayed on the dashboard to show predicted energy use, and if the building performs outside of that range, an alarm would be triggered.

Commercial energy measuring devices exist and are used to monitor a person's home. Watt meters that serve as a medium between the outlet and a device's power cord connect wirelessly to an app. A cellphone is used to give the owner daily summaries of energy usage and real-time consumption. Through the app, the device can also be turned on or off or can be scheduled for control. Other companies have solutions that plug directly into the circuit breaker of a home to monitor each switch to create an overall usage profile. The Nest thermostat closely resembles an energy dashboard and allows home owners to have control of their home from miles away. Cellphone applications make not only the monitoring, but also the control of a building accessible from anywhere in the world simply through WiFi.

2.5. Chapter Summary

The design of NZEBs requires complex building controls and renewable energy design. The research and government support behind NZEBs prove that the deployment of these buildings is expected to expand over time. Building controls are complex but KPIs are used to increase understanding of buildings and occupant-centric control. One avenue for displaying KPIs is through energy dashboards. An energy dashboard is designed around a demographic and uses KPIs to display a building's performance. Human behavior has shown to have a bigger impact on how buildings perform than expected. The combination of designing KPIs and human interaction with energy dashboards is expected to overcome the knowledge gap between a building's performance and its occupants.

CHAPTER 3: RESEARCH METHOLOGY

3.1. Introduction

This experiment evaluated whether a modern energy dashboard improved a users' ability to understand the building performance metrics of a net zero energy building. An energy dashboard was integrated directly into the BAS and used lifelike equipment graphics to illustrate a building's operations. Trends and numerical data were added to create a level two energy dashboard. The energy dashboard was considered the link between users and the performance metrics of building.

The model of a building for this research is the Applied Energy Laboratory (AEL), which features a sophisticated BAS for tracking the performance of HVAC and solar energy equipment. Energy dashboards were already designed for individual equipment but were not up-to-date graphically. A unified NZEB dashboard was created to encompass all energy data from individual pieces of equipment to determine if the AEL operated as a net zero laboratory.

The posttest energy dashboard survey asked users to rank building performance KPIs. The answers were compared to a similar survey done in Li *et al.*'s study to classify the users to help future improvements on the energy dashboard. Understanding the demographics of the user through KPIs was researched to help the optimization of energy dashboard design.

Users were students enrolled in a HVAC class used the energy dashboard interface to complete a survey before and after retrofitting the energy dashboard. The experiment compared pretest and posttest survey answers to measure effectiveness of accurately displaying energy performance metrics to a group of moderately skilled users. Overall, the users were asked to complete two seemingly identical surveys. The answers were used to analyze the energy dashboard's ability to display building performance data.

3.1.1.Hypotheses

The experiment was a comparative study designed to test two proportion of correct answers from a survey about an energy dashboard before and after design alterations. The performance of the users in the pretest and posttest determined the effectiveness of an energy dashboard to simplify thousands of building performance data points. The users and the energy dashboard are the independent variables in this study. The dependent variables were the number of correct answers on each test. The delimitation is that the electrical loads changing seasonally. All equipment operated on a schedule or known operating conditions, in order to validate that the AEL is a NZEB.

The assumption for the survey was that the users were the users and completed the assignment independently from each other. The energy dashboard study also assumed that the AEL operated as a net zero building thus making an energy dashboard to demonstrate that assumption was justified. Assumptions based on occupancy level and plug load were used. Submetering at the plug load level was not available but discussed in section 5.2.1.

The hypothesis of the energy dashboard study is that a well-designed user interface provides diagnostic information that improves building energy management. The updates to the energy dashboard were expected to show statistical significance that a well-designed graphical interface impacted a user's understanding of building performance metrics. The test hypothesis is as follows:

- Null Hypothesis | H_0: Proportion $\text{Correct}_{pretest}$ = Proportion $\text{Correct}_{posttest}$
- Alternative Hypothesis | H_a: Proportion $\text{Correct}_{pretest}$ < Proportion $\text{Correct}_{posttest}$

3.2.Applied Energy Laboratory Equipement

The AEL in Knoy Hall at Purdue University in West Lafayette, IN mimics the mechanical and electrical systems of a commercial building. The AEL is used for teaching and conducting research into NZEBs. The laboratory is a multipurpose room used for graduate research and undergraduate exploration of basic HVAC concepts.

The AEL has mechanical systems such as an air handling unit (AHU), chiller, and an environmental chamber (EC) for testing purposes, as seen in Figure 3.1. The EC is used to control an environment for testing purposes generally focused on plant research, a subset of research in the AEL. The AHU and chiller are used for research purposes and demonstrating to undergraduate classes the mechanics of HVAC. Each piece of equipment has sensors and mechanical parts that are controlled through a central BAS located in the laboratory.

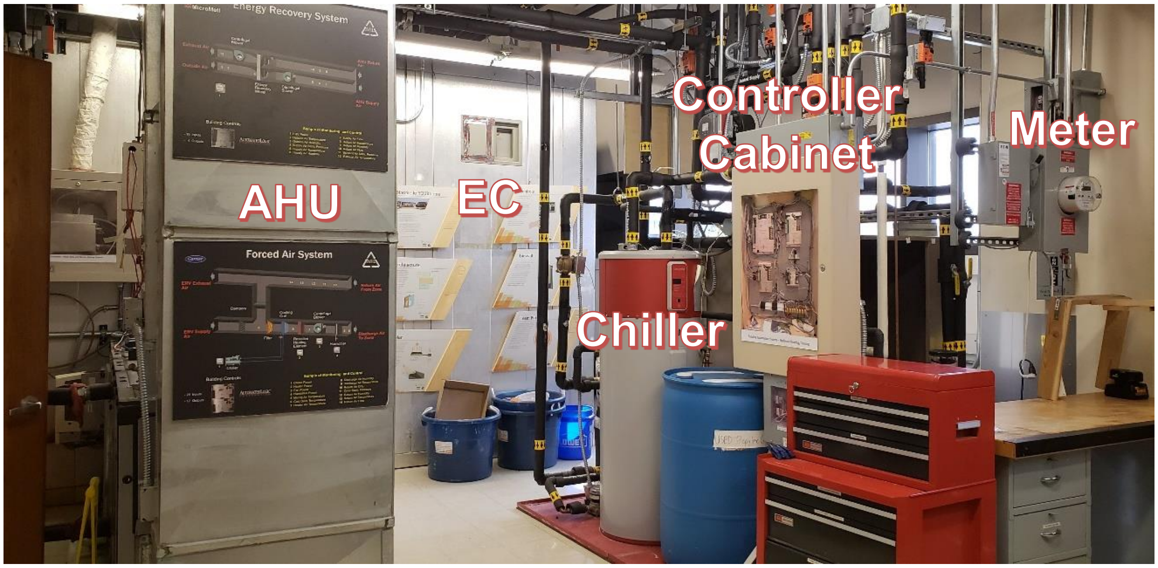

Figure 3.1 3. The Applied Energy Lab (AEL) monitored through the energy dashboard

The equipment does not continuously run, the operations are dependents on certain conditions such as outside air temperature or research purposes. Figure 3.1 does not show all the equipment controlled by the BAS for AEL. Although the laboratory space is petite, glycol piping and pumps are located in the space too. Equipment for the renewable energy is located on the roof.

The roof as shown in Figure 3.2 has the outdoor equipment. An 8 kW solar photovoltaic (PV) array that was installed in May 2017, the PV is considered the renewable energy for the NZEB research. The roof is also equipped with solar heated glycol systems to heat AEL in the summertime but also provide nighttime cooling in the summer.

Figure 3.2. The renewable energy resource for the AEL.

A comprehensive BAS monitors and controls all the equipment in the AEL. The controllers used are located in the AEL, labeled in Figure 3.1, and on the roof. One challenge with BAS is a hardwire connection is used for security purposes. The controller needs to be located on site, within reasonable physical range for short wire runs as wireless systems are vulnerable to wireless tampering. Figure 3.3 is an example of the controller inside AEL used to send and receive signals from sensors, fans, and other mechanical equipment.

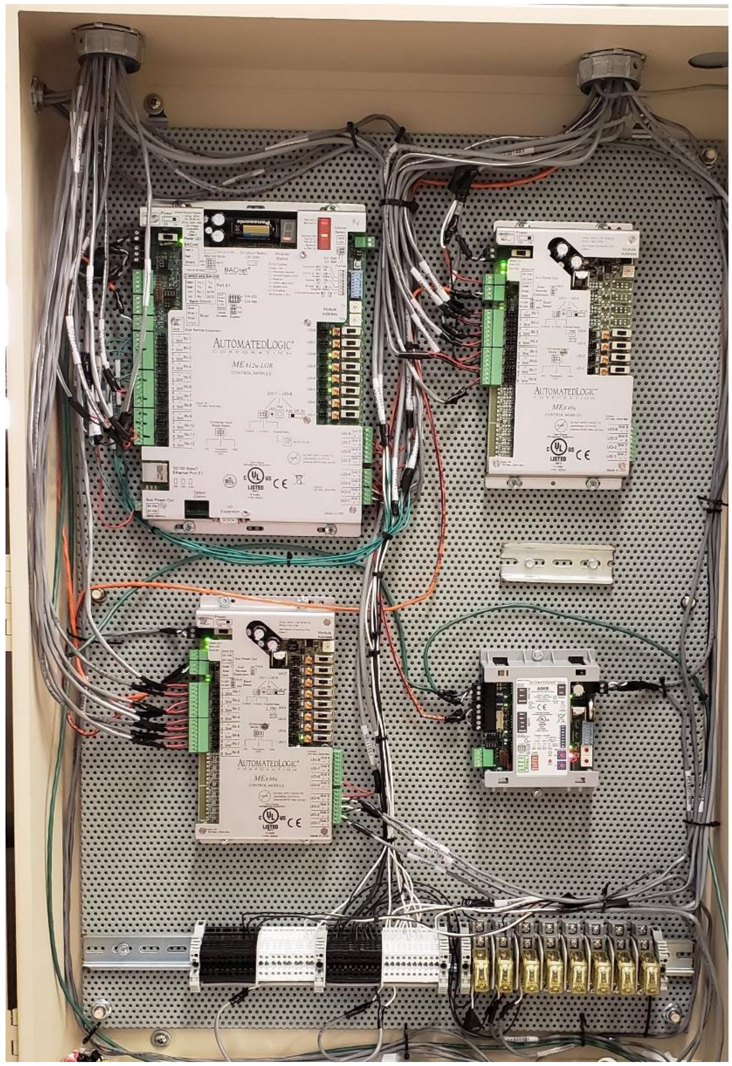

Figure 3.3. The controllers used to transmit signals to sensors and equipment in the AEL.

The setup in the AEL is focused on a central BAS that controls all the equipment. Every component has at least an input or output signal that requires a hardwire connection into a controller. Even though AEL is a relatively small physical space, the laboratory has a sophisticated BAS that controls pumps and fans. Figure 3.3 is an example that shows the controls for the solar heat pump, one of several systems in operation. In all, there are more than 200 sensors and actuators that monitor and control the AEL.

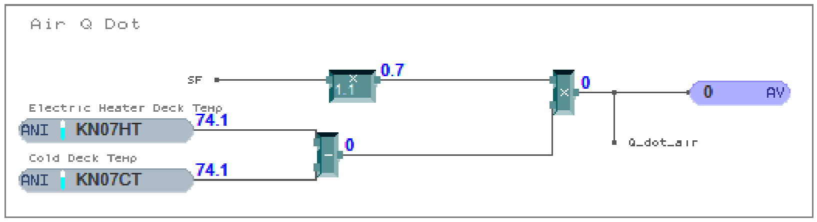

Figure 3.4. BAS for Solar Heat Pump System at AEL.

Algorithms as shown in Figure 3.3, are coded to control the equipment and process calculations. The calculations are either used to display on an energy dashboard or analyzed to control equipment. For example, the solar heated glycol system only runs if the insolation and outside temperature indicate that it's cold and sunny. If any one of these points is not operating correctly, the operation of the entire AEL is less than optimal. Early detection of component malfunctions is one reason that the development of energy dashboards is important to increasing the efficiency in buildings.

4.2.1. Energy Dashboards

The various mechanical systems at AEL had existing energy dashboards prior to this study. These dashboards are individualized by equipment; an example is shown in Figure 3.5. Information such as the outdoor temperature is shown, along with trends from the last twenty-four hours of on energy consumption. The various energy dashboards range in date integrated and vary in data granularity. There are several energy dashboards that, because of changes in code, now have empty data slots. The energy dashboard shown in Figure 3.5 used to be littered with broken data links before the updates were integrated into the system.

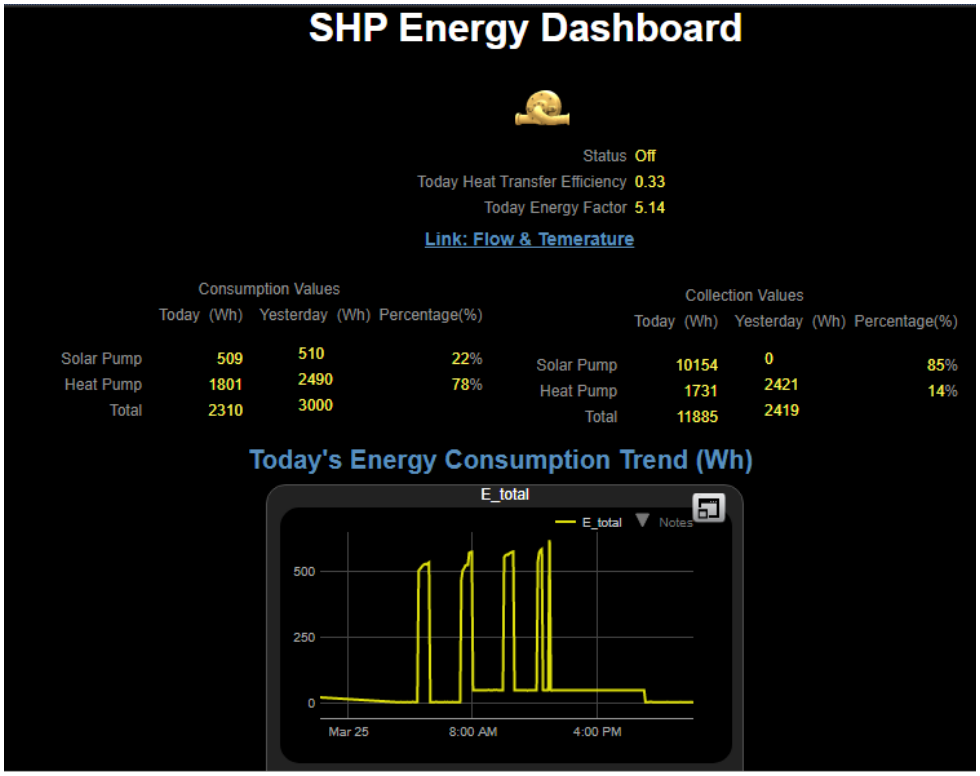

Figure 3.5. The dashboard for the Heat Pump in AEL analyzed in the posttest.

The energy dashboard in Figure 3.5 shows trends, numerical data, links and graphical representation of the pump that rotates to imitate the heat pump. Different levels of energy dashboard focus on graphic types. The dashboards designed for AEL are at a level two. The user has some knowledge of the system but primarily uses the dashboard for monitoring. The energy dashboard has energy consumption data and links to detailed data about actual readouts from sensors.

The assessment was conducted using a rubric included in Appendix A. The purpose of the BAS assessment is to document the status of the mechanical equipment and to prioritize which elements of the dashboard need the most attention. The rubric presented in Appendix A also helps monitor progress throughout the study and includes all the equipment that could possibly be monitored, as well as information regarding status and data points used.

This evaluation served as the researcher’s first impressions of the energy dashboard. The assessment rubric helped the researcher diagnose system issues that need fixing prior to the study being conducted. The rubric was completed as the researcher verifies the functionality of the mechanical equipment in the AEL.

3.3. Design of the Experiment

The experiment was broken into three different levels that were found in literature. The levels are listed divided into a hierarchy chart shown in Figure 3.6. The levels were used to pass or fail the improvements made on the energy dashboard. Time spent on improvements was split into different levels for the baseline evaluation in Appendix A in the baseline evaluation.

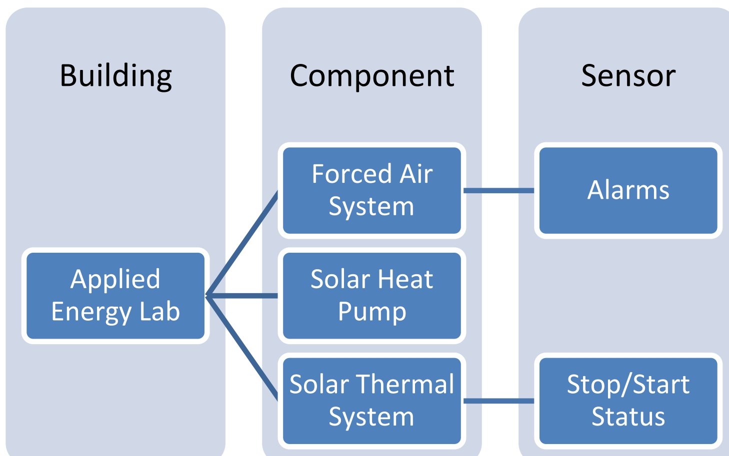

Figure 3.6. The hierarchy for the levels used to analyze the energy dashboard.

The different levels were a key aspect of the statistical analysis for the energy dashboard. A proportions statistical test was done with a 95% confidence level. A z-statistic was used because the two proportions from the pretest and posttest were compared. The equation used to find the statistical significance is shown in Equation 1.

$$z = \frac{(p_1 - p_2)}{\sqrt{p_{pool} * (1 - p_{pool}) * (\frac{1}{n_1} + \frac{1}{n_2})}} \quad where\ p_{pool} = \frac{X_1 + X_2}{n_1 + n_2} \qquad \textbf{Eq. (1)}$$

Three questions per individual level were asked in the survey, the hierarchy is broken down in Figure 3.6. For each individual level to pass, two out of three questions had to show statistical improvement at 95% confidence level. If two of the three questions showed improvement using the proportions z-test the level passed and was considered to make effective improvement between the two tests.

3.3.1 Building Level

The highest level of evaluating the energy dashboard is the building level. The upper level evaluated how effectively the dashboard could articulate energy usage for the entire AEL. This level was integrated into the BAS through a new energy dashboard for the posttest. The building level analysis integrated the concept of energy dashboards displaying NZEB parameters. The analysis was focused on if the new building level dashboard improved a users' ability to find NZEB energy data. The highest level energy dashboard was integrated into the BAS and statistically evaluated to validate a higher level of observing building energy consumption.

3.3.2. Component Level

The component level is focused on evaluating effectiveness of displaying AEL's mechanical systems through an energy dashboard. The middle level of BAS hierarchy focused on if a certain component was operating and ability to find associated performance metrics for the mechanical equipment. The component level required users to navigate through the BAS to find the equipment. The users answered specific questions about the operations and what information on the dashboard was useful for diagnostics.

3.3.3. Sensor Level

At the sensor level, the survey asked users if any alarms were activated on the equipment that is being monitored. The sensors that are used to control the equipment such as temperature and humidity were used in the survey to validate if the energy dashboard passed at the sensor level. Design edits to the energy dashboard at the sensor level were focused on adding animation and correcting areas containing missing sensor data.

3.3.4. Institutional Review Board Approval

An exemption was granted to the researcher from the Institutional Review Board (IRB) at Purdue University to use the students from an HVAC design class for the energy dashboard study. In the students' best interest an IRB form was completed to grant access to use the students. The students were considered the user for the energy dashboard experiment. The user population identifed as upper level engineering technology students. Users' names were removed from the results for confidenuality.

The experiment was controlled by expressing to users the purpose of the assignment to encourage individuality. Users were told that they were helping in the evaluation of an energy dashboard and graded for technicality. The assumption is that users completed the assignment to the best of their ability because they received a grade. The energy dashboard is accessible to the users through an online portal and they were given a week to complete the assignment.

Users were asked a total of sixteen questions about information displayed on the energy dashboard. Both times, the users completed the approximately the same survey with minor adjustments. The only difference between the surveys is the layout of the energy dashboard. The first time the users complete the assignment, they were assessing the energy dashboard as of September 2017. The second time the survey was completed, the users were viewing the energy dashboard that used pretest response answers, review of literature, and recent innovations in software to make altercations.

3.4.Initial Assessment: Pretest

A survey format, exhibited in Appendix B, was used to collect data on the users' ability to find energy performance metrics on the energy dashboard. Students in a senior-level HVAC design class were asked to complete the survey as a homework assignment. The students were the users of the energy dashboard for this experiment.

The pretest survey given to the users, provided in Appendix B, was instructed to be completed individually and graded for technical correctness. The pretest was given at the start of the semester to evaluate the baseline performance of energy dashboard. The first time this survey was completed marked the beginning status for the energy dashboards for the AEL.

A similar assessment was done by the researcher, shown in Appendix A. The completion of Appendix A was to find where the researcher found room for improvement compared to the students. The assessment helped the researcher to understand what type of glaring weaknesses are in the system that needed priority. Appendix A shows a hierarchy list of tasks within each mechanical system's energy dashboard. Organization of the BAS was an overarching goal of this research and Appendix A was the approach used to help with BAS organization.

The students represented a person who owns a NZEB or someone worked in the field of mechanical systems. The students in the classroom are expected to be upper-level mechanical engineering technology (MET) students interested in buildings. These are students that could work in careers interfacing with energy dashboard interaction. The sample size of students was 25 out of a population of roughly 150 MET seniors in the college.

The pretest is used for qualitatively analyzing the starting point of the study and compared the energy dashboard's starting and finishing points. In addition, the pretest helped to identify the knowledge of the users and give direction on how to design the dashboard.

3.5.Dashboard Design Improvements

The energy dashboard is a web-based system that can be accessed by a login-based account, and its programing platform is based on WebCTRL from Automated Logic Corporation (ALC) (Automated Control Logic, 2016). The company ALC is a leading BAS vendor that has recently expanded its features in deploying energy dashboards (Automated Control Logic, 2016). ALC is one of the two major BAS vendors on Purdue's campus. Engineers that use the system daily were consulted for best practices. While all the mechanical equipment resides in one BAS, system functions was not designed to work as a singular unit. Synchronizing all the energy dashboards was a known weakness, the pretest was used to find exactly where the synchronize errors existed. The pretest assessed the current state of individual equipment energy dashboards. The users were graded for technical correctness of their answers to incentivize an honest effort for the pretest assignment.

3.5.1. Graphic Examples

The study focused on the data presentation of the energy dashboard through a BAS. A variety of graphics were provided through ALC's graphics package. The graphics range from realistic mechanical equipment and gauges to trends and tables. Understanding the correct placement of graphics was iterated on through the study. The focus of the energy dashboard was to display data justifying that AEL is a net zero energy laboratory.

One type of graphic that was added is animation of components. Pumps and alarm graphics were added to react when equipment is operating in real-time. One of the most recent additions to the ALC graphics package was gauges to show real-time values. Gauges, shown in Figure 3.7, were integrated to the energy dashboard for the first time.

Figure 3.7. An example of the gauge recently added to the graphics package.

Familiar to users to who drive vehicles, gauges are graphical representation of numerical data. Gauges are the middle ground between trends and numerical data. The exact number is not shown but users looking at the graphic are able to visualize increases and decreases. Gauges are tested in the new energy dashboards to determine if they should be used throughout the system.

The measure of success for the study was be based on the usefulness and ease of understanding of the data being displayed. This study is focused on how to rapidly deploy an energy dashboard and what types of data can be displayed to a facility manager without the use of a third-party company.

3.5.2. Plug Load Analysis

The energy dashboard study considered plug loads from the classroom lights and computer screens. An estimation was made for the plug load based on the occupancy level assumed. Through software, the study mimicked the plug load behaviors, as they are not individually sub-metered. The occupancy levels used the default for typical office building by EnergyPlus were used. The laboratory equipment and PV production are individually metered. Laboratory equipment and combined classroom plug loads determined AEL's energy consumption. Equation 2 was the fundamental outline for calculating NZEB in the energy dashboard. The mechanical electrical load (MEL) is the load for the lab equipment at AEL.

Eq. (2)

$$Net\ Zero\ Energy = PV\ Production - (Plug\ Load + MEL_1 + MEL_2 +\ MEL_n)$$

A delimitation is that the load from HVAC systems was not considered because the AHU used to heat and cool the classroom is not individually metered. This study focused only on the NZEB parameters of the electrical load and how to display it. A characteristic of AEL is equipment designed to be heated and cooled with solar thermal resources, a future research project is needed to add the HVAC loads into the energy dashboard.

3.6. Final Assessment: Posttest

The posttest followed the same format as the pretest, with minor adjustments. The primary adjustment was the addition of the KPI survey in posttest located in Appendix C. The final assessment included a KPI assessment to compare user's answers against those found in Li *et al.*'s study on KPIs and professionals in industry. An in-depth description of the KPI alignment test is explained in 3.6.1.

The same three levels of assessment were used for the energy dashboard: building, component, and sensor. Each of these distinct levels evaluated a different feature of the energy dashboard. The three distinct levels of analysis were used the results of the survey from both tests to judge effectiveness of conveying real-time and trended energy performance.

Similar to the pretest, qualitative and quantitative questions were asked in the survey. The quantitative answers in the posttest were graded for technical correctness. Each question was compared with the pretest correct proportion to determine pass/fail for statistical significance. Three questions were asked for each level of analysis. A level was considered passing if 2/3rds of the questions showed statistical significance.

The focus was effectiveness of an energy dashboard to display net zero energy characteristics of the laboratory. The building level net zero energy dashboard analyzing AEL was integrated into the BAS. The users' evaluation at the building level tested the quality of the newest energy dashboard. The performance of this study is not dependent on whether the building operated within NZEB mode but rather could the dashboard display whether it was operating in NZEB mode.

3.6.1. Key Performance Indicators

The research field of KPIs was expanded in the posttest to determine if ranking importance of building performance metric KPIs was an effective way to classify a user. The answers are used to categorize the users and determines graphics that resonated with the users of the AEL energy dashboard. The energy dashboard used guidelines provided through KPIs to help define appropriate graphics and effectively judge these graphics. Users were asked a series of 25 questions and told to rank them on importance. These KPI analyses focused on types of KPIs for a building that could be of importance to a user of an energy dashboard. The answers are compared against Li *et al.*'s study to determine identity of sample.

The results from the users ranking were averaged to determine the samples overall ranking of a KPIs. Equation 3 was used to calculate alignment with the four different groups from Li *et al.*'s study. The answers from Li *et al.*'s study were all rounded to the nearest whole number. A tolerance of ±15% of the average was used to classify the results.

Eq. (3)

$$Average(KPI_{Student}) \pm .75 == KPI_{Li\ et\ al}$$

Dashboards are not solely used for energy data. They are also used in factories and sales offices to display the performance of production lines. KPIs originate from the business setting of displaying data; however, the fundamentals for how to calibrate graphics for ease of use is the same for energy-related applications. Understanding the KPIs important to the user helps to optimize the design of the energy dashboard.

3.7. Summary

The design of the experiment is a pretest and posttest question format. A survey that was completed twice by students in an HVAC design class. The students in the class were considered the users for this study. The users answered the survey based on the September 2017 energy dashboard and the updated December 2017 version. The results were compared and analyzed to assess the usability of the dashboard for three distinct levels. This study delivers a critique on building an energy dashboard that brings direction to understanding energy usage. The experiment also advanced the field of KPI research to further identify energy performance metrics and how to use them to identify what metrics are important to users.

An energy dashboard is not a new concept; however, best practices are still under investigation. Research shows that if occupants are informed of energy consumption they reduce energy consumption. An energy dashboard is the connection between the building data and humans. In this study, a low-cost solution is investigated and statistically evaluated based on performance at three distinct levels. The research focused on the ability of an energy dashboard to improve ability to identify building performance metrics.

CHAPTER 4: RESULTS

A statistical analysis was conducted to identity demographics according to key performance indicator (KPI). The user's answers were compared to KPIs that categorize user knowledge following protocols from Li *et al.*'s study. This was done to classify the population. The analysis examined highly correlated KPI's and the current design of AEL's energy dashboards to assist future development. The pretest and posttest responses were then evaluated to determine if the energy dashboard statistically improved users' responses. Lastly, a qualitative analysis was completed for best practices designing energy dashboards interrupting written responses. The results were used to analysis the usefulness of an energy dashboard's ability to help users identify building performance metrics. The advancement of research on energy dashboard and KPIs was explored through this study.

4.1 Quantitative Pretest and Posttest Analysis

Table 4.1 is a statistical comparison that summarizes the results from the pretest and posttest to examine the statistical significance of the energy dashboard improvements. The questions were divided into the three levels of analysis, building (blue), component (yellow), sensor (orange). The left side of the table identifies the level of analysis and the right side (green) determines if the level passed. The middle columns of Table 1 show the percentage of correct responses for the pretest and posttest based on technical merit.

Table 4.1. Statistical results showing that the energy dashboard passed.

Level	*Question*	*Pretest Correct %*	*Posttest Correct %*	*P-value*	
Building	Systems Monitored	39%	65%	0.038	Pass
	AEL Net Zero	17%	26%	0.000	
	Energy Consumption of AEL	**60%**	**72%**	**0.458**	
Component	Operated Outside Setpoints	39%	74%	0.009	Pass
	FA Currently Operating	87%	100%	0.037	
	SHP Currently Operating	87%	100%	0.037	
Sensor	**Real-time Conditions**	**96%**	**96%**	**0.500**	Pass
	Solar Air Thermal Running	26%	78%	0.000	
	Alarm Notification	4%	87%	0.000	

The statistical evaluation was the quantitative measure determining if the energy dashboard increased a user's ability to find building performance data. The energy dashboard exhibited statistical significance on all three levels. The complete numerical tabulated data resides in Appendix F. The following paragraphs describe this analysis in more detail.

A one-sided proportions statistical analysis was done using 95% confidence. The null and alternative hypothesis were used to determine if an energy dashboard improved a user's ability to identify building performance data.

- H_0: proportion $\text{correct}_{\text{pretest}}$ = proportion $\text{correct}_{\text{posttest}}$
- H_a: proportion $\text{correct}_{\text{pretest}}$ < proportion $\text{correct}_{\text{posttest}}$

A proportions statistical test was chosen because the comparison of two proportions of correct answers for each individual question.

Rows with red font in Table 1 indicate that the question did not pass the statistical test at a 95% confidence level. A p-value of less than .05 was needed to prove statistical significance. All three levels passed by 2/3 of the questions showing statistical significance. The null hypothesis was rejected because the data shows statistical significance that a well-designed energy dashboard increases a user's ability to find building performance metrics.

The component level was the only level that showed statistical significance of improvements for all three questions. The adjustments made at the component level were rather simple because component level energy dashboard was prevalent. Errors were easily found in the pretest and Appendix A evaluation because they existed in detail. Section 4.5 elaborates on the concept of where time was spent making revisions and how the dashboard preformed. The component level showed greater statistical improvements than the other two levels evaluated.

4.2 Population Description

The survey participants were classified based on their self-identified knowledge to further optimize the energy dashboard design. Two rounds of classification were used to understand the users. The first classification asked users to self-identify their knowledge of the energy dashboard. The second looked at the how users ranked KPIs to understand their thought process for important building performance metrics. Both methods to classify the sample population became a powerful resource to improve the energy dashboard design.

Figure 4.1 is a histogram of the data representing that the users felt confident that they could complete the assignment. A total of 23 users were in the sample for the pretest and posttest experiment. The pretest asked the users to rate their knowledge level of energy dashboards. On a scale 1-10, the users averaged a 4.7 for pre-existing knowledge of energy dashboards. The users had not received any specific energy dashboard training prior to this assignment.

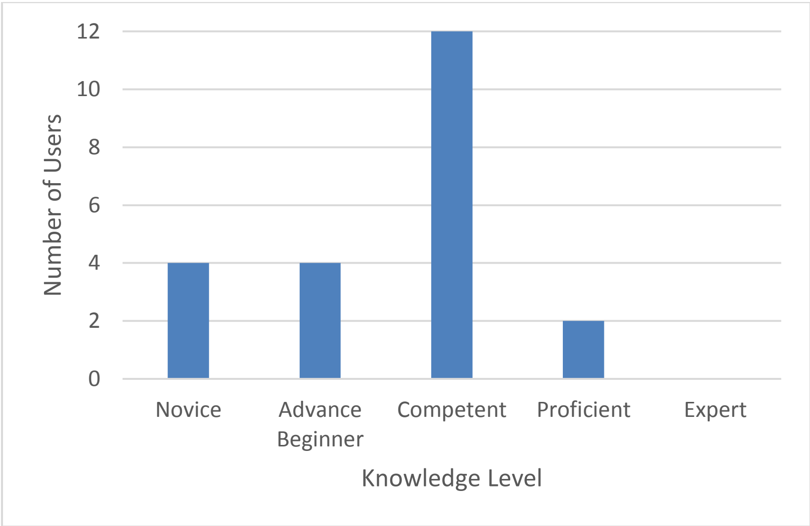

Figure 4.1. Self-identified energy dashboard knowledge.

As referenced earlier in section 2.4, literature recognizes four different levels of energy dashboards, varying by granularity of data. A level two energy dashboard was initially thought to be the energy dashboard granularity of data needed for the AEL. Reviewing the self-identification data confirmed that the users of the dashboard were competent enough to use a level 2 or level 3 dashboard. A level two energy dashboard integrates controls and analytics (Shadpour, 2015).

Understanding the demographics of the energy dashboard user is a key component to optimizing the design. The survey found that the users were all upper classman in Engineering Technology. The self-evaluations showed that the users felt comfortable using an energy dashboard. The users were competent enough to complete the assignment without any prior training specifically on energy dashboards.

4.3 KPI Comparison-Designing Dashboard for the Right Person

A KPI ranking of importance methodology was used to further evaluate the background of the survey users. The hierarchy chart in Figure 4.2 lists the classifications of person type used to categorize the users. To the left of the chart is the appropriate level of energy dashboard used for person type. The users in Figure 4.2 represent the organizing committee users that designed the solar decathlon for Li *et al.*'s study.

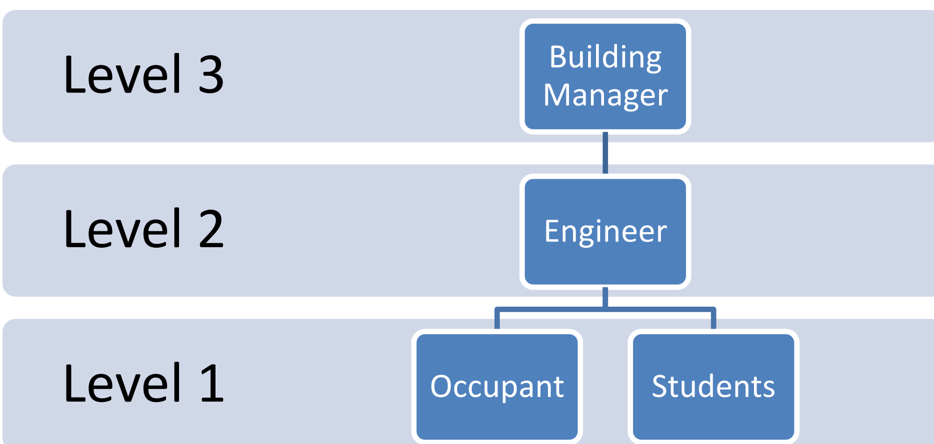

Figure 4.2. A hierarchy of KPI classification in relation to level of energy dashboard.

Understanding who the user that is interfacing with the energy dashboard is a priority for optimizing design. Multiple avenues of gaining knowledge about the user assists optimizing the energy dashboard to the user.

Figure 4.3 shows that the survey group aligned most closely with the Engineering category and the least with students from the organizing committee. Figure 4.3 shows percentages that the users agreed with rankings of KPIs from Li *et al.*'s study. Although no perfect alignment was found, users in this sample are classified as ranking KPIs 45% of the time the same as engineers. The alignment with a more technical role validated the choice for a level two energy dashboard.

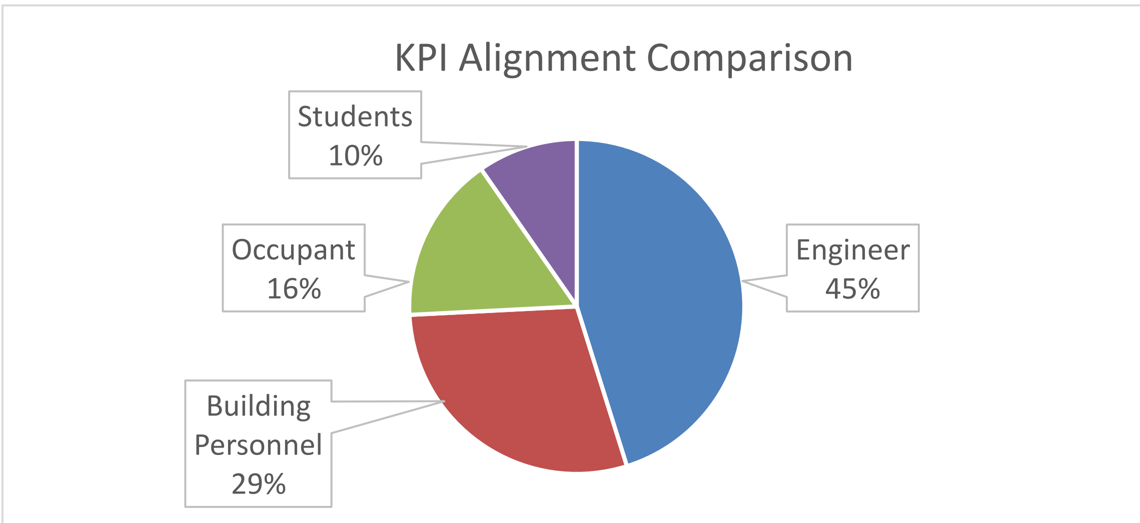

Figure 4.3.12The users' alignment with engineers from Li *et al.*'s study.

The users in the sample identified mainly with engineers rather than occupants or students. The engineers from Li *et al.*'s study were district energy engineers and microgrid engineers. Since the population for this study evaluated were engineering technology students nearing the end of their college career the data corresponds as expected.

Li *et al.*'s study was written by students in a Solar Decathlon project. An unexpected result of the KPI alignment phase was the comparison between Solar Decathlon students and the Purdue students. The students from Purdue aligned with other students on a solar decathlon team only 10% of the KPIs. The students in the Purdue sample identified more with other engineers 4 times as much than engineering students from the University in China. The result is at the end of an engineering technology degree the users have been trained to think like engineers.

Designing a high-quality energy dashboard requires fully understanding who the users is and what are they expected to do with the energy dashboard. Engineers want to be able to evaluate system performance and understand equipment energy efficiency, something that is not important to all building occupants.

4.4 KPIs of High Importance

An analysis of KPI performance is an important detail that shows insight to what users finds important. A survey of this type would be most useful at the beginning of the design phase to classify the user. Although, it is worth noting that the user is not always correct. A comparison between what the users deems important verse practical information needs to be done. The KPIs of high importance should be included in the energy dashboard but the designer should also follow other guidelines and design requirements.

The users were asked to rank KPIs from a 1-5 scale on importance. The calculation below was done to find KPIs that the users found to be of high importance.

$$Average(KPI_{Student}) > 3.5$$

The KPIs were taken from a list compiled by a group of engineers designing a home for the Solar Decathlon in China. From the list of 23 the users found 12 to be of high importance to add to a dashboard. The list of high importance considered renewable energy generation to be of least importance. Human comfort KPIs and equipment efficiencies made of the list of high importance. Located in the appendix is a complete list ranked from highest to lowest.

4.5 Qualitative Findings-Time Spent Verse Complaints

The time spent editing the energy dashboard for the posttest revisions was recorded and broken up into the three distinct levels, building, component and sensor. Table 2 was made to identify the most time-consuming task for each level of analysis. The study was focused on adding the most current graphics from the ALC toolbox. Animation for equipment and real-time data displayed through gauges were added to the energy dashboard. Simple editions to the graphics required more organization of data than was originally thought when Appendix A was outlined.

Table 4.2. Time consuming tasks broken down by corresponding level.

Building	Total energy consumption calculation
Component	Removing Unused Data
Sensor	Adding Animation

Appendix A was created to prioritize time spent on the energy dashboard. Updates originally thought to be simple were falsely assumed to be an easy task. Focus on the main goals had to be kept to not get caught up in the minute details. For example, unused data points were found across the entire system due to the graphics not being updated in over two years. Keeping an energy dashboard up-to-date requires that all data points associated with any dashboard be commented so data links are not accidentally deleted. An energy dashboard requires organization of the whole BAS to coordinate data points and graphics. Updates to control programs without updating graphics is the biggest hurdle for the longevity of any energy dashboard.

The revisions were overwhelming spent at the building level, 75% of the time editing at the building level. The most time-consuming task for the entire energy dashboard study was the net zero calculations. The pie chart located in Figure 4.4 shows the percentage of time spent at each level. The result from the users showed that areas with the least amount of time dedicated to restructuring were referred to the most when users identified weaknesses.

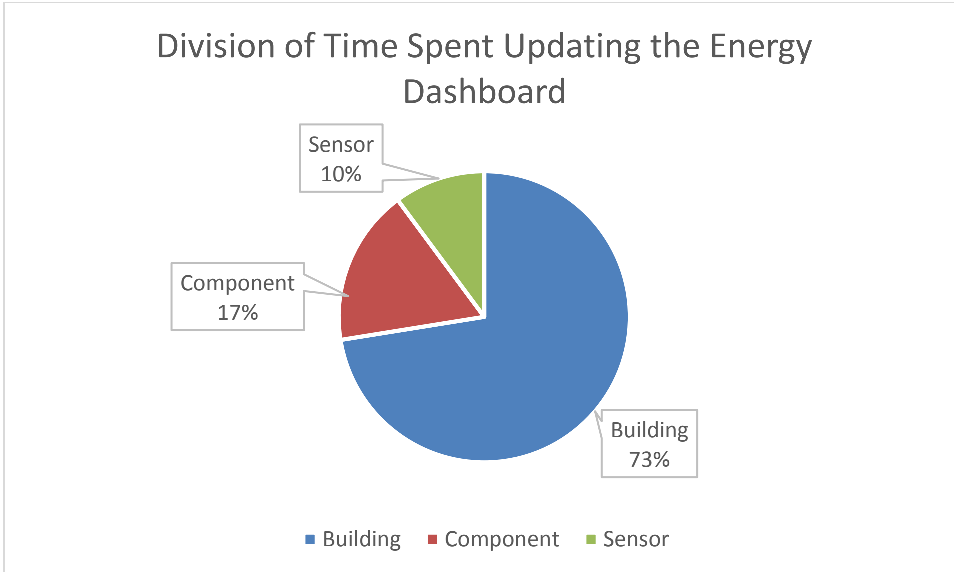

Figure 4.4. The breakdown of time spent editing at the three different levels.

The results revealed that the weaknesses and strengths of the energy dashboard were issues at the component level. A consistent template was needed for all the equipment in AEL for users to fluidly navigate the system. The flow between different equipment energy dashboards in AEL was difficult for the users because of the inconsistency of the layouts and location of data. Little time was spent creating a more consistent flow because this issue was not identified in the first round of weaknesses. Regardless of the overall layout of each dashboard the users expressed hardship finding information because design varied from each equipment's energy dashboard.

The users were asked to identify what on the energy dashboard is used for diagnostic information on the pretest and posttest. The answers changed between tests but the results showed that what the research considered an effective tool for diagnostics did not align with the users. For example, the users were asked to list the diagnostic information found in the screen capture below, Figure 4.5. Users listed: consumption and collection values and COP. However, only two people from the entire study listed the energy consumption trend. Users focused on numerical consumption values but not the trend over an entire day.

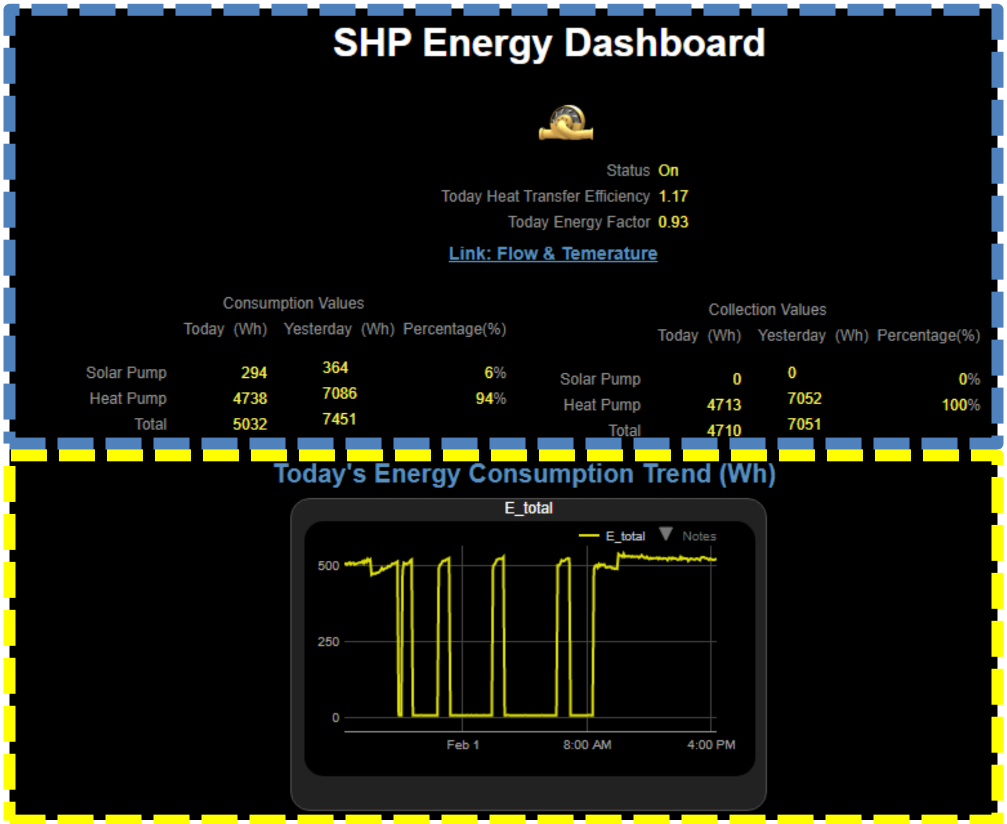

Figure 4.5. The energy dashboard that users used to answer questions in the posttest.

The users identified the numerical energy data but glazed over the trends as being helpful for diagnostic information on the energy dashboard. This shows insight to the idea that people with minor knowledge of energy dashboard would rather see whole values rather than a trend. Trend data is the next level of energy dashboard. Even though users identified with engineers when ranking KPIs they still prefer an entry level dashboard. Understanding what users notice when they view an energy dashboard is insight into what they find important about that dashboard.

4.6 Conclusion

The aesthetics of an energy dashboard are important but a sexy dashboard is not useful if the energy dashboard is built for users of a different skill set. Comparing building performance goals and KPIs important users allows for an optimized energy dashboard to be constructed. The sample for this study were classified as competent to complete the assignment and categorized as engineers through KPIs. A level two dashboard was used and analyzed by users with the desired skill set. The energy dashboard passed on all three levels showing statistical significant that an energy dashboard increased the ability to identify building performance data. An energy dashboard is an effective way to display parameters for a NZEB through a typical BAS.

CHAPTER 5: SUMMARY, CONCLUSIONS, AND RECOMENDATIONS

This chapter makes final remarks for assessing the performance of an energy dashboard for net zero buildings. A pretest and posttest survey compared the performance of a user's ability to find energy performance data before and after integration of edit for a new energy dashboard. The energy dashboard found statistical significance that a purposefully designed energy dashboard increases a user's ability to find building performance metrics.

This energy dashboard study added the evolving field of KPIs within the field of building performance metrics to optimize design for energy dashboards. This study used content from Li *et al.*'s study to classify the sample. Understanding the demographic and what metrics are important to the user is a key component to optimal design and user interaction.

Energy dashboards are becoming increasingly important as future energy costs will become demand based kilowatt cost, a reality for places Europe. Energy will begin to cost differently based on time of usage to help level out peak demands. Cellphone applications have been developed to monitor at home energy use remotely through the internet. Energy dashboard are moving from the laptop to the cellphone quickly through smart devices. Changes in the way people interface with buildings requires algorithms for displaying energy performance data, a needed area for research development.

5.1 Discussion

As NZEB becomes prevalent, occupants and facility managers are increasingly becoming aware of the operations of the building. Occupants have repeatedly shown in research to reduce energy use when aware of their consumption (Abrahamse *et al*, 2005). Research efforts have attempted to find the best way to promote energy conservation habits. A major obstacle is understanding the best way to display the data to promote these habit changes. One study showed that only 10% of people stated that they looked at the online energy dashboard for their work office (Cuadrado Borbones, 2013). Psychological research on people and energy consumption shows correlation to increased awareness decreases energy wasting habits, humans are able to be influenced to reduce consumption (Coltran, 1989)(Ambrahamse, 2005). This study and others are researching the best methods to integrate consumption patterns into people's daily lives to promote change in energy consumption.

The net zero energy dashboard research discovered key components to aid in the design of making an energy dashboard. The research discovered that a consistent theme and tactful use of graphics is essential. Understanding who is going to be interacting with your energy dashboard is just as important as processing the data.

Three key factors were highlighted in this research as major findings:

- Surveying the users to determine the demographic skill set
- Energy dashboards increases the ability to identify building performance metrics
- Consistency and organization in a BAS should be of high importance

5.1.1. KPIs and Energy Dashboards in Net Zero Buildings

An analysis was done on KPIs that the users ranked important to their understanding of a building's performance. The sample of users in this study identified KPIs with similar importance to engineers in Li *et al.*'s study. This finding was originally obscure because the sample identified the least with seemingly similar students Li *et al.*'s study. The reason for the difference is assumed to be the age of the sample in the two studies. Also, the demographics of the students interviewed in Li *et al.*'s study are unknown. The sample in the net zero energy dashboard study are senior level mechanical engineering technology students. They are users entering the workforce as engineers. The results speak highly of the engineering technology program that students who are nearing graduation have an engineering mindset rather than a student or occupant.

The KPIs that were ranked of high importance, the sample group identified several that differed from what engineers in Li *et al.*'s study found important. The sample surveyed found appropriate temperature, humidity and fresh air to be important KPI performance perimeters. Engineers from Li *et al.*'s study felt oppositely about these KPIs. This is the major difference between the two groups of engineers ranking KPIs.

The difference between importance is attributed to users being influenced by the energy dashboard they recently finished evaluating in AEL. The users potentially have been influenced by data that is already on the energy dashboard and assumed that it was important. Moving the KPI importance test to the beginning of the survey is one method to prevent influence from other energy dashboards.

Another reason for the difference in ranking is because of building ownership. The users were in the AEL weekly for class, rather than an engineer designing a dashboard for a customer. Attributes about comfort are not always important to an engineer that does not have to study or work in the building.

A KPI importance test is an excellent way find out what is important to users to help with human centered design. Outside influences have the potential to effect what users find important but a comparison or brief energy dashboard education has the potential for impacting how users understand the data.

5.1.2. Three Levels of Analysis

Dividing the BAS into three diverse levels aided ability to find in depth performance faults. All three levels passed, showing statistical significance that the changes to the dashboard helped users find diverse level of building performance data.

The component level was the only level that passed 100% of the statistical significant test for the three questions relating to that level. The component level was focused on fixing broken data links. These fixes were relatively easy and issues that were found in the pretest were easier to be fixed for the posttest. The pretest and posttest format is an easy way to find where the faults in the energy dashboard exist.

The sensor level of analysis failed to show improvement displaying real-time conditions. The reason this statistical test failed was because the same proportion, 96%, of users got the answer correct. This question was found to be relatively easy for users to identify on the energy dashboard. The answers to the real-time question helped the researcher to classify when the users was completed the energy dashboard survey. A question that allows for a researcher to determine when the survey was completed helped greatly for other portions of the research.

The building level was the most difficult level to integrate into the BAS and showed the least amount of improvement. The building level in the end was focused on displaying the overall energy usage and net zero status of the energy dashboard. After the posttest was completed several of the points that needed to be trended were found to be incorrectly setup. An energy dashboard needs to go through multiple rounds of critique to optimize data organization.

5.1.3. Consistency

After the two tests were completed users had complaints about the consistency between different equipment's energy dashboards. Humans are creatures of habit and crave a level of consistency. The issue of inconsistent font sizes, colors and links was overlooked because of all the other issues within the energy dashboard. After the posttest was completed time was spent to fix the issue of consistency between the systems. A theme was implemented into the energy dashboard but more follow through is needed to synchronize the energy dashboards.

Continuing the constant theme and implementing a layout that is similar between equipment is the next step. Users found it difficult that the data displayed for each of the pieces of equipment was different. Although the same data is not needed for each piece of equipment, a consistent theme of where certain type of data is located is needed. Creating a template or guidelines for future energy dashboard edits is needed to keep a continuous theme as researchers cycle through AEL.

5.1.4. Graphics

A new graphical feature, gauges, were added to the energy dashboards to test their effectiveness of displaying energy data. Gauges were found to be the middle ground between displaying real time data and trying to get occupants to understand performance. Gauges work best for real time data and are not as effective at displaying trended data.

There is also another unexplored feature within gauges that was not experimented due to time constrictions. After reading through literature from ALC the gauges have the ability to change colors to help users identify if the data is in a good or bad zone. The color-coded method is the next step to help users identify if the AEL is operating within net zero parameters and should be considered for other research on energy dashboards.

Animation was added to the dashboards to help show when pumps and fans were on and off. Users identified that the visual schematics and moving fluids as the overall most useful feature. This is assumed because the users were able to walk into the lab and see the setup of the individual systems, but the pipes can be confusing. Seeing the layout on the energy dashboard helps with the visualization of someone with minor knowledge of HVAC systems. Data is not the only important feature of an energy dashboard, the use of graphics illustrates how the system functions to users.

5.2 Future Improvements

Research in the energy dashboard field has room to grow deeper into the understanding of KPIs, user experience (UX) and increase accuracy of load calculations. Energy dashboards are the interface between a building's performance and humans. Smart homes technologies are expected to become a $137 billion market by 2023 (Hutton, 2017). Across the nation residential builders are adding home automation controlled through personal assistant devices like Amazon. Research on UX for enhancing residential home automation experience as a means for consumers to increase energy conservation is the next step for energy dashboards.

5.2.1. Load calculations

A missing piece to the load calculation is the heating and cooling that is needed for AEL. The solar thermal assists the traditional HVAC by heating and cooling the classroom when appropriate. The HVAC load needs to be combined with the savings from the solar thermal system to create an accurate description of the energy needed to condition the air in AEL. The traditional HVAC system used in AEL also supplies air to three other classrooms. Creativity is needed to solve the HVAC load calculation but one possible solution would be to trend the data to make an estimate for loads in the winter and summer months. The purpose of an energy dashboard is to give an overview of the AEL's performance of exact consumption is not always the most important detail.

Another level of calculating the load of AEL would be to individually submeter each outlet within the classroom. Devices are readily available to be purchased that can track energy usage of an outlet through WiFi or Bluetooth. Researching methods to individual submeter and inputting them into the BAS is the function that could be further developed. Individually in submetering the outlets would give an accurate classroom load calculation but the interfacing between several electronics makes it a research project focused on BAS networking.

5.2.2. User Experience

The field of UX focuses on enhancing the experience for user's interaction with technology. Research in UX uses psychology and fundamental usability heuristics to understand how people use technology. Research within the UX field lacks energy dashboard research. The research for energy dashboard and UX is focused on how older people will interface with demand based energy costs and electronics such as the Nest.

UX research compiles what is important for users to see versus what are they actually viewing on an interface. One way of researching is by tracking eye movements. A next layer of research for the energy dashboards in AEL would be to track eye movement as users are asked to complete a list of questions, similar to this research. A heat map is made from the tracking of the eye moments to find out where users are looking at the screen most and what catches their attention. The purpose is to have the most important building performance data align with the most looked at feature.

5.3. Conclusion

The results of the energy dashboard study validated methods to classify the users to optimize navigation of building performance metrics. Key performance indicators (KPI) were used to determine users' identity among a set of diverse energy dashboard users. The study found statistical significances that a purposefully designed an energy dashboard improves a user's ability to find building performance metrics. Understanding the user's knowledge level and role in the building is an essential aspect to proper energy dashboard design.

This study aimed to create an energy dashboard that was a rapid deployable prototype for net zero energy commercial buildings of the future. Current research has revealed that occupants want more control over their buildings, and energy dashboards can allow for this, thus helping reduce energy use. Coupled with the expansion of smart home technology, energy dashboards are increasing in prevalence; understanding proper design aims to increase positive user experience and forming more sustainable behaviors.

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APPENDIX A. BASELINE EVALUATION OF THE APPLIED ENERGY LAB

Priority	Level	System	Subsystem	#inputs	Operating Dashboard? (Y/N)	Up-to-date graphics? (Y/N)	Tree Level	# of programs
5	Component	Forced Air			N-Only instantaneous values	Y-detailed layout of design	HVAC	3
6	Sensor		ERV		Y-Instantons & current kWh values	Y-detailed layout of design	HVAC	1
6	Sensor		Humidifier		Y-Logged values for usage & peak for Wk, Mnth, Yr	N-Soley table of values	HVAC	1
6	Sensor		Fan		Y-Loged values for usage & peak for Wk, Mnth, Yr	N-Soley table of values	HVAC	1
6	Sensor		Elect. Heat		Y-Loged values for usage & peak for Wk, Mnth, Yr	N-Soley table of values	HVAC	1
6	Sensor		Solar Reheat		Y-trends, instant values, performance metric values	Y-detailed layout of design	Solar Heat Pump	5
9	Component	Solar Thermal Glycol			N-Only instantious values, real time power usage	Y- flow of glycol is depicted and meter	Indoor Solar	1
2	Component	Solar Thermal Air			Y- But not all points are operating	N-Trends, table values and 2 fans that animate	Indoor Solar	1
7	Component	Solar Thermal			N-Only instantious values, real time power usage	Y-Detailed graphics of thermal panels	Outdoor Solar	1
6	Sensor		Solar Data		N-Only instantious values, real time power usage	Y-Detailed graphics of solar panels	Outdoor Solar	1
4	Component	Chiller			N- data points not fuctioning	Y- Chiller is depicted	HVAC	1
1	Building	PV Solar			N- Wh table summary for Day, Wk, Mnth, Yr, Lifetime	N-Soley table of values	PV Solar	2
3	Sensor	Plug Load (lights, etc.)					N.A	

APPENDIX B. PRETEST SURVEY

In questions regarding a scale of 1 - 10, 1 is poor and 10 is expert

1. Using a scale of 1-10, how would you assess your knowledge of dashboards?
2. What is your class ranking?   Jr. Sr. Gradate

- -

1. What is an energy dashboard for a building automation system?
2. What are the main mechanical/electrical systems being monitored?
3. Has any system generated an alarm in the last week?
4. What is the temperature setpoint range for the Forced Air System?
5. Has the Forced Air System operated outside of its setpoints any time in the last week?
6. Is the Forced Air System operating now? How do you know?
7. What diagnostic information (useful information about efficient operation) is provided for the Forced Air System?
8. Is the Solar Heat Pump System operating now? How do you know?
9. What diagnostic information (useful information about efficient operation) is provided for the Solar Heat Pump System?
10. The energy consumption of all equipment in the AEL is measured and recorded
    a. What is the total energy use (Wh) of the air handling system this month?
    b. What is the total energy use (Wh) of the chiller so far this year?
    c. What is the total energy use (Wh) of the solar heat pump system in the previous day?
    d. How much energy (Wh) has been delivered by the solar PV system in the past week?
11. What is today's date/time and weather conditions?
12. What time did the indoor solar air thermal system turn on yesterday?
13. Is the AEL operating at net zero energy?
14. What is the most useful feature of this BAS graphic interface?
15. What is the biggest weakness in this BAS graphic interface?
16. What improvements would make this BAS graphic interface more useful?
17. How long did it take you to complete the assignment?

APPENDIX C. POSTTEST SURVEY

1. What are the main mechanical electrical system being monitored?
2. Has any system generated an alarm in the last week?
3. What was the energy factor for the solar air thermal system on Friday 12/08? What time did the system turn on that day?
4. What diagnostic information (useful information about efficient operation) is provided for the solar thermal air system?
5. Has the forced air system operated outside of it setpoints any time in the last week?
6. Is the forced air system operating now? How do you know?
7. What diagnostic information (useful information about efficient operation) is provided for the chiller?
8. Is the solar heat pump system operating now? How do you know?
9. What diagnostic information provided for the Solar Heat System?
10. The energy consumption of all equipment in the AEL is measured and recorded
    a. What is the total energy use (Wh) of the air handling system this week?
    b. What is the total energy use (Wh) of the chiller so far this month?
    c. What is the total energy use of the solar heat pump system in the previous day?
    d. How much energy has been produced by the solar PV system in the past week?
11. What equipment in AEL used the most energy in the last week? How do you know?
12. What is today's date/time and weather conditions?
13. What time did the indoor solar air thermal system turn on yesterday?
14. On Friday 12/8, did AEL operating at net zero energy?
15. What is the most useful feature of this BAS graphic interface?
16. What is the biggest weakness in this BAS graphic interface?

APPENDIX D. USERS' KPI OF IMPORTANCE AVERAGES

	Average
Reduction in CO2 emissions	3.2
Energy cost savings	3.9
Energy balance	4.0
Overall energy use reduction	3.7
Individual equipment energy balance	2.8
Time correlation between energy generation & use	2.6
Peak demand reduction	2.8
Renewable energy share	2.7
System Performance	4.4
Renewable energy generation	3.2
Renewable energy generation monthly	3.3
Solar generation system efficiency	3.1
Consumption system efficiency	4.2
Significant energy use reduction	3.8
Human comfort	4.0
Accuracy of prediction of energy supply and demand	3.4
Equipment energy efficiency	3.8
Operational schedule and occupancy consistency	3.3
Occupancy stability indicator	3.2
Thermal load reduction	3.3
Thermal comfort	3.8
Light comfort	3.5
Appropriate temperature	4.2
Appropriate humidity	4.2
Appropriate amount of fresh air	4.5

APPENDIX E. KPI ALIGNMENT RAW ANSWER

	District Energy Engineer	Microgrid system company	Building owners	Building energy managers	Occupants	Organizing committee of the competition
Reduction in CO_2 emissions	FALSE	FALSE	FALSE	FALSE	TRUE	FALSE
Energy cost savings	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Energy balance	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE
Overall energy use reduction	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE
Individual equipment energy balance	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE
Time correlation between energy generation & use	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE
Peak demand reduction	FALSE	TRUE	FALSE	TRUE	FALSE	FALSE
Renewable energy share	FALSE	TRUE	FALSE	FALSE	FALSE	FALSE
System Performance	TRUE	TRUE	TRUE	TRUE	TRUE	TRUE
Renewable energy generation	FALSE	FALSE	TRUE	FALSE	TRUE	FALSE
Solar generation system efficiency	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Consumption system efficiency	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Significant energy use reduction	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Human comfort	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
Accuracy of prediction of energy supply and demand	FALSE	FALSE	FALSE	TRUE	FALSE	FALSE
Equipment energy efficiency	TRUE	FALSE	TRUE	FALSE	FALSE	TRUE
Operational schedule and occupancy consistency	TRUE	FALSE	FALSE	FALSE	TRUE	FALSE
Occupancy stability indicator	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE
Thermal load reduction	TRUE	FALSE	FALSE	FALSE	FALSE	FALSE

Thermal comfort	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Light comfort	FALSE	FALSE	TRUE	FALSE	FALSE	FALSE
Appropriate temperature	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Appropriate humidity	FALSE	FALSE	FALSE	FALSE	FALSE	FALSE
Appropriate amount of fresh air	FALSE	FALSE	FALSE	TRUE	TRUE	TRUE

APPENDIX F. STATISTICAL DATA ANALYZED

	Correct	Incorrect	Mean	Standard D	Correct	Incorrect	Mean	Standard D	z-value	p-value
Systems Monitored	9	14	0.391	0.499	15	8	0.652	0.487	-1.77098	0.038
Alarm Notification	1	22	0.043	0.209	20	3	0.870	0.344	-5.6241	0.000
Operated Outside Setpoints	9	14	0.391	0.209	17	6	0.739	0.449	-2.3794	0.009
FA Currently Operating	20	3	0.870	0.499	23	0	1.000	0.000	-1.79145	0.037
SHP Currently Operating	20	3	0.870	0.344	23	0	1.000	0.000	-1.79145	0.037
Energy Consumption of AEL	60%		0.598	0.344	72%		0.717	0.242	-0.10578	0.458
Real-time Conditions	22	1	0.957	0.209	22	0	1.000	0.511	0	0.500
Solar Air Thermal Running	6	17	0.261	0.449	18	4	0.818	0.209	-3.54196	0.000
AEL Net Zero	4	19	0.174	0.388	6	2	0.750	0.422	-3.40269	0.000